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MEMOIR 413

# QUATERNARY GEOLOGY AND GEOMORPHOLOGY, SMITHERS-TERRACE-PRINCE RUPERT AREA, BRITISH COLUMBIA

JOHN J. CLAGUE

Canada

1984

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Wedeene River valley in the Coast Mountains northwest of Kitimat
Photo by S.R. Hicock. (GSC 203257-A)

**Critical Reader**

*R.J. Fulton*

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## Preface

Skeena Valley is an important corridor connecting the central and northern interior of British Columbia to the Pacific Ocean. Major road and rail lines, providing access to the coastal ports of Prince Rupert and Kitimat, are located in this valley and in adjacent areas.

During the last three decades, this region has experienced extensive economic development based primarily on forestry, fishing, tourism, aluminum smelting, and the export of raw materials. Economic growth is likely to accelerate in the future as mineral and forest resources in northern British Columbia are further developed. This growth will be accompanied by increased demands on, and competition for, land in Skeena, Bulkley, Kitimat, and Kitsumkalum valleys, and on the coastal lowland near Prince Rupert. Efficient use of this land will only be possible if adequate information is available concerning the terrain.

This report contains a detailed description and explanation of the unconsolidated sedimentary materials and landforms in the Smithers-Terrace-Prince Rupert region, and an account of the geological processes that have been active in shaping this area during late Quaternary time. The information in this report is vital to an understanding of the character and distribution of agricultural soils, the nature of foundation conditions, the location and extent of construction aggregate and aquifers, and the nature of natural hazards in the region.

*R.A. Price*
Director General
Geological Survey of Canada

OTTAWA, March, 1984

## Préface

La vallée de la rivière Skeena est un important couloir qui relie le centre et le nord de la Colombie-Britannique à l'océan Pacifique. Dans cette vallée et dans les régions adjacentes, la construction d'importantes routes et voies ferroviaires a permis l'accès aux ports côtiers de Prince Rupert et de Kitimat.

Depuis une trentaine d'années, la région est le théâtre d'une vaste mise en valeur économique qui repose essentiellement sur l'industrie forestière, les pêches, le tourisme, la fonte de l'aluminium et l'exportation de matières premières. La croissance économique va probablement s'accélérer dans l'avenir, à mesure que se poursuivra l'exploitation des ressources minérales et forestières du nord de la Colombie-Britannique. Cette croissance s'accompagnera d'une augmentation de la demande et de la concurrence pour les terres situées dans les vallées des rivières Skeena, Bulkley, Kitimat et Kitsumkalum de même que sur les basses-terres côtières à proximité de Prince Rupert. Cependant, une utilisation efficace de ces terres ne sera possible que si l'on dispose de données adéquates au sujet du terrain.

Le présent rapport décrit et explique à fond les matériaux sédimentaires non consolidés et les formes de relief observées dans la région de Smithers, Terrace et Prince Rupert, et rend compte des processus géologiques qui ont contribué à façonner cette région à la fin du Quaternaire. L'information contenue dans le rapport est d'une importance capitale pour les personnes désireuses de se renseigner sur le caractère et la répartition des sols agricoles, la nature des conditions des fondations, le lieu et l'étendue des aggrégats de construction et des aquifères et la nature des risques naturels présents dans cette région.

Le directeur général de la
Commission géologique du Canada
*R.A. Price*

OTTAWA, mars 1984

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# QUATERNARY GEOLOGY AND GEOMORPHOLOGY, SMITHERS-TERRACE-PRINCE RUPERT AREA, BRITISH COLUMBIA


### *Abstract*

*The Smithers-Terrace-Prince Rupert area is located in west-central British Columbia and includes parts of the Coast, Skeena, and Hazelton mountains, Hecate Depression, Nass Basin, and Interior Plateau. It is an area of rugged mountains which are thinly mantled with Quaternary sediments and deep valleys which in places contain thick unconsolidated deposits. Quaternary sediments in the study area record at least one major period of glaciation and one or two nonglacial intervals.*

*The oldest exposed Quaternary sediments, identified only in Bulkley Valley, comprise silt, sand, and gravel deposited during the later part of the penultimate (Olympia) nonglacial interval and/or the early part of the last (Fraser) glaciation. These sediments accumulated during a period of valley-floor aggradation within a regional physiographic setting similar to that of the present.*

*Deposits of the Fraser Glaciation occur throughout the study area and consist of till, glaciofluvial, glaciolacustrine, glaciomarine, and deltaic sediments. Fraser glaciers advanced from the mountains into major valleys and coastal lowlands. At the height of glaciation a complex of confluent valley and piedmont glaciers enveloped all land areas, except some high peaks and montane uplands, and terminated on the continental shelf west of the study area. Deglaciation occurred by downwasting and complex frontal retreat. Early during deglaciation about 13 500-14 000 years ago, the ice front in Hecate Strait retreated rapidly eastward, partially in response to rising sea levels caused by water transfers from ice sheets to oceans. Ice soon became restricted to valley tongues which persisted until about 10 000 years ago. During glacier retreat, the sea transgressed Skeena Valley and the Kitsumkalum-Kitimat trough to the vicinity of Terrace, and glacial lakes formed at several other localities. Large amounts of sediment were transported by meltwater streams from receding glaciers and deposited on floodplains, deltas, and on the floors of lakes and the sea.*

*Alluvial, colluvial, lacustrine, marine, and organic deposits have accumulated during the present (postglacial) nonglacial interval. Major slope erosion and valley aggradation occurred during and immediately after deglaciation, but as vegetation became established and slopes stabilized, streams entrenched older deposits and achieved their modern regimes.*

### *Résumé*

*La région de Smithers-Terrace-Prince Rupert se situe au centre-ouest de la Colombie-Britannique. Elle englobe partiellement la chaîne Côtière et les chaînons Skeena et Hazelton, la dépression d'Hécate, le bassin de la Nass et le plateau Intérieur. Il s'agit d'un terrain très accidenté aux montagnes couvertes d'une mince couche de sédiments du Quaternaire et creusé de vallées profondes qui, par endroits, contiennent des épaisseurs considérables de dépôts non consolidés. Les sédiments du Quaternaire recouvrant la région à l'étude rendent compte d'au moins une glaciation majeure et d'un ou de deux intervalles non glaciaires.*

*Il n'y a que dans la vallée de la rivière Bulkley que l'on rencontre des affleurements des plus anciens sédiments du Quaternaire; ces derniers se composent de limon, de sable et de gravier mis en place à la fin de l'avant-dernier intervalle non glaciaire (Olympia) ou au début de la dernière glaciation (Fraser). Ces sédiments se sont accumulés au cours d'une période d'aggradation du fond de la vallée, dans un milieu géomorphologique régional semblable au milieu actuel.*

*Les dépôts de la glaciation de Fraser se rencontrent dans toute la région qui fait l'objet de la présente étude et se composent de till, ainsi que de sédiments fluvio-glaciaires, glaciolacustres, glaciomarins et deltaiques. Au sortir des montagnes, les glaciers du Fraser ont progressé dans des vallées importantes et des basses-terres côtières. A l'apogée de la glaciation, plusieurs glaciers de vallée et de piémont confluents ont recouvert toutes les terres, sauf certains sommets et certaines zones plus élevées de la montagne, pour finalement s'arrêter sur le plateau continental, à l'ouest de la région à l'étude. La déglaciation s'est effectuée par fusion sur place et par retraite des fronts glaciaires. Au début de la déglaciation, il y a environ 13 500 à 14 000 ans, le front glaciaire présent dans le détroit d'Hécate a reculé rapidement vers l'est, en partie sous l'effet de l'élévation du niveau de la mer causée par des échanges d'eau entre les glaciers et les océans. En peu de temps, la glace a été réduite à des langues de vallée qui ont persisté jusqu'à il y a environ 10 000 ans. Au cours du recul des glaciers, la mer a transgressé la vallée de la rivière Skeena et la dépression de Kitsumkalum-Kitimat au voisinage de Terrace, et des lacs glaciaires se sont formés à plusieurs autres endroits. Des sédiments ont été transportés en grandes quantités par les eaux de fonte des glaciers en recul pour se déposer sur des plaines d'inondation, sur des deltas et au fond de la mer et de certains lacs.*

*Des dépôts alluviaux, colluviaux, lacustres, marins et organiques se sont accumulés au cours du présent intervalle non glaciaire (post-glaciaire). Pendant la déglaciation et tout de suite après, la région a subi l'effet des processus importants d'érosion des talus et d'aggradation des vallées mais, à mesure que le couvert végétal s'est constitué et que les talus se sont stabilisés, les cours d'eau ont entaillés les dépôts plus anciens et progressivement atteint leurs régimes actuels.*

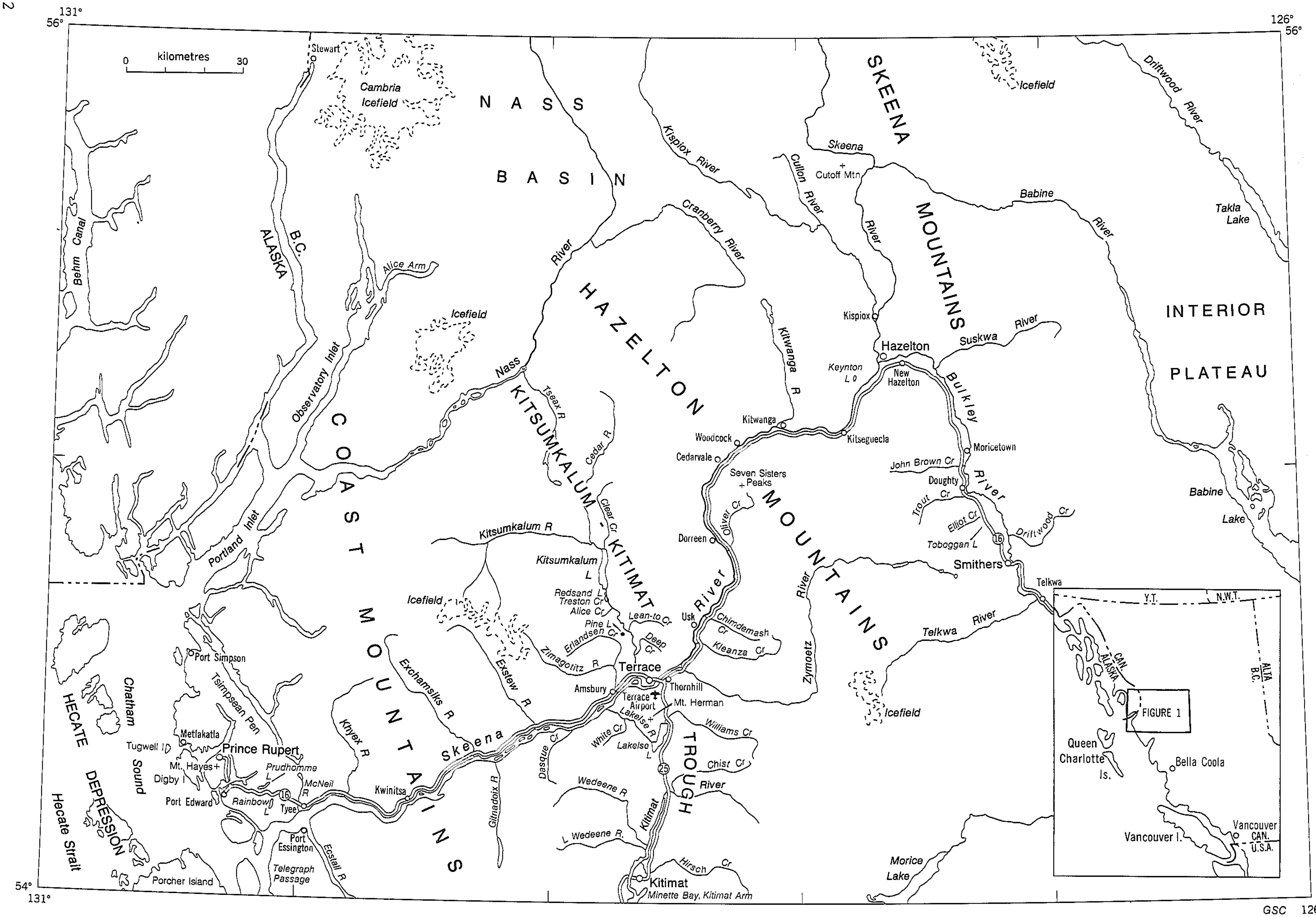


*Figure 1.* *Index map.*

## INTRODUCTION

### *General Statement*

The Smithers-Terrace-Prince Rupert study area is located in west-central British Columbia between 54° and 56°N and 126° and 131°W (Fig. 1). Surficial mapping and related geological studies were undertaken in accessible valleys of this area, specifically in Bulkley Valley north of Smithers, in Skeena Valley from Kispiox to the Pacific Ocean, and in the broad valley containing Kitsumkalum, Lakelse, and Kitimat rivers (henceforth referred to as the "Kitsumkalum-Kitimat trough"). This report is concerned mainly with the Quaternary geology and geomorphology of these valleys, although some observations pertain to the larger study area.

### Environmental Setting

The study area consists of rugged mountains cut by deep valleys (Fig. 2). The main valleys of the study area lie within the Coastal Western Hemlock and Sub-Boreal Spruce biogeoclimatic zones of Krajina (1969, 1973) (Fig. 3). At higher elevations are the Mountain Hemlock, Engelmann Spruce-Subalpine Fir, and Alpine Tundra zones. Most of the area below about 1500 m was forested prior to human settlement, but large parts of the more accessible valleys have been cleared during this century in support of the forest industry, agriculture, and other activities of man.

Precipitation in the study area, as elsewhere in British Columbia, is controlled by topography and the predominant flow of moisture-laden air towards the east (Fig. 4, Table 1). In the mountains near the coast, mean annual precipitation exceeds 2500 mm and locally is greater than 3500 mm (Farley, 1979). Somewhat lower precipitation (1000-2500 mm/a) occurs within the Kitsumkalum-Kitimat trough. There is a pronounced decrease in precipitation east from the Coast Mountains towards the British Columbia interior; in Bulkley Valley mean annual precipitation is only 400-500 mm.

Air temperature, like precipitation, is strongly influenced by topography (Fig. 5, Table 1). Winter temperatures in the study area decrease with increasing elevation and distance inland. For example, at Prince Rupert (52 m elevation) on the coast, the mean January temperature is about 1.8°C; in contrast, at Smithers (515 m) in Bulkley Valley, it is -10.5°C (Atmospheric Environment Service, N.D.). Summer temperatures also vary as a function of elevation. Mean July temperatures in the main valleys are about 14-17°C, several degrees higher than on mountain tops.

### Population and Industry

All settlements are in the main valleys. The principal urban centres and their populations as of 1976 are: Prince Rupert, 14 754; Kitimat, 12 570; Terrace, 10 251; and Smithers, 3783 (Canada Department of Energy, Mines and Resources, 1980). These communities are connected by highways and a railway. Major airports are located at Smithers, Prince Rupert, and Terrace.

Forestry, fishing, agriculture, smelting, and mining are the main industries. One or more sawmills are present in most large communities, and pulp and paper mills are located at Kitimat and near Prince Rupert. Important commercial tree species in the area include western and mountain hemlock (**Tsuga heterophylla, Tsuga mertensiana**), amabilis and subalpine fir (**Abies amabilis, Abies lasiocarpa**), western red cedar (**Thuja plicata**), yellow cedar (**Chamaecyparis nootkatensis**), Sitka, white and Engelmann spruce (**Picea sitchensis, Picea glauca, Picea engelmannii**), and lodgepole pine (**Pinus contorta** var. **latifolia**).

Several fish processing plants and canneries are located at Prince Rupert and nearby coastal villages. Catches of salmon and groundfish, including halibut, by fleets based in these towns provide a major source of income to the region.

Agriculture is based, in large part, on mixed farming and ranching. The main agricultural products are hay and beef and dairy cattle. Most agricultural activity is concentrated in Bulkley Valley, but there is substantial cattle grazing in Skeena Valley near Hazelton and Kitwanga and in Kispiox Valley. Specialty crops such as potatoes and vegetables are grown on a small scale in the Terrace area and at a few other localities.

A major aluminum smelter (Alcan Smelters and Chemicals Ltd.) is located at Kitimat. With a rated annual capacity of about 295 000 tonnes, this is one of the largest aluminum smelters in the world and is a major source of employment at Kitimat. The smelter was built in the 1950s to take advantage of inexpensive hydroelectric power, easy tidewater access, and offshore supplies of raw materials. With the exception of energy, the major raw materials come from foreign sources, and most of the finished product (aluminum ingot) is exported by sea to markets in the United States and elsewhere. The power for the electrolytic furnaces is derived from the Tweedsmuir Lake chain (Nechako Reservoir) and developed at Kemano for transmission to Kitimat. The townsite of Kitimat was constructed at the same time as the smelter and is one of the first planned communities in the province. The availability of abundant inexpensive power and a stable work force are stimulating economic growth at Kitimat. Recently, a large methanol plant was opened there, and the town is being promoted as a future petrochemical and industrial centre on the north coast of British Columbia.

Mining in recent years has directly employed several hundred people in the study area. Two large open-pit porphyry copper mines (Granisle and Bell (Newman)) operate on Babine Lake, and an open-pit molybdenum mine (Kitsault) recently was opened at the head of Alice Arm. In addition, small amounts of silver and gold are mined near Hazelton and Smithers.

Considerable economic activity in the study area centres on cargo transportation. Deep-water ports at Kitimat and Prince Rupert are loci of barge, freighter, and rail traffic. Port facilities in the vicinity of Prince Rupert are being expanded to handle anticipated large coal shipments from northeastern British Columbia and expanded grain exports from the Prairies.

In addition to the primary industries cited above, tourism provides a substantial source of revenue to the region. There are small provincial parks, all under 10 000 ha in size, within the main valleys. Salmon and steelhead fishing in Skeena and Kitimat rivers and their tributaries attract a large number of visitors each year. Finally, Prince Rupert is a terminus for car and passenger ferries travelling to Alaska and the Queen Charlotte Islands.

### *Previous Work*

Although many geologists have worked in the Smithers-Terrace-Prince Rupert area, little published information exists on the surficial geology of this part of British Columbia. Limited information on physiography and surficial geology is found in some bedrock geology reports dealing with various parts of the region. The most notable of these is a report by Duffell and Souther (1964), in which unconsolidated deposits in the southern Kitsumkalum-Kitimat trough are described and a deglacial history for the area proposed. Additional information on surficial deposits and physiography is contained in geological reports by Dawson (1881b),

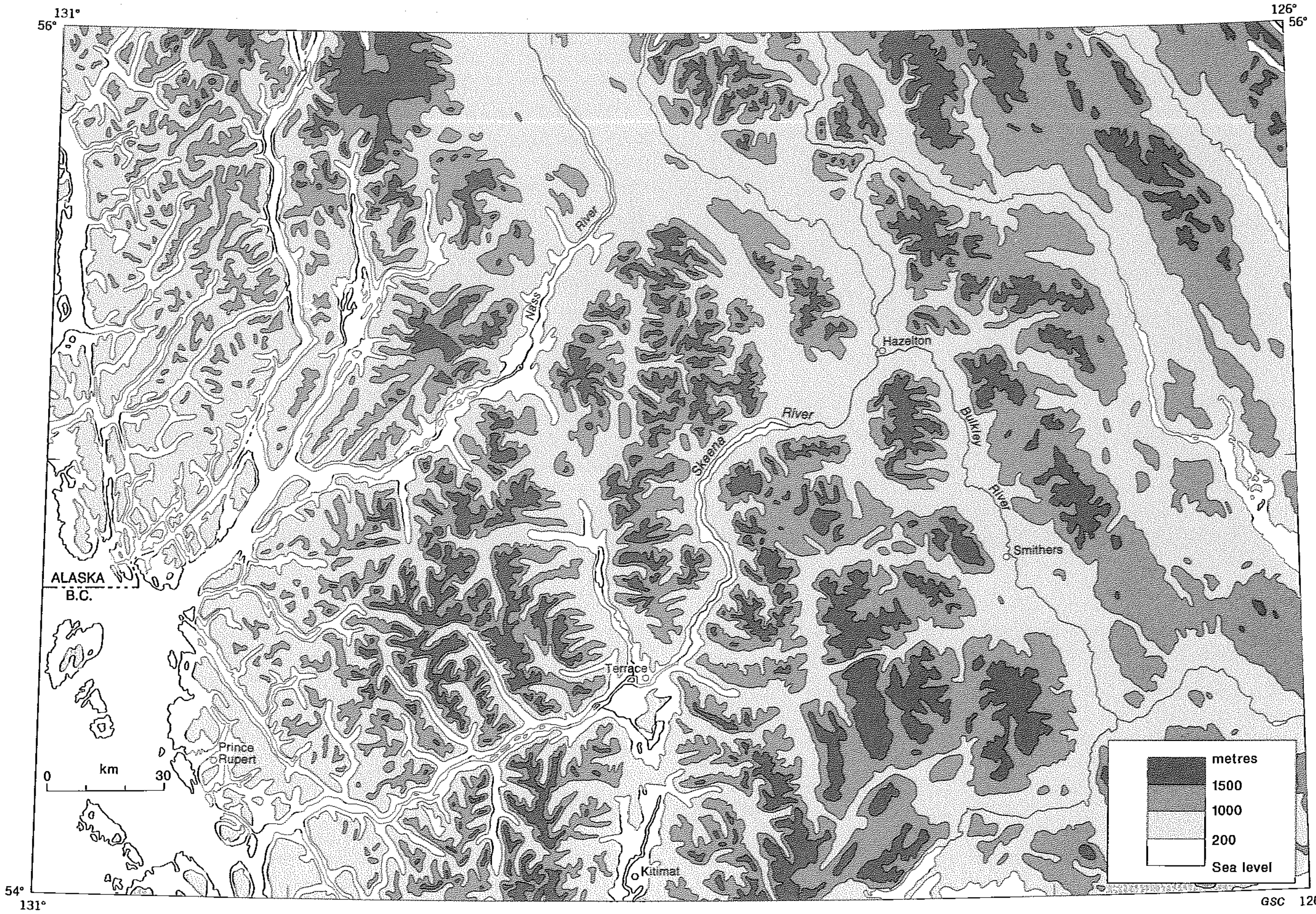


***Figure 2.*** *Topography of the study area.*

McConnell (1914), O'Neill (1919), Dolmage (1923), Hanson (1923, 1924, 1925a, b, 1926), Kindle (1937a, b, 1954), Sutherland Brown (1960), and Hutchison (1967, 1982). Published inventories of environmental information for Skeena and Kitimat river estuaries (Hoos, 1975; Bell and Kallman, 1976) also contain short sections on surficial geology.

Economic development at Terrace and Kitimat during the last three decades and the recent expansion of port facilities at Prince Rupert have led to a variety of engineering and Quaternary geology studies in these areas. Hardy and Ripley (1954) conducted geotechnical studies at Kitimat to determine potential settlement of the aluminum smelter there. Armstrong (1966a, b) investigated the unconsolidated sediments of the southern Kitsumkalum-Kitimat trough following destructive landslides in the vicinity of Lakelse Lake in 1962; he commented on the timing and character of deglaciation of the Terrace-Kitimat area at the close of the Pleistocene. A proposal in the early 1970s to construct an oil pipeline from the British Columbia interior to tidewater at Kitimat sparked surficial geology studies in the Smithers-Terrace-Prince Rupert area by the Geological Survey of Canada. Clague (1977b, 1978b), the main participant in these investigations, produced a surficial geology map of the southern Kitsumkalum-Kitimat trough and commented on potential natural hazards in some of the large valleys of the study area. In addition, Clague and Hicock (1976) summarized the sand and gravel resources of Kitimat, Terrace, and Prince Rupert, and Fair (1978) reported on the stability of glaciomarine sediments between Kitimat and Terrace. At the same time that field studies were being conducted by Clague for the Geological Survey of Canada, personnel of the British Columbia Ministry of Environment were systematically mapping landforms and unconsolidated sediments in the Terrace-Prince Rupert region. Unpublished 1:50 000-scale terrain maps resulting from this study and covering NTS 103I (Terrace) and part of 103J (Prince Rupert) are available from the Ministry of Environment. Additional studies of sites slated for economic development have been made by geotechnical consultants, and some of their reports contain information on surficial geology. In most cases, however, the reports are confidential or of restricted distribution and thus are not referenced or discussed further here.

Useful information on the surficial sediments and Quaternary history of the study area is contained in soils reports and maps by Farstad and Laird (1954) and Runka (1972), and in geological reports on nearby offshore areas by Luternauer (1976), Bornhold (1977), Luternauer and Swan (1978), Swan (1978), Swan and Luternauer (1978), and Prior et al. (1982). Luternauer (1976) reported on the sediments and sedimentary environments of the Skeena River delta. Bornhold (1977) described the succession of Quaternary sedimentary units underlying the sea floor of Douglas Channel and Kitimat Arm, a major fiord terminating at Kitimat. Luternauer and Swan (1978), Swan (1978), Swan and Luternauer (1978), and Prior et al. (1982) reported on submarine landslide deposits at the head of Kitimat Arm.

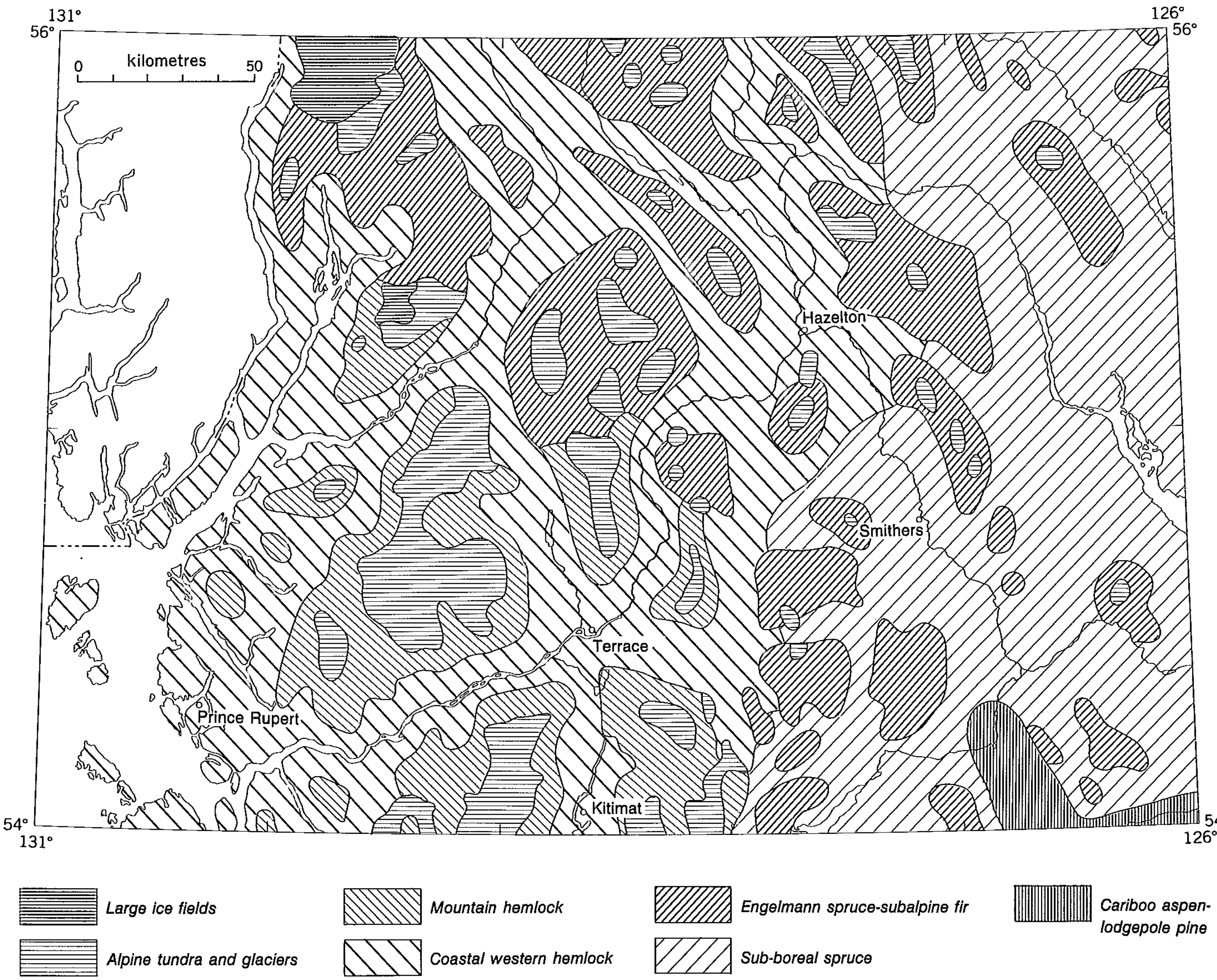


***Figure 3.*** *Biogeoclimatic zones (adapted from Farley, 1979, Map 23; original compilation by Krajina, 1973).*

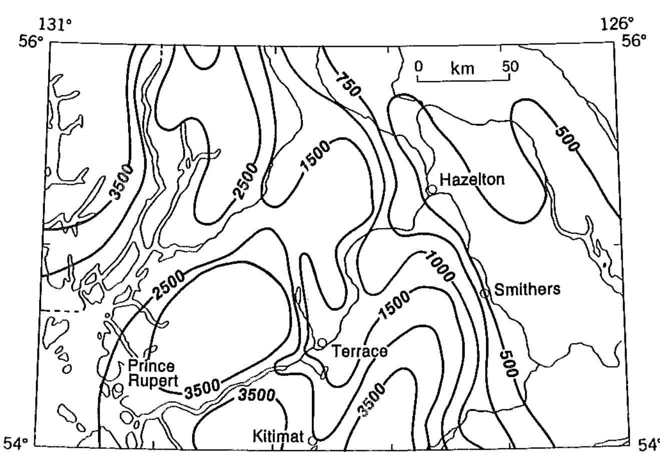


***Figure 4.*** *Mean annual precipitation (mm); positions of isohyets are approximate (adapted from Farley and Rheumer, 1965-1966, Map 17).*

Paleoecological studies have been made on fossiliferous glaciomarine sediments in the Kitsumkalum-Kitimat trough (Smith, 1965, 1970) and on peat deposits in the Prince Rupert area (Heusser, 1960; Banner, 1983; Banner et al., 1983). Smith (1970) showed that late Pleistocene foraminiferal faunas in the Kitsumkalum-Kitimat trough were impoverished and existed in cool (0 to 15°C) water of relatively low salinity (15 to 20°/₀₀). Heusser (1960) examined two peat sections in the Prince Rupert area. A 4-m thick peat at Rainbow Lake, 19 km southeast of Prince Rupert, contains a record of local vegetation dating back to the end of the last glaciation. The earliest arboreal vegetation at this site was dominated by willow (**Salix**), alder (**Alnus**), and lodgepole pine (**Pinus contorta**), and was adapted to cool moist climatic conditions. During a subsequent warm interval (Hypsithermal), hemlock (**Tsuga mertensiana** and **Tsuga heterophylla**), and spruce (**Picea sitchensis**) attained dominance over pine and willow, with alder remaining abundant. A return to cooler and perhaps moister conditions during late postglacial time was marked by an increase in

**Table 1.** Summary of meteorological data for six sites in the study area

| Climatic station | Climatic parameter | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stewart | mean temperature (°C) | -4.8 | -2.2 | 0.8 | 4.7 | 9.7 | 12.9 | 14.3 | 13.8 | 10.3 | 5.3 | 0.0 | -3.3 | 5.1 |
| | mean precipitation (mm) | 187 | 147 | 121 | 93 | 66 | 79 | 84 | 110 | 184 | 359 | 203 | 212 | 1843 |
| Prince Rupert | mean temperature (°C) | 1.8 | 2.7 | 3.7 | 6.2 | 9.6 | 11.8 | 13.6 | 13.9 | 12.0 | 8.7 | 5.1 | 2.9 | 7.7 |
| | mean precipitation (mm) | 214 | 209 | 180 | 184 | 123 | 107 | 121 | 147 | 242 | 359 | 269 | 259 | 2415 |
| Kitimat | mean temperature (°C) | -3.9 | 0.1 | 2.2 | 6.1 | 10.3 | 13.7 | 16.8 | 16.4 | 12.9 | 7.5 | 2.1 | -1.3 | 6.9 |
| | mean precipitation (mm) | 355 | 270 | 219 | 199 | 78 | 77 | 77 | 96 | 226 | 460 | 384 | 387 | 2826 |
| Terrace A | mean temperature (°C) | -5.7 | -0.9 | 1.8 | 5.7 | 10.2 | 14.0 | 16.2 | 15.6 | 11.9 | 6.3 | 1.8 | -3.4 | 6.0 |
| | mean precipitation (mm) | 147 | 126 | 79 | 63 | 39 | 39 | 59 | 57 | 98 | 232 | 168 | 196 | 1301 |
| New Hazelton | mean temperature (°C) | -9.8 | -4.3 | 0.3 | 4.9 | 10.1 | 13.4 | 15.2 | 14.4 | 10.2 | 5.2 | -1.1 | -6.7 | 4.3 |
| | mean precipitation (mm) | 44 | 29 | 15 | 21 | 31 | 46 | 51 | 46 | 61 | 57 | 46 | 43 | 490 |
| Smithers CDA | mean temperature (°C) | -10.5 | -5.8 | -1.7 | 3.8 | 8.8 | 11.9 | 14.1 | 13.6 | 9.7 | 4.3 | -2.8 | -8.2 | 3.1 |
| | mean precipitation (mm) | 48 | 28 | 22 | 21 | 35 | 44 | 48 | 42 | 39 | 55 | 54 | 56 | 490 |

Notes: Data from Atmospheric Environment Service (N.D.). Data are for the period 1941-1970.

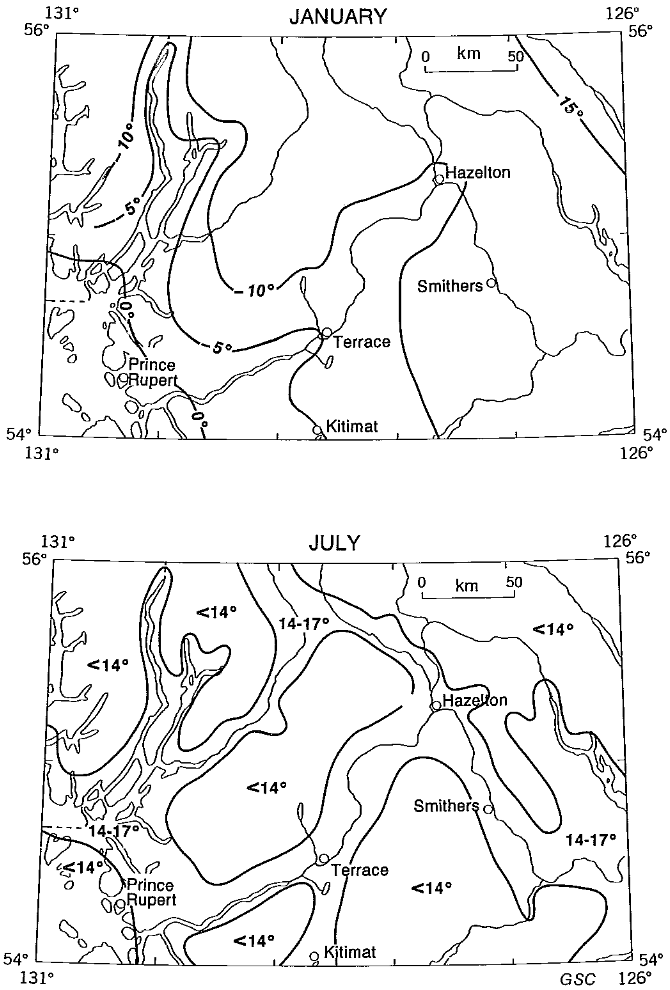


*Figure 5.* *Seasonal mean daily temperature (°C); positions of isotherms are approximate (adapted from Farley and Rheumer, 1965-1966, Maps 2 and 4).*

pine, hemlock, and spruce, and a decline in alder. Heusser's second peat section on the outskirts of Prince Rupert, although thicker (5.8 m) than that at Rainbow Lake, dates back only to the Hypsithermal interval. The record of middle and late postglacial vegetation, however, is similar at the two sites. An 8700-year pollen record from another bog in the Prince Rupert area was described and discussed by Banner (1983) and Banner et al. (1983). The vegetational succession at this site, from early coastal forest to bog, was interpreted by Banner and co-workers as having been controlled mainly by changes in substrate drainage rather than changes in climate.

Finally, the record of late Quaternary sea level changes in the Prince Rupert-Terrace-Kitimat area has been summarized by Fladmark (1975) and Clague (1975), and recently updated by Clague et al. (1982). Shorelines in the southern Kitsumkalum-Kitimat trough during deglaciation were up to 200 m higher than at present – a result of isostatic depression of the crust by the decaying Cordilleran Ice Sheet. As the region became free of glacier ice, the crust rebounded and the sea rapidly approached its present level relative to the land. Glaciomarine and deltaic sediments which dominate the Kitsumkalum-Kitimat trough were deposited during this short period of high sea levels at the close of the Pleistocene.

### *Field Work and Acknowledgments*

The major valleys of the Smithers-Terrace-Prince Rupert area are readily accessible via a network of highways and logging roads. Geological investigations and mapping were concentrated in these valleys because of the ease of access and the relative abundance of natural and man-made exposures. Investigations were conducted by vehicular and foot traverses in conjunction with airphoto interpretation. Forested areas were mapped mainly from aerial photographs with little or no field checking.

Access is poor outside of the main valleys, thus mountain areas were not mapped. In general, the unconsolidated deposits in the mountains are thin and highly variable in character; thick continuous deposits, mainly colluvium and alluvium, are common only in intramontane valleys. Additional information on the unconsolidated materials of these poorly accessible mountain areas is provided on terrain maps available from the British Columbia Ministry of Environment; these maps were compiled largely from aerial photographs supplemented with ground observations made during helicopter traverses.

Field work south and west of Terrace was conducted during the summer of 1975 with the assistance of S.R. Hicock and S. Marshall. Additional work was undertaken there, and other parts of the region were mapped, during the summers of 1976 and 1977 with A. Wallingford and A.E. Fair assisting. J. Jordan helped compile the surficial geology maps.

Much of the sediment analytical data presented in this report was provided by the Geological Survey of Canada (GSC), and special thanks are extended to W.E. Podolak for Atterberg limits and grain-size analyses and to R.N. Delabio for clay-mineral determinations. Bondar-Clegg and Company performed heavy metal analyses on sediment samples. W. Blake, Jr. (GSC) supplied most of the radiocarbon dates cited in this report.

The writer benefited from discussions with J.E. Armstrong (formerly with GSC) on the Quaternary geology of the study area. Armstrong, R.J. Fulton (GSC), J.M. Ryder (formerly with B.C. Ministry of Environment), and A.N. Boydell (Environment Canada) made visits to the field area, and their assistance and advice are gratefully acknowledged. Fulton critically reviewed a draft of the manuscript.

## BEDROCK AND PHYSICAL FEATURES

### *Bedrock*

The study area includes portions of two major northwest-trending geological zones in the Canadian Cordillea – the Coast-Cascades Belt and the Intermontane Belt (Fig. 6; Tipper et al., 1981). These two zones, together with the Insular-St. Elias Belt to the west, form the eugeosynclinal portion of the Cordillera in which volcanic flows and volcanogenic sediments accumulated to great thicknesses in subsiding basins during Paleozoic and Mesozoic time.

#### Coast-Cascades Belt

The major element of the Coast-Cascades Belt is the Coast Plutonic Complex, which in the study area consists mainly of Paleozoic to early Tertiary granitic rocks and Proterozoic to Paleozoic high-grade metamorphic rocks (Roddick and Hutchison, 1974; Hutchison et al., 1979). The most abundant granitic rocks are quartz diorite and granodiorite; diorite and quartz monzonite are less common; and gabbro and granite are rare. Some of the granitic rocks occur in partly allochthonous zoned plutons that may root within, and form an integral part of, a complex of gneiss and migmatite located in the centre of the Coast-Cascades Belt (i.e., the Central Gneiss Complex; Hutchison, 1970; Hollister, 1979). Early major recumbent folds in the Central Gneiss Complex north of Skeena River have east-west axes and may verge north or south; in contrast, younger structures trend north-northwest and typically have steep dips. Large recumbent structures between Douglas Channel and Skeena River verge west. Metasedimentary and metavolcanic schists forming discontinuous, northerly plunging synformal screens occur locally within the Central Gneiss Complex and between plutons.

#### Intermontane Belt

The Coast-Cascades Belt is bordered on the east by the Intermontane Belt. Within the study area, this belt is dominated by sedimentary and volcanic rocks of early Jurassic-Cretaceous age, intruded by Jurassic and late Cretaceous-early Tertiary felsitic to porphyritic plugs (Hutchison et al., 1979; Tipper et al., 1979). In detail, late Jurassic marine sedimentary rocks of the Bowser Lake Group are overlain locally by late Cretaceous-early Tertiary nonmarine sedimentary rocks of the Sustut Group and by early Cretaceous, mainly marine, sedimentary and volcaniclastic rocks of the Skeena Group. Near the south end of the study area, early and middle Jurassic volcanics of basaltic to rhyolitic composition (Hazelton Group) are dominant. The Jura-Cretaceous rocks were extensively block-faulted during Cretaceous and Tertiary time.

### *Tectonics*

The history, present disposition, and structure of the eugeosynclinal rocks of the Canadian Cordillera have been explained in terms of accretion of distinct tectonostratigraphic assemblages, or terranes, to the margin of the North American continent during the Mesozoic (Monger, 1977; Monger and Price, 1979; Coney et al., 1980). Much of the plutonic and volcanic activity in the western Cordillera is related to accretionary processes and to the establishment of a magmatic arc above a late Mesozoic to early Cenozoic subduction zone (Monger et al., 1972). Plutonism and orogenesis culminated in the northern Cordillera of British Columbia in the Eocene. A marked reduction in thermal activity in this area shortly thereafter resulted from the cessation of rapid subduction and a change to transform motion along plate boundaries north of about 52°N (Coney, 1978).

Crustal thickening during the terminal Eocene orogenic episode led to uplift of mountains in the north (Hollister, 1979). Uplift and denudation probably continued during the middle Tertiary, although at low rates in most areas (Parrish, 1981). Accelerated uplift south of 52°N during the Pliocene and Quaternary elevated a broad region to form the present southern Coast Mountains. In contrast, uplift rates in the north were relatively low during late Cenozoic time ($\leq$0.2 km/Ma vs. >0.5 km/Ma south of 52°N), and the mountains that formed there were not as high as in the south (Parrish, 1981).

### *Physiography*

The study area lies within the Western System and Interior System of the Canadian Cordillera (Fig. 7, Table 2). The boundary between these two physiographic regions is approximately the same as that separating the two major geological belts described in the preceding section (i.e., the Coast-Cascades and Intermontane belts). The Western and Interior systems may be subdivided into smaller physiographic regions according to the classifications of Bostock (1948) and Holland (1964), as shown in Table 2. Table 2 provides a

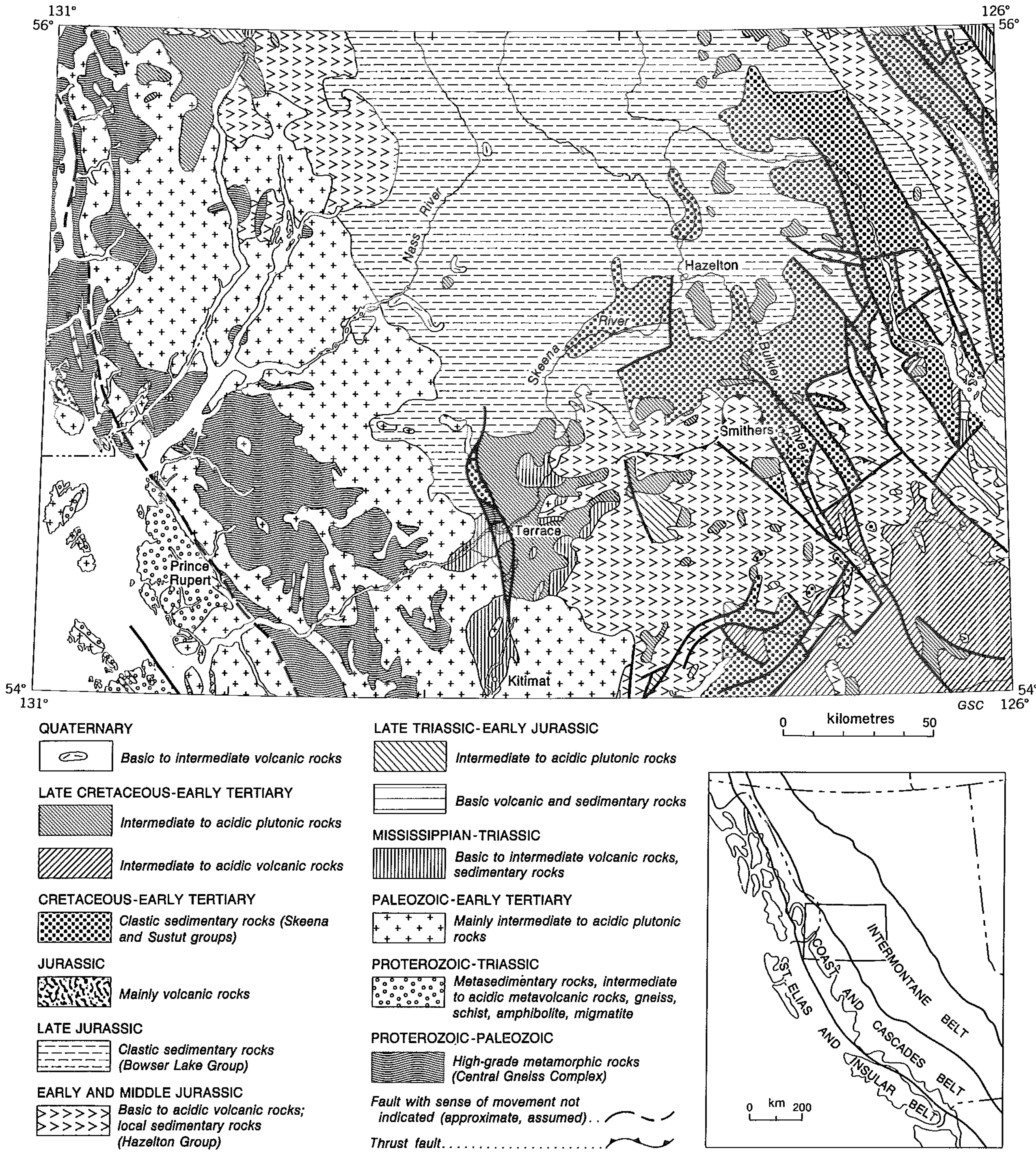


***Figure 6.*** *Generalized bedrock geology (adapted from Tipper et al., 1981).*

skeletal outline of the physiography of the study area but does not adequately describe local physiographic complexities; the latter are better shown by focusing on the basic physiographic elements of the region, namely mountains, valleys, coastal lowlands, and plateaus (Fig. 2, 7, 8).

## Mountains

Mountains include those parts of the landscape characterized by a series of high summits or ridges standing well above the surrounding countryside and having restricted summit areas (Fig. 9). Mountain areas contain valleys, because crests and ridges must be separated by ravines, troughs, and basins to restrict their summit areas.

Mountains in the study area are bounded by large, deeply incised valleys (Fig. 10) and, in the Kitimat Ranges, by fiords. For the most part, the peaks are 1800-2400 m in elevation, although some reach to almost 2800 m. Locally within the Kitimat Ranges the peaks are round-topped and dome-like, presenting a rather uniform summit elevation above which matterhorns project (Holland, 1964). In other parts of the region, mountains are serrate and extremely rugged.

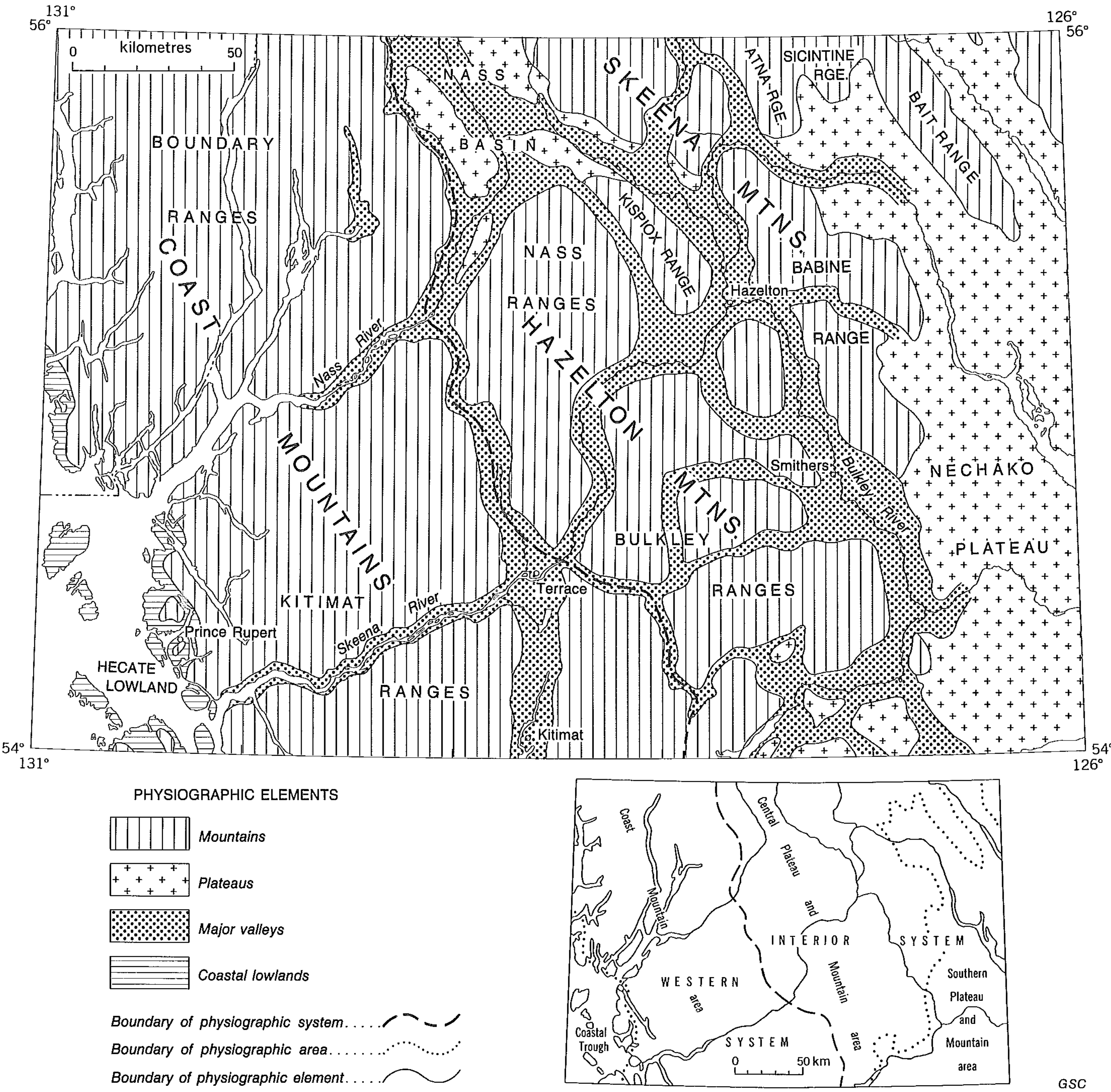


*Figure 7.* *Physiographic elements and subdivisions of the study area.*

Valley glaciers and small ice fields occur in the high mountains of the study area, but ice cover is less extensive here than in the ranges to the north and south. The mountains have been heavily glaciated in the past, as attested by the presence of numerous cirques, many of which are presently free of ice.

## Valleys

Areas identified as valleys include both low-lying depressions that do not have their origins within any specific mountain range (e.g., Skeena Valley and the Kitsumkalum-Kitimat trough), and large valleys located within specific ranges (e.g., Khyex, Exchamsiks, Exstew, Zymoetz, and Telkwa valleys). All are presently occupied by rivers, but at times during the Pleistocene they served as channels down which glacier ice moved. Most valleys are underlain by thick Quaternary sediments.

The valleys of the study area vary widely in morphology and elevation. Relatively narrow, steep-walled troughs with floors below about 200 m elevation occur in the Kitimat Ranges. In contrast, valleys in the Hazelton and Skeena mountains in the eastern part of the study area are relatively wide, are bordered by gentler slopes, and have floor elevations of about 600-900 m. Still different are the large

**Table 2.** Physiographic subdivisions of the study area

| System | Area | Subdivision: Primary | Subdivision: Secondary |
|---|---|---|---|
| Western System | Coastal Trough | Hecate Depression | Hecate Lowland |
| | Coast Mountain Area | Coast Mountains | Kitimat Ranges<br>Boundary Ranges |
| Interior System | Central Plateau and Mountain Area | Skeena Mountains | Babine Range<br>Atna Range<br>Bait Range<br>Sicintine Range |
| | | Nass Basin | |
| | | Hazelton Mountains | Nass Ranges<br>Kispiox Range<br>Bulkley Ranges |
| | Southern Plateau and Mountain Area | Interior Plateau | Nechako Plateau |

troughs transecting mountain ranges, for example Skeena, Bulkley, Kispiox, and Kitwanga-Cranberry valleys, and the Kitsumkalum-Kitimat trough.

Skeena River heads in the Skeena Mountains northeast of the study area and flows to the Pacific Ocean south of Prince Rupert in a valley ranging from about 2 to 15 km wide. West of Terrace, Skeena Valley is less than 5 km wide with a floor below 100 m in elevation, and has a U-shaped cross profile (Fig. 11). Northeast of Terrace to the vicinity of Dorreen, the valley remains narrow, although the bordering slopes are less steep than farther west. Northeast of Doreen, Skeena Valley broadens and gradually rises in elevation. At Kitwanga and north of Hazelton, it is intersected, respectively, by Kitwanga-Cranberry and Kispiox valleys which extend north-northwest into Nass Basin and have elevations of about 300-400 m at their southern ends.

Bulkley Valley (Fig. 12, 13) stretches northwest from Nechako Plateau to Skeena Valley at Hazelton. It is most prominent as a landform northwest of Telkwa where it is bordered by the Babine and Bulkley ranges. In this area, the valley ranges in width from about 5 to 20 km, narrowing towards the northwest, and its floor is about 300 to 600 m in elevation; bordering slopes are much less steep than those of lower Skeena Valley. Southeast of Telkwa, Bulkley Valley occurs within Nechako Plateau and is not as well defined physiographically as to the northwest.

The Kitsumkalum-Kitimat trough is a broad depression extending south from Nass Basin to the head of Douglas Channel. It cuts perpendicularly across Skeena Valley at Terrace. The trough is 1-15 km wide and its floor is below 300 m in elevation. The southern part of the trough is drained by Kitimat River and the northern part by Kitsumkalum, Cedar, and Tseax rivers.

### Coastal Lowlands

Coastal lowlands are low relief regions that are bordered by the sea and are below a few hundred metres in elevation. Within the study area, such lowlands are restricted to the mainland between Port Simpson and Prince Rupert and to adjacent offshore islands (Fig. 14, 15). This region forms part of the Hecate Lowland, a 15-40 km wide strip of low-lying country that extends for 600 km along the east side of the Coastal Trough (Fig. 7).

### Plateaus

Plateaus include flat, gently sloping, or hilly terrain standing well above valleys but below the level of surrounding mountains. Extensive plateau is restricted to the southeast corner of the study area, where Bulkley Valley extends southeastward into Nechako Plateau, a rolling hilly region that is mainly below 1500 m elevation. In this region, Nechako Plateau is bordered on the west by the Hazelton Mountains and on the north by the Skeena Mountains.

### Bedrock Control on Physiography

Bedrock structure and lithology appear to control the disposition of many valleys. For example, many fiords and valleys in the Kitimat Ranges have a northwest-southeast orientation parallel to the regional structural trend. Some of these are associated with belts of metamorphic rocks of the Coast Plutonic Complex, whereas others probably are located along fault zones. Northwest-oriented valleys in the eastern part of the study area (e.g., Bulkley Valley) are bordered by normal faults; the Kitsumkalum-Kitimat trough may be, in part, fault-controlled.

In contrast, some major valleys have no obvious structural control. Skeena Valley and Douglas Channel, for example, cut across the regional structural grain and apparently are not controlled by faults, folds, or lithology.

## *Drainage*

Almost the entire mapped part of the study area lies within the Skeena River drainage basin. Exceptions include the southern part of the Kitsumkalum-Kitimat trough which is drained by Kitimat River, and the westernmost Kitimat Ranges and Hecate Lowland near Prince Rupert, drained by small streams that flow directly to the sea.

The regional drainage pattern is dominated by a connected system of major valleys that represents the main preglacial drainage network of this part of west-central British Columbia. Although existing valleys in the study area probably predate the Pleistocene, patterns of stream flow almost certainly have shifted in response to the growth and decay of ice sheets. For example, a through-flowing river may have occupied Kitwanga-Cranberry valley at some time during or prior to the Pleistocene, thus connecting the drainage basins of Nass and Skeena rivers. At present, part of this valley lies within the Nass drainage basin and drains to the north, and the remainder is in the Skeena basin and drains to the south. The change from throughgoing to discontinuous drainage in Kitwanga-Cranberry valley perhaps resulted from differential glacial deepening of Nass and Skeena valleys, both of which are parallel to the main direction of Pleistocene glacier flow. Differential glacial erosion apparently left Kitwanga-Cranberry valley, which trends perpendicular to the main ice-flow direction, hanging above Nass and Skeena valleys, thus preventing the re-establishment of throughgoing drainage following glaciation. Other drainage anomalies in the study area are outlined in the next section of this report.


*Figure 8. Satellite image of the western part of the study area. Light-coloured areas are snow-covered mountains. The major north-south valley in which Kitimat and Terrace are located is the Kitsumkalum-Kitimat trough. Skeena Valley has a northeast-southwest orientation and crosses the Kitsumkalum-Kitimat trough at Terrace. ERTS image E-1481-19075-8.*

The preglacial drainage system has been modified in other ways by Pleistocene glaciers. Many valleys were enlarged and deepened by the glaciers that flowed down them. V-shaped preglacial valleys were transformed into classical U-shaped glacial troughs by this process. Major antecedent stream valleys transecting the mountains were subject to especially severe erosion by glaciers streaming westward at high velocity from major ice accumulation areas. The lower parts of these valleys were scoured to such great depths that they were flooded by the sea at the close of glaciation, giving rise to fiords. Several large fiords occur within and at the margins of the study area (e.g., Douglas Channel-Kitimat Arm, Observatory Inlet-Alice Arm). Parts of some of these fiords have been isostatically uplifted and filled with sediment since the end of the Pleistocene; for example, Skeena River west of Terrace flows in a valley that was a fiord at the close of the Pleistocene. An arm of the sea also occupied the southern Kitsumkalum-Kitimat trough at the same time; this body of water was continuous with that in Skeena Valley west of Terrace.

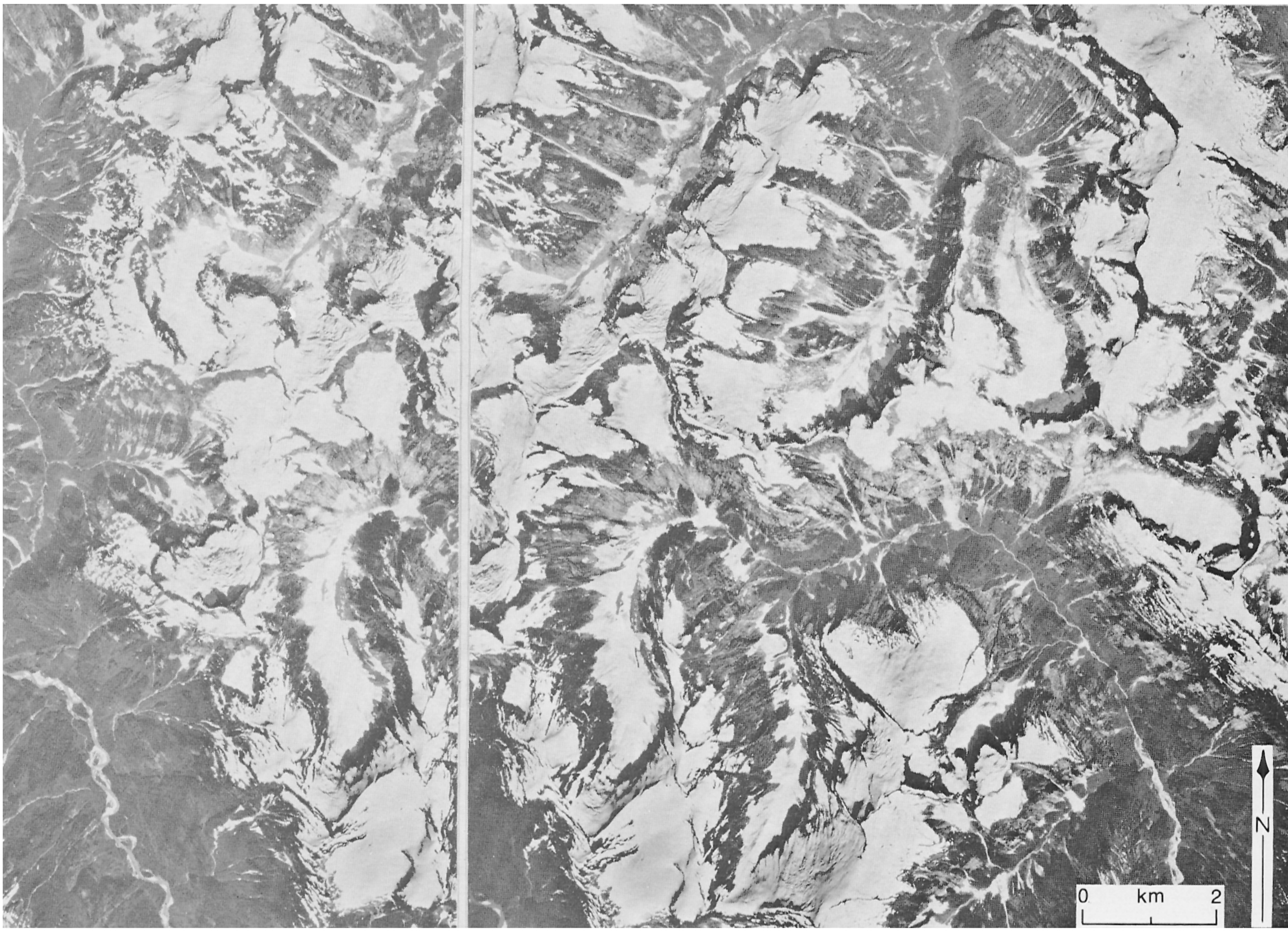


**Figure 9.** *Stereogram of typical mountain terrain in the study area (Kitimat Ranges near Exchamsiks River). Province of British Columbia photos BC5608-126, -127.*

**Figure 10**

*Hazelton Mountains and Skeena River near Hazeltcn. (GSC 203257-B).*

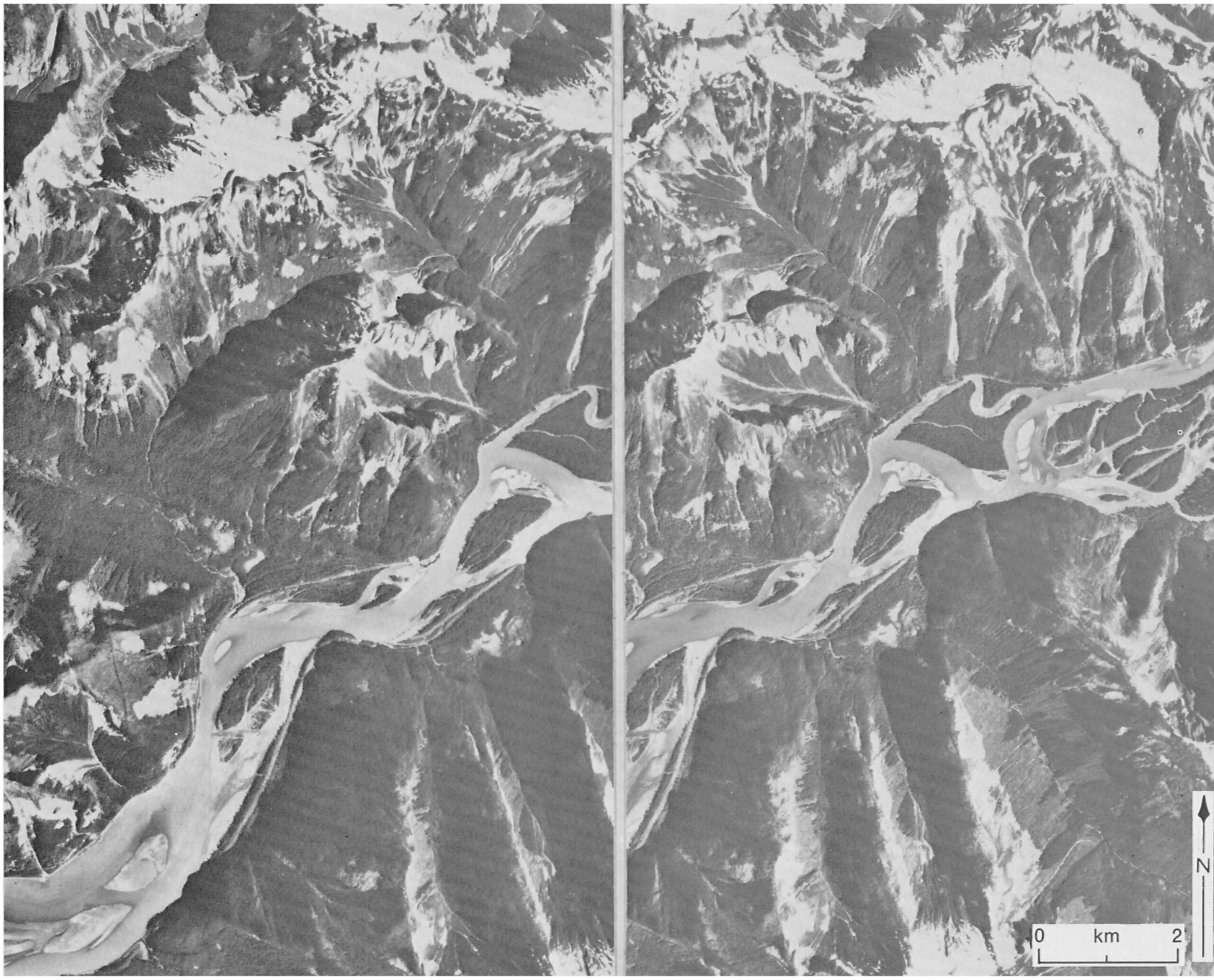


***Figure 11.*** *Stereogram of lower Skeena Valley and bordering mountains (Kitimat Ranges) near Kwinitsa. Province of British Columbia photos BC5619-027, -028.*

## Drainage Anomalies

The drainage history of the main valleys cannot be easily deciphered with available geological and geomorphic data. Underfit and barbed stream patterns, however, indicate that stream piracy and other types of drainage derangement have played a major role in producing the present pattern of stream flow. Several examples of drainage anomalies are given below.

(1) Between the mouth of Suskwa River and Hazelton, Bulkley River flows in a narrow deep bedrock gorge (Hagwilget-Bulkley Canyon) that is incised into the floor of Bulkley Valley (Fig. 16A, 17). In contrast, south of Suskwa River, Bulkley River occupies a relatively wide inner valley bounded by slopes consisting mainly of Quaternary sediments. Hagwilget-Bulkley Canyon was carved, at least in part, after lowermost Bulkley River was forced north of its interglacial course by differential melting of stagnant glacier ice at the close of the last glaciation. The old interglacial valley of the Bulkley was filled with sediment prior to deglaciation and thus was not available for reoccupation by the river.

(2) At its point of entry into Kispiox Valley, Skeena River abruptly flows east back into Babine Range for about 15 km, then swings southwest back through the mountains into Kispiox Valley (Fig. 16B). The easterly trending valley segment is narrow and perhaps has been occupied by Skeena River only recently (during late Quaternary time?). It seems likely that Skeena River at one time flowed directly into Kispiox Valley in the vicinity of Cullon Creek, while Babine River flowed more or less along the present course of Skeena River southeast of Cutoff Mountain, joining Kispiox River north of the present Skeena-Kispiox confluence. Relatively minor tributaries of Skeena and Babine rivers probably occupied the narrow easterly trending valley north of Cutoff Mountain. Easterly diversion of Skeena River through this valley may have resulted from disruption of drainage by Pleistocene glaciers.

(3) Kitsumkalum-Kitimat trough, like Kitwanga-Cranberry valley, is a major valley lacking a through-flowing river. Skeena River at one or more times in the past probably flowed south down the trough from the vicinity of Terrace rather than west down lower Skeena Valley. Kitsumkalum-Kitimat trough at times was an arm of the sea into which Skeena River discharged directly. At the close of the last glaciation, however, thick drift was deposited in the southern part of the trough, and the Skeena was forced to flow west towards Prince Rupert rather than south towards Kitimat.

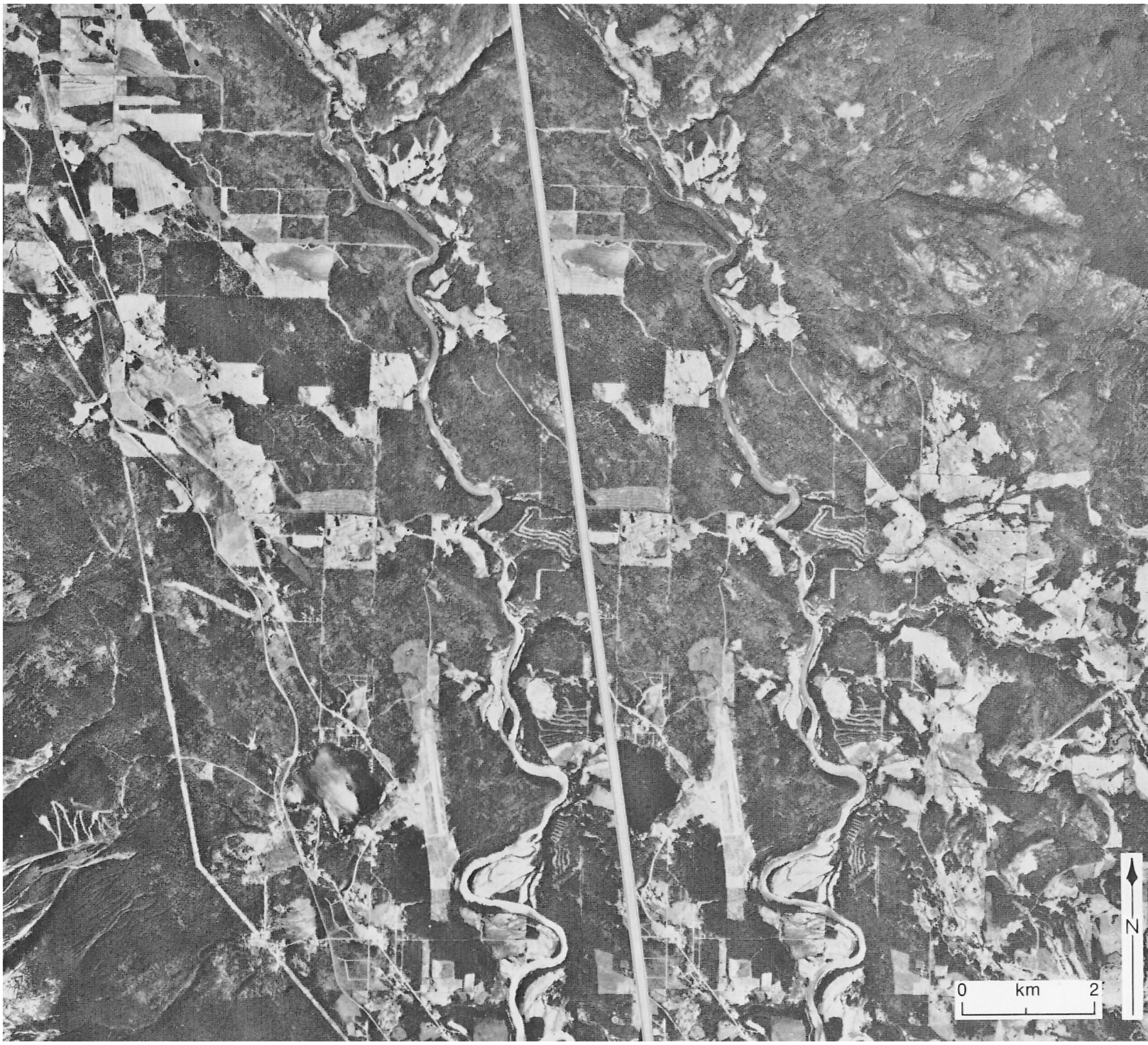


***Figure 12.*** *Stereogram of Bulkley Valley north of Smithers. Province of British Columbia photos BC5621-115, -116.*

(4) Many streams entering the Kitsumkalum-Kitimat trough from bordering mountain ranges flow south along the trough margins rather than directly to its centre as might be expected (Fig. 16C). Examples include Zymagotitz, Wedeene, and Kitimat rivers. These streams owe their peculiar courses, in part, to localization of meltwater flow along the margins of large outwash bodies that were accumulating in the Kitsumkalum-Kitimat trough during deglaciation and, in part, to southward diversion of flow at the edges of the downwasting, northward-retreating trunk glacier in the trough. The streams became incised along their courses before glacier ice disappeared from the area and thus were unable to flow more directly to the centre of the trough.

## Lakes

Lakes within the study area may be grouped into two genetic categories – those formed by alluvial damming during postglacial time and those formed by the action of glaciers during the Pleistocene. Alluvial-dammed lakes are relatively uncommon and, in general, are shallow and of small size. Most have formed behind alluvial fans built across valleys by tributary streams. Toboggan Lake north of Smithers is a typical example.

Glacially formed lakes may be subdivided into those produced mainly by glacial erosion and those impounded by Pleistocene sediments. The two groups are not mutually exclusive, because a lake in a glacially scoured basin may be partly dammed by sediments.

Lakes formed by glacial erosion are common in mountains bordering the main valleys and also occur on the floors of some major valleys. In general, they are small and vary in shape from elongate to very irregular. Most occupy basins scoured in bedrock, for example Prudhomme Lake east of Prince Rupert and cirque lakes throughout the study area. Some occupy basins which, although scoured in bedrock, are mantled by till and other glacial deposits, for example Keynton Lake southwest of Hazelton.

***Figure 13***

*Bulkley Valley and bordering mountains (Bulkley Ranges) near Smithers. (GSC 203257-C).*

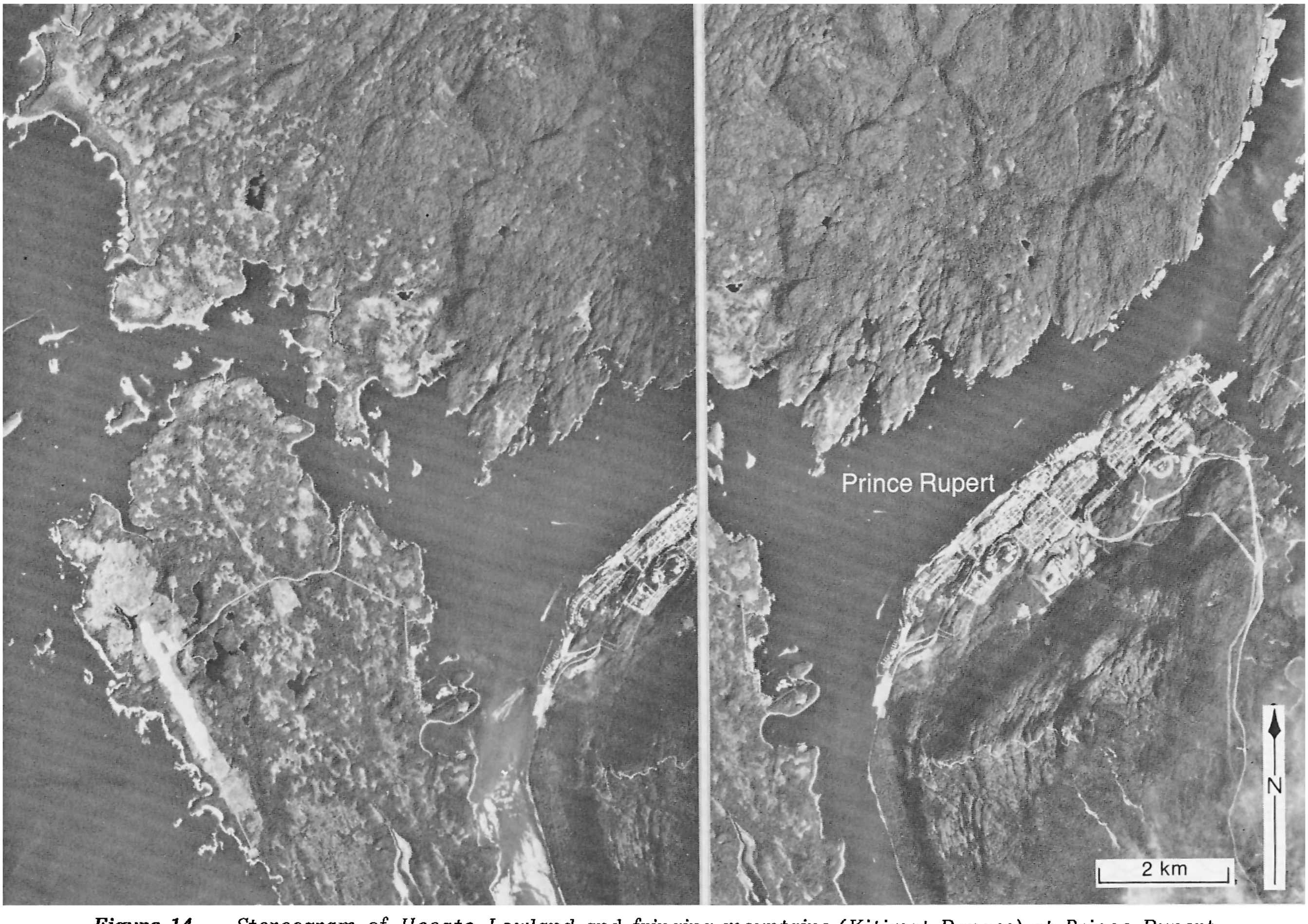


***Figure 14.*** *Stereogram of Hecate Lowland and fringing mountains (Kitimat Ranges) at Prince Rupert. Province of British Columbia photos BC5619-046, -047.*

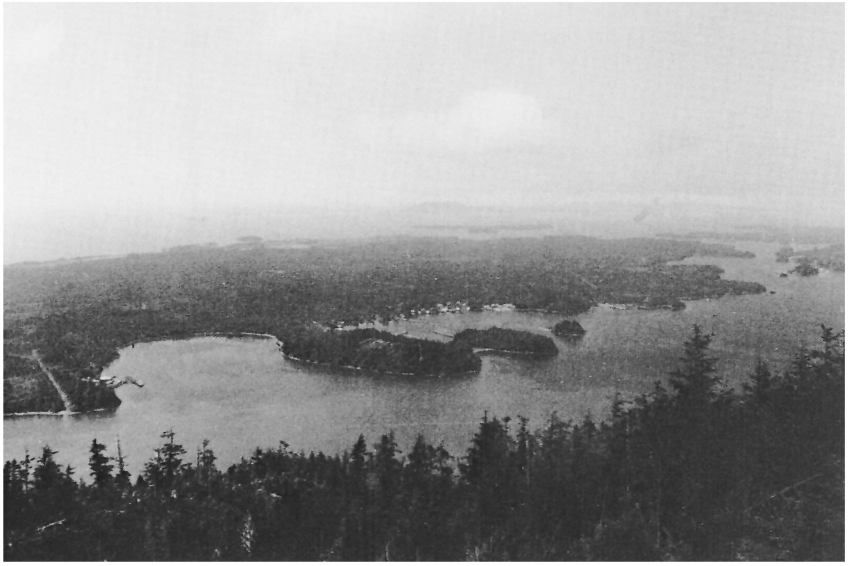

***Figure 15*** *(opposite)*

*Digby Island, an area of low relief forming part of Hecate Lowland. (GSC 203257-D).*

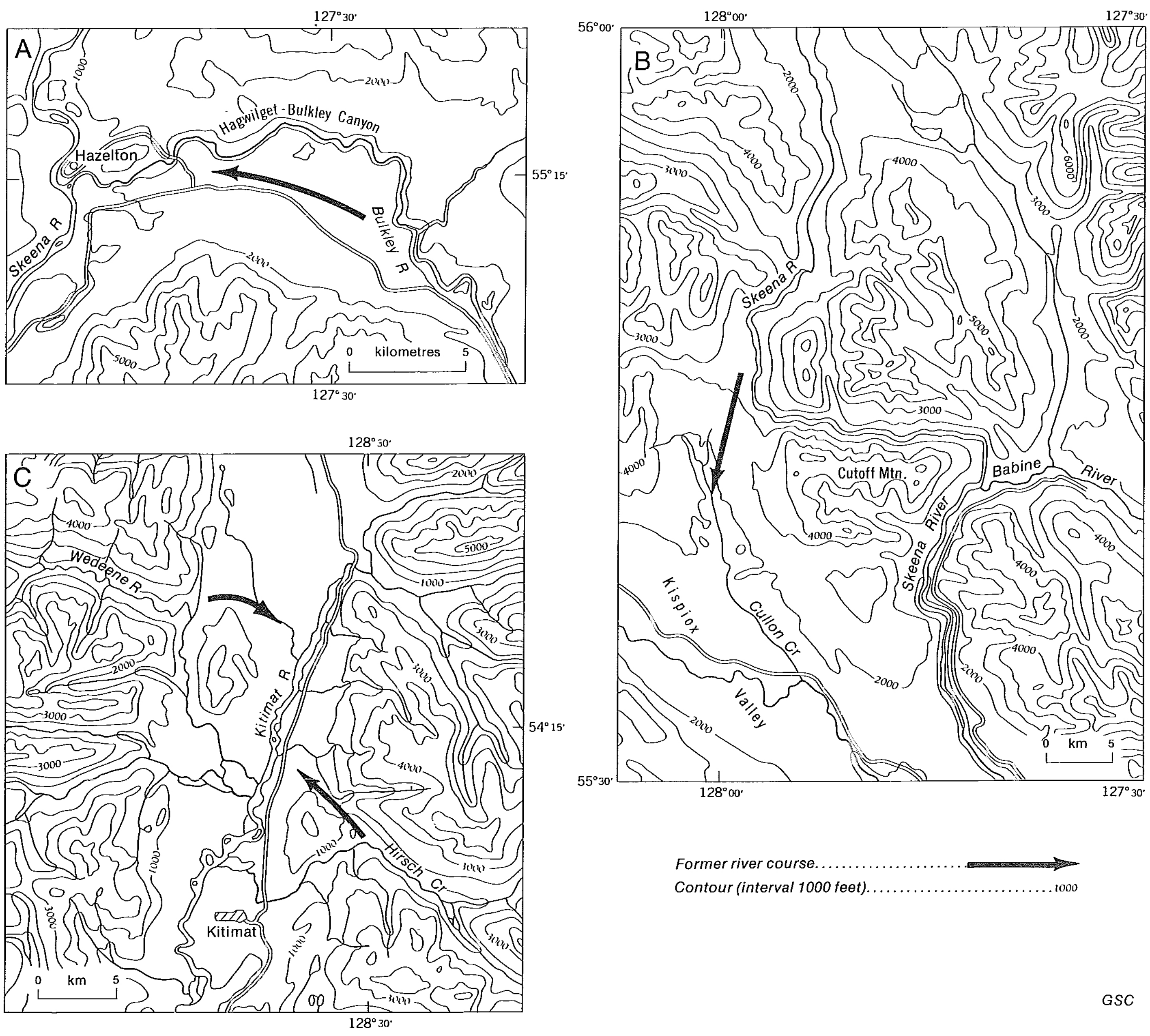


***Figure 16*** *(below)*

*Examples of drainage anomalies in the study area. A – Hagwilget-Bulkley Canyon. B – Skeena River at Cutoff Mountain. C – Southern Kitsumkalum-Kitimat trough. See text for details.*

GSC

***Figure 17***

*Hagwilget-Bulkley Canyon. Bulkley River flows in a bedrock gorge cut partly or wholly during postglacial time. (GSC 203257-E).*

**Table 3.** Classification of surficial materials; modified from Terrain Classification System (Resource Analysis Unit, 1976)

| Genesis | Texture | Landforms | Geomorphic processes |
|---|---|---|---|
| X - man-made* | g - gravel* | a - apron* | A - avalanching* |
| I - ice* | s - sand | b - blanket* | V - gullying* |
| O - organic* | $\underline{s}$ - silt* | d - delta* | F - mass movement* |
| C - colluvial* | $\bar{f}$ - fines* | f - fan* | H - kettling* |
| A - alluvial (fluvial)* | boulders | h - hummocky topography* | cryoturbation |
| $A^G$ - glaciofluvial* | blocks | m - rolling (or undulating) topography* | nivation |
| $L^G$ - glaciolacustrine* | cobbles | p - plain* | solifluction |
| $W^G$ - glaciomarine* | pebbles | r - ridged topography* | thermokarst |
| M - morainal* | rubble | s - steep slope* | frozen ground |
| D - drift* | clay | t - terraced* | braiding channel |
| U - undifferentiated* | mud | v - veneer* | irregularly sinuous channel |
| R - bedrock* | diamicton | x - complex* | anastomosing channel |
| distintegrated bedrock | angular fragments | cone+ | meandering channel |
| eolian | fibric | depression | flooding |
| lacustrine | mesic | gentle slope | karst |
| pyroclastic | humic | moderate slope | piping |
| marine** | | mantle of variable thickness | deflation |
| | | | washing |
| | | | erosion |

Symbolization sequence: texture — genesis — landform — geomorphic process: $sW^Gm$ - V

* Symbol used on Map 1557A
** Relict marine sediments in the study area are included with glaciomarine sediments
\+ Cones in the study area are included with fans

Lakes dammed by glacial sediments are most common in the main valleys and are round to elongate. The sediments impounding these lakes were deposited during deglaciation at the close of the Pleistocene. Kitsumkalum[1] and Lakelse lakes, the two largest lakes in the mapped part of the study area, are in this group.

## SURFICIAL GEOLOGY

### *Classification of Landforms and Surficial Materials*

Geological materials, in general, may be divided into two broad groups: (1) consolidated materials (bedrock) and (2) unconsolidated materials (Quaternary sediments). This report focuses on the latter, which have been classified and mapped according to the British Columbia Terrain Classification System (Resource Analysis Unit, 1976). In this system, surficial materials are grouped according to their mode of origin (e.g., alluvial, marine) and are further subdivided on the basis of texture (e.g., clay, sand) and surface expression (e.g., terrace, fan) (Table 3). Secondary processes that have modified landforms and surficial materials (e.g., avalanches) may also be used to further subdivide and categorize terrain.

### Genesis

The following genetic groups have been identified in the mapped part of the study area.

*R - Bedrock.* Exposed rock and rock covered with very thin sediments are designated as "bedrock" on the surficial geology maps (Map 1557A). In areas of high relief, such as cirque headwalls, steep valley walls, and some stream-cut canyons, bedrock occurs at the surface over large areas. More commonly, however, bedrock has a patchy cover of colluvium and till. Such areas are mapped as "R" where this cover constitutes isolated patches less than 50 cm thick on the average. Thicker, more continuous mantles are symbolized according to the dominant sediment type, thickness, and surface expression.

*U - Undifferentiated.* "Undifferentiated" is a composite genetic term that is used on the maps (Map 1557A) accompanying this report to indicate a layered sequence of several types of sediment outcropping on a steep erosional slope. The slope may be partly mantled by colluvium. Constituent stratigraphic units of contrasting lithologies are so closely juxtaposed on scarps that they cannot be differentiated on the maps.

*D - Drift.* "Drift" is a general genetic term for undifferentiated intermixed glacial, glaciofluvial, fluvial, and colluvial sediments. The term is used in this report and on the accompanying surficial geology maps for: (1) till, colluvium, and fluvial and glaciofluvial gravel that are intimately associated and cannot be differentiated at the scale of mapping; and (2) sediments with physical characteristics intermediate between those of till, outwash, and colluvium. The latter probably are morainal deposits reworked to a minor extent by meltwater and/or downslope gravitational movements.

*M - Morainal.* Morainal deposits, or till, are laid down directly from glacier ice with little or no reworking by meltwater or mass movement processes. Deposition may occur beneath, on top of, or at the margin of a glacier. Morainal materials are poorly sorted and have a wide range of particle sizes; stones of various sizes and shapes are mixed with clay, silt, and sand. They generally are massive or crudely stratified, although lenses of silt, sand, and gravel are common in some tills.

The texture, structure, and mineral composition of morainal deposits are highly variable. This variability stems from differences in the provenance and transportational and depositional history of the sediments. Tills in the study area may be subdivided into two groups on the basis of their physical properties: (1) clay- and silt-rich tills and (2) sand-rich tills (Fig. 18A; Appendices 1, 2, 3).

(1) Tills with a matrix rich in clay and silt occur in the main valleys of the Interior System and on Nechako Plateau. These tills characteristically are compact, massive, and contain angular to subrounded stones. The constituents of these tills have been eroded from sedimentary and volcanic rocks of the Hazelton, Bowser Lake, and Skeena groups, and were deposited by lodgment processes at the base of active glaciers, with little or no reworking by meltwater.

(2) Sandy tills occur within the Western System and, to a lesser extent, in the mountainous parts of the Interior System. They are crudely stratified to massive, have a matrix dominated by sand, and commonly contain discrete lenses of sand and gravel. These tills tend to be more stony (>20% gravel-size material, in general) and less compact than the clay- and silt-rich tills described above. They contain abundant detritus of granitic, gneissic, and schistose rocks, which probably accounts for their sandy texture. These tills were deposited, in part, at the base of glaciers by lodgment processes and, in part, on top of and at the edges of glaciers by ablation and mass wasting. Meltwater-winnowing removed some fines and produced localized sorting of the tills. Much of the tills deposited in the Western System during the last glaciation were completely reworked by meltwater, giving rise to derivatives such as ice-contact sediments (sand, gravel), proglacial outwash (sand, gravel), and glaciomarine and glaciolacustrine sediments (clay, silt).

*$W^G$ - Glaciomarine*[2]. Glaciomarine sediments are deposited in the sea, mainly by settling from suspension and turbidity flows; they also are deposited on the shore by waves and longshore currents. Much of the detritus is introduced into the sea by streams flowing from melting glaciers; some is released directly from the toes of tidewater glaciers and from icebergs. Sediments deposited below wave base consist of massive and bedded mud (Fig. 18B, Appendix 1) and minor sand. Scattered ice-rafted stones and shells are present in some deposits. Sedimentary structures include load casts, ripple marks, graded bedding, and convolute bedding. Glaciomarine sediments deposited above wave base adjacent to the shore consist of bedded and massive, well sorted sand and gravel.[3]

Glaciomarine sediments occur on land as rolling and flat remnants of sea floor that have been elevated above sea level as a result of glacio-isostatic rebound accompanying deglaciation. These sediments, in general, are gullied

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[1] Although a postglacial alluvial fan has been built out across the south end of Kitsumkalum Lake, the lake is fundamentally dammed by late Pleistocene glaciofluvial and deltaic deposits.

[2] Relict seafloor sediments in the study area have been classified as glaciomarine ($W^G$) rather than simply marine (W) mainly because of their association with outwash and ice-contact sediments deposited during deglaciation at the close of the Pleistocene. Mapped glaciomarine sediments, in most cases, are texturally and structurally similar to marine sediments presently accumulating in nearby fiords and marine basins.

[3] Sand and gravel deposited in deltas that were built out into the sea are grouped with glaciofluvial sediments, which they resemble texturally.

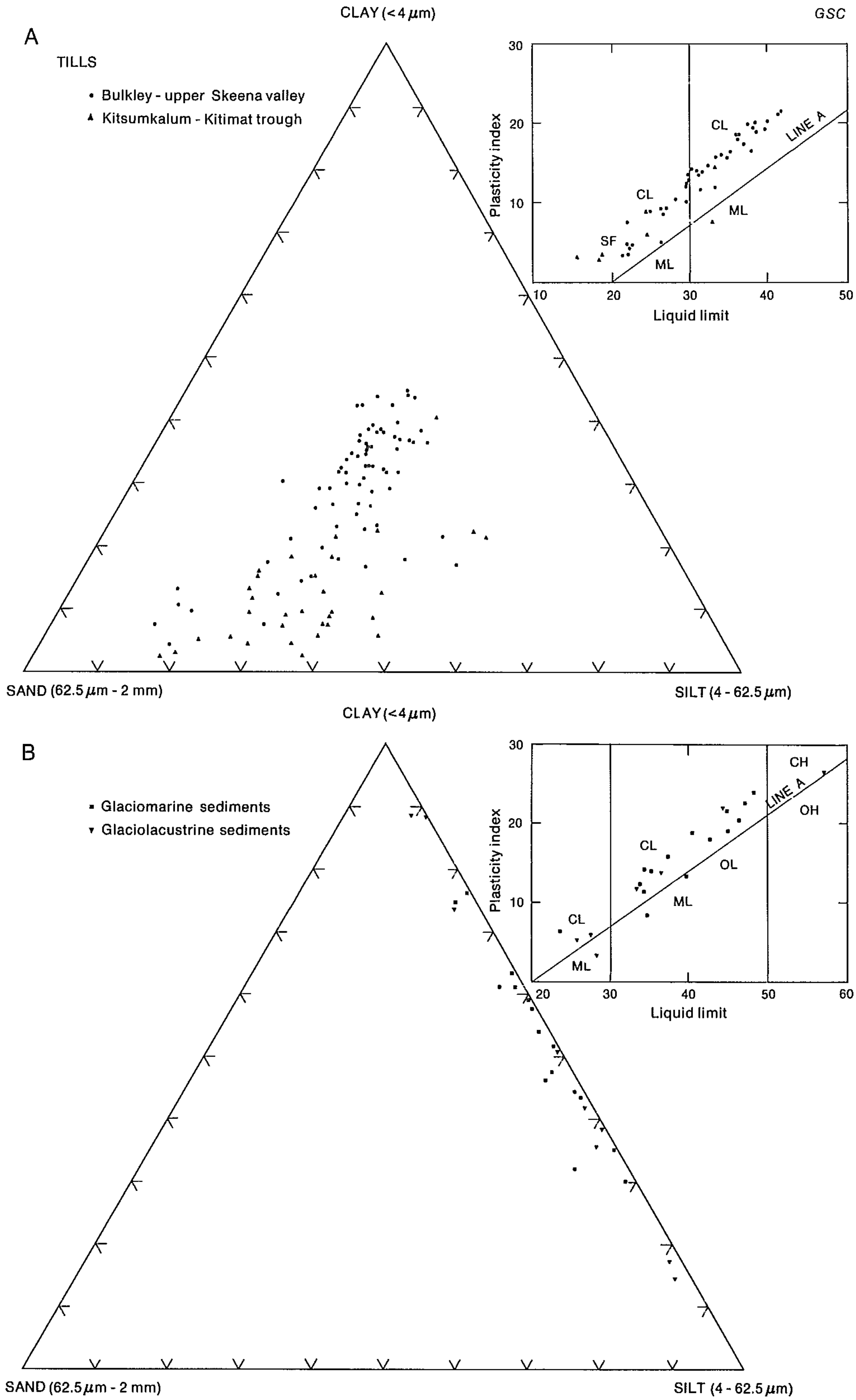


*Figure 18. Grain-size and engineering properties of representative samples of (A) tills and (B) glaciomarine and glaciolacustrine sediments in the study area. Material coarser than 2 mm was not analyzed. The plasticity charts bordering the triangular grain-size plots show the relationship between liquid limit and plasticity index (after Casagrande, 1932). In general, Bulkley-upper Skeena tills and glaciolacustrine and glaciomarine sediments throughout the study area are rich in fines and have medium pasticity. In contrast, many Kitsumkalum-Kitimat till samples possess sand-rich matrixes and are either cohesionless or have low plasticity values.*

and terraced. Thin patchy glaciomarine deposits with little or no independent surface expression overlie bedrock and unconsolidated sediments in many areas.

*LG - Glaciolacustrine.* Glaciolacustrine sediments are deposited on the floors and margins of glacial lakes, chiefly by settling from suspension, turbidity flows, wave action, and currents. Much of the sediment is introduced into the lakes by meltwater streams; some is released directly from the toes of glaciers and icebergs. Glacial-lake sediments comprise bedded and laminated mud (lake-bottom facies, Fig. 18B, Appendix 1), and minor sand and gravel (shoreline facies).[1] Scattered ice-rafted stones occur in some glaciolacustrine mud deposits. Sedimentary structures common in lake-bottom sediments include load casts, ripple marks, graded bedding, and convolute stratification. Shoreline deposits typically are well sorted and conspicuously bedded.

Thick surface glaciolacustrine deposits are rolling or flat and are commonly terraced. Thin deposits irregularly mantle other unconsolidated materials and bedrock and have little surface expression of their own.

Glaciolacustrine sediments are texturally and structurally similar to glaciomarine sediments. The two may be distinguished on the basis of constituent fossils if these are present. Regional geomorphic relationships and inferred Quaternary history also may help in the discrimination of the two sediment groups.

*AG - Glaciofluvial.* Glaciofluvial sediments are transported by glacial meltwater and deposited in proglacial and ice-contact environments. They occur in kames, kame terraces, ice-contact fans and deltas, eskers, crevasse fillings, and outwash plains. Glaciofluvial sediments comprise sand and/or gravel which are poorly sorted to well sorted and massive to well bedded. Crossbedding and imbrication are present locally, especially in outwash.

Both outwash and ice-contact sediments have physical attributes that reflect the unstable nature of the glaciofluvial environment: abrupt changes in texture, interlensing of beds, common coarse poorly sorted gravel, isolated beds or lenses of diamicton that may be flowtill, isolated large clasts that may have been ice-rafted, and till clasts. In addition, ice-contact sediments may have faults, warped and distorted beds, and clastic dykes that are produced by slumping and settling accompanying the melting of supporting ice.

Topography developed on ice-contact sediments commonly is irregular, hummocky, or undulating; closed depressions (kettles) and mounds (kames) produced by the melting of stagnant glacier ice are common locally. Long sinuous ridges (eskers) or short parallel, en echelon ridges (crevasse fillings) occur in areas of englacial and subglacial meltwater deposition. Outwash deposits laid down at the margins of, and some distance in front of, glaciers occur as terraces, fans, and deltas which commonly are kettled or dissected by meltwater channels. In many cases, outwash is structurally and texturally similar to alluvium; its glaciofluvial origin can be inferred only because the deposit can be traced to a former glacier snout or because the late glacial history of the region clearly indicates a glacial source.

*A - Alluvial (Fluvial).* Alluvial sediments are transported by and deposited from streams and rivers. They range from extremely coarse, poorly sorted gravel on steep alluvial fans to moderately to well sorted sand and mud on low-gradient floodplains. Crossbedding, imbrication, and ripple marks are common sedimentary structures.

The chief types of alluvial sediments and associated landforms include: (1) Floodplain deposits consisting of channel and overbank facies. Channel sediments, mainly sand and gravel, occur beneath present and former stream courses; they may underlie the entire floodplain in zones of rapidly shifting braided channels. Overbank sediments, mainly silt and sand, are deposited away from channels during floods; they may underlie extensive areas of floodplains with relatively stable channels. (2) Terrace deposits, also consisting of channel and overbank facies. Many terraces have a capping of overbank sandy silt and sand on top of coarser channel deposits. (3) Alluvial fan deposits comprising channel sand and gravel, locally with interbeds of diamicton. These deposits are common on the floors of valleys adjacent to high-gradient tributary streams. (4) Deltaic deposits consisting mainly of sand and gravel. Deltaic sediments commonly coarsen upward and overlie silt and clay deposited in the sea or in lakes.

*C - Colluvial.* Colluvium is material that has reached its present position as a result of direct, gravity-induced movement (mass movement). It occurs as mantles on sloping ground and as fans and hummocky accumulations at the base of some slopes. The former accumulate by slow downslope creep and, in the case of talus, by rockfall. In contrast, colluvial fans and hummocky colluvial deposits generally are the products of rapid sporadic mass movements such as debris flows, deep-seated landslides, and avalanches.

The character of specific colluvial deposits and landforms depends, in part, on the nature of the source material and on the formative mass movement process. Colluvial mantles on mountain slopes commonly consist of poorly sorted gravel and diamicton containing abundant pebble- to boulder-size clasts and a matrix of clay, silt, and/or sand. Clasts dislodged directly from bedrock generally are angular, whereas those derived from sediments are more rounded. Lenses and beds of poorly sorted alluvium may occur within such colluvial deposits where streams have eroded and resedimented material. Talus, a type of colluvium derived entirely from the ravelling of bedrock cliffs and steep rocky slopes, comprises rubble and blocks of a relatively narrow size range. Landslide deposits derived from bedrock also consist mainly of rubble and blocks, although sorting in general is poorer than in talus. In contrast, landslide deposits produced by the failure of unconsolidated sediments consist mainly of clay, silt, sand, and/or gravel. The grain-size characteristics of these last landslide deposits are similar to those of the source materials from which they are derived. For example, mudflows from glaciomarine and glaciolacustrine sediments produce colluvial deposits consisting almost entirely of clay and silt. In contrast, debris flows involving till and coarse glaciofluvial sediments produce diamicton and extremely poorly sorted gravel.

*O- Organic.* Organic sediments are accumulations of dead vegetal matter, including mosses, sedges, shrubs, and trees. These sediments consist of undecomposed (fibric) to moderately decomposed (mesic) peat, locally interstratified with or containing admixed clay, silt, and sand. Organic deposits occur in and around closed basins and on poorly drained gentle to moderate slopes.

*I - Ice.* Perennial snow and ice.

*X - Man-Made.* Substrate materials constructed by man or geological materials so modified by human action that their original physical properties, such as structure, cohesion, compactness, and strength, have been significantly altered

[1] Sand and gravel deposited in deltas that were built out into glacial lakes are grouped with glaciofluvial sediments, which they resemble texturally.

are termed "man-made" or "anthropogenic". Man-made materials include those transported and redeposited by man, usually in conjunction with mining, waste disposal, and industrial activity.

### Texture

Texture refers to the geometric aspects and interrelationships of component particles or crystals of unconsolidated sediments and rock. The three most significant aspects of texture for unconsolidated sediments are particle size, particle roundness, and sorting (i.e., the range of particle sizes). Textural terms used in this report include the following (modified from Wentworth, 1922; Resource Analysis Unit, 1976):

| | |
|---|---|
| boulders: | rounded particles >256 mm |
| blocks: | angular particles >256 mm |
| cobbles: | rounded particles 64-256 mm |
| pebbles: | rounded particles 2-64 mm |
| rubble: | angular particles 2-256 mm |
| sand: | particles 62.5 µm-2 mm |
| silt: | particles 4-62.5 µm |
| clay: | particles <4 µm |
| gravel: | pebbles, cobbles, or boulders; or a mixture of these three components |
| mud: | mixture of clay and silt |
| fines: | clay or silt; or a mixture of these two components; or any of these with minor sand |
| diamicton: | mixture of clay, silt, sand, and gravel |

In this report, "clay", "silt", "sand", and "gravel" are used to describe deposits containing minor constituents other than those denoted by the specific textural terms. Thus, naturally occurring "gravels", although dominantly formed of rounded particles larger than 2 mm, generally have a matrix of sand. Most natural "clays" contain some silt-size material; "silts" may contain some fine sand and/or clay-size material; and "sands" generally contain minor pebbles and/or silt-size material.

The mode of genesis of a sedimentary deposit is a major determinant of texture. For example, sediments deposited directly from glacier ice are diamictons, and those laid down in glacial lakes are mainly muds. Thus, the genetic groups described in the preceding section implicitly convey textural information. The dominant textures of these genetic groups are shown in Table 4. Textural symbols are used on the surficial geology maps (Map 1557A) accompanying this report only where the texture of a terrain unit differs from that of the dominant or expected texture.

**Table 4.** Dominant textural attributes of genetic groups occurring within the study area

| Genetic group | Dominant texture |
|---|---|
| X - man-made | diamicton, gravel, rubble, blocks |
| C - colluvial | diamicton, rubble, blocks |
| A - alluvial | gravel and sand |
| AG - glaciofluvial | gravel and sand |
| LG - glaciolacustrine | fines |
| WG - glaciomarine | fines |
| M - morainal | diamicton |
| D - drift | diamicton, gravel |
| U - undifferentiated | variable |

Note: These textures are the most common for the mapped units; however, other textures also may be present locally.

### Landforms

Landforms are recognizable features of the Earth's surface that have characteristic shapes and are produced by natural causes. They are recognized, and may be defined, on the basis of slope, geometric shape, and spatial pattern. Landforms associated with Quaternary sediments in the study area include the following.[1]

*a - Apron.* A surface with a gradient of 25-35° and a longitudinal profile that is either straight or smoothly concave or convex. An apron is a constructional feature formed on unconsolidated materials that are derived from a bordering steeper slope (Fig. 19).

*b - Blanket.* A mantle of unconsolidated sediments of relatively uniform thickness draping older Quaternary materials or bedrock and greater than 1 m thick on the average (Fig. 20). A blanket conforms to and locally masks underlying units, but generally has no constructional form characteristic of the material's genesis.

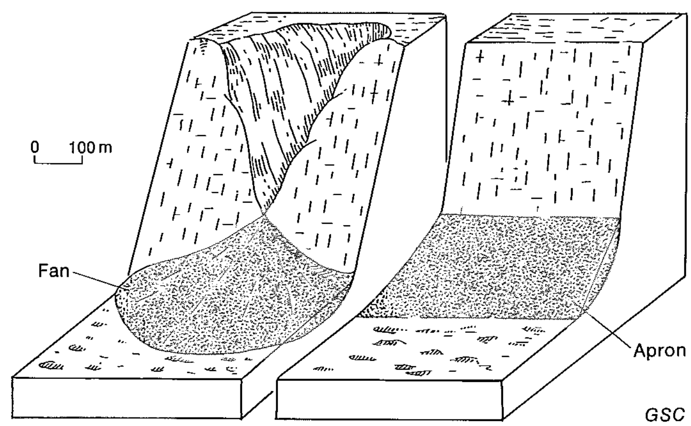


***Figure 19.*** *Representative landforms: fan and apron.*

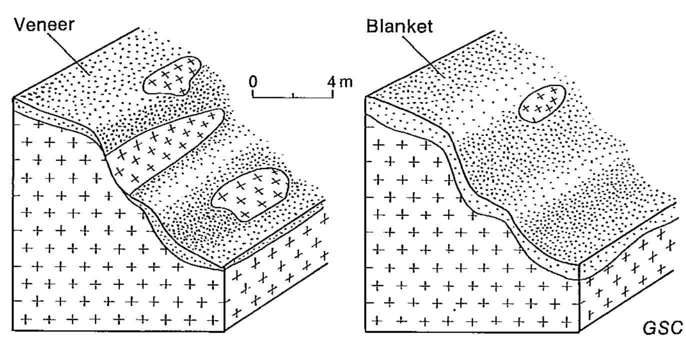


***Figure 20.*** *Representative landforms: veneer and blanket.*

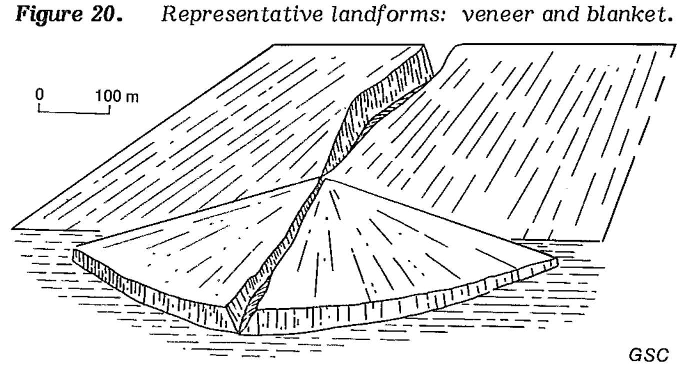


***Figure 21.*** *Representative landform: relict incised delta.*

[1] Slope angles cited in this section are characteristic of landforms in the study area and may differ from those for comparable landforms in other regions.

*d - Delta.* A flat to gently inclined (0-10°) depositional surface (i.e., delta top) that slopes towards, and is in contact with, a more steeply dipping (up to 25°) depositional surface (delta foreslope) (Fig. 21).

*f - Fan.* A fan-shaped form that is a sector of a cone, with a longitudinal profile that is either straight, smoothly concave, or smoothly convex (Fig. 19). Radial gradients generally are less than 15°, but locally are as high as 30°. A fan is a constructional feature that occurs at the foot of a moderate to steep slope, generally at the end of a valley, ravine, or gully.

*h - Hummocky Topography.* Steep-sided hills and hollows that are rounded or irregular in cross-profile and nonlinear in plan (Fig. 22). The steeper parts of hummocky forms slope between 15° and 35°, and local relief exceeds 1 m. Hummocky landforms developed on unconsolidated materials are constructional in origin.

*m - Rolling (or Undulating) Topography.* Gently sloping rises and depressions that are either rounded or irregular in cross-profile and either linear or nonlinear in plan (Fig. 22). Gradients are less than 15°, and local relief is greater than 1 m. Rolling and undulating landforms developed on unconsolidated materials are constructional in origin. This category differs from "hummocky" only by virtue of having gentler slopes. Glacial lineations on undulating terrain (e.g., drumlins, crag and tail) are indicated on the surficial geology maps by symbols.

*p - Plain.* A flat or very gently sloping (0-3°) unidirectional surface with local relief generally less than 1 m. Plains developed on unconsolidated materials may be either erosional or constructional (those within the study area are all constructional).

*r - Ridged Topography.* Elongate and steep-sided hills and intervening depressions that are parallel or subparallel in plan (Fig. 23). The steeper slopes or ridged forms have gradients between 15° and 30°, and local relief exceeds 1 m. Ridged landforms developed on unconsolidated materials are constructional in origin.

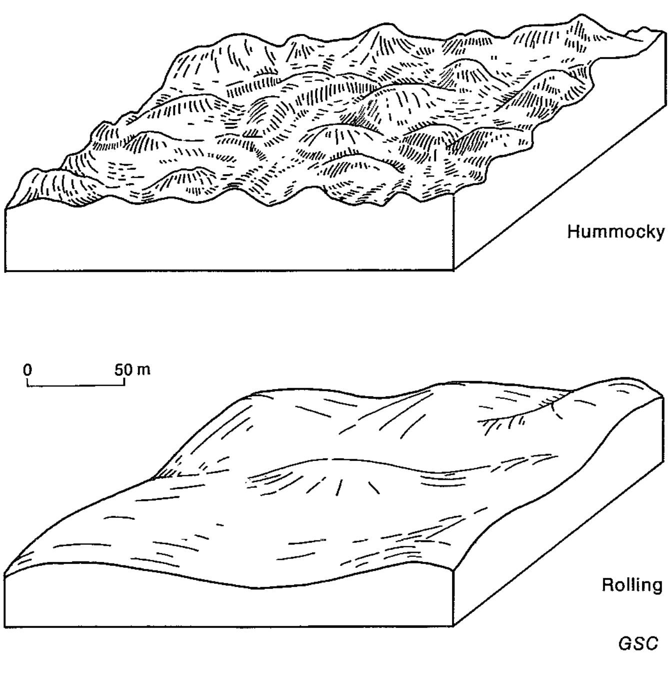


***Figure 22.*** *Representative landforms: hummocky and olling topography.*

*s - Steep Slope.* A slope with a gradient exceeding 30°. Steep slopes are mainly erosional forms (e.g., terrace scarps, canyon walls), but constructional features are also possible (e.g., steep ice-contact faces).

*t - Terrace.* Stepped or benched topography consisting of one or more well defined scarps separating horizontal or gently inclined (0-3°) surfaces (treads) (Fig. 24). Terraces include both erosional (e.g., most river terraces) and constructional (e.g., kame terraces) forms; however, treads of the former generally are capped by sediments deposited as the alluvial surface is abandoned and the adjacent lower scarp carved.

*v - Veneer.* A mantle of unconsolidated sediments of relatively uniform thickness draping older Quaternary materials or bedrock and 50 cm to 1 m thick on the average (Fig. 20, 25). Veneers possess no form typical of the material's genesis; rather, the surface topography is the same as that of the underlying unit. Outcrops of the underlying unit commonly project through a veneer; these outcrops may be sufficiently widespread and the veneer itself so patchy that the terrain must be mapped as an association comprising the veneer and the underlying unit.

*x - Complex.* Terrain consisting of several distinct landforms that are too small to map separately. On the surficial geology maps of the study area (Map 1557A), "x" is used only for valley-floor complexes consisting of alluvial plains and terraces, and alluvial and colluvial fans. Terrain units consisting of only two genetic or landform components are not mapped as x; rather, each of the two components is denoted separately.

### Geomorphic Processes

Materials and landforms on the Earth's surface are modified by processes of weathering, mass movement, erosion, and deposition. Those geomorphic processes that have significantly modified landforms or ground surface conditions in the study area or that affect human activities there are shown on the accompanying surficial geology maps. Letter symbols denoting process are attached to genetic-landform descriptors (Table 3) where a relatively large part of a terrain unit has been modified by areally extensive geomorphic processes or where several sites within a unit have been affected by such processes. In contrast, site symbols are used where a geomorphic process has affected only a small part of a terrain unit.

Four geomorphic processes are shown on the surficial geology maps: avalanching, gullying, mass movement, and kettling. The last is a process that was active during deglaciation at the close of the Pleistocene, but which has been inactive subsequently. The other processes are presently active or have been active some time during postglacial time.

Avalanching is the rapid downslope movement of snow, ice, and incorporated debris, and typically occurs in areas of high local relief and moderate to heavy snowfall. Avalanche areas (Fig. 26, 27) are indicated on the surficial geology maps both by a site symbol and by a letter symbol (-A) attached to the map-unit descriptor; the former is used to depict individual avalanche tracks, and the latter larger areas affected by frequent avalanche activity.

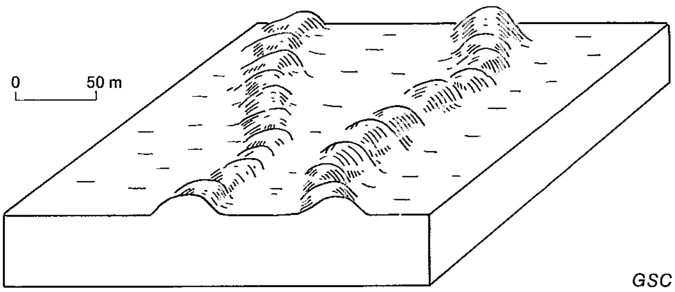


***Figure 23.*** *Representative landform: ridged topography.*

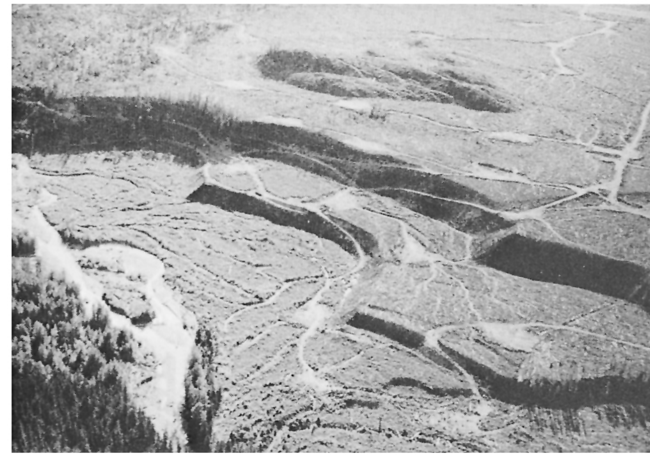

***Figure 24.*** *Representative landform: fluvial terraces of Chist Creek. (GSC 203257-F).*

***Figure 25.***

*Representative landforms: organic veneer on bedrock near Prince Rupert (top); drift veneer on mountain slope southeast of Lakelse Lake (bottom). Note abundant bedrock outcrops projecting through the drift veneer. (GSC 203257-G).*

Gullying is the modification of surfaces by fluvial erosion, resulting in the development of parallel and subparallel, steep-sided and narrow ravines (Fig. 28). This process is indicated on the maps by a letter symbol (-V) appended to the map-unit descriptor.

Mass movement is the downslope transfer of earth material under the influence of gravity. Landslide areas are shown on the surficial geology maps both by site symbols (i.e., landslide scars) and by the map-unit descriptors Ch and Cm. Active mass movement is indicated by a letter symbol (-F) attached to the map-unit descriptor.

Kettling is the formation of depressions in glaciofluvial, glaciolacustrine, and morainal materials by the melting of included ice blocks. Kettle depressions generally have steep sides and are bounded by an abrupt convex break in slope. This process is indicated both by site symbols and by a letter symbol (-H).

### Description of Map Units

Map units used in this study are defined on the basis of the four parameters described previously: texture, genesis, surface expression, and modifying processes. The method of symbolizing map units is shown in Table 3. Genetic type is

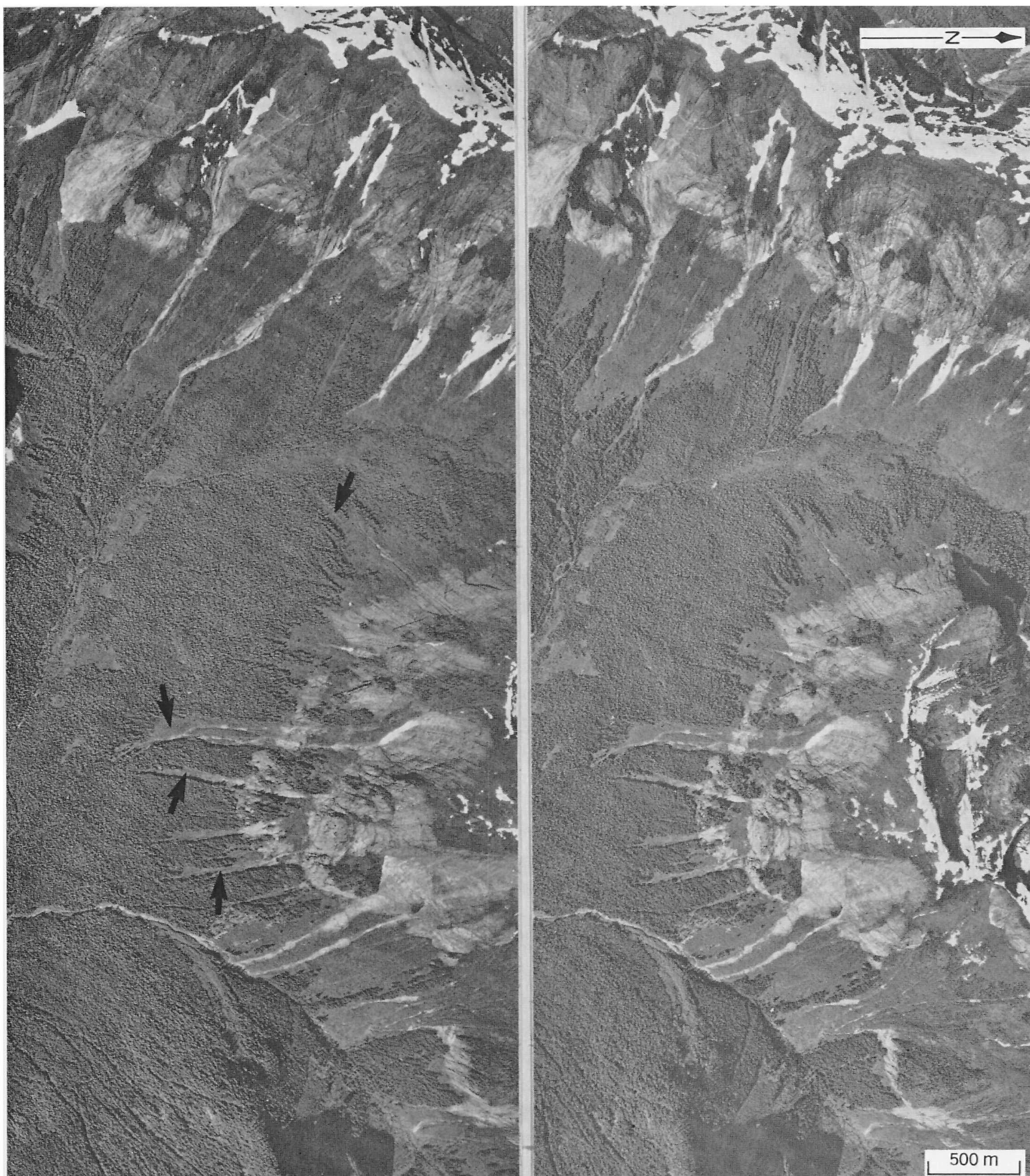


***Figure 26.*** *Stereogram of typical mountain slopes subject to winter and spring avalanche activity (Coast Mountains near Kwinitsa). Most of the nonforested upper slopes are swept periodically by avalanches. Avalanche tracks also extend onto lower forested slopes (examples are indicated by arrows). Province of British Columbia photos BC5111-106, -107.*

*Figure 27.* *Avalanche track crossing the Canadian National Railways tracks and Highway 16 in lower Skeena Valley. (GSC 203257-H).*

***Figure 28***

*Gullied drift on a mountain slope east of Kitsumkalum Lake. (GSC 203257-I).*

**Table 5.** Occurrence of terrain units in various parts of the map area

| Terrain | unit | Bulkley Valley | Upper Skeena Valley | Middle Skeena Valley | Lower Skeena Valley | Hecate Lowland | Kitsumkalum-Kitimat trough |
|---|---|---|---|---|---|---|---|
| Man-made | X | - | - | - | - | 2 | 2 |
| Organic | O | 2 | 2 | 2 | 2 | 2 | 1 |
| | Ob | - | - | - | 2 | 2 | 2 |
| | Ov | - | - | - | 2 | 1 | 2 |
| Colluvial | Ch, Cm | 2 | 2 | 2 | 2 | - | 2 |
| | Cf | 2 | 1 | 2 | 1 | 2 | 2 |
| | Ca | - | 2 | 2 | 2 | 2 | 2 |
| | Cb | 2 | 2 | - | 2 | - | 2 |
| | Cv | 2 | 2 | 1 | 1 | 1 | 1 |
| Alluvial | Af | 1 | 1 | 1 | 2 | 2 | 1 |
| | Ap | 2 | 2 | 1 | 1 | 2 | 1 |
| | Ax | - | - | - | 2 | 2 | 2 |
| | Av | - | - | - | - | - | 2 |
| | At | 1 | 1 | 1 | 2 | 2 | 1 |
| | Ad | - | - | - | - | - | 2 |
| Glaciofluvial | A$^{G}$m, A$^{G}$h | 2 | 1 | 1 | 2 | - | 1 |
| | A$^{G}$r | 2 | - | - | - | - | - |
| | A$^{G}$b | - | - | 1 | - | - | 2 |
| | A$^{G}$v | - | 1 | 2 | - | - | - |
| | A$^{G}$f | - | - | - | - | - | 2 |
| | A$^{G}$t | 2 | 2 | 2 | 2 | - | 2 |
| | A$^{G}$d | 2 | 2 | 2 | 2 | - | 1 |
| Glacio-lacustrine | L$^{G}$m | - | - | 2 | - | - | 2 |
| | L$^{G}$t | 2 | - | - | - | - | - |
| | L$^{G}$b | 2 | - | - | - | - | - |
| | L$^{G}$v | 2 | - | - | - | - | - |
| Glacio-marine | W$^{G}$m | - | - | - | 2 | - | 1 |
| | W$^{G}$p | - | - | - | - | - | 2 |
| | W$^{G}$b | - | - | - | - | 2 | 2 |
| | W$^{G}$v | - | - | - | - | 2 | 2 |
| Morainal | Mm | 1 | 1 | 2 | - | 2 | 2 |
| | Mb | 1 | 1 | 2 | 2 | 2 | - |
| | Mv | 2 | 2 | 2 | - | - | - |
| Drift | Dm, Dr | 2 | 2 | 2 | 2 | - | 2 |
| | Db | 2 | 2 | 2 | 2 | 2 | 2 |
| | Dv | 1 | 1 | 1 | 2 | 1 | 1 |
| Undiff. | Us | 2 | 2 | 2 | 2 | - | 2 |
| Rock | R | 2 | 2 | 1 | 1 | 1 | 1 |
| | Rs | 2 | 2 | 2 | - | - | 2 |

1 = major unit
2 = minor unit
- = not mapped

specified by a capital letter(s), which generally is followed directly by a lower case letter denoting surface expression. The letter for surface expression, in turn, may be followed by a dash and a second capital letter to indicate that a secondary process has, or is, modifying the terrain. A lower case letter preceding the genetic descriptor indicates sediment texture; this is included only where the texture differs from that expected for the unit.

The mapped part of the study area may be subdivided into six regions on the basis of the distribution, abundance, and association of Quaternary map units (Table 5):

(1) Bulkley Valley. Morainal landforms (Mm, Mb, Mv) are dominant, and the constituent till characteristically has a silt- and clay-rich matrix. Drift (Dm, Db, Dv) is common on moderate and steep slopes. Glaciofluvial sediments (mainly A$^{G}$m) are present locally, but are less common than in regions 2, 3, 4, and 6. Fluvial terrain (mainly Af and At) is widespread in some parts of the valley. Colluvial and organic areas are rare.

(2) Upper Skeena Valley (Kispiox-Kitwanga). Morainal landforms (Mm, Mb, Mv) are common in this part of Skeena Valley, as in region 1. Rolling ice-stagnation deposits (A$^{G}$m)

and thin glaciofluvial sand (sA$^{G}$v) occur in a wide strip bordering Skeena River and are more common in this region than in any other. River terraces (At) are the dominant alluvial landform. Some of the larger colluvial fans (Cf) and landslides (Ch) in the map area are in region 2. Organic areas are rare.

(3) Middle Skeena Valley (Kitwanga-Terrace). This part of Skeena Valley is much narrower than Skeena Valley upriver of Kitwanga. The morainal sediments that dominate region 2 are replaced by drift and colluvium (Db, Dv, Cv) in region 3. Glaciofluvial units (A$^{G}$m, A$^{G}$b, A$^{G}$v) are locally common in region 3, as are river terraces. Areas of Skeena River floodplain (Ap) assume increased importance in region 3 relative to region 2. Few colluvial fans occur in region 3, and large landslides are present on the walls of Skeena Valley only at the upriver end of the sector. There are no mapped organic areas in middle Skeena Valley.

(4) Lower Skeena Valley (Terrace-Tyee). The dominant valley bottom terrain unit in region 4 is alluvial plain (Ap). Bedrock (R) and colluvium (Ca, Cf, Cb, Cv) are by far the most common surface materials on valley walls. Thin drift (Db, Dv) is a subordinate constituent of region 4, and glaciofluvial, glaciolacustrine, and glaciomarine units are rare, as are river terraces. Organic units (O, Ob, Ov) become increasingly common in poorly drained, low-lying areas towards the mouth of Skeena River.

(5) Hecate Lowland. Although relief in the Hecate Lowland is relatively low, only thin sediments mantle bedrock in most areas. Organic, glaciomarine, and drift veneers (Ov, W$^{G}$v, Dv) are dominant on low-lying gently inclined slopes, whereas bedrock and thin colluvium (R, Cv) underlie moderate to steep slopes and occur at higher elevations. Thick sediments are restricted to small alluvial and colluvial fans and aprons (Af, Cf, Ca), patchy ground moraine (Mm, Mb), and narrow short floodplains; these collectively cover less than 1% of region 5.

(6) Kitsumkalum-Kitimat trough. Glaciomarine sediments (W$^{G}$m, W$^{G}$p, W$^{G}$b, W$^{G}$v) cover substantial areas of the valley bottom between Kitimat and Terrace. Large ice-contact deltas (A$^{G}$d) in the Kitsumkalum-Kitimat trough dwarf those in other regions. Other glaciofluvial deposits (e.g., A$^{G}$t, A$^{G}$m, A$^{G}$h) are also common locally in region 6. Morainal landforms, on the other hand, are rare; instead, slopes above the marine limit (ca. 200 m) are covered by drift and colluvium (mainly Db, Dv, Cv), or have bedrock at or near the surface. Large areas of alluvial plain and river terraces occur adjacent to Kitsumkalum, Kitimat, and Skeena rivers. Colluvial fans are subordinate to alluvial fans, except in avalanche-prone alpine valleys tributary to the Kitsumkalum-Kitimat trough. Relatively large organic areas (O, Ob) occur in the trough where drainage is poor (e.g., on silty floodplain sediments of upper Kitsumkalum River and on glaciomarine muds south of Lakelse Lake). The largest landslides in region 6 are mudflows (Cm) developed in glaciomarine sediments.

### Bedrock (R, Rs)

Rolling, sloping, hummocky, and ridged terrain developed on bedrock or near-surface bedrock (<50 cm thick cover of Quaternary sediments) is mapped as R. Bedrock on very steep slopes (>45°) is identified as Rs (i.e., steep rock slopes); Rs is used mainly in conjunction with Us for postglacial canyon walls.

Exposed bedrock is widespread at high elevations where till, colluvium, and drift are thin and patchy. Bedrock outcrops are most common in the Coast Mountains above treeline, increasing both towards the west and in areas of extreme topographic ruggedness. Steep fresh glacial landforms such as cirques, arêtes, and horns are important rock outcrop areas.

Large areas of rock outcrop are common at low elevations only in the western part of the map area (e.g., Prince Rupert region), and here only on moderate to steep slopes. Elsewhere at low elevation, widespread surface rock is restricted to the steepest parts of valley walls (i.e., slopes steeper than 45°) and to river canyons.

Where bedrock does not outcrop at high elevations and on steep slopes, it commonly is mantled by sediments less than 50 cm thick. Near-surface rock (R) is the most common terrain type both above treeline and on steep slopes below treeline in the Coast Mountains and perhaps in the Skeena and Hazelton mountains as well. On lower, less steep mountain slopes, sediment veneers (Cv, Dv, Mv) dominate the landscape.

### Terrace Scarps and River Banks (Us)

Erosional scarps in unconsolidated sediments were created when rivers and streams incised Pleistocene valley fills during postglacial time. These scarps are up to about 140 m in height and occur in all major mapped valleys except Skeena Valley west of Terrace. Scarps are especially prominent in Bulkley Valley, in Skeena Valley upriver from Woodcock and near Terrace, and in the Kitsumkalum-Kitimat trough between Terrace and Treston Lake. The lower parts of many of the scarps in Bulkley and Skeena valleys are developed in bedrock; these are indicated on the surficial geology maps as Us:R.

Some mapped scarps are constructional, rather than erosional, in origin. For example, the scarps bordering two large glaciomarine deltas (A$^{G}$d) north and south of Lakelse Lake are ice-contact faces produced when thick deltaic and glaciofluvial sediments accumulated against the toe of the trunk glacier in the Kitsumkalum-Kitimat trough. The ice-contact faces were left as scarps when this glacier retreated to the north away from the deltas.

### Drift (Dm, Dr)

Thick sandy diamicton containing beds and lenses of ice-contact gravel (Dm) is present at a few sites in the Kitsumkalum-Kitimat trough and in Skeena Valley. Dm differs from the thick morainal deposits of Bulkley and upper Skeena valleys in having large amounts of sorted stratified material and relatively little clay-size detritus. These differences are thought to be due, in large part, to variable meltwater reworking of till at the glacier sole during deposition. Meltwater was so widespread in the Kitsumkalum-Kitimat trough during deglaciation that till in most places was completely reworked into other sediment types (e.g., glaciofluvial sand and gravel; glaciomarine mud). Even where this did not occur, meltwater still winnowed much of the fine material from subglacial debris, producing a hybrid sandy till containing tongues of sand and gravel. In contrast, meltwater apparently was much less common at the base of the ice sheet in Bulkley Valley, and there was relatively little reworking of subglacial debris there.

A cross-valley ridge cored mainly by sandy diamicton and poorly sorted gravel (Dr) occurs at Kitimat. This ridge is concave towards the north, has up to nearly 100 m of local relief, and is buried in places by thick glaciomarine mud. It probably is a remnant of an end moraine constructed at the toe of the large valley glacier flowing south down the Kitsumkalum-Kitimat trough and into the sea. The ridge likely was built during a stillstand or minor readvance of this glacier near the end of the Fraser Glaciation.

### Drift Blankets and Drift Veneers (Db, Dv)

Many moderate to steep slopes in the study area are underlain by thin patchy sediments consisting of a complex of till, colluvium, and glaciofluvial and fluvial gravel.

These sediments originated in a variety of ways: (1) till deposited on slopes during the Fraser Glaciation was reworked locally by meltwater; (2) till and other sediments on some slopes slowly moved downhill under the influence of gravity, thus becoming mixed and crudely layered parallel to the slope; (3) some slope sediments were washed and sorted by streams and sheet flow during postglacial time. These processes have produced colluviated drift complexes that differ from lodgment till in that they are better stratified, better sorted, less compact, and more permeable. Like till, however, drift displays systematic changes in thickness and areal extent as a function of slope steepness. In general, as slopes become steeper, the drift cover becomes thinner and more patchy. On slopes steeper than 30°, drift generally is subordinate to both thin colluvium (Cv) and exposed or near-surface bedrock (R).

**Ground Moraine (Mm)**

Thick till deposits with rolling and undulating surface expression are common in Bulkley Valley (Fig. 29) and, to a lesser extent, in Skeena Valley upriver from Kitwanga, but are rare elsewhere in the map area. These thick deposits are intimately associated with till blankets and veneers which cover sloping bedrock surfaces within and at the margins of Bulkley and upper Skeena valleys.

Most slopes in areas of ground moraine are gentle (<15°). In some places, these slopes are oriented randomly, whereas in others they have a preferred linear orientation caused by differential erosion and deposition at the base of glaciers. In Bulkley Valley, broad subdued ridges and swales are weakly aligned parallel to the axis of the valley. In this area, there was only weak flow at the base of the Cordilleran Ice Sheet, thus the land was not strongly moulded by the ice. In contrast, in the valley of Trout Creek, strong westerly glacier flow produced a series of well defined linear ridges and troughs. Most of these streamlined forms have bedrock cores and are only thinly mantled by till; some, however, are true drumlins consisting entirely of till. An even larger area of glacially streamlined terrain occurs in Skeena Valley between Hazelton and Kitwanga. Here, ground moraine and till-mantled bedrock have a pronounced northeast-southwest linear grain resulting from the flow of ice down Skeena Valley during late Pleistocene time. In this valley, as in Trout Creek valley, true drumlins are subordinate to bedrock-cored drumlinoid ridges. Long flutings and grooves, scoured

***Figure 29.*** *Typical rolling terrain (top) underlain by thick till (bottom) in Bulkley Valley. (GSC 203257-J).*

in bedrock and mantled with till, are associated with the drumlinoid ridges and drumlins in Skeena Valley, but were not observed in Trout Creek valley.

### Till Blankets and Till Veneers (Mb, Mv)

Till-covered terrain lacking constructional morainic forms has much the same regional distribution as, and occurs in association with, ground moraine. Till blankets and till veneers occur locally on the walls of Bulkley Valley and Skeena Valley upriver from Kitwanga, and on the floors of these valleys where bedrock reaches to within a few metres of the surface. For example, the large area of streamlined topography in Skeena Valley between Hazelton and Kitwanga consists, in part, of relatively thin till mantling bedrock.

Units Mb and Mv are uncommon in the western part of the map area. In lower Skeena Valley and in the Kitsumkalum-Kitimat trough, sediments on gentle to moderately steep valley walls typically consist of a mixture of colluvium, stratified gravel, and diamicton (Db, Dv). These sediments are quite different from the silt- and clay-rich tills on comparable slopes in Bulkley and upper Skeena valleys.

### Glaciomarine Terrain ($^{W}Gm$, $^{W}Gp$)

Rolling and planar glaciomarine terrain is widely distributed below 200 m elevation in the Kitsumkalum-Kitimat trough from the head of Kitimat Arm to north of Terrace. This terrain represents relict sea floor flooded during and shortly after deglaciation, but subsequently isostatically uplifted.

At the end of the Pleistocene, glaciomarine sediments covered most of the floor of the southern Kitsumkalum-Kitimat trough; they were absent only on moderate to steep slopes, glaciofluvial deltas, kame terraces, and in areas of hummocky ice-contact deposits. During postglacial time, however, surficial glaciomarine sediments were removed from many parts of the trough by fluvial erosion and mass wasting. In other parts of the trough, glaciomarine sediments were covered by alluvium. The floodplain gravels of Kitimat River and its tributaries, for example, cover glaciomarine muds.

Due to postglacial erosion and burial beneath alluvium, glaciomarine sediments presently have a patchy distribution in the Kitsumkalum-Kitimat trough. The largest area of relict sea floor occurs between Skeena River and Lakelse Lake. This area is bounded on the north by alluvium of the Skeena River floodplain; it is bordered on the east and west both by alluvium (e.g., Williams Creek and White Creek fans) and by the walls of the Kitsumkalum-Kitimat trough; on the south, it is partially obscured by organic deposits but abuts against the steep ice-contact face of the large deltaic platform south of Lakelse Lake. The continuity of this large area of glaciomarine deposits is broken by drift-veneered bedrock knobs and ridges (e.g., Mount Herman) and by a large ice-contact delta north of Lakelse Lake (Fig. 30). Because these elevated features were not covered by the sea during the late Pleistocene, the present distribution of glaciomarine sediments in this area probably is similar to that prevailing at the close of the last glaciation. The west margin of the deltaic platform north of Lakelse Lake is a relict foreset slope built into the sea by meltwater streams. This foreslope became inactive when the glacier flowing down Skeena Valley

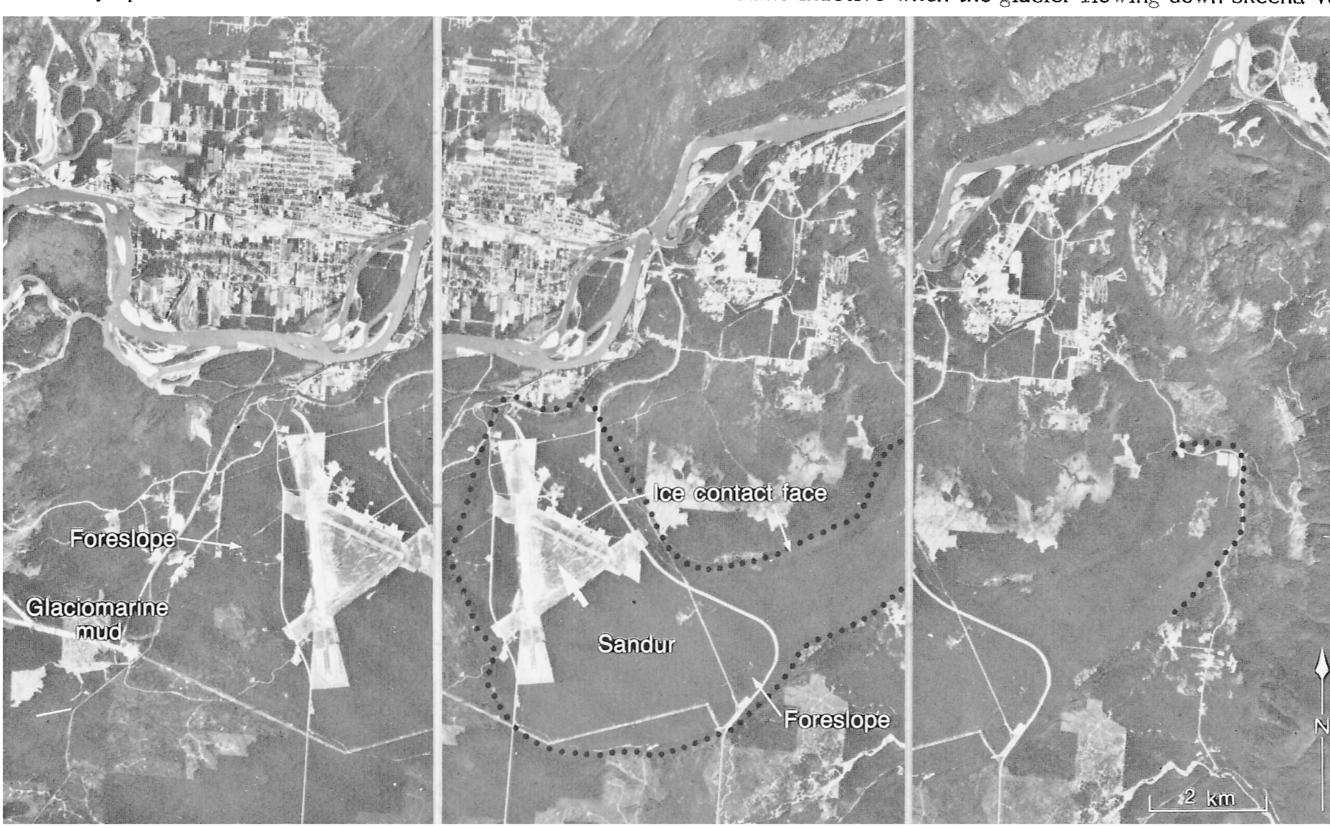


*Figure 30. Stereogram of a large delta-sandur complex that was built into the sea in the Kitsumkalum-Kitimat trough during deglaciation (dotted lines define the boundaries of this complex). The gently sloping sandur surface is bordered on one side by a steep ice-contact face and on the other by a delta foreslope. Glaciomarine sediments south and west of the foreslope accumulated on the sea floor while the delta was being constructed. Note indistinct meltwater channels (arrows) at the Terrace Airport. Province of British Columbia photos BC5608-134, -135, -136.*

retreated back from the arcuate ice-contact face at the northeast (proximal) edge of the delta. Shortly thereafter, rapid isostatic rebound lifted much of the glaciomarine terrain in this area above sea level.

A second large area of rolling glaciomarine terrain is associated with the large ice-contact deltaic platform south of Lakelse Lake. The foreset slope at the south end of this platform borders glaciomarine deposits that have been extensively gullied during postglacial time. The gullies expose a thick sequence of interbedded sand, which was carried down the delta slope by currents and waves, and mud deposited mainly from turbidity flows and suspension. This area of glaciomarine terrain is bounded on the south and east by the floodplains and associated fluvial terraces of Kitimat and Wedeene rivers, and on the west by higher ground underlain by till, glaciofluvial and colluvial deposits, and bedrock.

Other substantial areas of glaciomarine terrain occur north and west of Terrace and at and northwest of Kitimat.

Thick glaciomarine sediments also occur in the subsurface in the Kitsumkalum-Kitimat trough and in Skeena Valley west of Terrace. In one drillhole at Lakelse Lake, for example, about 80 m of silty clay and clayey silt were penetrated to about 5 m below sea level before drilling was stopped. The thick marine and glaciomarine fill in these valleys may have accumulated during more than one glaciation.

### Glaciomarine Blankets and Glaciomarine Veneers ($W^{G}b$, $W^{G}v$)

Thin glaciomarine deposits that lack independent surface expression are mapped as blankets and veneers. Glaciomarine deposits thin over sloping bedrock and drift-covered surfaces within and at the margins of the Kitsumkalum-Kitimat trough. In general, these sediments also become thinner and more patchy with increasing elevation and are absent above 200 m.

Typical glaciomarine blankets on bedrock occur within the large area of rolling glaciomarine terrain northwest of Lakelse Lake. Near Terrace, a blanket of glaciomarine mud overlies sand and gravel (glaciofluvial or deltaic deposits). Examples of glaciomarine veneers are present near the mouth of Wedeene River and in the vicinity of Thornhill.

### Glaciolacustrine Terrain ($L^{G}m$, $L^{G}t$)

Rolling and terraced glaciolacustrine terrain is rare in the study area, in marked contrast to its widespread occurrence in parts of the central Interior Plateau to the southeast. Small areas of $L^{G}m$ and $L^{G}t$, characterized by massive and laminated muds, are present in Skeena Valley at Kleanza and Chimdemash creeks, in Bulkley Valley near Moricetown, and in the Kitsumlakum-Kitimat trough north of Treston Lake. Raised deltas at the mouths of Kleanza and Chimdemash creeks are genetically related to the rolling lake floor terrain in the same area. Glaciolacustrine deltas also occur in Kitsumkalum Valley at the north and south ends of Treston Lake and at various places in Bulkley Valley (e.g., Elliot Creek).

Areas mapped as $L^{G}m$ and $L^{G}t$ are remnants of the floors of ice- and sediment-dammed lakes that formed when the study area was becoming deglaciated at the end of the Pleistocene. Most of these lakes were short-lived and of small size, developing between valley walls and glaciers covering adjacent valley floors. A relatively large lake, however, occupied northern Kitsumkalum Valley in the vicinity of Kitsumkalum and Treston lakes. This lake formed between northward-retreating glaciers and a large body of deltaic and glaciofluvial sediments that blocked Kitsumkalum Valley south of Alice Creek. At its maximum, the lake probably extended to or beyond the northern limit of mapping.

In some areas, glaciolacustrine sediments occur in the subsurface beneath younger geological materials. In part of Bulkley Valley, for example, laminated to massive stony mud underlies glaciofluvial gravel and till. The distribution and stratigraphic position of this mud indicate that it was deposited in one or more relatively large lakes that inundated part of Bulkley Valley during the period of glacier growth at the beginning of the Fraser Glaciation (see section entitled Fraser Glaciation).

Lacustrine or glaciolacustrine sediments also occur beneath fluvial terrace gravel near the mouth of Suskwa River. Wood recovered from these sediments yielded a radiocarbon age of 9360 ± 180 BP (GSC-2463). The lake in which these sediments accumulated probably was very small and may have been dammed by residual stagnant ice or by alluvium deposited by Suskwa River. Alternatively, the lake may have occupied a small, ice-scoured basin that drained some time after about 9360 years ago[1] as Bulkley River incised its valley.

### Glaciolacustrine Blankets and Glaciolacustrine Veneers ($L^{G}b$, $L^{G}v$)

Blankets and veneers of glaciolacustrine mud cover glaciofluvial gravel and till in Bulkley Valley near Trout Creek and Doughty. These sediments are similar to thicker sediments ($L^{G}t$) occurring to the north near Moricetown and presumably were deposited in the same lake. There are no other occurrences of thin glaciolacustrine sediments in the map area that are sufficiently large to be shown on the surficial geology maps.

### Kames and Ice-Stagnation Terrain ($A^{G}h$, $A^{G}m$)

Hummocky, rolling, and undulating terrain underlain by sand, gravel, and diamicton is widespread in the main valleys of the map area, with the exception of lower Skeena Valley west of Terrace. The irregular surfaces that characterize ice-stagnation terrain formed during deglaciation by: (1) melting of dead ice in contact with drift and (2) reworking of drift at the base of stagnating glaciers by meltwater. Much of the ice-stagnation terrain in the study area is located along the edges of valleys, where a variety of sediments accumulated between active ice and higher ground (as, for example, in the Kitsumkalum-Kitimat trough between Wedeene and Little Wedeene rivers). In other places, ice-stagnation terrain extends across the full width of a valley (for example, in Skeena Valley north of Kitseguecla). Hummocky and rolling ice-disintegration landforms also occur in association with ice-contact deltas and kame terraces ($A^{G}d$, $A^{G}t$).

### Eskers ($A^{G}r$)

Sinuous and irregular ridges consisting of poorly sorted gravel and diamicton deposited in ice tunnels at the base of decaying glaciers occur in Bulkley Valley north and east of Smithers and near the mouth of Suskwa River. These features are relatively small (a few metres high and a maximum of 3 km long) and occur both as single isolated ridges on ground moraine and as part of larger complexes of ice-contact drift. No eskers were noted within the mapped part of the study area outside Bulkley Valley, except for a short (1 km) esker on the east wall of the Kitsumkalum-Kitimat trough near Kitimat.

[1] All ages and dates in this report are in radiocarbon years.

### Glaciofluvial Blankets and Glaciofluvial Veneers ($A^{G}b$, $A^{G}v$)

Glaciofluvial sand and gravel, which mantle other terrain units but which do not completely obscure their morphology, are mapped as blankets and veneers. Thin glaciofluvial deposits commonly occur in association with terrain mapped as $A^{G}h$ and $A^{G}m$ (kames, ice-stagnation terrain). In general, the deposits are gravelly, although thin glaciofluvial sand mantles rolling morainal deposits on parts of the Skeena Valley floor between Hazelton and Kitwanga. In the vicinity of Hazelton, this sand is well exposed in roadcuts and excavations; here it drapes over irregular morainal topography and is up to 3 m thick (average thickness ≃ 1 m). The sand is moderately well sorted, of fine to medium size, and appears structureless. The sandy glaciofluvial deposits between Hazelton and Kitwanga probably were laid down at the base of, or directly in front of, a stagnant glacier by meltwater flowing southwest down Skeena Valley.

In the Kitsumkalum-Kitimat trough and in Skeena Valley between Kitwanga and Terrace, glaciofluvial blankets and veneers are gravelly and poorly sorted, and occur most commonly on bedrock slopes.

### Kame Terraces ($A^{G}t$)

These are terraced landforms consisting of sand and gravel deposited by meltwater streams at the margin of a melting glacier or a large body of dead ice. Kame terraces may be distinguished from fluvial terraces by the presence of kettles, meltwater channels, and sedimentary structures indicative of deposition against ice (e.g., faults, deformed stratification). Where such features are absent, regional geomorphic relationships still may indicate that a terrace formed against ice, and such a feature would be mapped as $A^{G}t$ rather than At.

Kame terraces are present in the Kitsumkalum-Kitimat trough, in Skeena Valley between Terrace and Hazelton, and in lowermost Bulkley Valley near the mouth of Suskwa River. They commonly occur at the margins of these valleys, having formed between higher ice-free ground and glaciers that covered the valley floors. When the glaciers disappeared, the glaciofluvial deposits were left standing as terraces. Kame terraces stand well above adjacent nonglacial river terraces that formed during a period of fluvial aggradation followed by downcutting after ice had disappeared from the area.

### Deltas ($A^{G}d$, Ad)

Deltas shown on the surficial geology maps (Map 1557A) are raised inactive features that formed in the sea and in former glacial lakes. Active deltas (e.g., Skeena and Kitimat river deltas) are not mapped as Ad because their foreslopes are subaqueous and thus are not shown on the base maps, and because their subaerial portions are modern floodplains that are more appropriately mapped as Ap (Fig. 31).

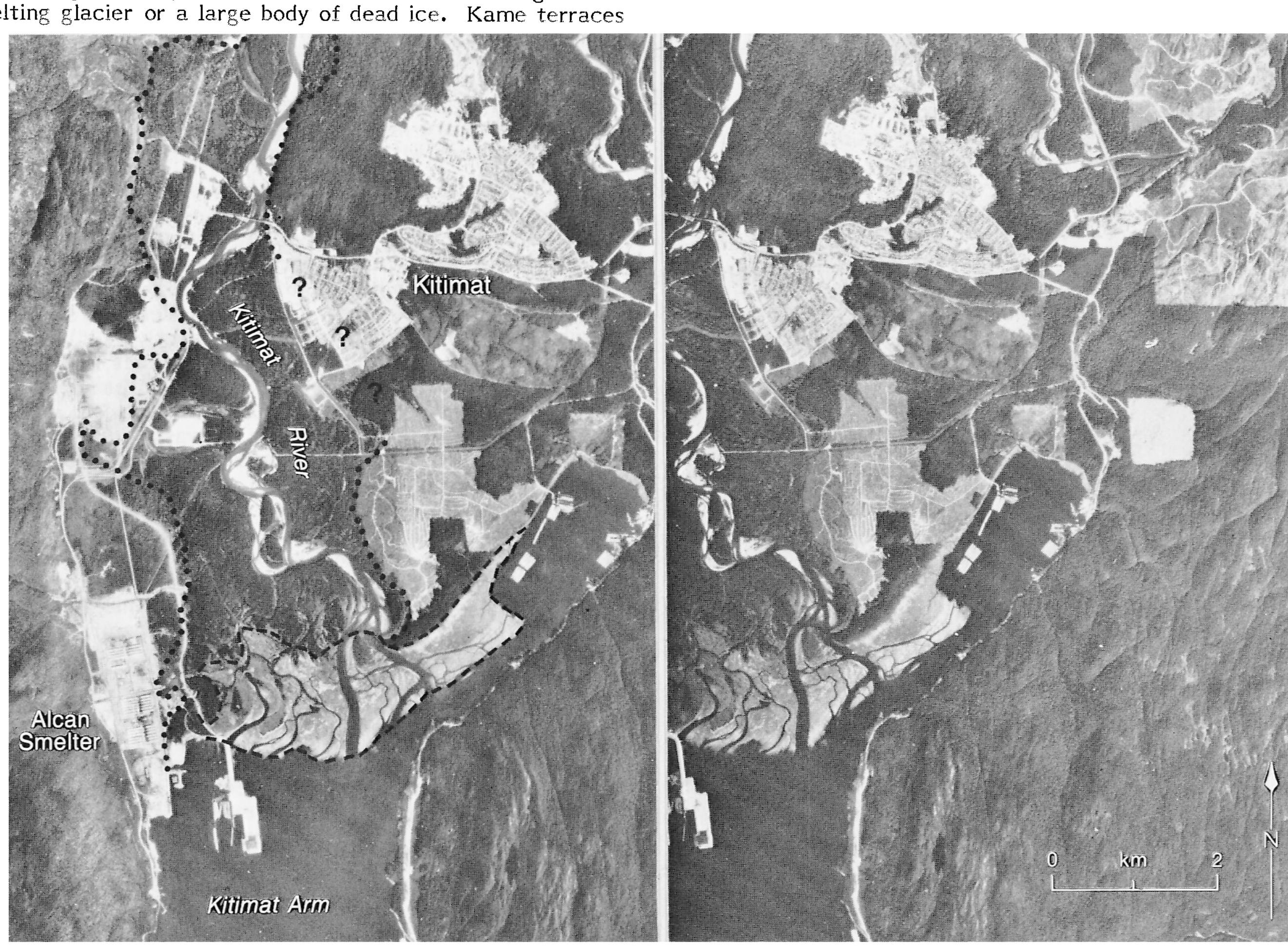


***Figure 31.*** *Stereogram of the modern floodplain and delta of Kitimat River. The dotted lines are the approximate boundaries of the floodplain; dashed lines enclose the intertidal zone of the delta. The delta foreslope, which is covered by water, is located directly south of the intertidal zone. Province of British Columbia photos BC5608-31, -32.*

Raised deltas are similar in many respects to terraces and are differentiated from them mainly to call attention to the deltas having been constructed in a body of standing water. This means that, rather than being underlain by coarse channel deposits, as is the case with most terraces, raised deltas consist of foreset-bedded sand and gravel which commonly overlie silt and clay of glaciomarine or glaciolacustrine origin. In some cases, however, it is unclear whether a terraced feature is deltaic ($A^{G}d$, Ad), fluvial ($A^{G}t$, At), or some combination of the two. For example, the high terrace on which the northernmost part of the municipality of Terrace is located slopes gently (<2°) west and is directly underlain by sand and gravel with near-horizontal bedding similar to that found in fluvial deposits. About 20 m below the terrace surface, however, the sediments exhibit foreset bedding indicative of deposition in standing water. This terrace is mapped as a delta, although it is recognized that the uppermost sediments may be alluvial rather than deltaic in origin. A similar but much larger feature, which extends across the full width of the Kitsumkalum-Kitimat trough 7-12 km north-northwest of Terrace, likewise has been mapped as a delta because it too is cored with foreset-bedded sand and gravel.

Other landforms have been identified as deltaic only if there is unequivocal evidence of their having been built into a lake or the sea. The evidence includes foreset bedding and a sharp break between a gently inclined depositional surface, or delta top, and a moderately steep depositional surface, or foreslope (Fig. 32). Sediments directly underlying the delta top are flat-lying or gently inclined, whereas those beneath the foreslope, in general, dip parallel to the foreslope surface.

Raised deltas in the study area are subdivided into three groups according to their environment of deposition and time of formation: (1) deltas built into ice- and sediment-dammed lakes during deglaciation at the close of the Pleistocene ($A^{G}d$); (2) deltas built into the sea during deglaciation ($A^{G}d$); and (3) deltas built into the sea after glaciers had completely disappeared from the area, but before the sea had fallen to its present level relative to the land (Ad).

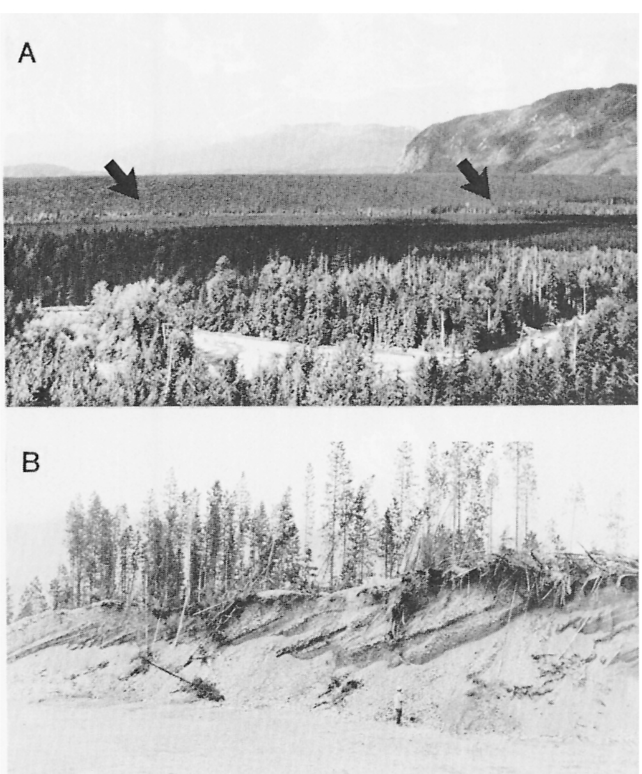


***Figure 32.*** *Raised delta in the Kitsumkalum-Kitimat trough. A delta foreslope (arrows). B foreset-bedded sand and gravel exposed on the foreslope. (GSC 203257-K).*

(1) The first group consists mainly of small, deeply incised, fan-shaped forms bounded by foreslope escarpments and located on valley walls near the mouths of some tributary streams. Foreset-bedded sand and gravel are the main constituents of these deltas. They occur in Bulkley Valley at Elliot and Driftwood creeks, and in Skeena Valley between Oliver and Kleanza creeks. The deltas probably formed where streams entered small lakes trapped between dead ice and valley walls.

Small deltas in the Kitsumkalum-Kitimat trough at Treston Lake also are included in this group because they too formed in a late glacial lake. These differ, however, from other mapped glaciolacustrine deltas in having ice-contact faces proximal to the sediment source. In addition, they extend part way across Kitsumkalum Valley and thus are not restricted to valley-side positions as are the other glaciolacustrine deltas. The deltas at Treston Lake formed at the toe of the glacier retreating north up Kitsumkalum Valley. The lake in which the deltas were built was dammed to the south by a large body of sand and gravel extending across the full width of the valley.

(2) Raised glaciomarine deltas occur in the Kitsumkalum-Kitimat trough and in Skeena Valley southwest of Terrace. Some of these were built into the sea by tributary streams and are identical in morphology and internal structure to the glaciolacustrine deltas described above. They are known to be of marine origin because of their association with muds containing fossil marine molluscs.

In addition to the relatively small valley-side glaciomarine deltas, there are several large ice-contact deltas on the floor of the Kitsumkalum-Kitimat trough (Fig. 30, 32). The largest of these, south of Lakelse Lake, extends across the full width of the trough and covers an area of approximately 60 $km^2$. These large deltas are expressed topographically as platforms sloping gently (<2°) south and southwest from steep (up to 35°), ice-contact faces towards foreslopes inclined from a few degrees to as much as 25° (Fig. 30). The gently sloping platform surfaces, which are underlain by nearly horizontal outwash gravel, are the subaerial tops of formerly active deltas. The large platforms south of Lakelse Lake and north of Terrace are crossed by conspicuous meltwater channels and are locally pitted by kettles. Indistinct channels, visible only on aerial photographs, also cross the platform north of Lakelse Lake (Fig. 30). Sediments on the foreslopes of these large deltas become increasingly fine grained in a downslope direction: gravel gives way to sand, and sand in turn locally grades into mud deposited from suspension and turbidity flows.

(3) Some raised deltas in the study area were constructed after deglaciation was complete. They are similar to the valley-side glaciomarine deltas described above but slope less steeply and occur at lower elevations. Like the glaciomarine deltas, they have been incised by streams to produce terraced landforms. An example of a probable early postglacial raised delta is a sloping terrace just south of Little Wedeene River at the west edge of the Kitsumkalum-Kitimat trough. Here, foreset-bedded sand and gravel underlie a surface that slopes gently (<5°) eastward towards the centre of the trough, locally terminating in a steeper depositional face. This delta was built into the Kitsumkalum-Kitimat trough by Little Wedeene River; it is inset into higher older deltas of late Pleistocene age. Although the low delta has not been directly dated, regional relationships

indicate that it probably is 9000-10 000 years old, and thus postdates the final disappearance of lowland glaciers from the region (see section entitled Quaternary History).

Postglacial delta deposits are locally buried beneath fluvial terraces and fans; for example, alluvial gravel of the Hirsch Creek terrace north of Kitimat overlies delta foreslope deposits that contain wood which has been radiocarbon dated at 9300 ± 90 BP (GSC-2425).

### Alluvial Fans and Glaciofluvial Fans (Af, $A^{G}f$)

Alluvial fans (Af) occur in all valleys of the study area, although they are subordinate to avalanche and debris-flow fans (Cf) in parts of Skeena Valley and in most high mountain valleys. Most of the alluvial fans have been constructed by perennial streams that experience a spring freshet. They consist of sand and gravel deposited where the gradient and carrying capacity of the transporting stream decline, commonly at the junction of tributary and trunk valleys. Rapid deposition resulting from the abrupt gradient change produces a poorly sorted, fan-shaped deposit that generally fines from the apex to the toe. The slope of the fan varies with the coarseness of the constituent materials, from as much as 20° at the apex to about 1° at the toe. All alluvial fans have crude stratification roughly parallel to the fan surface. Maximum accumulation takes place near the main stream crossing the fan; accumulation decreases both downstream and away from the channel.

Individual fans in the mapped part of the study area are less than 2 km wide at the toe; however, in some places (e.g., Bulkley Valley), several fans have coalesced to form complexes up to 8 km wide.

Many alluvial fans have channels incised to such a depth that further deposition cannot take place on the fan surface. Such "raised" or "terraced" fans (Aft) are not at grade with present base level; a typical example is the fan dissected by John Brown Creek near Moricetown. Channel incision on fans may be caused, among other things, by decreases in sediment supply, streamflow, or runoff periodicity, or an increase in channel gradient (Fulton, 1975, his Table VIII). Ryder (1971a, b) and Fulton (1975) have suggested that most alluvial fan sediments in the southern interior of British Columbia accumulated during a relatively short period of time during and immediately after deglaciation, and the same is probably true for the Smithers-Terrace-Prince Rupert area. During deglaciation, conditions were favourable for the formation of alluvial fans: there were extensive bare unstable slopes, evapotranspiration was low, and streams were aggrading their valleys. Subsequent stabilization and vegetation of slopes led to a reduction in sediment supply and, ultimately, to the entrenchment of many fans by the streams crossing them.

Fan formation likely began while there still was glacier ice in the study area. A gravelly fan near the confluence of Erlandsen Creek and Zymagotitz River has an irregular kettled surface indicating deposition on stagnant ice. This glaciofluvial fan ($A^{G}f$) formed at the close of the Pleistocene when upland areas were ice-free, but before major lowland valleys such as the Kitsumkalum-Kitimat trough were completely deglaciated.

### Floodplains (Ap, Av)

Floodplains of various sizes are present in most major valleys in the study area. Broad alluvial plains, up to about 4 km wide, occur along Kitimat River in the Kitsumkalum-Kitimat trough and along Skeena River between Terrace and Kwinitsa. Smaller, although still substantial floodplains also are present in Skeena Valley between Terrace and Kitwanga and west of Kwinitsa, in the Kitsumkalum-Kitimat trough north of Terrace, and in Bulkley Valley near the mouth of Suskwa River and in the vicinity of Smithers. Each floodplain consists of two parts, an area of active stream channels underlain by sand and gravel, and an area adjacent to channels which is periodically flooded and which commonly is underlain directly by silt, sand, and peat.

In Skeena Valley west of Terrace, floodplain sediments fine in a downriver direction. From Terrace to the vicinity of Gitnadoix River, gravel is the main floodplain sediment. Farther west, gravel persists as the dominant material on active bars, but sand is most common elsewhere. West of Khyex River in the upper estuary of Skeena River, silty sand and sandy silt are the most common alluvial sediments.

Borehole records indicate that floodplain deposits of Skeena and Kitimat rivers are locally more than 20 m thick. Most mapped alluvial deposits probably are several metres thick on the average, although some are so thin that they fail to mask topography developed on underlying materials (for example, those adjacent to a small unnamed stream draining into Minette Bay at Kitimat); the symbol Av is used for this last group of deposits.

### River Terraces (At)

Terraced alluvial deposits of postglacial age occur in most valleys in the study area. River terraces are particularly prominent along Kitimat River and some of its tributaries, and along lowermost Kitsumkalum River, Bulkley River, and Skeena River upstream from the mouth of Lakelse River. Between Kispiox and Cedarvale, Skeena River has a nearly continuous fringe of alluvial terraces. In contrast, river terraces are rare in Skeena Valley west of Lakelse River.

River terraces stand from a few metres to about 70 m above the floodplains of adjacent streams. They occur singly and in sets of two or more treads bordered by steep erosional scarps. Terrace surfaces are flat to gently sloping and are underlain by well sorted, horizontally stratified gravel which is generally mantled by sand. Flat stones in terrace gravels have upstream dips, locally giving rise to well developed imbricate structure.

River terraces formed during postglacial time as streams incised bedrock and valley fills consisting of unconsolidated sediments. The highest terrace in each region approximates the upper limit of aggradation achieved by trunk streams immediately after deglaciation. In contrast, lower terraces formed as base levels fell and are largely erosional in origin. Alluvial fans are superimposed on many terraces.

### Valley-Floor Complex (Ax)

Alluvial and colluvial deposits and landforms in some mountain valleys cannot be differentiated at the scale of mapping. In these areas, colluvial and alluvial fans are intimately associated with narrow discontinuous floodplains and/or river terraces. This complex of landforms is referred to as a "valley-floor complex" and is designated on the surficial geology maps (Map 1557A) by the symbol Ax.

### Landslides (Ch, Cm)

Landslides, including debris flows, mudflows, translational and rotational slides, rockfalls, and complex landslides (Varnes, 1978), are common in the study area, although typically of small size. Most landslides are associated with: (1) steep bluffs eroded in unconsolidated sediments and bordering the main rivers; (2) terrain underlain by glaciomarine mud and clay-rich till; and (3) steep rock slopes.

(1) Slumps and flows from bluffs are particularly common in Bulkley Valley. Bulkley River and many of its tributaries flow in canyons and valleys incised up to about 100 m below the late Pleistocene floor of Bulkley Valley. The steep scarps bordering these canyons and valleys formed during a period of fluvial incision following deglaciation; many have subsequently failed, giving rise to a narrow fringe of hummocky colluvium at their base. Where slumping has been the dominant failure mechanism, the landslide deposits differ little from materials exposed in adjacent scarps; original structures commonly are retained in the displaced mass. In contrast, debris-flow deposits typically are diamictons produced by flowage and redeposition of scarp materials; no original structures are preserved.

(2) Slumps and flows in fine textured unconsolidated sediments are most common in Bulkley Valley and in the southern Kitsumkalum-Kitimat trough. Clay-rich tills in Bulkley Valley are susceptible to small-scale rotational sliding, especially where the surface has been disturbed by man. Most slumps in Bulkley Valley are too small to be mapped; however, a few of the larger failures are shown on the surficial geology maps (for example, just north of Driftwood Creek). Relatively large historic flows in glaciomarine and marine muds have occurred in the Kitsumkalum-Kitimat trough at the northeast end of Lakelse Lake and at the head of Kitimat Arm (Fig. 33; Golder Associates, 1975; Bell and Kallman, 1976; Clague, 1978b; Luternauer and Swan, 1978; Swan, 1978; Swan and Luternauer, 1978; Prior et al., 1982). The subaerial mudflow deposits near Lakelse Lake are rolling and less commonly hummocky, covering gentle slopes far (locally >1 km) from source scarps.

(3) Landslides on steep rock slopes in the study area are of two types: deep-seated bedrock failures and debris avalanches – debris flows involving only a thin layer of unconsolidated sediments. The former are the largest, and the latter the most common, landslides in the region.

Deep-seated bedrock failures, including slumps and complex landslides, are scattered through the mountainous parts of the study area. In general, these landslides have hummocky or rolling surfaces and well defined head scarps. Most of those in the map area are in Skeena Valley between Hazelton and Cedarvale and involve sedimentary rocks of the Bowser Lake and Skeena groups. All identified deep-seated bedrock failures are of latest Pleistocene or postglacial age. Most apparently are inactive at present, although a large landslide 2 km southwest of Kitseguecla is still moving. There is a possibility that some of the other mapped landslides also may be active, although definitive indicators of recent movement, such as fresh scarps, tension cracks, and tilted trees, were not found in the course of this study.

Fluid, fast-moving debris avalanches and debris flows triggered by the failure of a thin surface layer of water-saturated colluvium and/or glacial deposits are common on moderate to steep slopes in the western part of the study area (Fig. 34, 35). They are especially abundant on slopes underlain by foliated metamorphic rocks in areas of high precipitation (>2500 mm/a). The failures generally involve small volumes of material ($10^3$-$10^5$ $m^3$) that travel long distances downslope, producing linear tracks of devastation in forest similar to avalanche paths (Fig. 34). The deposits of these avalanches and flows are mainly diamictons; they generally are thin and cover small areas.


***Figure 33.*** *Stereogram of a mudflow that occurred in 1962 in glaciomarine sediments at the northeast end of Lakelse Lake. This landslide severed the Terrace-Kitimat highway and damaged a provincial park campsite. Province of British Columbia photos BC5083-081, -082.*

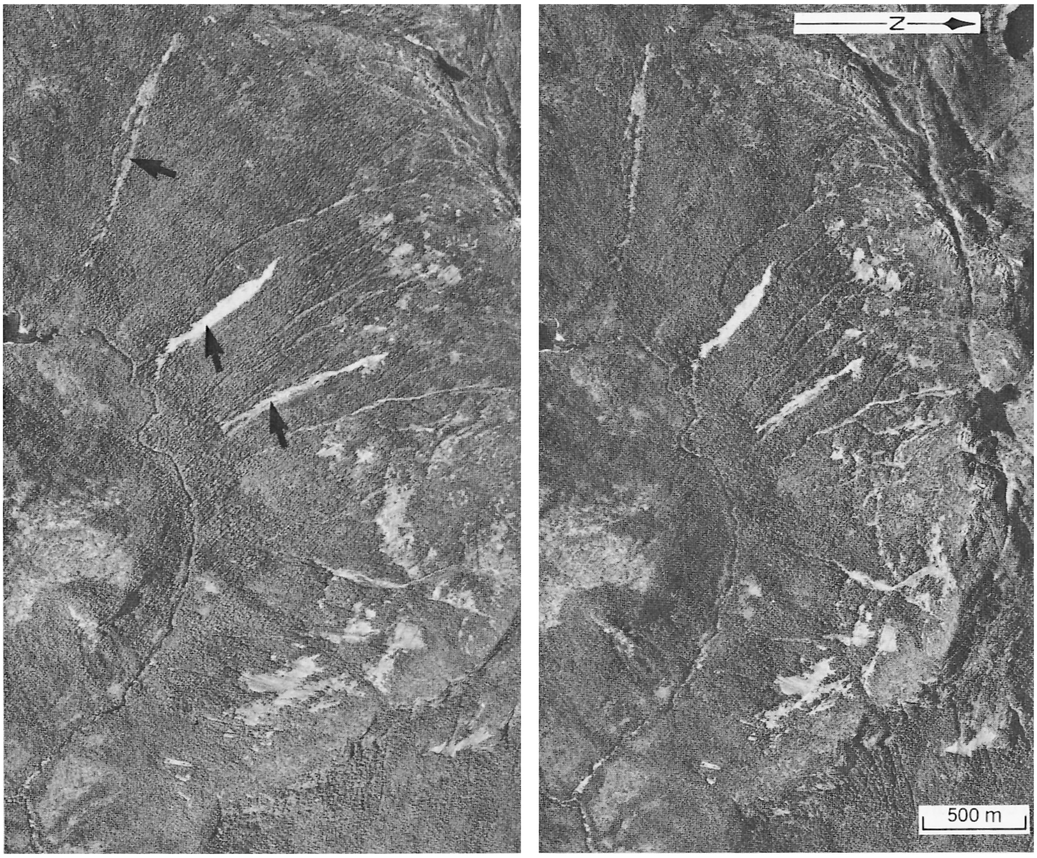


***Figure 34.*** *Stereogram of a mountain slope near Port Essington showing long narrow scars resulting from debris flows and debris avalanches (arrows). Province of British Columbia photos BC5085-039, -040.*

***Figure 35***

*Debris flow track and deposits, Skeena Valley near Amsbury. (GSC 203257-L).*

## Avalanche and Debris-Flow Fans (Cf)

Relatively steep fans (or cones) occur at the lower ends of many ravines that are subject to avalanching and debris-flow activity. Such fans are common in the valleys of the Coast Mountains, especially adjacent to slopes that extend above treeline in areas of high precipitation. They are less common, although by no means rare, in the mountain valleys of the Interior System where precipitation, in general, is lower than in the Coast Mountains.

Colluvial fans consist of poorly sorted, bouldery gravel and diamicton deposited during winter-spring avalanches and during spring-fall debris flows. Stratification in these sediments is crudely parallel to the surface of the fan. Debris-flow and debris-avalanche materials commonly are reworked by running water soon after their deposition, giving rise to hybrid sediment types.

Colluvial fans, as a group, are steeper than alluvial fans (the former slope up to 30°, the latter less than 20°). In general, colluvial fans also consist of coarser, more poorly sorted material than alluvial fans, although both become finer in a downslope direction.

Most colluvial fans in the study area are the product of sporadic mass movements and snow avalanches that have occurred throughout postglacial time. Many of the fans are active at present, as indicated by the presence of immature forest and youthful debris-flow and avalanche tracks on fan surfaces.

## Colluvial Aprons (Ca)

Aprons of rubbly and blocky debris border some steep slopes within the map area (e.g., lower Skeena River region) and are common in the higher unmapped parts of the study area. These talus aprons and small talus cones have formed by rockfall from adjacent steep bedrock slopes. Talus slopes subject to frequent rockfall activity generally slope between 30° and 35°, and are sparsely vegetated. Vegetated talus slopes with infrequent rockfall activity are typically less steep.

## Colluvial Blankets and Colluvial Veneers (Cb, Cv)

Discontinuous thin mantles of colluvium overlying bedrock and unconsolidated sediments are common on moderate slopes (15-30°) throughout the study area. In any given area, colluvial blankets generally are present on gentler slopes than colluvial veneers. The former also are more continuous, with fewer outcrops of underlying materials. As the slope angle approaches 30°, bedrock becomes increasingly common as a surface material, and colluvium and drift become thinner and more restricted. The thickness of colluvium, however, depends not only on the steepness of the underlying slope, but also on the nature of the parent material and the local climate. All other things being equal, colluvium is thicker on slopes underlain by sedimentary, foliated metamorphic, and some volcanic rocks than on slopes underlain by granitoid rocks. The formation of colluvium also is promoted by abundant moisture and by frequent freeze-thaw activity.

Most thin colluvial mantles in the study area consist of Pleistocene sediments that have moved downslope under the influence of gravity, mixed with rubble derived from local bedrock. There is a continuum between drift that has been completely reconstituted into colluvium by downslope creep and drift that has experienced little or no downslope gravitational movement. As a result, the positions of some map boundaries separating Cb (or Cv) from Db (or Dv) are poorly defined and somewhat arbitrary.

## Organic Units (O, Ob, Ov)

Deposits of peat in various stages of decomposition occur in bogs and swamps and on some slopes. In those parts of the study area where precipitation is relatively low (e.g., Bulkley Valley), organic deposits are restricted to small depressions developed on drift and bedrock and to floodplains underlain by fine grained sediments. Organic accumulations are more common and extensive in areas of high precipitation. For example, in the vicinity of Prince Rupert, where precipitation averages about 2400 mm/a, peat covers most flat and gently sloping surfaces, and folisols (layers of leaf litter, wood, and mosses) directly overlie bedrock on some moderately steep slopes; in some closed depressions in this area, organic deposits are more than 20 m thick (Radforth, 1969, p. 13).

Terrain mapped as O is flat-lying to very gently sloping (<3°) and is underlain by organic deposits thick enough (generally <3 m, but locally >20 m) to mask the surface form of underlying materials. Substrate materials commonly are fine grained and poorly drained (e.g., glaciomarine mud, floodplain silt). Peaty sediments in many closed depressions are underlain by marl which grades downward into lacustrine or glaciolacustrine mud. In contrast, organic accumulations on floodplains and at the toes of alluvial fans are directly underlain by, and locally interstratified with, fluvial mud and sand.

Organic blankets and veneers (Ob, Ov) incompletely mask the surface morphology of underlying materials. These deposits are most common on bedrock and drift-covered slopes inclined less than 15° west of Ecstall River but also occur on the floodplain of Skeena River and its tributaries in the same general region.

## Ice (I)

Perennial snow and ice occur at high elevations throughout the study area (Fig. 36). The "glaciation level" – the lowest elevation at which glaciers can develop – rises inland from about 1500 m near Prince Rupert to about 2100-2200 m at the eastern edge of the study area (Østrem, 1972). Cirque and valley glaciers and icefields are most abundant and extensive in the Coast Mountains. By far the largest expanse of ice and snow is Cambria Icefield which covers more than 500 $km^2$ of mountainous terrain east of Stewart in the northwest corner of the study area. In contrast, most valley glaciers are relatively small, few exceeding 5 km in length. Almost all glaciers in the study area have receded from climax positions attained in the nineteenth (?) century (Fig. 36).

## Man-Made Areas (X)

Man-made substrate materials that are extensive enough to be shown on the surficial geology maps include the foundation materials of the Alcan smelter at Kitimat and the fill upon which some port facilities at Prince Rupert are located.

## Composite Map Units

Many map units consist of two or more of the above-described units that are not separable at the scale of mapping. Such composite units are indicated on the surficial geology maps (Map 1557A) by sets of letters separated by colons. The component to the left of a colon is more common within the area of the terrain unit than that to the right. Most composite map units comprise two components, although a few three-component units also occur.

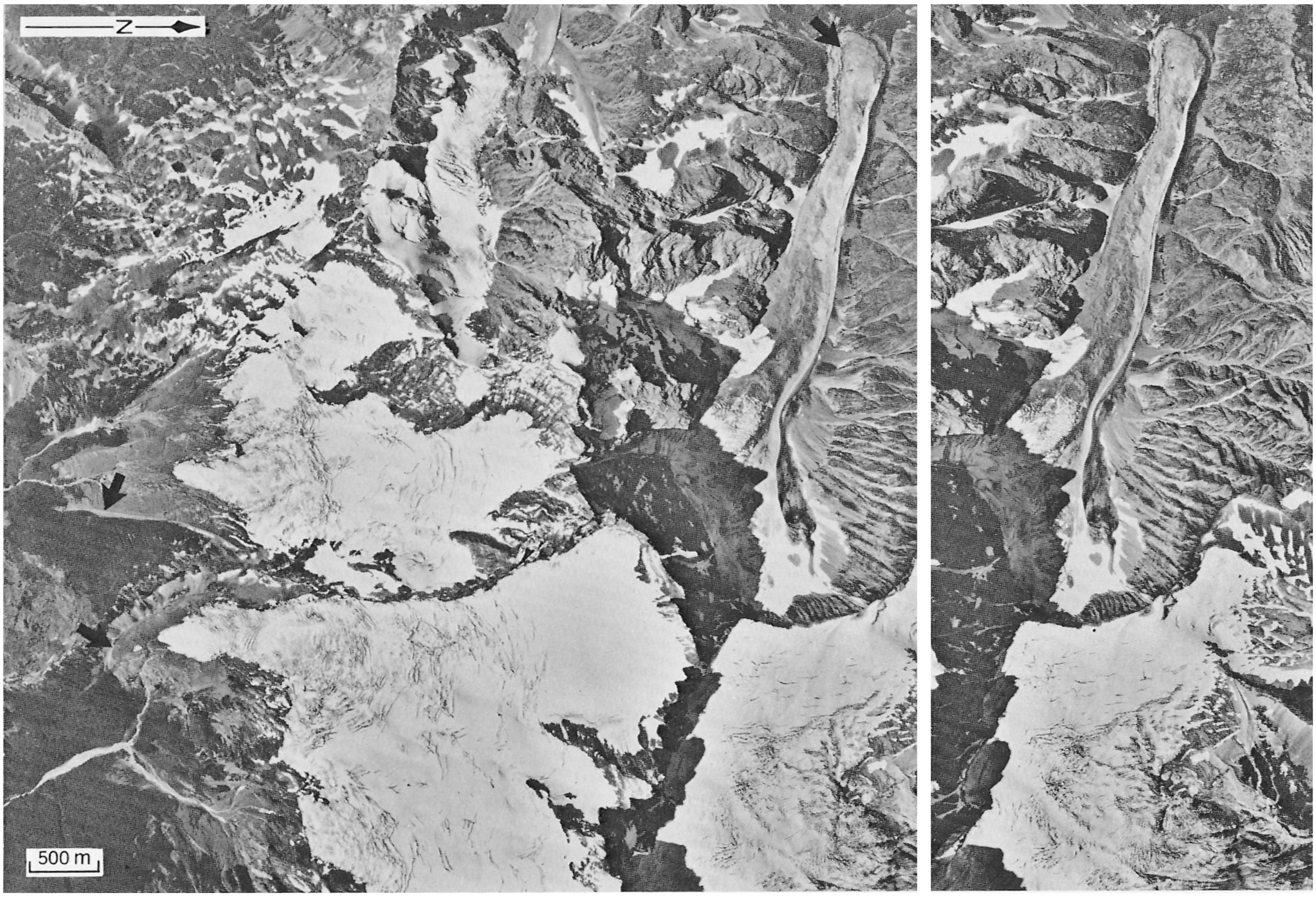


***Figure 36.*** *Stereogram of alpine glaciers on Seven Sisters Peaks southeast of Cedarvale. Note fresh morainal deposits (arrows) beyond present ice margins, defining formerly more extensive glaciers. Province of British Columbia photos BC5305-013, -014.*

Composite map units are most common in areas where bedrock is at or near the surface and where the overlying sediments vary markedly in thickness over short distances. In such areas, rock, morainal, colluvial, and drift units commonly occur together in various associations (Table 6). Composite map units also occur in areas of thick Quaternary deposits, for example where morainal and ice-contact sediments are intermixed and where small alluvial plains cannot be separated from bordering river terraces.

### *Stratigraphic Relationships*

#### Shallow Stratigraphy

The surficial geology maps (Map 1557A) portray the character and areal distribution of surface unconsolidated sediments in the Smithers-Terrace-Prince Rupert region. In addition, the maps show the stratigraphic relationships of thin surface units (i.e., blankets and veneers) to underlying sediments and bedrock. Where the subsurface unit comprises sediments, the succession is depicted by means of a diagonal line separating components arranged in stratigraphic order. In contrast, where the subsurface unit is bedrock, no diagonal lines are used.

*Glaciomarine Sediments above Glaciofluvial Sediments and Drift* ($W^{G}b/A^{G}d$, $W^{G}v/A^{G}d$, $W^{G}v/A^{G}m$, $W^{G}v/Dm$). Blankets and veneers of glaciomarine mud cover glaciofluvial sand and gravel and drift at a few sites in the Kitsumkalum-Kitimat trough (Fig. 37). North and south of Skeena River near Terrace, mud overlies flat-lying sand and gravel that were deposited either as subaqueous outwash or, more likely, as proglacial deltaic sediments. In the southern Kitsumkalum-Kitimat trough west of Kitimat River, a thin layer of mud overlies weakly stratified, poorly sorted gravel and diamicton that were deposited in contact with ice on the sea floor.

*Glaciolacustrine Sediments above Till and Glaciofluvial Sediments* ($L^{G}b/Mm$, $L^{G}v/A^{G}t$). A thin layer of glaciolacustrine mud mantles till and glaciofluvial gravel in Bulkley Valley near Trout Creek and Doughty. The mud was deposited in a short-lived lake that probably was dammed by decaying glacier ice at the close of the last glaciation.

*Glaciofluvial Sediments above Till* ($A^{G}v/Mm$, $A^{G}v/Mb$). A veneer of glaciofluvial sand covers ground moraine in Skeena Valley in the vicinity of Hazelton and Kitwanga. The sand drapes over irregular topography and probably was deposited at the base of, or directly in front of, a stagnant glacier by meltwater flowing southwest down Skeena Valley.

*Fluvial and Glaciofluvial Sediments above Glaciomarine Sediments* ($Av/W^{G}m$, $A^{G}b/W^{G}m$, $A^{G}b/W^{G}p{:}A^{G}t$, $A^{G}v/W^{G}m$). Thin deposits of sandy and gravelly alluvium and outwash overlie glaciomarine mud at a few localities in the Kitsumkalum-Kitimat trough. They occur in association with much thicker alluvial and glaciofluvial deposits which also overlie glaciomarine sediments.

**Table 6.** Composite terrain units in the map area

| Primary component | O | Ov | Cm | Cf | Ca | Cb | Cv | Af | Ap | Ax | Av | At | AGm | AGb | AGt | WGb | WGv | Mm | Mb | Mv | Dm | Db | Dv | Us | R | Rs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | | | | | | | | | | | | | | | | | | | | | | | | | 2 | |
| O | | | 2 | | | | | | 1 | | | | | | | | | | | | | | | | | |
| Ov | | | | | | | | | | | | | | | | | 1 | | | | | 2 | 1 | | 1 | |
| Ch | | | | | | | | | | | | | | | | | | | | | | | | | 2 | |
| Cf | | | | | | | | 2 | | | | | | | | | | | | | | | | | | |
| Ca | | | | | | | 1 | | | | | | | | | | | | | | | | | | 2 | |
| Cv | | | | | 1 | 2 | | | | | | | | | | | | | | | | 2 | | | 1 | |
| Af | | | | | | | | | 2 | | | | | | | | | | | | | | | | | |
| Ap | 1 | | | | | | | 2 | | | | 1 | | | | | | | | | | | | | | |
| At | | | | | | | | | 2 | | | | | | | | | | | | | | | | 2 | |
| AGm | | | | | | | | | | | | | | 2 | | | | 1 | | | | | | | | |
| AGr | | | | | | | | | | | | | | | | | | 2 | | | | | | | | |
| AGb | | | | | | | | | | | | | 2 | | | | | | | | | | | | 2 | |
| AGv | | | | | | | | | | | | | | 2 | | | | | | | | | | | 2 | |
| AGt | | | | | | | | | | | | | | | | | | | | | | | | | 2 | |
| AGd | | | | | | | | | | | | | | | | | | | | | | | | | | 2 |
| WGm | 2 | | | | | | | | | | | 2 | | | | | | | | | 2 | 2 | | | | |
| WGp | | | | | | | | | | | | | | | 2 | | | | | | | | | | | |
| WGb | | | | | | | | | | | | | | 2 | | | | | | | | | 2 | | 2 | |
| WGv | | | | | | | | | | | | | | | | | | | | | | | | | 1 | |
| Mm | | | | | | | | | | | | | 2 | | | | | | 1 | | | 2 | | | | |
| Mb | | | | | | | | | | | | | 2 | | | | | 1 | | 1 | | | 2 | | | |
| Mv | | | | | | | | | | | | | | | | | | | 1 | | | | | | | |
| Dm | | | | | | | | | | 2 | | | | | | | | | | | | 1 | | | | |
| Db | 2 | | | | | 2 | 2 | | 2 | | | | | | | | | | | 2 | 2 | | 1 | | | |
| Dv | | 2 | | | | 2 | | | | | | | | | | 2 | 2 | | | | | 1 | | | 1 | |
| Us | | | | | | | | | | | | | | | | | | | | | | | | | 1 | |
| R | | 1 | | 2 | | 1 | 1 | | | | 2 | | | | | | | | 2 | | | | 1 | 2 | | |
| Rs | | | | | | | | | | | | | | | | | | | | | | | | 1 | | |

1 = common association
2 = rare association

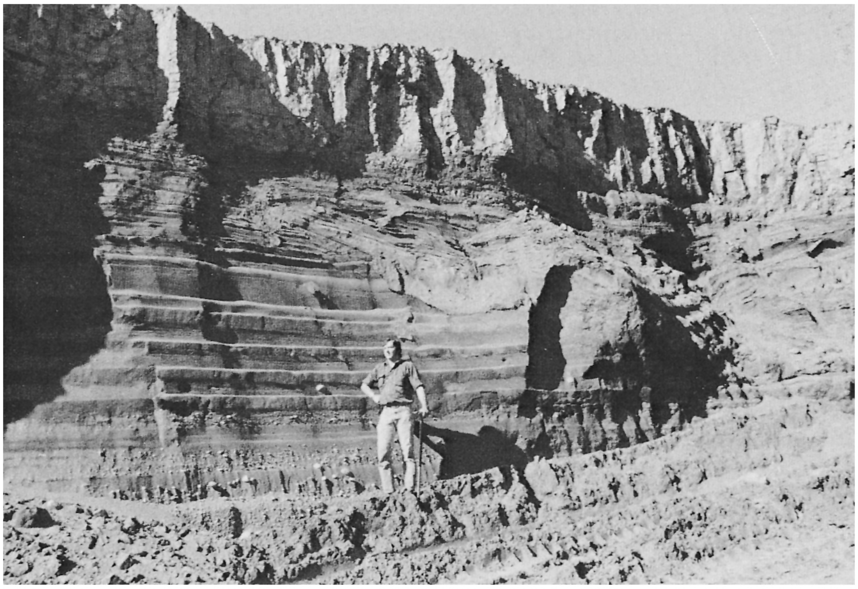

*Figure 37. Examples of stratigraphic relationships among late Quaternary sediments in the study area. Top: glaciomarine mud ($W_Gb$) overlying marine deltaic or subaqueous outwash sand ($A_Gd$) at Terrace. Bottom: till (Mm) overlying lacustro-deltaic sand ($A_Gd$) in Bulkley Valley. (GSC 203257-M).*

*Organic Sediments above Till (Ov/Mm, Ov/Mb).* A veneer of peat locally mantles till in the Prince Rupert area.

*Organic Sediments above Alluvium (Ob/Ap, Ob/Ap:At, Ob/Af, Ov/Ap).* Organic blankets and veneers overlie alluvium in lower Skeena Valley and in some valleys tributary to the northern Kitsumkalum-Kitimat trough. Relatively high precipitation, poor drainage, and low rates of clastic sedimentation at these sites provide conditions conducive to the growth of organic deposits on top of alluvium.

*Sediments above Bedrock (Ov, Cb, Cv, Av, $A^Gb$, $A^Gv$, $W^Gb$, $W^Gv$, Mb, Mv, Db, Dv).* Thin deposits of a wide variety of sediment types directly overlie bedrock in all parts of the study area. Blankets and veneers of colluvium and till are especially common in mountain areas and on bedrock hills within major valleys. Veneers of organic material are widespread on gentle and moderate slopes in the Hecate Lowland. These and other similar stratigraphic relationships are indicated on the maps solely by the landform symbols b and v following the genetic class descriptor. No diagonal lines follow the blanket and veneer symbols, as they do in the examples cited previously; their absence shows that the thin mantle of surface sediments covers bedrock rather than another sediment unit.

## Deep Stratigraphy

Thick surface sediments (i.e., those possessing a surface expression independent of that of underlying units and generally more than 2 m thick) overlie unconsolidated materials of different texture and/or genesis in the major valleys of the study area. In general, there is insufficient data from drillholes and natural exposures to map deep subsurface units, thus they are not shown on the maps in the same manner as shallow units. Some deep stratigraphic information is provided, however, in 26 representative stratigraphic sections illustrated on the maps. From these and other sections and drillhole records, the following generalizations can be made concerning the subsurface sediments in the main mapped valleys.

*Bulkley Valley.* Much of the floor of Bulkley Valley is underlain by till. Although this till in many areas directly overlies bedrock, it elsewhere rests unconformably on stratified sediments, mainly fluvial, glaciofluvial, and deltaic sand and gravel, and glaciolacustrine mud (Fig. 37; Map 1557A, sections 1-6). The fluvial and glaciofluvial sediments (sections 1, 3, 5) are horizontally stratified and probably were deposited during the penultimate interglaciation and the early part of the last glaciation (see section entitled Quaternary History). The glaciolacustrine mud (sections 2, 3, 4, 6) is weakly bedded to rhythmically laminated, contains dropstones, and was deposited in one or more lakes that probably were impounded in front of glaciers expanding into Bulkley Valley from nearby mountain areas during the early part of the last glaciation. Foreset-bedded sand and gravel (Fig. 37; Map 1557A, sections 1, 6) were deposited where streams dumped their loads into these lakes.

Subtill stratified sediments in Bulkley Valley typically are a few tens of metres thick and probably have rather limited areal extent. This is suggested by the fact that bedrock hills are common on the valley floor and that near-surface rock in places extends across nearly the full width of the valley. Thick subtill sediments appear to occupy a preglacial or interglacial river valley that roughly parallels, and locally coincides with, the present valley of Bulkley River.

Thick sediments, in places, overlie till and older stratified materials in Bulkley Valley. For example, glaciofluvial and fluvial gravels, deposited during and shortly after deglaciation, unconformably overlie till and form terraces along Bulkley River and many of its tributaries (sections 3, 4). Alluvial fans, which are common along the margins of the valley, consist of thick silt, sand, and gravel which generally overlie till. Finally, alluvium underlying the present floodplain of Bulkley River rests in places on till and older stratified sediments.

*Upper Skeena Valley (Kispiox-Kitwanga).* As in Bulkley Valley, the dominant surface material in upper Skeena Valley is till. The till in many places is thin and rests directly on bedrock; however, in other places it is more than 20 m thick and is underlain by, or interstratified with, ice-contact sand and gravel (section 11). Subtill glaciolacustrine and deltaic sediments, which are common in Bulkley Valley, have not been found in upper Skeena Valley.

Thick stratified sediments in upper Skeena Valley occur in a wide strip bordering Skeena River. The bulk of these sediments are ice-contact sand and gravel overlying or intertonguing with morainal deposits (sections 9, 10). Foreset bedding in some of these materials (sections 7, 9) indicates localized deposition in ponds or lakes that were dammed by decaying glacier ice. Most of the sediments, however, were deposited by meltwater flowing beneath stagnant ice covering the floor of the valley. Ice-contact and morainal deposits bordering Skeena River are unconformably overlain by fluvial terrace gravels deposited during postglacial time (sections 7, 8, 10). In addition, thick gravel and diamicton associated with alluvial and colluvial fans cover ice-contact and morainal deposits in parts of upper Skeena Valley, especially along its margins south and southwest of Hazelton and south of Kitwanga.

*Middle Skeena Valley (Kitwanga-Terrace).* The middle section of Skeena Valley is relatively narrow, and unconsolidated deposits in most places are thin. Thick glaciofluvial and fluvial sediments occur only in a narrow strip bordering Skeena River. Raised deltas (section 12) and colluvial fans occur at the mouths of some tributary valleys, and their constituent sediments overlie till and other unconsolidated materials.

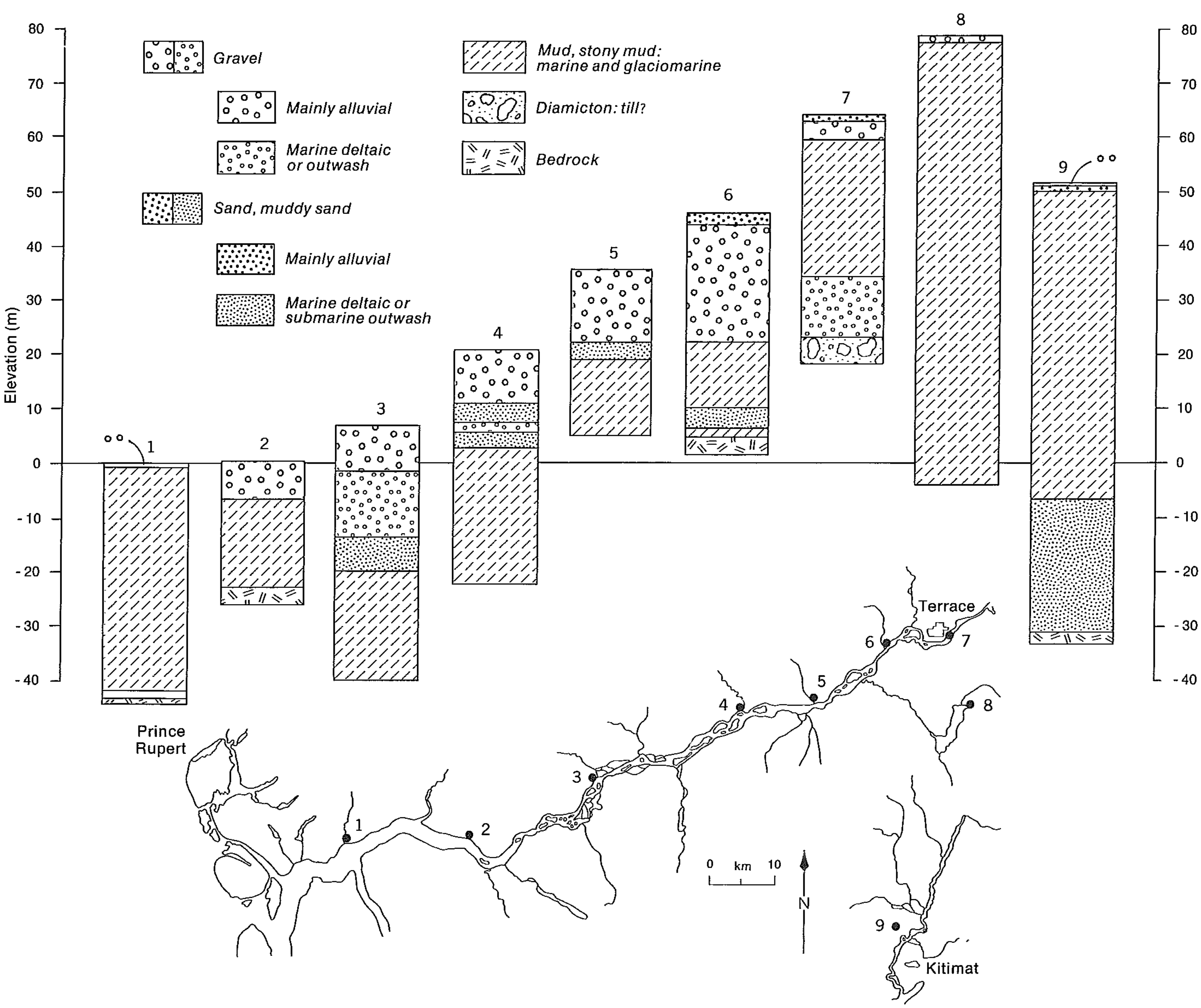


***Figure 38.** Representative generalized drillhole records from lower Skeena Valley and the Kitsumkalum-Kitimat trough, showing deep stratigraphic relationships among late Quaternary sediments.*

*Lower Skeena Valley (Terrace-Tyee).* Thick unconsolidated sediments in lower Skeena Valley occur mainly beneath the floodplains of Skeena River and its tributaries. Drillhole records indicate that Skeena River alluvium overlies deltaic, marine, and glaciomarine sediments deposited in a former fiord (Fig. 38). At the end of the last glaciation, an arm of the sea occupied Skeena Valley from its mouth to the vicinity of Terrace. Marine and glaciomarine muds deposited on the sea floor in this fiord were progressively covered by deltaic and alluvial sediments during postglacial time as Skeena River prograded its delta and floodplain westward down the valley.

*Hecate Lowland.* Thick sediments are rare within the mapped part of the Hecate Lowland. No subtill sediments have been identified, and bedrock is almost everywhere near the surface. In areas of low elevation and low relief, organic deposits overlie patchy colluvium, till, and glaciomarine sediments, which in turn overlie bedrock. On moderate and steep slopes, rock occurs within a few tens of centimetres of the surface.

Thick Quaternary sediments occur on Tugwell Island at the west edge of the map area and probably underlie parts of the coastal lowland north of Metlakatla, outside the map area. These sediments were not examined, thus their character and stratigraphic relationships remain unknown.

*Kitsumkalum-Kitimat Trough.* The Kitsumskalum-Kitimat trough, like lower Skeena Valley, is a former fiord containing thick deltaic, marine, and glaciomarine sediments (Fig. 38, 39). The upper part of this sedimentary fill was deposited during a 2000 year period at the close of the last glaciation. At that time, a large glacier flowing down the trough retreated northward in contact with the sea. Glaciomarine muds accumulated on the submerged valley floor away from the glacier front. At the same time, deltas consisting of sand and gravel formed where meltwater streams entered the sea (sections 13, 14, 18, 19, 22-24). The large deltaic platforms south and north of Lakelse Lake were built in contact with the snout of the trunk glacier flowing down the trough. Smaller deltas were built at the sides of the trough at the mouths of tributary valleys. All of these deltas prograded seaward through time, and thus generally fine downward and commonly overlie glaciomarine mud (sections 14, 18, 19, 23, 24).

Glaciomarine, deltaic, and other sediments deposited at the end of the last glaciation in the Kitsumkalum-Kitimat trough and lower Skeena Valley were locally eroded and/or covered by alluvium and colluvium during postglacial time. Sand and gravel underlying the floodplains and fluvial terraces of Kitsumkalum, Skeena, and Kitimat rivers unconformably overlie glaciomarine, deltaic, glaciofluvial, and morainal deposits (section 23). Gravel and diamicton forming alluvial and colluvial fans at the margins of the Kitsumkalum-Kitimat trough likewise bury sediments deposited during the last glaciation.

*Stratigraphic Summary.* The stratigraphic relationships of major sediment types in the map area are summarized in Table 7. The possible vertical succession of sediment types in each region is shown in this table using previously defined letter codes. Each of the listed units may overlie one or more units lower in the same column; thus, the stratigraphic order of sediments within a region is the same as the sequence of units in the appropriate column of the table. For example, in Bulkley Valley, postglacial alluvium (terraces, fans, and floodplains) occurs stratigraphically above glaciofluvial sediments deposited during deglaciation. The latter, in turn, occur above till, and the till above glaciolacustrine and deltaic sediments deposited during the early part of the last glaciation. Of course, at any given site within a region, some of the possible stratigraphic units characteristic of that region may be missing, due either to nondeposition or erosion. In the above example, postglacial alluvium might directly overlie glaciolacustrine sediments with no intervening glaciofluvial or morainal deposits. In conclusion, a number of possible permutations of units are possible for a specific locality, although in no case would the order of units shown in Table 7 be reversed.

## QUATERNARY HISTORY

The physiography of the Smithers-Terrace-Prince Rupert area is mainly a product of Tertiary and Quaternary geological events. The major valleys of the study area became established in early or middle Tertiary time during uplift of the Coast, Skeena, and Hazelton mountains (Parrish, 1981). Recurrent glacial erosion and deposition during the Pleistocene Epoch modified these valleys and altered drainage patterns (see section entitled Drainage). Glaciers also eroded mountain areas, producing increased terrain ruggedness and greater local relief.

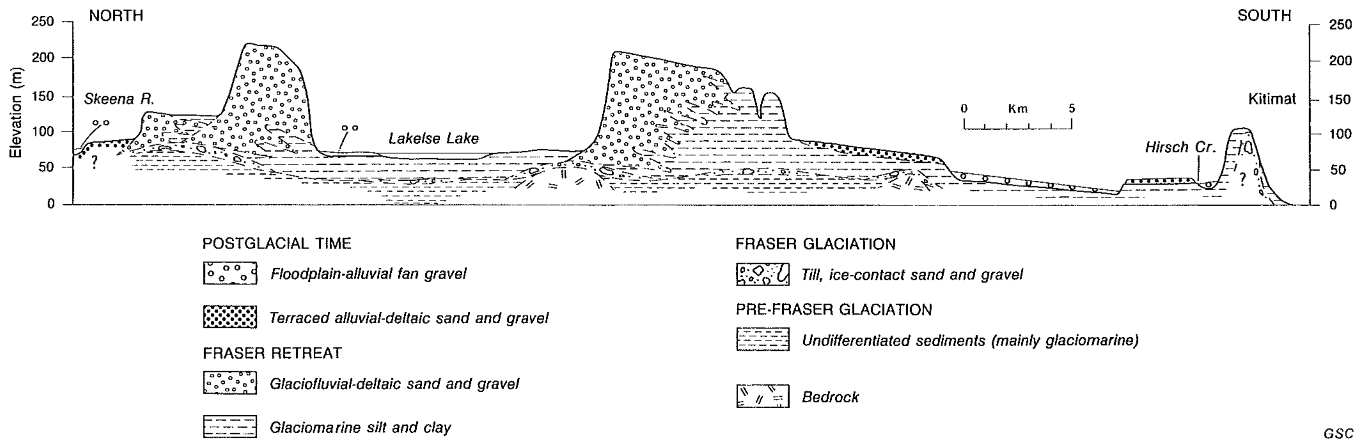


***Figure 39.*** *Schematic diagram illustrating stratigraphic relationships of Quaternary sediments in the Kitsumkalum-Kitimat trough between Skeena River and Kitimat. Interfingering of deltaic and glaciomarine sediments is diagrammatic. Units below glaciomarine silt and clay are inferred.*

**Table 7.** Major stratigraphic sequences in the map area

| Interval | Bulkley Valley | Upper Skeena Valley | Middle Skeena Valley | Lower Skeena Valley | Hecate Lowland | Kitsumkalum-Kitimat trough |
|---|---|---|---|---|---|---|
| Postglacial | Af,Ap,At | Af,Ap,At,Cf | Ap,At,Af | Af,Ap,Ad*,W*,Cf, | O | Af,Ap,At,Cf |
| Fraser deglaciation | AG** | AG** | AG** | WG | - | WG,AG** |
| Fraser Glaciation climax | M | M | D | - | - | D |
| Early Fraser Glaciation | LG,AG** | AG | - | - | - | - |
| Olympia nonglacial interval | A | - | - | - | - | - |

Notes: Each listed unit may overlie any older unit also present in the region (however, not all of the units occurring within the region will be present at individual sites). Minor units, blankets, and veneers are not shown, but are discussed in the text.

* Deltaic (Ad) and marine sediments (W) are covered by Skeena River alluvium

** Deltaic in part

The Quaternary Period in British Columbia was characterized by alternating nonglacial intervals, during which conditions were broadly similar to those of the present, and glacial intervals, during which glaciers occupied intermontane valleys, plateaus, and coastal lowlands. Glacial and nonglacial events predating the last (Fraser) glaciation in the study area are poorly known because most of the pertinent sedimentary record for these events has been removed or covered. Some inferences concerning the nature of these earlier events, however, may be made on the basis of Quaternary studies elsewhere in British Columbia. In contrast, sediments and landforms generated during the Fraser Glaciation and during postglacial time are abundant in the study area, allowing a reasonably complete reconstruction to be made of geological events of latest Quaternary age. The following discussion focuses on this relatively short portion of geological time and, to a lesser extent, on the penultimate (Olympia) nonglacial interval.

### *Olympia Nonglacial Interval*

The Olympia nonglacial interval is the period of time preceding the last major glaciation in British Columbia when intermontane valleys, basins, plateaus, and coastal lowlands were largely free of glacier ice (Armstrong et al., 1965). During this interval, sediments were deposited within a geomorphic framework similar to that existing today (Fulton, 1971, 1975). Sedimentation patterns were complex, as they are at present: a variety of fluvial and organic sediments were deposited in the channels of small streams and on floodplains; soil and colluvium formed on slopes bordering floodplains; marine sediments were deposited in offshore areas; fans were built out into valleys; and deltas prograded into lakes and the sea.

Extensive deposits of Olympia age occur in the lowlands surrounding the Strait of Georgia in southwestern British Columbia (Armstrong and Clague, 1977) and in many valleys in south-central British Columbia (Fulton, 1975; Fulton and Smith, 1978). In addition, Olympia-age deposits of limited or unknown areal extent occur at scattered localities elsewhere in the province (Clague, 1981). For example, at Babine Lake 60 km east of Smithers, organic-rich silt deposited during the Olympia interval and exposed during stripping operations at a mine site contained wood dated at 42 900 ± 1860 and 43 800 ± 1830 BP (GSC-1657 and GSC-1687, respectively) and mammoth bone dated at 34 000 ± 690 BP (GSC-1754) (Harington et al., 1974).

Olympia-age deposits are uncommon within the mapped part of the study area. Sediments of possible Olympia age have been identified only in Bulkley Valley, where interbedded silt, sand, and gravel are exposed beneath the surface till in bluffs along Bulkley River. These sediments apparently were laid down in fluvial and lacustrine environments at a time when local base level was higher than at present. Although the sediments may have been deposited under conditions similar to those of the present, it seems more likely that they accumulated in response to a deterioration of climate marking the end of the Olympia nonglacial interval and the beginning of the Fraser Glaciation. Climatic cooling and concomitant glacier growth in nearby mountains at that time probably caused rivers such as the Bulkley to aggrade their valleys, giving rise to thick fluvial and lacustrine sequences, remnants of which are preserved beneath Fraser Glaciation sediments.

Although it seems likely that most valleys in the study area became aggraded at the end of the Olympia interval, there is no direct evidence for this outside of Bulkley Valley. All exposed sediments in Skeena Valley and the Kitsumkalum-Kitimat trough were deposited during the Fraser Glaciation and postglacial time.[1] Olympia-age sediments, if present in these areas, are covered and probably are below the present level of erosion. Most Olympia sediments, however, likely were removed by glaciers which scoured Skeena Valley and its tributaries during the Fraser Glaciation. Because glacier flow in Bulkley Valley was not as strong as elsewhere in the study area, Olympia sediments suffered less erosion there.

Climatic conditions in the study area during the Olympia nonglacial interval are not known, although some constraints are provided by paleoecological findings from other parts of the Pacific Northwest: (1) Fossil beetle and pollen assemblages and oxygen-isotope data from speleothems suggest that the Olympia climate in coastal southwestern British Columbia was at times similar to, and at times cooler than, the present (Fyles, 1963; Armstrong and Clague, 1977; Clague, 1978a, 1981; Alley, 1979; Gascoyne et al., 1980, 1981). At no time during the Olympia interval was the climate in this region so severe that glaciers advanced from the mountains into coastal lowland areas. (2) Pollen and plant macrofossils from an Olympia-age peat bed on the Queen Charlotte Islands indicate that the climate there during much of the Olympia interval was somewhat cooler (perhaps 1-2°C) and wetter than at present (Warner et al., in press). (3) Fossil animal and plant remains of Olympia age in south-central British Columbia suggest that the climate there was not significantly different from that of the present (Fulton, 1975; Alley and Valentine, 1977). During at least part of the Olympia interval, the climate in this region was sufficiently warm and humid to support large vertebrates such as **Equus** sp., **Equus** cf. **conversidens**, **Bison** sp., and **Mammuthus** cf. **columbi** (Fulton, 1975). Leaf impressions, wood fragments, and molluscs also suggest climatic conditions similar to those of the present. (4) Fossil pollen from the Olympia-age, mammoth-bearing silt at Babine Lake, mentioned previously, were interpreted by Harington et al. (1974) to be a product of a shrub-tundra flora. If this interpretation is correct, a much colder climate than that at present is indicated for at least part of the Olympia interval in central British Columbia, because Babine Lake today is within the boreal forest zone well below, and far south of, treeline. This interpretation is quite different from that made for south-central British Columbia by Fulton (1975). Although some difference in Olympia-age climate between these two regions, which are 4° of latitude apart, would be expected, it seems unlikely that an arctic climate at Babine Lake could have coexisted with the much warmer continental climate of south-central British Columbia. The paleoclimatic reconstruction at Babine Lake made by Harington and co-workers should be viewed with caution because it is based on the analysis of a single sample.

In conclusion, sedimentation in the study area during the Olympia nonglacial interval took place within a geomorphic framework similar to that of the present. Near the close of this period, probably in response to climatic deterioration, streams and rivers aggraded their valleys. Although there is considerable uncertainty concerning the nature of the Olympia-age climate in the study area, it probably was at times similar to that at present and at times cooler. No evidence exists for significant glacier expansion into large valleys and lowland areas at any time during the Olympia interval.

### *Fraser Glaciation*

The Fraser Glaciation is the last major glaciation of British Columbia during which ice covered most of the province (Armstrong et al., 1965). At the beginning of the Fraser Glaciation 25 000-30 000 years ago, climatic cooling and perhaps increased precipitation triggered the growth of glaciers in high mountain areas (Clague, 1981). With continued cooling, these glaciers coalesced to form piedmont complexes and small mountain ice sheets. Eventually, piedmont glaciers from separate mountain source areas joined to cover most of British Columbia (Davis and Mathews, 1944).

As glaciers grew during the early part of the Fraser Glaciation, the long-established Olympia drainage system in British Columbia was disrupted and rearranged. As mentioned previously, the buildup of ice was accompanied by aggradation, with outwash flooding into interior and coastal valleys from mountain areas. Fine grained sediments accumulated in lakes that formed in front of advancing glaciers. These lakes eventually were overriden by ice and destroyed.

Evidence of the growth of glaciers in the study area during the early part of the Fraser Glaciation is recorded in subsurface sediments in Bulkley Valley. At several sites in the valley (e.g., Map 1557, sections 1-6), glaciofluvial and glaciolacustrine sediments outcrop beneath till. The glaciofluvial sediments consist of sand and gravel and are of deltaic, ice-contact, and outwash origin. The glaciolacustrine sediments consist of massive and laminated muds containing scattered dropstones; they were deposited in one or more lakes dammed by glaciers extending into and blocking Bulkley Valley. The locations of the ice dams are unknown, although it is possible that a glacier flowing down Skeena Valley blocked the mouth of Bulkley Valley, thus impounding a lake in the latter. Neither is the history of the lake(s) known, although lake waters probably became increasingly restricted areally as glaciers expanded.

Glaciofluvial and glaciolacustrine sediments probably accumulated in all valleys of the study area during the advance phase of the Fraser Glaciation. Most of these deposits, however, were later removed by high-velocity glaciers that drained the major accumulation areas of the Cordilleran Ice Sheet. For example, Skeena Valley at the climax of the Fraser Glaciation was a major conduit for ice flowing to the Pacific Ocean from the British Columbia Interior Plateau and from the Coast, Skeena, and Hazelton mountains. This ice apparently eroded most of the sediments deposited in Skeena Valley during the Olympia nonglacial interval and the early part of the Fraser Glaciation.

As the Cordilleran glacier complex expanded, its nourishment and surface flow patterns became less controlled by ground-surface topography and more controlled by ice-sheet morphology. It has been suggested that at the climax of the Fraser Glaciation, ice was sufficiently thick over the Interior Plateau for an ice dome to exist, with surface flow radially away from its centre (Dawson, 1881a; Kerr, 1934; Mathews, 1955; Wilson et al., 1958; Fulton, 1967; Flint, 1971). The formation of such an ice dome would have been accompanied by a reversal of glacier flow in the Coast Mountains, as the ice divide (the axis of outflow) shifted from the mountain crest eastward to a position over the Interior Plateau (Flint, 1971, p. 469). A comparable westward shift and reversal of flow would have occurred also in the Rocky Mountains in eastern British Columbia and western Alberta.

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[1] However, wood from a thin layer of lacustrine mud underlying ice-contact gravel at a site 10 km northwest of Terrace (section 15) yielded a radiocarbon date of 37 200 ± 1060 BP (GSC-2528, Table 8). This date suggests that the mud and an underlying gravel unit may have been deposited during the Olympia nonglacial interval. Alternatively, these sediments may predate the Olympia interval (in which case the radiocarbon date is merely a minimum for the age of the lacustrine mud) or may have been deposited during the Fraser Glaciation (in which case the dated wood was reworked from older sediments).

Some workers, however, have questioned the existence of an ice dome over central British Columbia at the climax of the Fraser Glaciation. Tipper (1971a, b), for example, proposed that the Cordilleran Ice Sheet at the Fraser maximum consisted of coalescent piedmont glaciers which covered the Interior Plateau, but which were fed entirely from alpine centres. This conclusion was based largely on the regional pattern of drumlins, flutings, and striae on the central Interior Plateau.

Data from the study area are inadequate to evaluate whether or not an ice dome formed in British Columbia during the Fraser Glaciation. Skeena Valley and the Kitsumkalum-Kitimat trough transmitted ice southwest and west towards the coast throughout the Fraser Glaciation (Fig. 40); the pattern of ice flow there would have been little affected by the establishment of an ice dome over the Interior Plateau. On the other hand, ice flow in Bulkley Valley would have changed markedly with the formation of an ice dome: flow into the valley from bordering mountains during the early phase of the Fraser Glaciation would have been supplanted by westerly flow across the valley from the interior once a dome became established. Unfortunately, there are no well developed drumlins, drumlinoid ridges, or crag and tail on the floor of Bulkley Valley; thus Fraser Glaciation ice flow directions there are uncertain. The absence of such glacially streamlined landforms, however, could be considered evidence that the dominant direction of glacier flow was transverse, rather than parallel, to the axis of Bulkley Valley. Some support for this supposition is provided by westerly directed drumlins, drumlinoid ridges, and striae in Trout Creek valley near its junction with Bulkley Valley. The floor of Trout Creek valley "hangs" about 250 m above that of Bulkley Valley, thus the westerly directed streamlined forms suggest that ice at one time flowed across Bulkley Valley, perhaps from an interior ice dome.

At the climax of the Fraser Glaciation, ice covered all valleys and lowlands in the study area. An upper limit of glaciation has not been identified, but it seems likely that mountains below 1500-2000 m elevation were buried by ice at the Fraser maximum. Many high peaks and ridges probably projected above the ice surface to form substantial nunatak areas. The ice sheet thinned towards the coast and probably terminated in Hecate Strait west of the study area (Fladmark, 1975, 1978, 1979; Warner et al., 1982).

The timing of the onset and climax of the Fraser Glaciation in the study area is unknown, but probably is similar to that in other parts of British Columbia where there is better dating control. In coastal southwestern British Columbia, the Fraser Glaciation began about 29 000 years ago (Clague, 1976, 1977a, 1980; Alley, 1979), and in south-central British Columbia, about 25 000 years ago (Alley and Valentine, 1977). Glaciers were confined to the major mountain ranges until 20 000-25 000 years ago, depending on locality, and the Cordilleran Ice Sheet did not

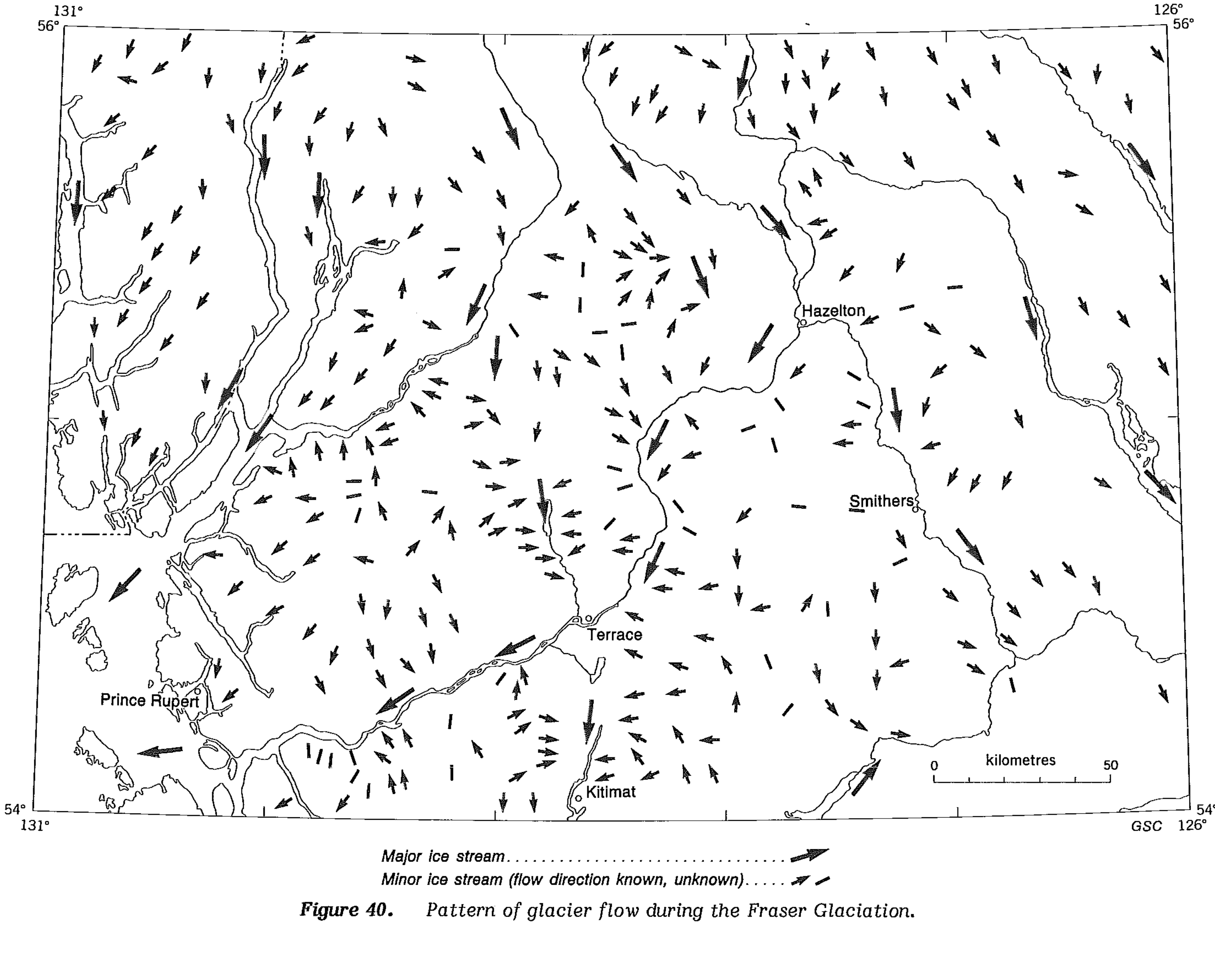


*Figure 40. Pattern of glacier flow during the Fraser Glaciation.*

attain its maximum extent in southern British Columbia until 14 500-15 000 years ago (Clague et al., 1980; Clague, 1980, 1981).

### *Fraser Retreat*

The Fraser Glaciation terminated with rapid climatic amelioration. Deglaciation of British Columbia was characterized by complex frontal retreat in peripheral glaciated areas and by widespread stagnation accompanied by downwasting in areas of low and moderate relief in the interior (Fulton, 1967, 1975; Tipper, 1971a, b). In each region, uplands appeared through the ice cover first, dividing the ice sheet into a series of valley tongues that decayed in reponse to local conditions. Active ice eventually became restricted to the major mountain systems, locally as piedmont complexes, but in most areas as valley glaciers. In many areas, recession was interrupted by glacier stillstands and minor readvances.

As during the growth phase of the Fraser Glaciation, aggradation and extensive drainage changes occurred during deglaciation. Large glacial lakes formed and evolved as glaciers downwasted and retreated over the Interior Plateau (Mathews, 1944; Fulton, 1969). Coastal lowlands, isostatically depressed by the decaying ice sheets, were flooded by the sea and became sites of glaciomarine sedimentation (Armstrong and Brown, 1954; Fyles, 1963; Mathews et al., 1970; Andrews and Retherford, 1978; Armstrong, 1981; Clague, 1981, 1983). Floodplains rapidly aggraded because rivers and streams were unable to cope with large volumes of sediment made available during deglaciation (Church and Ryder, 1972).

### Bulkley Valley

Much of the floor of Bulkley Valley is covered by lodgment till; by comparison, ablation till and glaciofluvial sediments are uncommon. This suggests that glacier ice remained active in most parts of the valley during deglaciation, and that there was only limited reworking of morainal deposits by meltwater. It is possible that the flow of meltwater through Bulkley Valley during deglaciation was relatively small in comparison to other areas where morainal materials were extensively reworked at about the same time (e.g., the Kitsumkalum-Kitimat trough). The small amount of ablation till and ice-contact sediments in Bulkley Valley also suggests that decaying glacier ice there contained relatively little debris.

There was, of course, some meltwater flow in Bulkley Valley during deglaciation. At a few sites, gravel and minor sand were deposited on the valley floor against and in front of bodies of decaying glacier ice (e.g., near Moricetown and the mouth of Suskwa River). Numerous small meltwater channels and eskers also formed at various places in the valley in association with this ice (e.g., northeast of Smithers and near Suskwa River), and meltwater was impounded in localized ice-dammed lakes. Thin deposits of mud accumulated in these lakes, and small deltas were built out into them. The lakes probably were short-lived and of small size; they ceased to exist when ice disappeared from Bulkley Valley and an integrated drainage network became established.

The time of deglaciation of Bulkley Valley is not precisely known, although a radiocarbon date from a site 3 km southeast of the mouth of Suskwa River provides some chronological control. Wood from lacustrine or glaciolacustrine sediments at this site yielded a radiocarbon date of 9360 ± 180 BP (GSC-2463, Table 8), indicating that the floor of the valley became ice-free at an earlier date. Dates on late glacial and early postglacial materials in other parts of British Columbia suggest that much of the interior of the province was still buried by ice 11 000 years ago, about 3000 years after the Cordilleran Ice Sheet began to decay (Clague, 1980, 1981). It seems probable that Bulkley Valley likewise was covered by ice 11 000 years ago; if so, the valley floor was deglaciated some time between about 11 000 and 9300 years ago.

### Upper and Middle Skeena Valley

Deglaciation of upper and middle Skeena Valley proceeded by downwasting and frontal retreat. Following the Fraser Glaciation maximum, the surface of the Cordilleran Ice Sheet in the study area lowered until uplands were exposed and ice became confined to valleys. Continued downwasting led to disengagement of valley ice into several masses, each of which decayed in response to local conditions. For example, the glacier in upper and middle Skeena Valley became separate from that in the Kitsumkalum-Kitimat trough and decayed more or less as an independent entity. As the Skeena Valley glacier thinned and retreated upvalley, it lost its mobility over large areas and stagnated.

Large amounts of meltwater were funnelled down Skeena Valley as the ice tongue there decayed. Till was reworked by this meltwater, and ice-contact debris was deposited at the base of the stagnating glacier. Ponds and small lakes formed in places against ice, and small deltas were built into these bodies of water at the mouths of meltwater streams (e.g., Map 1557A, sections 7, 9).

No radiocarbon dates have been obtained from upper and middle Skeena Valley, thus the timing of deglaciation there is somewhat uncertain. This area, however, probably became ice-free at about the same time as Bulkley Valley but after the southern Kitsumkalum-Kitimat trough. If so, deglaciation of upper and middle Skeena Valley probably was complete after about 10 700 BP but before 9300 BP.

### Lower Skeena Valley and Hecate Lowland

Deglacial sediments and landforms are uncommon in lower Skeena Valley and in the mapped part of the Hecate Lowland. Lower Skeena Valley is narrow and is bounded by steep walls, thus there are few localities where Pleistocene sediments might escape erosion during postglacial time. Drillhole records, however, indicate that thick marine and glaciomarine sediments underlie Skeena River alluvium between Terrace and the mouth of the river (Fig. 38, 39). At least part of this thick sedimentary fill was deposited during deglaciation when a tongue of active ice receded east up the valley in contact with the sea.

Because the crust was isostatically depressed by the weight of the decaying ice sheet, the sea reached well above its present level on the walls of lower Skeena Valley during deglaciation. For example, glaciomarine mud occurs to almost 200 m above sea level near Amsbury, 12 km southwest of Terrace. Mollusc shells collected from this mud yielded a radiocarbon date of 10 200 ± 100 BP (GSC-2306, Table 8), which is a minimum for the time of deglaciation of the area.

Streams flowing from tributary valleys into Skeena Valley during deglaciation built deltas at the sides of the fiord. Although remnants of a few of these deltas remain, most have been obliterated by erosion during postglacial time.

The mapped part of the Hecate Lowland has only a thin cover of late Pleistocene sediments. Apparently, glaciers retreated so rapidly across the lowland at the close of the Pleistocene that there was not enough time for significant glaciofluvial and glaciomarine sediments to accumulate.

**Table 8.** Radiocarbon dates

| Laboratory dating no. | Radiocarbon date (years BP) | $\delta C^{13}$ ‰ | Locality | Location lat. N | Location long. W | Elevation (m)[1] | Depth below surface (m) | Dated material | Collector[2] | Dated sediments or landform |
|---|---|---|---|---|---|---|---|---|---|---|
| GSC-2552 | 150 ± 50 | | Toboggan Lake | 54°51.9' | 127°14.0' | 481 | 0.6 | wood (**Alnus**) | JJC | alluvial fan |
| GSC-2411 | 450 ± 40 | -22.2 | Dasque Creek | 54°23.8' | 128°54.1' | 36 | 2 | wood (**Picea**) | JJC | floodplain |
| GSC-2535 | 660 ± 50 | | Toboggan Lake | 54°51.9' | 127°14.0' | 480 | 1 | wood (**Salix**) | JJC | alluvial fan |
| GSC-2457 | 2780 ± 80 | -27.1 | McNeil River | 54°12.4' | 129°58.5' | 13 | 1 | peat | JJC | organic deposit[3] |
| GSC-2546 | 3280 ± 50 | -24.0 | Deep Creek | 54°34.5' | 128°38.6' | 107 | 0.3 | wood (**Picea**) | JJC | organic deposit[4] |
| GSC-2222 | 4400 ± 70 | -24.0 | McNeil River | 54°12.4' | 129°59.0' | 5 | ~ 1.2 | wood (**Abies**)[5] | JJC | organic deposit[6] |
| GSC-2455 | 4640 ± 50 | -24.6 | Skeena River | 54°23.6' | 128°54.9' | 36 | 3-4 | charcoal[7] | JJC, AW | alluvial fan |
| GSC-2407 | 4660 ± 60 | -24.5 | Hirsch Creek | 54°05.5' | 128°36.7' | 38 | 1.9 | wood (**Picea**) | JJC | sandy silt[8] |
| GSC-2231 | 5930 ± 80 | -25.7 | Prince Rupert | 54°18.0' | 130°20.2' | 45 | 2.5 | wood (**Abies**)[5] | JJC | organic deposit[4] |
| GSC-2471 | 7710 ± 150 | -25.9 | McNeil River | 54°12.4' | 129°59.0' | 4 | ~ 2.5 | wood (**Abies**)[5] | JJC | estuarine sediments[9] |
| GSC-2392 | 7900 ± 90 | -25.4 | Doughty | 54°57.8' | 127°20.8' | 440 | 1.7 | wood (**Picea**) | JJC | alluvial fan[10] |
| GSC-2235 | 8120 ± 80 | -26.8 | McNeil River | 54°12.4' | 129°58.5' | 11 | 2.5 | wood (**Picea**) | JJC | organic deposit[4] |
| GSC-2248 | 8460 ± 90 | -25.0 | McNeil River | 54°12.4' | 129°59.0' | 3 | 3.8 | wood (**Picea**) | JJC | littoral-marine sediments[11] |
| GSC-2307 | 8580 ± 100 | | McNeil River | 54°12.4' | 129°59.0' | -1 | ~ 8 | bark | JJC | marine sediments[12] |
| GSC-3503 | 8900 ± 100 | -24.6 | Kitimat | 53°59.1' | 128°41.8' | 11 | ? | wood (**Picea**) | ASG | marine sediments |
| GSC-2343 | 9180 ± 150 | - 0.9 | McNeil River | 54°12.4' | 129°59.0' | -1 | ~ 8 | shell (**Clinocardium nuttalli**) | JJC | marine sediments[12] |
| GSC-2425 | 9300 ± 90 | -26.5 | Kitimat River | 54°06.0' | 128°36.8' | 30 | 11 | wood | JJC | raised delta |
| GSC-2463 | 9360 ± 180 | | Bulkley River | 55°12.8' | 127°24.4' | 320 | 7 | wood | JJC, AW | terraced lacustrine sediments |
| GSC-3497 | 9570 ± 120 | | Kitimat | 53°59.1' | 128°41.8' | 11 | ? | shells (**Saxidomus giganteus**) | ASG | marine sediments |
| GSC-522 | 9880 ± 160 | | Kitimat | 54°03' | 128°37' | 38 | ? | shells | JEA | glaciomarine sediments |
| GSC-2492 | 10 100 ± 160 | +1.7 | Hirsch Creek | 54°03.8' | 128°35.6' | 98 | ~ 24 | shells (**Mya truncata**) | JJC, AW | raised delta |
| GSC-2306 | 10 200 ± 100 | | Amsbury Creek | 54°28.5' | 128°45.6' | ~ 170 | ? | shells (**Balanus**) | JJC, SRH, SM | glaciomarine sediments |
| GSC-535 | 10 420 ± 160 | | Lakelse Lake | 54°21' | 128°31' | ~ 90 | ? | shells | JEA | glaciomarine sediments |
| GSC-2276 | 10 600 ± 110 | | Zymagotitz R. | 54°32.7' | 128°45.8' | ~ 85 | 2-3 | shells (**Mytilus**) | JJC, SRH, SM | glaciomarine sediments |
| GSC-2408 | 10 700 ± 160 | -1.2 | Zymagotitz R. | 54°32.2' | 128°43.8' | 64 | 2 | shells (**Mytilus**) | JJC, AW | glaciomarine sediments |
| GSC-523 | 10 790 ± 180 | | Lakelse Lake | 54°25' | 128°31' | ~ 90 | ? | shells | JEA | glaciomarine sediments |
| GSC-2290 | 12 700 ± 120 | +1.1 | Prince Rupert | 54°17.0' | 130°21.3' | 11 | ? | shells (**Mya truncata**) | JJC | glaciomarine sediments |
| GSC-2528 | 37 200 ± 1060 | | Erlandsen Ck. | 54°35.5' | 128°42.7' | 214 | 5 | wood (**Picea or Larix**) | ACC, JJC | silty clay[13] |

[1]Datum is mean sea level
[2]JEA, J.E. Armstrong; ACC, A.C. Clague; JJC, J.J. Clague; ASG, A.S. Gottesfeld; SRH, S.R. Hicock; SM, S. Marshall; AW, A. Wallingford
[3]Dated sample collected 1.5-1.6 m above base of peat, 1 m below top
[4]Dated sample collected from base of peat
[5]cf. **Abies amabilis.**
[6]Dated sample collected from pebbly sandy silt at base of peat
[7]**Picea** in part
[8]Dated sediments underlie surface peat and are of uncertain origin
[9]Dated sediments underlie surface peat
[10]Dated sample collected from base of fan
[11]Dated sample collected from contact between marine silty sand and overlying littoral gravel
[12]Dated sediments underlie littoral and estuarine deposits
[13]Dated sediments underlie an ice-contact complex of gravelly sand, gravel, and diamicton

Also, glaciers in this region perhaps were relatively clean and thus incapable of supplying large amounts of debris as they decayed.

Hecate Lowland was deglaciated before the main valleys of the study area. Mollusc shells from glaciomarine sediments at Prince Rupert yielded a radiocarbon date of 12 700 ± 120 BP (GSC-2290, Table 8), which is a minimum date for deglaciation of this area. In contrast, numerous radiocarbon dates from the Kitsumkalum-Kitimat trough indicate that deglaciation there was not complete until about 10 000-10 500 years ago (Table 8). Early deglaciation of the Hecate Lowland probably resulted from destabilization of the peripheral zone of the Cordilleran Ice Sheet in response to the late glacial eustatic rise in sea level. The ice sheet retreated rapidly along a broad front by calving into the sea. With continued retreat, ice in coastal areas became restricted to fiords where glacier termini stabilized due to reduced calving. Subsequent retreat of ice tongues up the fiords was at a much slower rate than earlier across the outer coastal lowlands (Fig. 41).

### Kitsumkalum-Kitimat Trough

Sediments deposited during deglaciation are widespread in the Kitsumkalum-Kitimat trough and provide an excellent record of late glacial events. The late Pleistocene glacier in the Kitsumkalum-Kitimat trough, like that in lower Skeena Valley, retreated in contact with the sea. Initially, this glacier was connected with ice tongues in Skeena Valley west and northeast of Terrace; however, the lower Skeena Valley tongue disappeared when the trough glacier receded north to the vicinity of Lakelse Lake. Continued recession led to the separation of the Kitsumkalum-Kitimat glacier from the tongue of ice in middle Skeena Valley northeast of Terrace (Fig. 42).

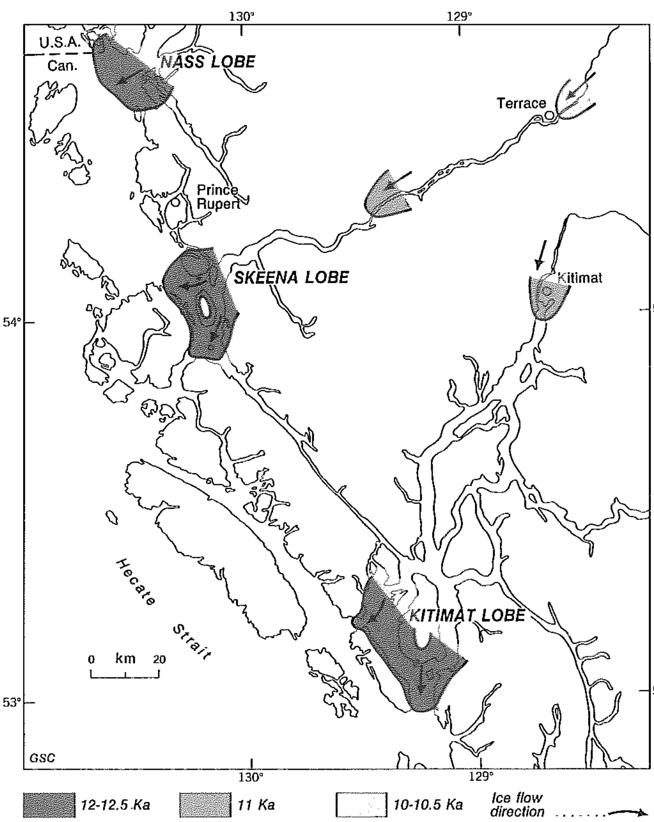


***Figure 41.*** *Terminal zones of major glacier lobes at various times during deglaciation. These lobes probably coalesced over eastern Hecate Strait at the climax of the Fraser Glaciation.*

Retreat of the Kitsumkalum-Kitimat glacier occurred in a nonuniform fashion. Intervals of catastrophic retreat were separated by periods of relative stability during which large, but localized, bodies of sand, gravel, and till accumulated in ice-marginal positions on the floor of the trough (Fig. 39, 42). The southernmost and oldest of these is a ridge-shaped body of till and glaciofluvial sediments that loops across the eastern half of the Kitsumkalum-Kitimat trough at Kitimat (Fig. 42A). This feature is an end moraine that was constructed when the glacier temporarily halted about 11 000 years ago as it retreated north up the trough. A rock ridge in the centre of the trough adjacent to this moraine probably buttressed and thus stabilized the glacier snout. At about the same time that the glacier terminated at the Kitimat moraine, large quantities of sand and gravel were deposited farther upvalley at the sides of the glacier. Hummocky and rolling ice-contact sediments are especially common on the west side of the Kitsumkalum-Kitimat trough between Little Wedeene and Wedeene rivers.

With continued downwasting, the snout of the glacier became unstable at the Kitimat moraine, and a period of catastrophic retreat by calving ensued. The glacier retreated 30 km in perhaps several years to a few decades and then stabilized again at the south end of what is now Lakelse Lake, where there is a neck in the Kitsumkalum-Kitimat trough (Fig. 42B). Large amounts of sediment-laden meltwater flowed into the sea from the now stable glacier snout. Coarse constituents accumulated on the sea floor adjacent to the ice front, whereas fine suspended detritus was carried farther south and deposited as glaciomarine mud. The body of coarse sediments at the ice front grew both upward and outward; eventually, it was built up above sea level, which in a relative sense was about 200 m higher than at present, and a subaerial outwash plain, or sandur, was born. The sandur grew as meltwater continued to pour off the glacier snout, and attained a size of about 60 $km^2$ before becoming fossilized due to glacier retreat from the ice-contact face south of Lakelse Lake. The sandur surface is more than 100 m higher than the adjacent floor of the Kitsumkalum-Kitimat trough and is bounded on the north by an ice-contact face and on the south by a relict delta foreslope.

This delta-sandur may have developed in a relatively short period of time (perhaps less than 100 years), in spite of the large volume of its constituent sediments ($10^9$-$10^{10}$ $m^3$). The evidence for this is that the entire Kitsumkalum-Kitimat trough apparently was deglaciated within a period of several hundred years to, at most, one thousand years (Fig. 42), and thus little time was available for the construction of any one sandur there. Radiocarbon dates on glaciomarine sediments in the trough fall within a relatively narrow range (Table 8) and show no systematic differences related to geographic position, as might be expected if ice retreat was relatively slow. Instead, the clustering of radiocarbon dates suggests that the sea transgressed the full length of the southern part of the trough (i.e., between Kitimat and Terrace) in a very short period of time after 11 000 years ago.

Rapid retreat from the Lakelse ice-contact face was followed by another stillstand 17 km to the north near the Terrace Airport (Fig. 30, 42C). A large body of sand and gravel again accumulated against the glacier snout, and a sandur prograded south and southwest into the sea. This sandur, like its counterpart south of Lakelse Lake, was graded to a shoreline about 200 m above the present. Most of the fine constituents carried away from the glacier by meltwater were deposited over a large area of sea floor southwest and south of the leading edge of the sandur.

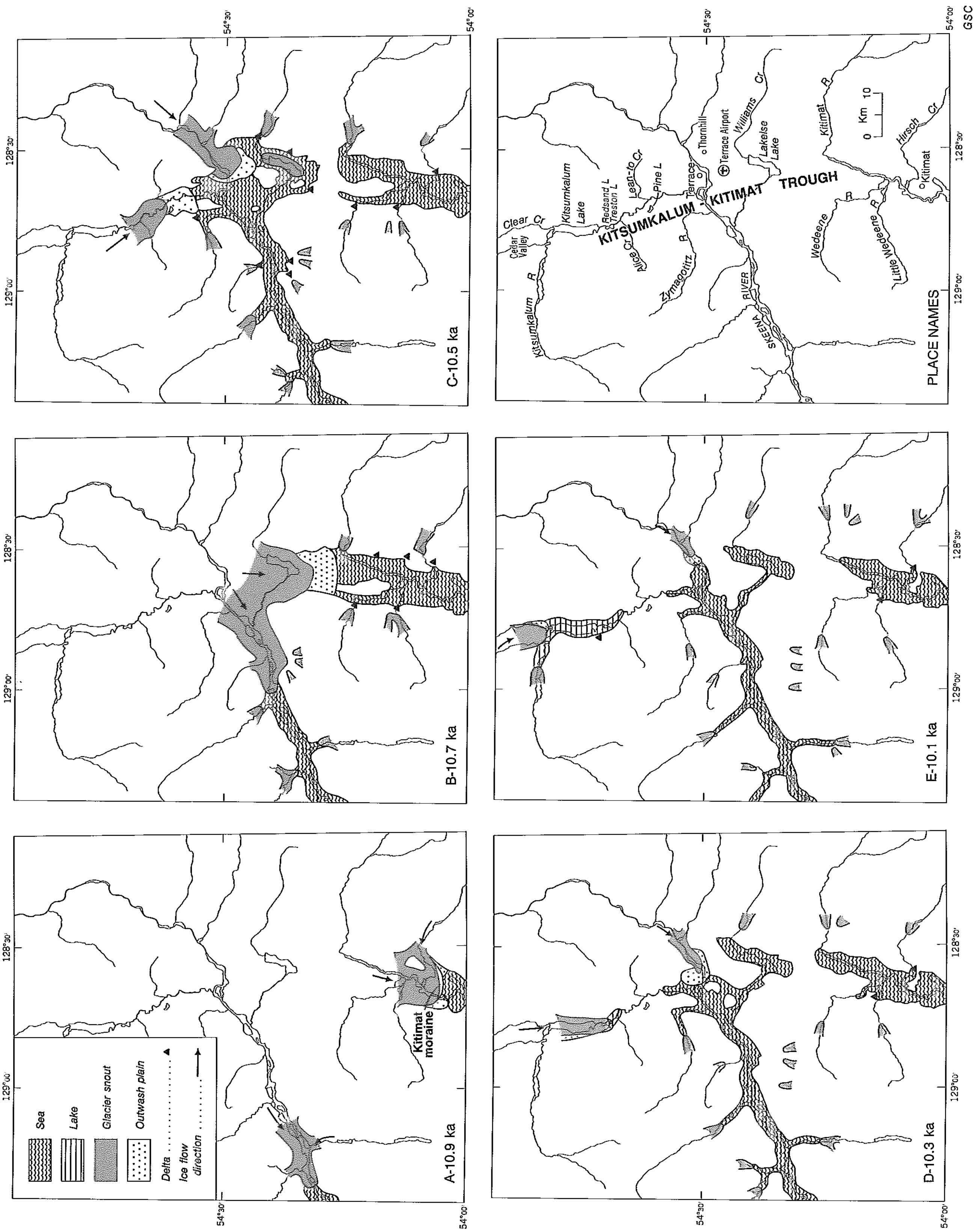


*Figure 42.* Deglaciation scenario, Terrace-Kitimat area. Only outwash plains and deltas for which there is direct sedimentary evidence are depicted on this diagram. Similar features may have formed elsewhere in the Kitsumkalum-Kitimat trough during deglaciation, but if so, they have been obliterated by erosion during postglacial time.

At this time, the depression in which Lakelse Lake is now located perhaps contained a large block of stagnant ice stranded during northward glacier retreat.

Radiocarbon dates of 10 420 ± 160 and 10 790 ± 180 BP (GSC-535 and GSC-523, respectively; Table 8) from glaciomarine sediments near Lakelse Lake constrain time of deglaciation and formation of the Terrace Airport sandur. The glacier in the Kitsumkalum-Kitimat trough had retreated north of Lakelse Lake and halted near the Terrace Airport prior to 10 790 ± 180 BP. Initial progradation of the delta-sandur complex southward from this ice-contact position also must have occurred before this date or at about the same time. In fact, the 10 790 BP date probably is close to the time of deglaciation of the Lakelse Lake area. The glaciomarine sediments that yielded this date are overlain by a till deposited by a glacier flowing west out of the valley of Williams Creek. This tributary glacier advanced into the Kitsumkalum-Kitimat trough shortly after 10 790 ± 180 BP, but retreated again prior to 10 420 ± 160 BP.[1]

The curvature of the Terrace Airport ice-contact face delineates the snout of a glacier extending south-southwest into the Kitsumkalum-Kitimat trough from middle Skeena Valley (Fig. 42C). The tongue of ice that extended west into lower Skeena Valley no longer existed, having disappeared when the trunk glacier in the Kitsumkalum-Kitimat trough retreated north from the Lakelse ice-contact face. The disappearance of the lower Skeena glacier coincided with the development of a calving embayment in the vicinity of Terrace. As this embayment enlarged, the lobe of ice in the Kitsumkalum-Kitimat trough north of Terrace separated from the glacier flowing southwest down middle Skeena Valley.

The Kitsumkalum glacier then retreated north in contact with the sea. It halted where Kitsumkalum Valley narrows north of Pine lake and constructed a large delta-sandur complex graded to a shoreline about 200 m above the present (Fig. 42C). The northern part of this complex between Lean-to and Alice creeks was built on top of stagnant ice. Later melting of this ice produced a kettled, rolling to hummocky surface. Fine detritus was transported south of the Pine Lake sandur and deposited on the submerged floor of the Kitsumkalum-Kitimat trough.

The Pine Lake sandur probably formed at the same time as the Terrace Airport sandur. The main evidence for this is that both landforms are graded to the same sea level position. Dates of 10 600 ± 110 and 10 700 ± 160 BP (GSC-2276 and GSC-2408, respectively; Table 8) from glaciomarine sediments exposed along Zymagotitz River west of Terrace are minima for deglaciation of the Kitsumkalum-Kitimat trough in the vicinity of Terrace. Growth of the Pine Lake delta-sandur complex probably was initiated 10 500 years ago, or shortly before.

The Pine Lake delta-sandur complex blocked Kitsumkalum Valley and served as a barrier to the continued northward transgression of the sea. It also acted as a dam behind which freshwater was ponded as the Kitsumkalum glacier continued its northward retreat. Thus, when this glacier abandoned the Pine Lake ice-contact face, it was retreating for the first time in a lake rather than in the sea. Ice-contact deltas at the south end of Treston Lake and between Treston and Redsand lakes (Fig. 42D) formed during short-lived stillstands of the Kitsumkalum glacier as it retreated north from the Pine Lake sandur. The tops of these deltas define lake levels ranging from about 190 to 200 m elevation, perhaps a few tens of metres below the highest part of the Pine Lake sandur. Farther north, on the west side of Kitsumkalum Lake and near the mouth of Clear Creek, kame terraces were constructed at the edges of the receding Kitsumkalum glacier.

As the Kitsumkalum Lake area became free of ice, glaciers flowing south out of Cedar Valley and east-southeast out of Kitsumkalum Valley separated and began to retreat independently of one another (Fig. 42E). At about the same time, the lake dammed by the Pine Lake delta-sandur complex attained its maximum size, extending from the vicinity of Alice Creek on the south to lower Cedar Valley on the north. This lake, however, soon began to decrease in size as its outlet across the Pine Lake sandur was incised, due in part to a rapid fall in sea level (see section entitled Sea Level Fluctuations).

During, or possibly shortly after, deglaciation of the Kitsumkalum Lake area, the glacier flowing down middle Skeena Valley retreated from the Terrace Airport ice-contact face to a new stillstand position about 5 km to the northeast (Fig. 42D). Yet another delta was built south and west of the restabilized glacier terminus at Thornhill. The highest gravelly surface at Terrace ($A^{G}d$) probably is an erosional remnant of this delta. This surface and others associated with the Thornhill ice-contact face were graded to sea levels approximately 100-130 m higher than the present. In contrast, shorelines were about 200 m above present sea level when the slightly older Terrace Airport sandur was active, suggesting that significant isostatic or tectonic uplift probably occurred in this area while the Thornhill delta was being built.

Deglaciation of the Kitsumkalum-Kitimat trough was completed when ice withdrew from the Thornhill ice-contact fact into Skeena Valley, probably about 10 100 years ago (Fig. 42E). The land continued to rebound rapidly, and by about 8000-8500 years ago, the sea had fallen to its present level (see section entitled Sea Level Fluctuations).

Streams entering the Kitsumkalum-Kitimat trough from tributary valleys constructed deltas at successively lower elevations as the land rebounded during and shortly after deglaciation. While many of these streams have only one raised delta, and others none, some (e.g., Hirsch Creek, Little Wedeene River) have two or more deltas graded to different sea level positions. The presence of multiple deltas suggests that either the supply of sediment by meltwater streams was highly variable, or the fall of the sea relative to the land at the end of Fraser Glaciation was irregular and nonlinear.

Fossil foraminifera (Table 9) and shells (Table 10) have been recovered from glaciomarine sediments in the southern Kitsumkalum-Kitimat trough. The fossil faunal assemblages

**Table 9.** Foraminifera in glaciomarine sediments at Lakelse Lake

| Species | Abundance |
|---|---|
| **Astrononion gallowayi** Loeblich and Tappan | r |
| **Buccella frigida** Cushman | r |
| **Cassidulina barbara** Buzas | r |
| **Cibicides lobatulus** (Walker and Jacob) | r |
| **Elphidium clavatum** Cushman | a |
| **Elphidium frigidum** Cushman | r |
| **Fissurina lucida** (Williamson) | r |
| **Islandiella teretis** (Tappan) | r |
| **Oolina collaris** (Cushman) | r |
| **Quinqueloculina stalkeri** Loeblich and Tappan | r |
| **Quinqueloculina** spp. | r |

Note: Data from Smith (1970).

a = abundant
r = rare

[1] The younger date was obtained from glaciomarine sediments that are not overlain by till.

**Table 10.** Fossil shells in glaciomarine sediments at Lakelse Lake and Kitimat

| Taxon | Lakelse Lake 54°25'N, 128°31'W | Kitimat 54°03'N, 128°37'W |
|---|---|---|
| Pelecypoda | | |
| **Chlamys hindsii** (Carpenter) | | X |
| **Clinocardium ciliatum** (Fabricius) | X | X |
| **Macoma calcarea** (Gmelin) | X | X |
| **Macoma inconspicua** (Broderip and Sowerby) | X | |
| **Mytilus edulis** Linné | X | |
| **Nuculana pernula** (Muller) | X | X |
| **Saxidomus giganteus** (Deshayes) | | X |
| **Serripes groenlandicus** (Bruguière) | | X |
| Gastropoda | | |
| **"Lora"** cf. **"L." pingelii** (Moller) | | X |
| **Natica clausa** Broderip and Sowerby | | X |
| ? **Colus** sp. | | X |
| Brachiopoda | | |
| **Laqueus vancouverensis** Davidson | X | |
| Annelida | | |
| **Serpula vermicularis** Linné | | X |
| Cirripedia | | |
| **Balanus crenatus** Bruguière | X | X |

Note: Data from unpublished GSC Paleontology Laboratory Report No. P1-4-1966-FJEW by F.J.E. Wagner.

are similar to contemporary faunal assemblages in fiords of coastal southeastern Alaska; thus, waters in the Kitsumkalum-Kitimat fiord during deglaciation probably were cold (although not polar) and had lower salinities than normal sea water (Smith, 1965, 1970).

### *Postglacial Time*

Erosion and sedimentation were more active immediately after deglaciation than at present in the Smithers-Terrace-Prince Rupert area. Streams were heavily loaded with debris stripped from oversteepened, poorly vegetated slopes. This debris was swept into larger valleys where it was deposited in fans and deltas and on floodplains. The bulk of the postglacial alluvial sediments were deposited within about 1000 years after deglaciation.

Once slopes were stabilized and vegetation became established, rivers and streams began to incise older sediments and bedrock, and soon reached present levels. Fluvial terraces, which border most rivers, were formed during this interval of downcutting during early postglacial time. Many alluvial fans also were incised at this time and now stand as relict features above the streams that formed them.

During this period of falling base levels, sediment deposition was restricted largely to lake basins, the sea, and valley-side alluvial fans. Deltas and fans were built into many lakes, most notably Kitsumkalum and Lakelse lakes. Arms of the sea extending up Skeena Valley to Terrace and up the Kitsumkalum-Kitimat trough almost to Lakelse Lake were gradually filled with deltaic and alluvial sediments deposited by Skeena and Kitimat rivers, respectively. Today, these rivers continue to prograde seaward, the former into Chatham Sound and Telegraph Passage and the latter into Kitimat Arm. Finally, alluvial fans were built at the mouths of many tributary valleys; some are telescoped within older fans graded to higher base levels of early postglacial time. Radiocarbon dates from alluvial fans in Bulkley and Skeena valleys indicate intermittent, or more likely continuous, activity throughout postglacial time: 7900 ± 90, 4640 ± 50, 660 ± 50, and 150 ± 50 BP (GSC-2392, -2455, -2535, and -2552, respectively; Table 8).

Other postglacial deposits include colluvium, marine sediments, and organic material. Colluvial debris produced by the weathering of bedrock forms thin patchy mantles on many slopes. Weathered bedrock and glacial sediments also have been transported by gravity, snow avalanches, and debris flows to the base of slopes and there redeposited in colluvial fans and aprons.

Marine sediments occur beneath floodplain and deltaic deposits of lower Skeena and Kitimat rivers and, in addition, underlie the sea floor in offshore areas. These sediments were not extensively investigated in the course of this study because they occur only below present sea level and thus are not exposed. Drillhole records, however, indicate that the marine sediments underlying the Skeena and Kitimat river floodplains are mainly muds. Similar muds also occur on the sea floor in Kitimat Arm, Douglas Channel, and other fiords of the study area (Bornhold, 1977, personal communication, 1982). In contrast, contemporary shallow marine sediments and beach deposits consist mainly of sand and/or gravel.

Organic sediments have accumulated in postglacial time to form bogs, fens, and swamps. These deposits, in general, are less than 3 m thick and occur on flat to gently sloping, poorly drained terrain. In the wet western part of the study area, however, organics locally are much thicker and also occur on steeper slopes.

### *Sea Level Fluctuations*

Changes in sea level along the coast of British Columbia during the Quaternary Period have resulted mainly from a combination of three factors: (1) diastrophism; (2) eustasy; and (3) hydro- and glacio-isostasy (Mathews et al., 1970; Clague, 1975, 1981, 1983; Fladmark, 1975; Andrews and Retherford, 1978; Armstrong, 1981; Clague et al., 1982; Riddihough, 1982).

(1) Western British Columbia is situated at the edge of the American lithospheric plate. Interactions of this plate with the Juan de Fuca, Explorer, and Pacific plates in the northeast Pacific Ocean have generated complex crustal deformations throughout the Canadian Cordillera. Diastrophism related to these plate interactions has caused vertical crustal movements that have altered land-sea positions. Under the present plate tectonic regime, outer coastal areas such as westernmost Vancouver Island and the Queen Charlotte Islands are being uplifted, whereas the mainland coast of British Columbia is either stable or slowly subsiding (Riddihough, 1982).

(2) The amount of water in ocean basins and, therefore, sea level vary as a function of the volume of continental glacier ice. At the height of major Pleistocene glaciations, sufficient water was locked up in continental ice sheets to lower sea level about 100 m or more (Flint, 1971). Conversely, sea levels at interglacial maxima probably were higher than at present (Broecker et al., 1968; Hopkins, 1973; Bloom et al., 1974).

(3) Water transfer from oceans to continents as a consequence of the growth and decay of ice sheets results in a redistribution of load on the Earth's surface. Isostatic adjustments of the crust and mantle in response to such load distribution can cause major shifts in the level of the land, even thousands of years after the disappearance of an ice sheet (Flint, 1971). Such adjustments have occurred globally during and following each Pleistocene glaciation, with the greatest displacements at the edge of and beneath large continental ice sheets, as for example in British Columbia (Walcott, 1970, 1972).

The net effect on past sea levels of diastrophic, eustatic, and isostatic adjustments can be determined by studying former shorelines and associated deposits. It is generally difficult, however, to assess the individual effects of each of these factors because eustasy and isostasy are interdependent and because there is disagreement about past eustatic fluctuations in sea level (Clark et al., 1978; Kidson, 1982). Eustatic sea level variations relate directly to changes in the volume of glacier ice, but the transfer of water from oceans to glaciers also produces variable worldwide, hydro- and glacio-isostatic adjustments. Thus, a eustatic change in sea level commonly is accompanied by isostatic changes, the direction and magnitude of which depend largely on distance from major ice accumulation areas. Because these isostatic adjustments occur globally, there is no stable datum site on the Earth's surface where one can measure sea level variations and assume the absence of isostatic and tectonic movements (Clark et al., 1978). Furthermore, because isostatic movements resulting from the last deglacial episode still may be occurring far from former ice sheets, caution must be exercised in deducing contemporary eustatic sea level change from geodetic and tidal records.

Notwithstanding these difficulties, it is possible to evaluate the relative importance of diastrophism, eustasy, and isostasy to sea level change during and following deglaciation on the British Columbia coast (Clague et al., 1982). In areas that were covered by thick ice during the Fraser Glaciation, glacio-isostatic depression of the crust more than compensated for lower eustatic water levels; consequently, during deglaciation, coastal lowlands were transgressed by the sea. Such a transgression occurred in some of the valleys and lowlands of the western part of the study area at the end of the Pleistocene. The sea advanced east up Skeena Valley and north up the Kitsumkalum-Kitimat trough as glaciers retreated from these areas; parts of Hecate Lowland also were inundated. This transgression culminated in the Terrace-Kitimat area about 10 500 years ago when the sea was about 200 m higher relative to the land than at present. At that time, marine waters extended east up Skeena Valley to the vicinity of Terrace and north up the Kitsumkalum-Kitimat trough to near Lakelse Lake. The upper level reached by the sea (marine limit) in Hecate Lowland almost certainly was lower than in the Kitsumkalum-Kitimat trough, because the former area had a smaller ice load and therefore experienced less isostatic depression than the latter. Heusser (1960, p. 193) proposed that the late Pleistocene marine limit near Prince Rupert was somewhere between about 40 m and 135 m in elevation.

Isostatic rebound at the close of the Pleistocene and during early postglacial time caused emergence of submerged valleys and lowlands. Radiocarbon dates from glaciomarine sediments near Lakelse Lake and from deltaic deposits near Kitimat indicate that shorelines were about 200 m above those at present 10 500-11 000 years ago, but had fallen to about 120 m by 10 100 ± 160 BP (GSC-2492), and to about 35 m by 9300 ± 90 BP (GSC-2425) (Table 8, Fig. 43; Clague et al., 1982). Because glacier retreat was diachronous, the timing of emergence in the Kitimat-Lakelse Lake area may have differed slightly from that in other areas. However, the sea in all regions had reached its present level relative to the land by about 8000-8500 years ago (Clague et al., 1982).

Stratigraphic evidence for late Pleistocene – early postglacial emergence is provided in exposures along McNeil River about 25 km east-southeast of Prince Rupert (Map 1557A, section 26; Fig. 43). Here, marine pebbly sandy mud containing abundant fossil wood and molluscan shells is sharply overlain by inclined parallel-bedded gravel, which in turn is overlain by organic-rich pebbly silty sand grading upwards into peat. The sandy mud of the lowest unit, which occurs below 3 m elevation and has yielded dates of 8580 ± 100 and 9180 ± 150 BP (GSC-2307 and GSC-2343, respectively; Table 8), was deposited in a shallow marine environment. A driftwood mat at the contact between this unit and the overlying gravel has been dated at 8460 ± 90 BP (GSC-2248, Table 8). The driftwood probably accumulated in the upper intertidal zone, the modern counterpart of which is about 0-2 m lower at this site. The gravel was transported

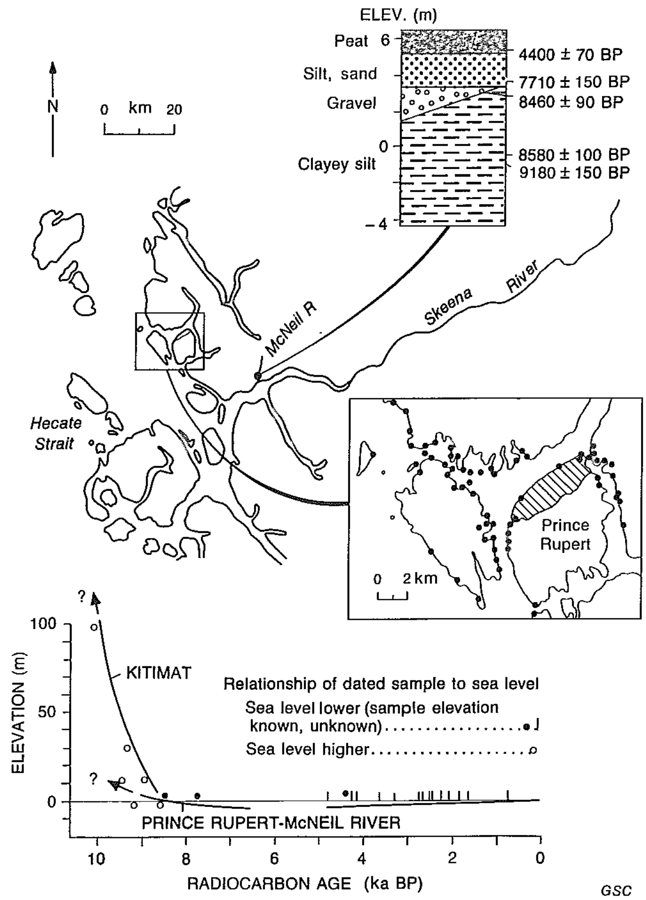


***Figure 43.*** *McNeil River section and Prince Rupert-Kitimat sea level curves. Inset map shows locations of coastal archeological sites in the Prince Rupert area (after MacDonald and Inglis, 1981, their Fig. 9). See Table 8 for details on radiocarbon dates.*

by Skeena River northwest into the McNeil River embayment and was deposited in shallow standing water. The upper surface of this unit, at slightly more than 3 m elevation (less than 1 m below present high tide), probably approximates high tide level at the time of deposition of the unit. Although the gravel has not been dated directly, the base of the overlying pebbly silty sand has yielded a date of 7710 ± 150 BP (GSC-2471, Table 8). The latter unit is interpreted to be estuarine in origin and to have been deposited when sea level was within a few metres of its present position. The peat at the top of the section was deposited when the sea was no higher, and possibly was lower, than at present. Wood collected from the transitional zone between this peat and underlying estuarine sediments yielded a radiocarbon date of 4400 ± 70 BP (GSC-2222, Table 8). The above evidence indicates that there was progressive emergence of the McNeil River area between about 9200 and 7700 BP and that the sea reached its present level there about 8000 years ago.

Archeological investigations at Prince Rupert Harbour have revealed the presence of more than 40 Indian villages, some of which have been continuously occupied for nearly 5000 years (Fig. 43; MacDonald, 1969). These sites are situated on or near the present shoreline, most being less than several metres above present high tide. The continuity of human occupation of these low coastal sites shows that sea level in the area was no higher than at present during the last 5000 years. The data do not preclude the possibility that the sea was lower than at present during and prior to this interval, as it was at many other sites on the British Columbia coast (for example in the Bella Bella – Bella Coola region (Andrews and Retherford, 1978), on southern Vancouver Island, and near Vancouver (Mathews et al., 1970; Clague et al., 1982)). Studies that might document such low sea levels, however, have not been made in the Prince Rupert area. Relevant to this matter is the apparent absence of archeological sites older than about 5000 years at Prince Rupert. In view of the fact that this area was so heavily utilized by Indians during the latter half of postglacial time and has been extensively investigated by archeologists, the lack of evidence for older habitation is puzzling. One possible explanation for this apparent enigma is that many habitation sites predating 5000 BP in the Prince Rupert area are now submerged or were washed away by a transgressing sea.

In summary, shorelines in the Prince Rupert-Terrace-Kitimat area were higher than at present during and immediately following deglaciation at the close of the Pleistocene. Isostatic rebound during early postglacial time caused a rapid marine regression from submerged coastal lowlands, with the sea reaching its present level relative to the land 8000-8500 years ago. The sea may have fallen below its present level after 8000 years ago; if so, a minor transgression during middle or late postglacial time established the present shoreline.

## ECONOMIC GEOLOGY

### *Engineering Applications*

The engineering properties and performance of surficial materials at specific sites in the study area can be determined only by means of detailed geotechnical investigations, which were beyond the scope of this study. Nevertheless, some comments relating to the engineering properties of sediments may be made on the basis of the general character of the mapped terrain units.

#### Foundation Conditions

The suitability of surficial materials for foundations is determined by physical properties such as particle-size distribution, water content, and degree of consolidation. Factors that bear on the cost of construction and the integrity of a man-made structure include bearing capacity (i.e., the load that a foundation can safely support without excessive yield), ease of excavation, and drainage (Table 11).

Bedrock in the study area, in general, has excellent bearing capacity and presents no major foundation problems, except for higher excavation costs. The clay-rich tills in Bulkley and upper Skeena valleys also provide excellent support for engineering structures, forming relatively stable slopes and standing well in open cuts. The degree of compaction and stoniness of these tills, however, may make excavation somewhat difficult; also, their low permeability may cause local drainage problems. Sandy till and drift in the western part of the study area are relatively easily excavated. Like the clay-rich tills, they have good bearing capacity and undergo little compaction when loaded.

Sand and gravel – the main constituents of alluvial, glaciofluvial, and raised delta deposits – are generally loose, permeable, and easily excavated. They also are well drained, except beneath the floodplains of present-day rivers and streams. The bearing capacities of coarse fluvial, glaciofluvial, and deltaic sediments are generally high. In many areas (e.g., much of lower Skeena Valley and parts of the Kitsumkalum-Kitimat trough), however, these sediments

**Table 11.** Foundation properties of sediments in the study area

| Material | Bearing strength | Ease of excavation | Drainage |
|---|---|---|---|
| Organic sediments | low | good | poor |
| Landslide deposits | variable | poor to moderate | generally good |
| Colluvium[1] | intermediate to high | poor to moderate | generally good |
| Alluvium (floodplain) | low to high[2] | good[3] | poor |
| Alluvium (terraces, incised fans) | high | good | good |
| Alluvium (nonincised fans) | high | good | poor to good[4] |
| Glaciofluvial sediments | high | good | good |
| Glaciolacustrine sediments | low to high[5] | moderate[6] | poor on flat surfaces |
| Glaciomarine sediments | low to high[5] | moderate[6] | poor on flat surfaces |
| Till | high | moderate to good[7] | poor on flat surfaces |
| Drift | intermediate to high | good | generally good |
| Bedrock | high | poor | good |

[1] Excluding landslide deposits
[2] Low for fine grained deposits and for thin alluvium overlying marine and glaciomarine sediments; high for thick gravelly deposits
[3] Excavated faces are unstable because the water table normally is near the surface
[4] Coarse fan sediments are better drained than fine fan sediments
[5] Low for saturated sediments; high for dry sediments and those that have been overriden by glaciers
[6] Wet sediments have high plasticity
[7] Tills with abundant clay in the matrix may be difficult to excavate; those with matrixes consisting mainly of sand and silt generally pose no excavation problems

overlie glaciomarine and marine clay and silt with high water contents. These fine grained materials have low bearing strengths (Fair, 1978) and consequently may deform when loaded. An example of such deformation occurred at Kitimat during construction of the Alcan aluminum smelter in the early 1950s (Hardy and Ripley, 1954). Prior to construction, a fill up to 9 m thick and covering an area of 178 ha was laid down on alluvium overlying thick deltaic, marine, and glaciomarine sediments. Over a period of 18 months following emplacement of this fill, the ground surface at this site subsided up to 1.1 m. Load-induced subsidence of this magnitude is possible anywhere on the Kitimat delta and on the floodplains of lower Kitimat and lower Skeena rivers and some Skeena River tributaries. Subsidence could be especially severe on the floors of Skeena Valley and its tributaries downstream from Exchamsiks River, because there surface alluvial deposits, as well as underlying marine and glaciomarine sediments, are fine grained and thus susceptible to compaction following loading.

Most glaciolacustrine, glaciomarine, and marine deposits in the study area consist of admixed clay, silt, and minor sand (Fig. 18B, Appendix 1). These materials have relatively high bearing strengths when dry, but virtually none when saturated. Under heavy loads, pore water may be expelled from the sediments causing settlement. Settlement may also occur when glaciolacustrine and glaciomarine sediments desiccate. Finally, because these fine grained deposits generally have low permeability, drainage may be a problem where the terrain is flat or very gently sloping. Some subsurface glaciolacustrine sediments in Bulkley Valley and some glaciomarine and marine sediments in lower Skeena Valley and in the southern Kitsumkalum-Kitimat trough have been overriden by glaciers and thus naturally preloaded. These sediments are similar in texture to glaciolacustrine and glaciomarine sediments deposited during glacier retreat at the close of the Pleistocene but probably have higher densities and lower void ratios. Because they have been loaded by about a 2000 m thickness of ice, the older deposits are not subject to the same settlement problems as their younger counterparts.

Organic deposits are highly compressible and, where thick, present major foundation problems for highways, buildings, and other structures. Fortunately, in most parts of the study area, organic sediments are thin and of limited extent, and either can be removed and replaced with fill or avoided altogether. In areas of extensive and thick organics, it may be necessary to preload prior to construction. Sufficient fill must be placed on the organic sediments to compact them and thus prevent later damage to structures.

Most colluvial deposits in the study area are coarse and poorly sorted. They have relatively high bearing strengths and are moderately to well drained. Except on landslides and some fans and aprons, colluvium in the study area is relatively thin (generally <2 m) and is not an important foundation material. Many colluvial fans and aprons and some landslide deposits are bouldery or blocky and thus are difficult to excavate. In contrast, alluvial fans consist mainly of sand and gravel which are easily excavated. The apexes of most alluvial fans are coarser and better drained than the more gently sloping toes.

### Granular Material

*Till.* Till is often used to build dams, dykes, roadbeds, and other structures that require an impermeable preconsolidated base or core. Tills in the study area exhibit major differences in texture and lithology that may affect their use as construction materials. In the western part of the area where plutonic and high-grade metamorphic rocks are dominant, tills have sandy matrixes (Fig. 18A, Appendix 1). In contrast, in valleys of the eastern part of the study area where volcanic and fine grained sedimentary rocks are common, tills are silt- and clay-rich and are much more plastic (Fig. 18A, Appendix 1). Thick deposits of till typically contain lenses of sorted sediments.

Till is widespread and locally thick (5-30 m) in Bulkley and upper Skeena valleys but is uncommon in lower Skeena Valley and in the Kitsumkalum-Kitimat trough. In the latter area, morainal deposits apparently were reworked during and shortly after their deposition by meltwater.

*Sand and Gravel.* Industrial and urban development is dependent on the availability of large amounts of sand and gravel. These materials are constituents of concrete and asphalt and are used extensively by the construction industry in roads, buildings, and other structures, and as fill.

Sand and gravel deposits are plentiful throughout the Kitsumkalum-Kitimat trough, in middle and upper Skeena Valley, and in Bulkley Valley. In contrast, they are rare in lower Skeena Valley and in the mapped part of the Hecate Lowland. Most of the aggregate presently mined in the study area comes from fluvial and glaciofluvial (including deltaic) deposits; small amounts of colluvium and till are extracted in areas where more suitable materials are unavailable (e.g., Prince Rupert area). Alluvial and glaciofluvial sediments which underlie till in Bulkley Valley are a large potential source of aggregate, but these materials probably will not be extensively exploited until easily accessible surface deposits are depleted.

The sand and gravel resources of the Kitsumkalum-Kitimat trough are immense; some individual deposits are larger than $10^9$ $m^3$ in volume (Clague and Hicock, 1976). The largest deposits are delta-sandur complexes that formed during deglaciation when glaciers temporarily halted during their retreat (see section entitled Fraser Retreat). The delta-sandur sediments locally exceed 150 m in thickness and consist of horizontally stratified sandy gravel overlying inclined sandy gravel and sand. The sediments become finer with increasing depth below the surface and with increasing distance from ice-contact faces at the upvalley ends of the deposits. Other important sources of sand and gravel in the Kitsumkalum-Kitimat trough are: (1) hummocky and rolling ice-contact deposits; (2) incised raised deltas at the mouths of tributary valleys; (3) fluvial and kame terraces; (4) alluvial fans; and (5) floodplain deposits of Skeena, Kitimat, and Kitsumkalum rivers. Small amounts of sand and gravel also are extracted from drift and colluvial mantles on bedrock slopes. The ice-contact deposits are the most variable of the major aggregate sources, comprising both well sorted sediments and poorly sorted mixtures of silt, sand, and gravel. Raised delta, fluvial terrace, and floodplain deposits are much more homogeneous in texture, consisting mainly of sorted sandy gravel.

Many of the same types of sand and gravel deposits found in the Kitsumkalum-Kitimat trough are also present in middle and upper Skeena Valley and in Bulkley Valley. These include ice-contact deposits, raised deltas, incised and nonincised alluvial fans, river terraces, and floodplains. However, delta-sandur deposits, which are the largest potential source of aggregate in the Kitsumkalum-Kitimat trough, are absent from Bulkley and Skeena valleys.

Lowermost Skeena Valley and the mapped part of the Hecate Lowland have no sand and gravel deposits of importance. The sediments in the estuary of Skeena River and beneath the floodplains of its major tributaries are mainly fine grained. Elsewhere, thin unconsolidated deposits, unsuitable for exploitation, overlie bedrock. A few borrow pits have been opened in till, outwash, coarse estuarine deposits, and colluvium in an attempt to meet aggregate demand in the Prince Rupert area, but the operations have been small and short-lived. In addition, the deposits are difficult to work and the product commonly of low quality. Unexploited sand and gravel deposits may be present on the lowlands of Tsimpsean Peninsula north of Prince Rupert and on Porcher Island to the south. Unfortunately, mapping necessary to confirm the presence of such deposits has not been undertaken. Most of the aggregate used in Prince Rupert in recent years has been crushed rock and material dredged from the sea floor of Prince Rupert Harbour and Chatham Sound. Dredging operations, for the most part, take place in shallow (<10 m) water adjacent to shoals and deltas.

*Clay.* Fine glaciomarine sediments, which outcrop extensively in the Kitsumkalum-Kitimat trough, have potential economic value in the manufacture of structural clay products such as hollow clay drain tile, structural tile, face brick, common brick, flue lining, and pots. These sediments have not been utilized on a large scale because of their high silt content and the limited local market.

### *Agricultural Applications*[1]

The texture, structure, and composition of surficial sediments are important factors controlling the development of soils. There are gross differences in the composition of soil parent materials related to the distribution of bedrock types in the study area. For example, most soils in the western part of the study area have formed on rocks and sediments rich in felsic minerals; in contrast, soils in many other parts of the study area (e.g., Hazelton Mountains) have developed from parent materials rich in ferromagnesian minerals.

The texture and structure of parent materials are perhaps the most important properties affecting soils. The textural and structural attributes of sediments are controlled mainly by the mode of genesis of the material. For example, sediment deposited at the base of a glacier has completely different physical characteristics from sediment deposited in a stream channel. Texture and structure determine porosity (percentage of pore space) and permeability (ease with which water will pass through material), and thus control leaching, movement of clay in the soil profile, water retention, and drainage.

*Soils on Till.* The tills of the study area range in texture from clay- and silt-rich diamictons to sandy diamictons containing minor fines. The former are compact and have low permeability, although soil-forming processes have produced loose surface horizons that allow efficient infiltration, transmission, and storage of moisture. The sandy diamictons commonly are loose throughout and have moderate to high porosity and permeability. The extreme stoniness and generally poor water retentiveness of these latter materials severely limit their use for agriculture.

*Soils on Sand and Gravel.* The productiveness of soils developed on sand and gravel depends on topography, subsurface drainage, and the texture of surface horizons. These soils generally are highly permeable and hence excessively drained. Good agricultural soils are developed on sand and gravel where less permeable subsoil horizons or a high water table promote retention of water. Coarse stony phases and areas of rough topography (as is common in hummocky and kettled ice-contact terrain) are unsuitable for cultivation.

*Soils on Clay and Silt.* Soils derived from clay and silt parent materials have few stones, good moisture retention, and extensive flat or gently rolling surfaces. Poor subsoil drainage is common in low-lying areas where the water table is at or near the surface (e.g., lowermost Skeena Valley beneath silty alluvial deposits) and in areas underlain by extremely fine grained sediments (e.g., parts of the Kitsumkalum-Kitimat trough). Glaciomarine and glaciolacustrine muds have been gullied in many areas, giving rise to irregular steep terrain unsuited for cultivation.

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[1] Soil reports covering parts of the study area include those by Farstad and Laird (1954) and Runka (1972).

### *Groundwater*

In spite of the wet climate and abundant surface water in the study area, groundwater is used in many homes, ranches, and farms. Groundwater also has the beneficial effect of stabilizing lake levels and maintaining stream flow during the dry season.

Groundwater is precipitation that infiltrates the soil, accumulates in subsurface layers, and flows slowly towards areas of lower hydraulic potential. A groundwater system is characterized by a recharge area (area of infiltration) and a discharge area (area where water flows to the surface in springs or discharges directly into a stream or lake).

Groundwater systems in the study area are complex, with both recharge and discharge occurring locally within the mountains and major valleys. Part of the precipitation in the mountains infiltrates unconsolidated deposits that underlie the floors of small and mid-size valleys. Much of this groundwater flows into the main valleys where it augments water derived from local sources. Minor amounts of groundwater probably flow into the main valleys through fractures in bedrock and through sheets of unconsolidated materials that extend up the valley walls. Within the main valleys, groundwater commonly discharges at escarpments bordering areas underlain by permeable alluvial and glaciofluvial sediments. Groundwater also may be tapped where permeable water-saturated beds outcrop at the surface (i.e., a spring) or where a dug or drilled well intercepts one of these beds.

*Groundwater in Mountain Areas.* Mountains contain many small hydrological systems, in which steep slopes act as recharge areas and valleys as areas of discharge. Within mountain areas, the best sites for groundwater extraction are valleys containing extensive unconsolidated deposits. These deposits will yield substantial supplies of groundwater if sufficiently permeable beds are present. Fractured bedrock and unconsolidated deposits away from the valley floors also may supply groundwater, but such aquifers are difficult to locate and their yields unpredictable.

*Groundwater in Main Valleys.* The principal groundwater reservoirs in the study area are located in the main valleys. These valleys may be viewed as containing both surface and subsurface water systems; the latter can be tapped wherever there are subsurface water-bearing sediments of moderate to high permeability.

The following are potentially important aquifers in the study area: (1) Alluvial fans at the mouths of tributary valleys. Groundwater entering a main valley from a tributary commonly can be extracted from the coarse permeable fan sediments. (2) Floodplains of streams and rivers. Sand and gravel underlying floodplains contain abundant groundwater which is readily recharged from local surface sources. (3) Terraced alluvial and glaciofluvial deposits. Large bodies of sand and gravel deposited during and shortly after deglaciation and now elevated above local base level may contain significant amounts of groundwater derived from adjacent mountain slopes and tributary valleys. (4) Sheets of sand and gravel underlying till. Flat-lying deposits of porous permeable unconsolidated sediments occur beneath till in Bulkley Valley. Although this aquifer has been breached by erosion during postglacial time, it possibly contains significant reserves of groundwater.

Artesian aquifers may exist in parts of the study area. Artesian conditions develop where water flows under pressure in an aquifer confined by an impermeable bed. Sediments capable of confining groundwater under pressure include till and glaciolacustrine and glaciomarine muds. Because groundwater enters the main valleys of the study area from sources far above the valley floors, high artesian pressures are a possibility.

### *Natural Hazards*

Natural processes operating within and at the surface of the Earth pose potential hazards to life and property. Earthquakes, floods, stream and river erosion, landslides, and snow avalanches are all capable of causing damage in the study area. Appropriate land-use planning and engineering design are capable of mitigating most of these hazards, although some damage from rare catastrophic events is unavoidable.

#### Earthquakes

Earthquakes occur in western Canada with sufficient frequency and intensity to be of concern (Fig. 44). Although most of these are small and cause no damage, an average of two earthquakes greater than 6.5 Richter local magnitude ($M_L$) occur in western Canada every decade (Whitham and Hasegawa, 1975). Bearing in mind the San Fernando (California) earthquake of 1971 ($M_L = 6.4$, 58 deaths, >$500 000 000 damage), the potential for earthquake damage in the region is rather large.

Much of the earthquake activity in western Canada occurs offshore at the boundaries between major lithospheric plates (Milne et al., 1978). Strain release calculations show that most seismic energy is released along the Queen Charlotte-Fairweather fault system, which separates the Pacific and American plates. Significant strain release also occurs on southern Vancouver Island and in the Strait of Georgia-Puget Sound region, inboard of the presumably convergent margin between the American and Juan de Fuca plates (Milne et al., 1978).

Far fewer earthquakes occur on the British Columbia mainland than in areas to the west. Mainland seismicity is not clearly associated with major physiographic, geological, or tectonic features, making it extremely difficult too assess seismic risk there. Furthermore, there have been too few recorded earthquakes on most parts of the mainland to permit reliable risk forecasting. This is especially true for the study area which, until 1973, was considered aseismic.

On November 5, 1973, a shallow focus earthquake ($M_L = 4.7$) occurred about 20 km southwest of Terrace in the mountains bordering the Kitsumkalum-Kitimat trough (Rogers, 1976). This quake was felt to distances of 120 km from the epicentre, with a maximum intensity of V on the Modified Mercalli scale. Damage was limited to a few broken windows and some cracked plaster. The main shock was preceded by a small foreshock of $M_L = 2.5$ and was followed by an aftershock of $M_L = 3.7$. Although it is tempting to associate the earthquake with the Kitsumkalum-Kitimat trough, which probably is fault-controlled, there is no evidence to do so. The epicentre was outside the confines of the trough and distant from any mapped fault. The lack of other historical earthquakes in the trough suggests that it is not an active structural feature. Thus, it seems likely that the 1973 event is one of the occasional earthquakes that appear to occur randomly in the Coast Mountains and for which a satisfactory explanation is not available (Rogers, 1976).

The establishment of a seismograph station at Fort St. James just east of the study area in 1965 has provided continuous monitoring of the region, permitting detection of all earthquakes greater than magnitude 3.0. With the exception of the November 1973 events, no earthquakes of magnitude >3 have been detected in the Terrace area since 1965; in addition, there are no records of earlier large

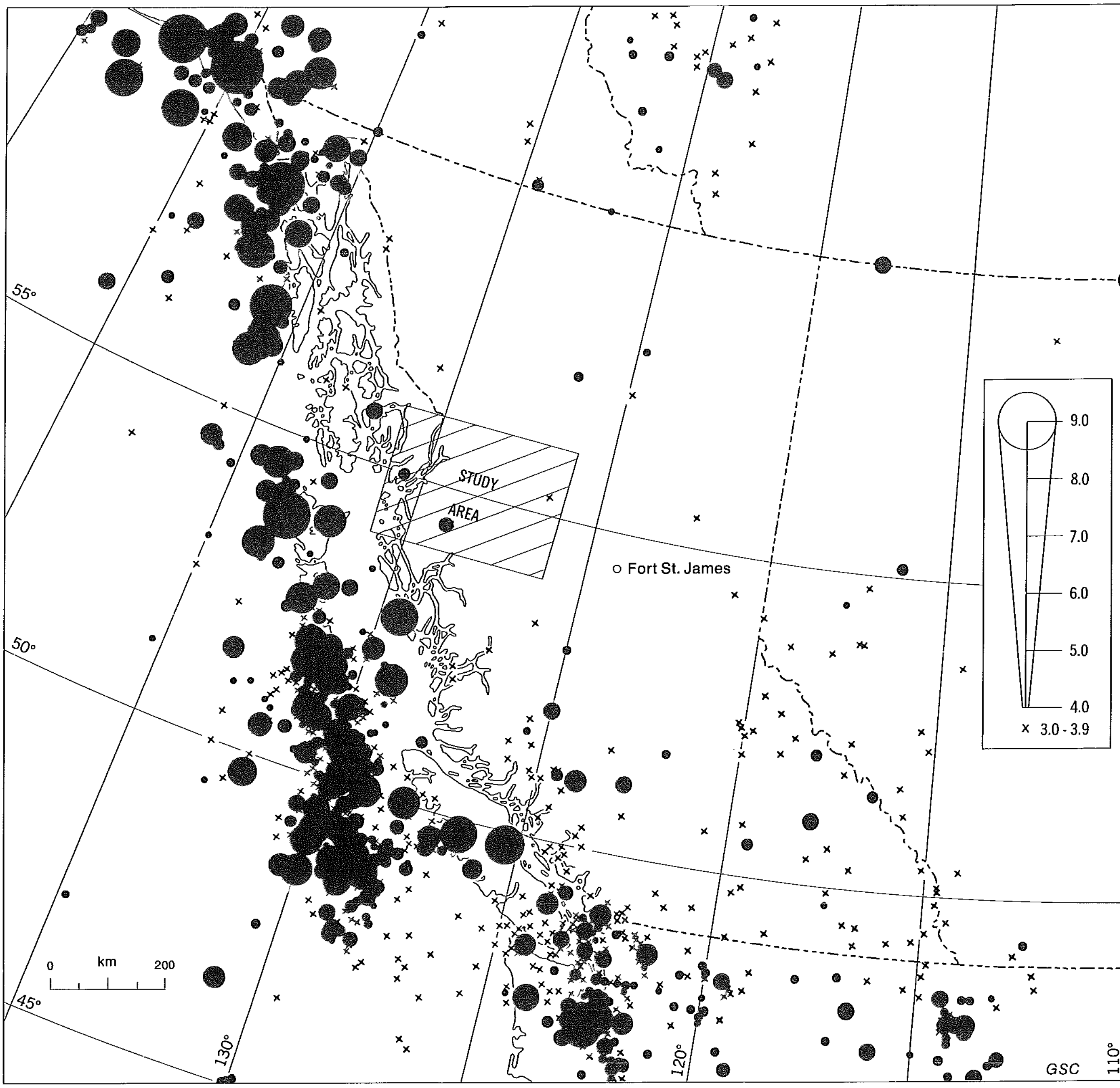


***Figure 44.*** *Regional distribution of earthquakes in western Canada from 1899 through 1975 (Richter scale magnitude ≥ 3.0). Diameters of circles are proportional to earthquake magnitude; earthquakes of magnitude 3.0–3.9 are denoted by "x". From Milne et al. (1978, their Fig. 4).*

earthquakes from this area (Milne, 1956). In fact, there have been few recorded earthquakes anywhere in the study area (Fig. 44). Perhaps the most recent of any consequence was a small quake ($M_L$ = 3.3) near Smithers in September 1977 (Horner et al., 1979).

In conclusion, although historical seismicity has been low, a rare intermediate-size earthquake conceivably could cause damage in the study area. Seismic risk increases westward towards the Queen Charlotte Islands at the edge of the American plate. This risk is expressed semiquantitatively on the Seismic Zoning Map of Canada (Fig. 45).[1] According to this map, the Prince Rupert area is within a zone of potential major earthquake damage, where peak ground accelerations in excess of 6% g have an annual probability of 1%. In contrast, ground accelerations of only about 3% g are likely at the same level of probability in Bulkley Valley in the eastern part of the study area.

### Floods

The climate and physiography of the study area make floods inevitable under natural conditions. Potential flood areas include floodplains and low terraces of rivers and streams, some alluvial fans located at the mouths of tributary valleys, and the shores of lakes (Clague, 1978b). Unfortunately, no quantitative estimate of the probability or magnitude of flooding can be made for these areas, in large

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[1] The limitations and weaknesses of the Seismic Zoning Map, and the data and methodology used in its construction are summarized by Whitham and Hasegawa (1975, p. 144-145).

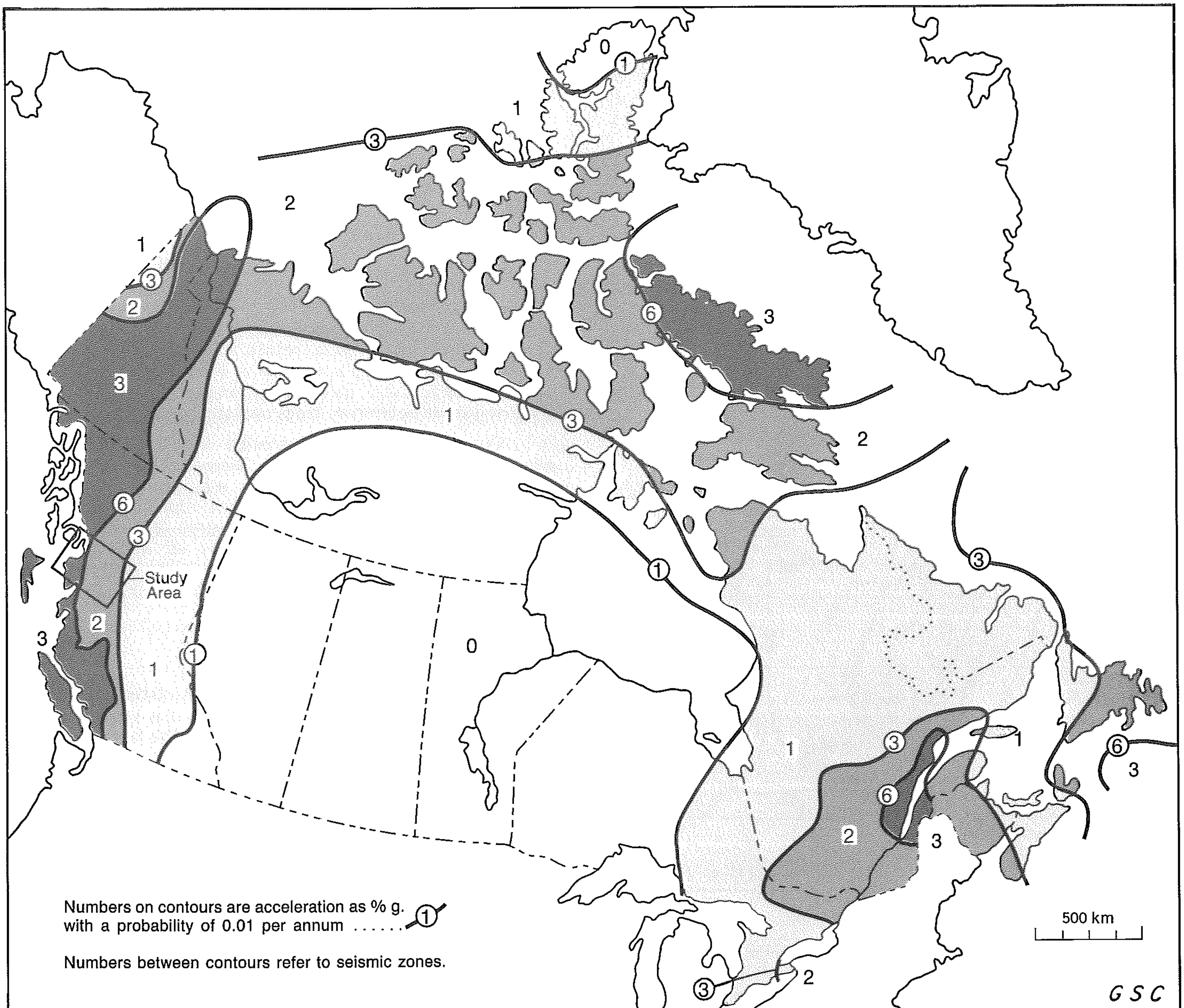


***Figure 45.*** *The Seismic Zoning Map of Canada (from Whitham and Hasegawa, 1975, their Fig. 3).*

part because pertinent streamflow records are either of short duration or nonexistent. Available records, however, do indicate that maximum instantaneous discharges of the major rivers for the period of measurement (ca. 50 years or less) are 10-20 times larger than mean annual discharges (Water Survey of Canada, 1980). Rare flood events (e.g., those with recurrence intervals of 100 years or more) would exceed the largest flows of the streamflow records. The rivers and streams in the study area thus are subject to large variations in discharge, and rare flood events are capable of inundating portions of floodplains, low terraces, and nonincised fans.

Many potential flood sites in the study area are uninhabited and undeveloped. However, low fluvial terraces at Telkwa, Hazelton, Kispiox, Kitwanga, Cedarvale, Usk, Terrace, and Kitimat are inhabited and may be inundated during unusually large floods. In addition, Highways 16 and 25 and the Canadian National Railways line, the main ground transportation routes in the area, are subject to flooding and washouts during catastrophic storms. Some homes and cottages at Lakelse Lake may be flooded due to rising lake levels during prolonged severe rainstorms.

Floods in the study area and elsewhere in the mountains of western British Columbia are of two types: (1) spring-early summer floods caused by melting of the winter snowpack; and (2) fall-winter floods triggered by intense rainstorms, sometimes accompanied by catastrophic snowmelt. Skeena and Bulkley rivers are relatively insensitive to localized severe storms and consequently rarely overflow their banks during the fall and winter. Serious flooding by these rivers is most likely when deep snowpacks melt rapidly during the spring and early summer. In contrast, most small streams, as well as some intermediate-size rivers (e.g., Kispiox, Zymagotitz, and Zymoetz rivers) may peak either during fall-winter rainstorms or during spring-summer snowmelt. Still others (e.g., Kitimat River) peak most commonly during the fall and only rarely in the spring or early summer.

Floods triggered by fall rainstorms generally affect relatively small areas in comparison to spring-summer floods. For example, a heavy rainstorm in late October-early November 1978 caused severe flood damage in the Terrace-Kitimat area, but none at Hazelton and Smithers. During this storm, small streams overflowed their banks, and some rivers (e.g., Kitimat and Zymoetz) attained maximum recorded levels (Water Survey of Canada, 1980). Road and rail links to Kitimat, Prince Rupert, and Terrace were severed due to high water levels and washouts, and houses and cottages at the edge of Lakelse Lake were flooded by rising lake waters.

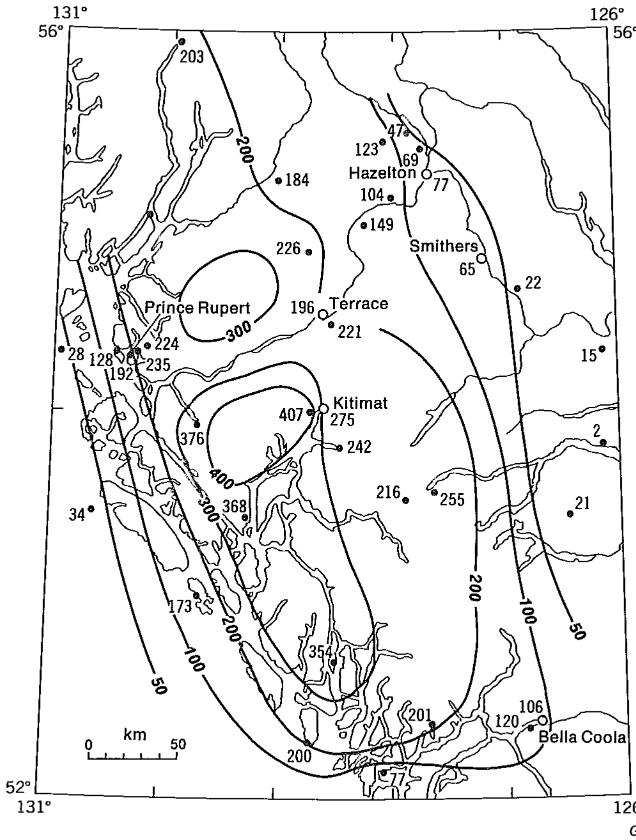


***Figure 46.*** *Isohyetal map of total precipitation (mm) for the five-day period from October 29 to November 2, 1978 (adapted from Schaefer, 1979, his Fig. 1).*

The storm that triggered this flooding occurred over a period of several days and was characterized by a frontal zone stretching from northeast to southwest parallel to a strong, warm, moist southwesterly flow of air aloft (Schaefer, 1979). More than 200 mm of rain fell over an area of at least 50 000 $km^2$ in the northern Coast Mountains, with a maximum of 400 mm west of Kitimat (Fig. 46). The return period for a storm of this size in the Terrace-Kitimat area is about 80-100 years (Schaefer, 1979).

## Stream and River Erosion

Much of the damage that occurs during floods results from the erosion of natural and artificial embankments by streams and rivers. During the 1978 rainstorm, for example, streams overflowed their banks and scoured roadbeds and bridge approaches. As a result, Highways 16 and 25 were severed in numerous places. Bank erosion during periods of high discharge also may be accompanied by slumping of unconsolidated sediments from oversteepened river banks.

Quantitative data on erosion in the study area are sparse. Rates of erosion by Skeena River at one site southwest of Terrace have been estimated by comparing aerial photographs flown at different times (Clague, 1978b). For a distance of several hundred metres at this site, Skeena River cut back a 7 m-high bank at an average rate of 9 m/year between 1963 and 1974. It must be emphasized, however, that erosion of this magnitude is very restricted in areal extent.

## Landslides

The probability of destructive landslides in the study area is relatively high, in part because the region has high local relief and abundant precipitation. The susceptibility of an area to mass movements, however, is also a function of the physical properties of surface and near-surface materials. Thus, for example, certain types of sediments common on the valley floors of the study area, such as glaciomarine mud, may fail on gentle slopes, whereas bedrock may be stable on very steep slopes.

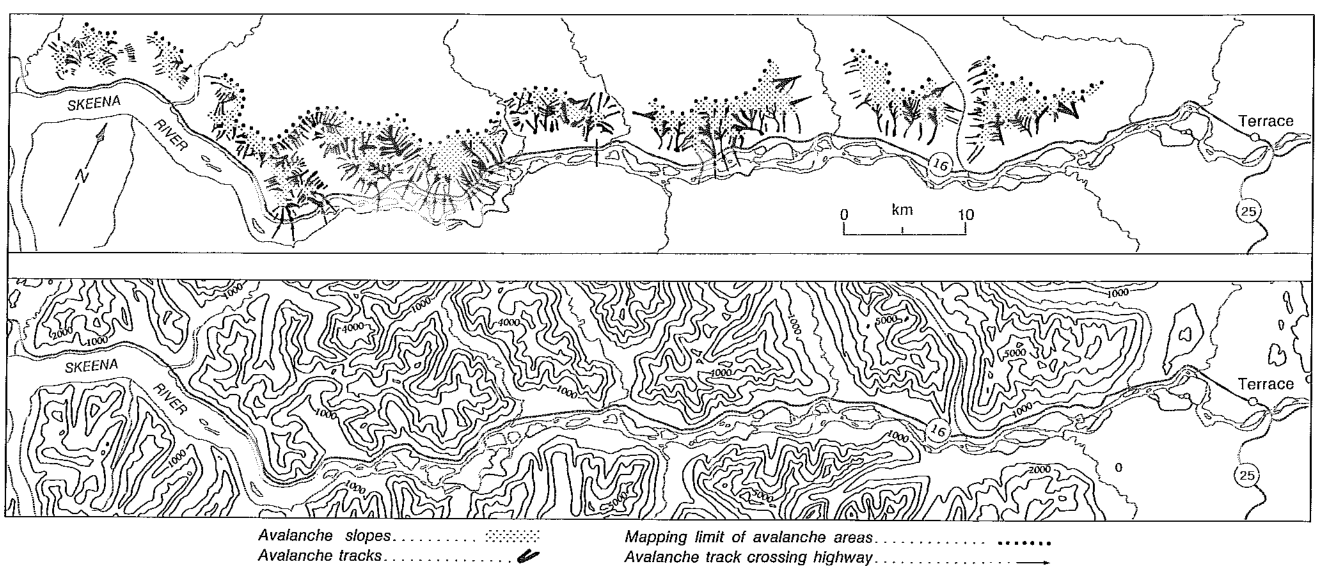


***Figure 47.*** *Avalanche areas on the north wall of Skeena Valley between Terrace and Tyee. Avalanche tracks which cross Highway 16 and the Canadian National Railways line are indicated by arrows. The topography of this part of the valley is shown at the bottom (contour interval 1000 feet). Adapted from Clague (1978b, his Fig. 37.5).*

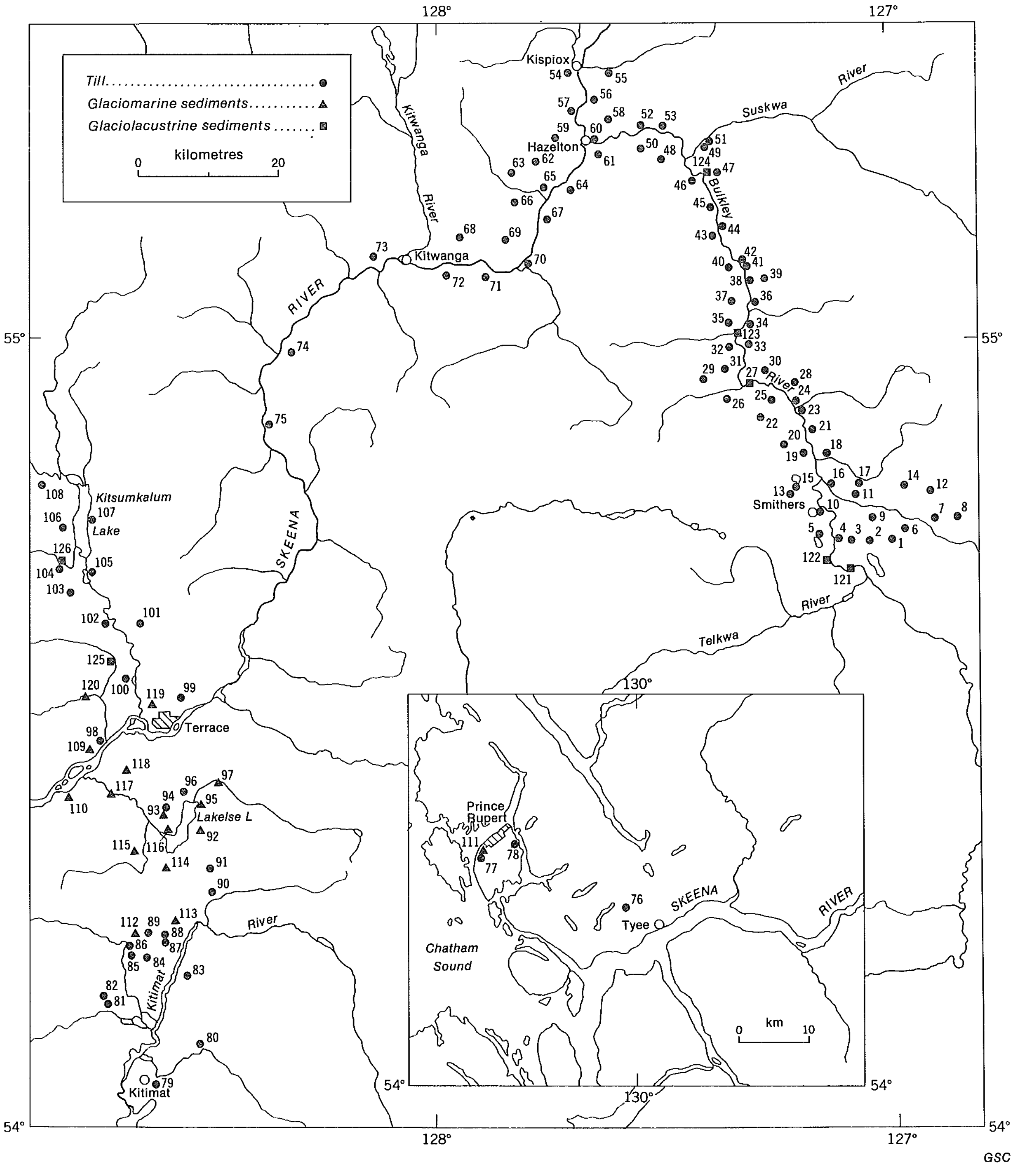


***Figure 48.*** *Index map of sample sites, Appendixes 1-3.*

Slope failures posing the greatest danger to life and property in the study area include: (1) mudflows in glaciomarine sediments and (2) thin-skinned debris flows and debris avalanches.[1]

(1) Two large mudflows occurred in 1962 at Lakelse Lake when sensitive glaciomarine mud liquefied (Fig. 33; Clague, 1978b). The more northerly of the two landslides destroyed part of a provincial park campsite and severed the highway linking Terrace and Kitimat. Landslides like those at Lakelse Lake may occur in the future elsewhere in the Kitsumkalum-Kitimat trough because fine grained glaciomarine sediments are widespread at the surface and at shallow depths in this region.

Several submarine landslides similar to the Lakelse Lake mudflows have occurred in Kitimat Arm during historic times. These landslides have resulted from the failure of glaciomarine and marine sediments perched on the walls of the fiord and of deltaic sediments lying on the foreslope of the Kitimat delta (Luternauer and Swan, 1978; Swan, 1978; Swan and Luternauer, 1978; Murty, 1979; Prior et al., 1982). One such slide in April 1975 involved perhaps as much as $6 \times 10^7 m^3$ of sediment and generated an 8.2 m-high sea wave that caused approximately \$600 000 damage to waterfront facilities at Kitimat (Golder Associates, 1975; Swan, 1978). As a result of this failure, a small bay near the head of Kitimat Arm was deepened by 26 m, and the floor of the fiord was buried beneath up to 30 m of landslide debris. Several smaller submarine landslides occurred in the same area between 1952 and 1968, in 1971, and in 1974 (Murty, 1979).

(2) Highly fluid, fast moving debris flows and debris avalanches occur regularly during intense rainstorms in the Prince Rupert-Port Edward area (Fig. 34). Although small in size, these slope failures can be extremely destructive. For example, a small debris avalanche that cascaded down the flank of Mount Hayes on November 22, 1957 during heavy rains crashed into three houses on the outskirts of Prince Rupert, killing 8 people; one survivor was carried 100 m inside his displaced house (The Vancouver Sun, November 23, 1957; Eisbacher and Clague, 1981). Similar landslides have blocked Highway 16 and other roads in the Prince Rupert-Port Edward area on numerous occasions.

Somewhat similar to the above are slushflows and debris flows of snow, ice, sediment, and water that move rapidly down high-gradient stream courses and avalanche tracks during spring thaw (Fig. 35). These flows terminate at the base of slopes as fan- and ribbon-shaped bodies of debris. Because such flows are common, they pose a serious, although areally restricted, hazard to future development in mountainous parts of the study area.

### Snow Avalanches

Skeena Valley between Terrace and Tyee has been identified as one of three highway corridors in British Columbia with a high avalanche hazard rating (Fig. 27, 47; Avalanche Task Force, 1974). Highway 16, which is located in this corridor, is closed for lengthy periods due to avalanches (average annual closure time is 13 days (Avalanche Task Force, 1974)).

The seriousness of this problem is highlighted by an avalanche that killed 7 people and destroyed a service station, cafe, and small trailer park 45 km west of Terrace in January 1974. This catastrophic avalanche was triggered by unusually heavy snowfall (200 cm in the 12 days preceding the event), followed by warmer temperatures and heavy rainfall.

Although the threat to life and property posed by avalanches is greatest in Skeena Valley west of Terrace, largely because of the proximity of the highway and railway to steep valley walls, avalanches are common in most mountain valleys in the study area. Slopes in the upper reaches of many of these valleys lack forest cover and appear to be swept regularly by avalanches (Fig. 26). Fortunately, most of these mountain valleys are uninhabited (although many are accessible by logging roads), so that avalanches pose a threat only to individuals entering the valleys during the winter and spring.

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## Appendix 1

Grain-size properties and Atterberg limits of sediments

| Site Fig. 48 | Region[1] | Location lat. | long. | Sand % | Silt % | Clay % | Liquid limit | Plastic limit | Plasticity index |
|---|---|---|---|---|---|---|---|---|---|
| Till | | | | | | | | | |
| 1 | BV | 54°44.6' | 127°00.0' | 29.6 | 33.4 | 37.0 | | | |
| 2 | BV | 54°44.6' | 127°02.7' | 40.4 | 32.8 | 26.8 | | | |
| 3 | BV | 54°44.6' | 127°04.8' | 25.8 | 35.8 | 38.4 | | | |
| 4 | BV | 54°44.8' | 127°06.7' | 24.9 | 31.0 | 44.1 | | | |
| 5 | BV | 54°45.1' | 127°09.4' | 32.4 | 35.7 | 31.9 | | | |
| 6 | BV | 54°45.6' | 126°57.8' | 36.1 | 31.1 | 32.8 | 36.0 | 17.7 | 18.3 |
| 7 | BV | 54°46.1' | 126°54.3' | 35.5 | 29.8 | 34.7 | 30.2 | 16.1 | 14.1 |
| 8 | BV | 54°46.3' | 126°51.0' | 44.7 | 26.2 | 29.1 | 34.3 | 18.4 | 15.9 |
| 9 | BV | 54°46.3' | 127°02.6' | 34.6 | 29.1 | 36.3 | 33.3 | 17.6 | 15.7 |
| 10 | BV | 54°46.9' | 127°08.9' | 38.3 | 43.8 | 17.9 | 22.0 | 18.6 | 3.4 |
| 11 | BV | 54°48.1' | 127°04.4' | 32.0 | 25.5 | 42.5 | 37.0 | 19.8 | 17.2 |
| 12 | BV | 54°48.3' | 126°54.6' | 45.2 | 31.8 | 23.0 | 29.6 | 19.5 | 10.1 |
| 13 | BV | 54°48.5' | 127°13.2' | 28.0 | 29.8 | 42.2 | | | |
| 14 | BV | 54°48.7' | 126°58.2' | 58.6 | 29.0 | 12.4 | 21.3 | 18.0 | 3.2 |
| 15 | BV | 54°48.7' | 127°12.2' | 24.1 | 32.1 | 43.8 | | | |
| 16 | BV | 54°49.1' | 127°08.1' | 41.1 | 33.9 | 25.0 | 27.0 | 17.9 | 9.1 |
| 17 | BV | 54°49.2' | 127°03.6' | 32.1 | 29.7 | 38.2 | | | |
| 18 | BV | 54°51.2' | 127°08.3' | 31.2 | 47.4 | 21.4 | | | |
| 19[2] | BV | 54°51.3' | 127°11.0' | 28.2 | 34.8 | 37.0 | | | |
| 19[2] | BV | 54°51.3' | 127°11.0' | 73.4 | 15.9 | 10.7 | | | |
| 20 | BV | 54°52.0' | 127°14.1' | 49.0 | 20.5 | 30.5 | 38.0 | 21.6 | 16.4 |
| 21 | BV | 54°53.1' | 127°10.3' | 37.9 | 31.4 | 30.7 | 31.3 | 19.7 | 11.6 |
| 22 | BV | 54°54.1' | 127°16.7' | 35.6 | 31.6 | 32.8 | | | |
| 23 | BV | 54°54.6' | 127°12.0' | 31.7 | 51.3 | 17.0 | | | |
| 24 | BV | 54°55.1' | 127°12.3' | 72.4 | 14.5 | 13.1 | 24.8 | 16.0 | 8.8 |
| 25 | BV | 54°55.4' | 127°15.6' | 63.0 | 29.5 | 7.5 | | | |
| 26 | BV | 54°55.4' | 127°21.1' | 29.1 | 27.0 | 43.9 | 41.9 | 20.6 | 21.3 |
| 27 | BV | 54°56.5' | 127°18.7' | 34.1 | 34.1 | 31.8 | | | |
| 28 | BV | 54°56.7' | 127°12.4' | 33.2 | 28.2 | 38.6 | 39.8 | 20.7 | 19.1 |
| 29 | BV | 54°56.9' | 127°24.7' | 34.7 | 29.5 | 35.8 | 38.1 | 18.7 | 19.4 |
| 30 | BV | 54°57.6' | 127°16.6' | 25.9 | 37.6 | 36.5 | | | |
| 31 | BV | 54°57.8' | 127°21.3' | 44.0 | 29.2 | 26.8 | 26.3 | 21.3 | 5.0 |
| 32 | BV | 54°59.3' | 127°20.7' | 31.2 | 30.6 | 38.2 | 41.5 | 20.5 | 21.0 |
| 33 | BV | 54°59.6' | 127°18.3' | 36.2 | 31.0 | 32.8 | 31.6 | 17.8 | 13.8 |
| 34 | BV | 55°01.2' | 127°18.4' | 34.3 | 33.6 | 32.1 | | | |
| 35 | BV | 55°01.4' | 127°21.0' | 39.6 | 37.2 | 23.2 | | | |
| 36 | BV | 55°02.8' | 127°17.8' | 34.9 | 29.7 | 35.4 | 37.5 | 18.5 | 19.0 |
| 37 | BV | 55°03.3' | 127°20.7' | 34.7 | 36.2 | 29.1 | 29.7 | 17.4 | 12.3 |
| 38 | BV | 55°04.4' | 127°18.7' | 39.8 | 28.7 | 31.5 | 29.7 | 17.6 | 12.1 |
| 39 | BV | 55°04.6' | 127°16.1' | 34.2 | 29.9 | 35.9 | | | |
| 40 | BV | 55°05.5' | 127°21.0' | 27.8 | 35.4 | 36.8 | | | |
| 41 | BV | 55°05.6' | 127°19.1' | 40.1 | 27.7 | 32.2 | 38.6 | 19.8 | 18.8 |
| 42 | BV | 55°05.8' | 127°19.1' | 24.5 | 30.6 | 44.9 | 34.8 | 19.2 | 15.6 |
| 43 | BV | 55°07.7' | 127°22.9' | 40.5 | 29.5 | 30.0 | | | |
| 44 | BV | 55°08.7' | 127°22.1' | 37.4 | 33.9 | 28.7 | | | |
| 45 | BV | 55°10.1' | 127°22.7' | 57.7 | 25.0 | 17.3 | 21.9 | 14.5 | 7.4 |
| 46 | BV | 55°12.4' | 127°25.8' | 30.6 | 33.9 | 35.5 | | | |
| 47 | BV | 55°12.9' | 127°22.6' | 28.5 | 31.9 | 39.6 | 33.2 | 21.3 | 11.9 |
| 48 | BV | 55°13.8' | 127°30.1' | 78.4 | 14.3 | 7.3 | 22.1 | 18.0 | 4.1 |
| 49 | BV | 55°14.7' | 127°24.2' | 32.9 | 24.7 | 42.4 | | | |
| 50 | BV | 55°14.7' | 127°32.6' | 30.0 | 32.5 | 37.5 | | | |
| 51 | BV | 55°15.1' | 127°23.9' | 72.1 | 18.2 | 9.7 | | | |
| 52 | BV | 55°16.2' | 127°32.3' | 36.8 | 28.9 | 34.3 | 30.9 | 16.9 | 14.0 |
| 53 | BV | 55°16.4' | 127°29.9' | 37.2 | 27.9 | 34.9 | 40.0 | 20.0 | 20.0 |
| 54 | USV | 55°20.6' | 127°42.0' | 40.9 | 27.5 | 31.6 | 28.2 | 17.9 | 10.3 |
| 55 | USV | 55°20.5' | 127°36.9' | 42.2 | 31.5 | 26.3 | 29.9 | 17.1 | 12.8 |
| 56 | USV | 55°18.3' | 127°39.2' | 52.6 | 32.1 | 15.3 | 22.4 | 17.9 | 4.5 |
| 57 | USV | 55°17.3' | 127°41.8' | 32.0 | 28.9 | 39.1 | 36.2 | 18.3 | 17.9 |
| 58 | USV | 55°16.7' | 127°37.0' | 43.2 | 27.6 | 29.2 | 35.2 | 19.0 | 16.2 |
| 59 | USV | 55°15.3' | 127°44.9' | 52.7 | 26.2 | 21.1 | 26.2 | 17.1 | 9.1 |

**Appendix 1** (cont.)

| Site Fig. 48 | Region[1] | Location lat. | long. | Sand % | Silt % | Clay % | Liquid limit | Plastic limit | Plasticity index |
|---|---|---|---|---|---|---|---|---|---|
| 60 | USV | 55°15.2' | 127°39.7' | 38.9 | 34.9 | 26.2 | | | |
| 61 | USV | 55°14.4' | 127°38.3' | 38.8 | 31.3 | 29.9 | 29.9 | 16.5 | 13.4 |
| 62 | USV | 55°13.7' | 127°47.0' | 31.4 | 30.0 | 38.6 | | | |
| 63 | USV | 55°12.8' | 127°50.4' | 46.9 | 27.1 | 26.0 | 31.1 | 17.7 | 13.4 |
| 64 | USV | 55°11.6' | 127°42.0' | 54.4 | 31.1 | 14.5 | | | |
| 65 | USV | 55°11.5' | 127°45.8' | 34.8 | 27.4 | 37.8 | 38.5 | 18.5 | 20.0 |
| 66 | USV | 55°10.5' | 127°49.6' | 41.5 | 35.8 | 22.7 | | | |
| 67 | USV | 55°09.4' | 127°45.4' | 47.4 | 34.6 | 18.0 | 26.5 | 18.1 | 8.4 |
| 68 | USV | 55°07.7' | 127°57.0' | 44.1 | 39.0 | 16.9 | | | |
| 69 | USV | 55°07.6' | 127°50.9' | 49.1 | 31.1 | 19.8 | 22.6 | 17.9 | 4.7 |
| 70 | USV | 55°05.7' | 127°48.5' | 38.6 | 27.5 | 33.9 | 32.4 | 17.7 | 14.7 |
| 71 | USV | 55°05.0' | 127°53.4' | 35.2 | 27.9 | 36.9 | 36.0 | 17.7 | 18.3 |
| 72 | USV | 55°05.0' | 127°59.0' | 78.0 | 17.8 | 4.2 | | | |
| 73 | MSV | 55°06.1' | 128°08.6' | 17.6 | 30.8 | 51.6 | | | |
| 74 | MSV | 54°59.2' | 128°19.4' | 55.0 | 32.6 | 12.4 | | | |
| 75 | MSV | 54°53.5' | 128°22.7' | 61.9 | 21.3 | 16.8 | | | |
| 76 | HL | 54°13.7' | 130°01.7' | 54.8 | 30.2 | 15.0 | 14.2 | 11.4 | 2.8 |
| 77 | HL | 54°17.5' | 130°20.8' | 39.4 | 39.0 | 21.6 | 22.3 | 15.8 | 6.5 |
| 78 | HL | 54°18.6' | 130°16.0' | 53.7 | 29.1 | 17.2 | 18.0 | 12.9 | 5.1 |
| 79 | KKT | 54°03.2' | 128°37.0' | 77.8 | 19.2 | 3.0 | | | |
| 80 | KKT | 54°06.4' | 128°30.9' | 64.4 | 26.3 | 9.3 | | | |
| 81 | KKT | 54°09.2' | 128°43.1' | 55.0 | 37.6 | 7.4 | | | |
| 82 | KKT | 54°09.8' | 128°43.5' | 47.4 | 44.1 | 8.5 | | | |
| 83 | KKT | 54°11.3' | 128°32.6' | 60.9 | 34.7 | 4.4 | | | |
| 84 | KKT | 54°12.9' | 128°37.6' | 48.0 | 46.2 | 5.8 | | | |
| 85 | KKT | 54°13.1' | 128°40.0' | 44.3 | 43.3 | 12.4 | | | |
| 86 | KKT | 54°13.7' | 128°40.4' | 60.1 | 24.8 | 15.1 | | | |
| 87 | KKT | 54°14.3' | 128°35.6' | 59.3 | 31.9 | 8.8 | | | |
| 88 | KKT | 54°14.5' | 128°35.6' | 26.6 | 51.1 | 22.3 | | | |
| 89 | KKT | 54°15.1' | 128°38.0' | 60.1 | 37.2 | 2.7 | | | |
| 90 | KKT | 54°17.8' | 128°28.9' | 60.7 | 32.1 | 7.2 | | | |
| 91 | KKT | 54°19.7' | 128°29.6' | 68.7 | 25.9 | 5.4 | | | |
| 92 | KKT | 54°22.6' | 128°31.2' | 54.4 | 38.3 | 7.3 | | | |
| 93 | KKT | 54°23.9' | 128°35.9' | 57.9 | 32.9 | 9.2 | | | |
| 94 | KKT | 54°24.2' | 128°35.7' | 53.4 | 37.9 | 8.7 | | | |
| 95[3] | KKT | 54°24.5' | 128°31.0' | 62.1 | 24.6 | 13.3 | 15.4 | 12.4 | 3.0 |
| 95[3] | KKT | 54°24.5' | 128°31.0' | 56.8 | 33.6 | 9.6 | | | |
| 96 | KKT | 54°25.5' | 128°33.3' | 62.4 | 25.9 | 11.7 | | | |
| 97 | KKT | 54°26.5' | 128°28.6' | 52.2 | 32.5 | 15.3 | | | |
| 98 | KKT | 54°29.1' | 128°44.4' | 46.1 | 32.4 | 21.5 | | | |
| 99 | KKT | 54°32.7' | 128°33.8' | 25.2 | 53.4 | 21.4 | 32.9 | 25.3 | 7.6 |
| 100 | KKT | 54°34.4' | 128°40.7' | 59.5 | 24.6 | 15.9 | 18.6 | 15.4 | 3.2 |
| 101 | KKT | 54°38.3' | 128°39.1' | 52.3 | 35.0 | 12.7 | 18.2 | 15.5 | 2.7 |
| 102 | KKT | 54°38.5' | 128°43.8' | 39.7 | 38.0 | 22.3 | | | |
| 103[4] | KKT | 54°40.6' | 128°48.6' | 22.8 | 36.8 | 40.4 | 33.2 | 18.9 | 14.3 |
| 103[4] | KKT | 54°40.6' | 128°48.6' | 48.3 | 33.6 | 18.1 | 24.5 | 18.6 | 5.9 |
| 104 | KKT | 54°42.6' | 128°49.9' | 66.7 | 29.0 | 4.3 | | | |
| 105 | KKT | 54°42.4' | 128°45.7' | 53.9 | 28.0 | 18.1 | 24.3 | 15.5 | 8.8 |
| 106 | KKT | 54°45.6' | 128°49.4' | 56.2 | 38.0 | 5.8 | | | |
| 107 | KKT | 54°46.2' | 128°45.8' | 80.1 | 17.5 | 2.4 | | | |
| 108 | KKT | 54°48.7' | 128°52.2' | 73.2 | 21.7 | 5.1 | | | |
| Glaciomarine Sediments | | | | | | | | | |
| 109 | LSV | 54°28.5' | 128°45.5' | 0.2 | 40.7 | 59.1 | 48.2 | 24.2 | 24.0 |
| 110 | LSV | 54°25.1' | 128°48.7' | 0.5 | 47.6 | 51.9 | 37.4 | 21.5 | 15.9 |
| 111 | HL | 54°18.0' | 130°20.3' | 7.7 | 60.3 | 32.0 | 23.7 | 17.6 | 6.1 |
| 112 | KKT | 54°14.9' | 128°39.5' | 0.9 | 55.8 | 43.3 | 39.8 | 26.5 | 13.3 |
| 113 | KKT | 54°15.8' | 128°34.6' | 1.3 | 54.3 | 44.4 | 34.3 | 20.2 | 14.1 |
| 114 | KKT | 54°19.7' | 128°35.9' | 3.0 | 22.2 | 74.8 | | | |
| 115 | KKT | 54°21.1' | 128°39.7' | 3.0 | 49.7 | 47.3 | 35.1 | 21.1 | 14.0 |
| 116 | KKT | 54°22.2' | 128°35.9' | 1.2 | 44.6 | 54.2 | 40.5 | 21.6 | 18.9 |
| 92 | KKT | 54°22.6' | 128°31.2' | 4.7 | 49.1 | 46.2 | 33.8 | 21.4 | 12.4 |
| 93 | KKT | 54°23.9' | 128°35.9' | 1.3 | 37.7 | 61.0 | 47.2 | 24.5 | 22.7 |
| 95 | KKT | 54°24.6' | 128°31.1' | 3.3 | 35.4 | 61.3 | 45.0 | 23.3 | 21.7 |

Appendix 1 (cont.)

| Site Fig. 48 | Region[1] | Location lat. | long. | Sand % | Silt % | Clay % | Liquid limit | Plastic limit | Plasticity index |
|---|---|---|---|---|---|---|---|---|---|
| 117 | KKT | 54°25.3' | 128°42.8' | 1.2 | 68.5 | 30.3 | 34.8 | 26.5 | 8.3 |
| 97 | KKT | 54°26.5' | 128°28.6' | 0.4 | 23.2 | 76.4 | 46.2 | 25.6 | 20.6 |
| 118 | KKT | 54°27.4' | 128°40.7' | 0.4 | 64.6 | 35.0 | 34.4 | 23.2 | 11.2 |
| 119 | KKT | 54°32.2' | 128°37.8' | 0.5 | 41.9 | 57.6 | 45.0 | 26.0 | 19.0 |
| 120 | KKT | 54°32.7' | 128°45.9' | 0.8 | 36.0 | 63.2 | 42.8 | 24.8 | 18.0 |
| Glaciolacustrine Sediments | | | | | | | | | |
| 121 | BV | 54°42.6' | 127°05.7' | 2.1 | 9.2 | 88.7 | | | |
| 122 | BV | 54°42.9' | 127°08.0' | 1.1 | 57.0 | 41.9 | | | |
| 27[5] | BV | 54°56.5' | 127°18.7' | 2.5 | 61.9 | 35.6 | 27.6 | 21.6 | 6.0 |
| 27[5] | BV | 54°56.5' | 127°18.7' | 2.3 | 83.2 | 14.5 | 28.1 | 24.9 | 3.2 |
| 27[5] | BV | 54°56.5' | 127°18.7' | 0.3 | 48.9 | 50.8 | 36.5 | 22.4 | 14.1 |
| 123 | BV | 55°00.6' | 127°19.8' | 1.8 | 80.9 | 17.3 | 25.8 | 20.6 | 5.2 |
| 124 | BV | 55°12.8' | 127°24.4' | 0.5 | 61.3 | 38.2 | 33.2 | 21.3 | 11.9 |
| 125 | KKT | 54°35.5' | 128°42.7' | 3.6 | 22.8 | 73.6 | 44.6 | 26.2 | 18.4 |
| 126 | KKT | 54°43.2' | 128°49.7' | 0.0 | 11.4 | 88.6 | 57.0 | 30.4 | 26.6 |

Notes: Analyses performed at Geological Survey of Canada laboratories in Ottawa and Vancouver. Grain-size determinations were made using sieve, pipette, and hydrometer methods. Sand = 62.5 μm - 2 mm; silt = 4 - 62.5 μm; clay = <4 μm.

[1] BV = Bulkley Valley; USV = upper Skeena Valley (Kispiox-Kitwanga); MSV = middle Skeena Valley (Kitwanga-Terrace); LSV = lower Skeena Valley (Terrace-Tyee); HL = Hecate Lowland; KKT = Kitsumkalum-Kitimat trough

[2] Two samples were collected at site 19: one from clayey lodgment till and the other from sandy ablation till

[3] Two samples were collected from lodgment till at site 95

[4] Two samples were collected at site 103: one from clayey lodgment till and the other from sandy ablation till

[5] Three samples were collected from glaciolacustrine sediments at site 27: two from sediments below till (i.e., the first two sets of data) and one from sediments above till (the third set of data)

**Appendix 2**

Heavy metal composition of sediments

| Site Fig. 48 | Region[1] | Location lat. | long. | Cu | Pb | Zn | Co | Ni | Mn | U | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Till | | | | | | | | | | | |
| 1 | BV | 54°44.6' | 127°00.0' | 44 | 22 | 182 | 26 | 64 | 1390 | 0.0 | 5.1 |
| 5 | BV | 54°45.1' | 127°09.4' | 59 | 24 | 173 | 28 | 66 | 1455 | 0.4 | 5.9 |
| 8 | BV | 54°46.3' | 126°51.0' | 68 | 23 | 165 | 27 | 53 | 895 | 0.1 | 5.6 |
| 14 | BV | 54°48.7' | 126°58.2' | 55 | 27 | 159 | 28 | 41 | 990 | 0.3 | 5.3 |
| 16 | BV | 54°49.1' | 127°08.1' | 65 | 24 | 154 | 24 | 55 | 700 | 0.9 | 5.3 |
| 20 | BV | 54°52.0' | 127°14.1' | 119 | 37 | 379 | 24 | 42 | 585 | 0.3 | 3.9 |
| 21 | BV | 54°53.1' | 127°10.3' | 85 | 28 | 179 | 26 | 63 | 895 | 0.3 | 6.0 |
| 22 | BV | 54°54.1' | 127°16.7' | 64 | 26 | 162 | 23 | 64 | 1350 | 0.4 | 5.6 |
| 23 | BV | 54°54.6' | 127°12.0' | 85 | 29 | 194 | 35 | 79 | 1820 | 0.0 | 6.9 |
| 26 | BV | 54°55.4' | 127°21.1' | 59 | 23 | 159 | 27 | 59 | 870 | 0.3 | 5.5 |
| 28 | BV | 54°56.7' | 127°12.4' | 63 | 26 | 141 | 27 | 64 | 660 | nd | 5.2 |
| 29 | BV | 54°56.9' | 127°24.7' | 38 | 22 | 112 | 22 | 35 | 710 | 0.6 | 4.3 |
| 32 | BV | 54°59.3' | 127°20.7' | 70 | 24 | 157 | 27 | 62 | 815 | 0.1 | 5.8 |
| 33 | BV | 54°59.6' | 127°18.3' | 80 | 26 | 193 | 30 | 66 | 1285 | nd | 6.1 |
| 36 | BV | 55°02.8' | 127°17.8' | 73 | 26 | 171 | 31 | 55 | 1000 | 0.1 | 6.0 |
| 37 | BV | 55°03.3' | 127°20.7' | 80 | 26 | 168 | 27 | 67 | 906 | 0.3 | 5.9 |
| 39 | BV | 55°04.6' | 127°16.1' | 47 | 20 | 114 | 24 | 24 | 990 | 0.0 | 5.3 |
| 40 | BV | 55°05.5' | 127°21.0' | 79 | 26 | 160 | 28 | 73 | 1360 | 0.0 | 6.0 |
| 45 | BV | 55°10.1' | 127°22.7' | 75 | 29 | 199 | 42 | 73 | 1720 | nd | 6.5 |
| 46 | BV | 55°12.4' | 127°25.8' | 71 | 24 | 170 | 35 | 88 | 1900 | 0.0 | 6.5 |
| 47 | BV | 55°12.9' | 127°22.6' | 78 | 23 | 125 | 23 | 38 | 665 | 0.1 | 5.2 |
| 48 | BV | 55°13.8' | 127°30.1' | 115 | 36 | 178 | 40 | 65 | 2485 | 0.1 | 7.0 |
| 51 | BV | 55°15.1' | 127°23.9' | 88 | 26 | 156 | 25 | 38 | 1500 | 0.0 | 6.0 |
| 53 | BV | 55°16.4' | 127°29.9' | 80 | 28 | 197 | 31 | 39 | 870 | nd | 5.9 |
| 54 | USV | 55°20.6' | 127°42.0' | 84 | 28 | 189 | 35 | 96 | 1810 | nd | 6.2 |
| 55 | USV | 55°20.5' | 127°36.9' | 80 | 30 | 195 | 33 | 56 | 1200 | 1.2 | 6.3 |
| 57 | USV | 55°17.3' | 127°41.8' | 77 | 27 | 185 | 36 | 103 | 1255 | nd | 6.2 |
| 58 | USV | 55°16.7' | 127°37.0' | 89 | 32 | 176 | 32 | 35 | 1000 | nd | 6.1 |
| 60 | USV | 55°15.2' | 127°39.7' | 88 | 25 | 186 | 40 | 106 | 1785 | 0.0 | 6.3 |
| 62 | USV | 55°13.7' | 127°47.0' | 67 | 22 | 167 | 28 | 80 | 1185 | 0.0 | 5.6 |
| 64 | USV | 55°11.6' | 127°42.0' | 100 | 28 | 192 | 32 | 73 | 2030 | 0.2 | 6.8 |
| 67 | USV | 55°09.4' | 127°45.4' | 85 | 32 | 175 | 34 | 58 | 1285 | 0.9 | 5.7 |
| 68 | USV | 55°07.7' | 127°57.0' | 68 | 24 | 160 | 24 | 78 | 1440 | 0.0 | 6.2 |
| 69 | USV | 55°07.6' | 127°50.9' | 77 | 28 | 175 | 34 | 70 | 1610 | 0.3 | 6.1 |
| 70 | USV | 55°05.7' | 127°48.5' | 90 | 34 | 215 | 35 | 89 | 1010 | 0.3 | 5.9 |
| 71 | USV | 55°05.0' | 127°53.4' | 75 | 29 | 186 | 33 | 87 | 945 | nd | 6.1 |
| 72 | USV | 55°05.0' | 127°59.0' | 96 | 36 | 147 | 28 | 76 | 2125 | 0.6 | 4.8 |
| 73 | MSV | 55°06.1' | 128°08.6' | 70 | 22 | 152 | 21 | 70 | 1000 | 0.0 | 5.3 |
| 74 | MSV | 54°59.2' | 128°19.4' | 92 | 30 | 165 | 24 | 54 | 1380 | 0.2 | 4.8 |
| 75 | MSV | 54°53.5' | 128°22.7' | 88 | 32 | 154 | 36 | 28 | 1195 | 0.0 | 5.8 |
| 76 | HL | 54°13.7' | 130°01.7' | 36 | 22 | 162 | 31 | 18 | 870 | 0.1 | 5.4 |
| 77 | HL | 54°17.5' | 130°20.8' | 67 | 28 | 206 | 37 | 65 | 1155 | 0.2 | 6.9 |
| 78 | HL | 54°18.6' | 130°16.0' | 59 | 26 | 200 | 41 | 74 | 875 | 0.3 | 5.9 |
| 79 | KKT | 54°03.2' | 128°37.0' | 155 | 30 | 130 | 33 | 64 | 1745 | 0.9 | 4.5 |
| 80 | KKT | 54°06.4' | 128°30.9' | 147 | 17 | 88 | 27 | 54 | 565 | 0.9 | 3.5 |
| 82 | KKT | 54°09.8' | 128°43.5' | 320 | 19 | 101 | 32 | 59 | 590 | 0.3 | 3.7 |
| 84 | KKT | 54°12.9' | 128°37.6' | 97 | 22 | 152 | 29 | 66 | 1215 | 0.6 | 4.4 |
| 90 | KKT | 54°17.8' | 128°28.9' | 250 | 30 | 191 | 27 | 36 | 760 | 0.9 | 3.8 |
| 91 | KKT | 54°19.7' | 128°29.6' | 46 | 24 | 96 | 21 | 25 | 790 | 7.5 | 2.7 |
| 94 | KKT | 54°24.2' | 128°35.7' | 83 | 22 | 119 | 25 | 48 | 1020 | 0.2 | 4.2 |
| 95 | KKT | 54°24.5' | 128°31.0' | 87 | 23 | 142 | 28 | 43 | 1305 | 1.7 | 5.0 |
| 99 | KKT | 54°32.7' | 128°33.8' | 64 | 35 | 140 | 35 | 56 | 1730 | 18.3 | 6.0 |
| 100 | KKT | 54°34.4' | 128°40.7' | 101 | 23 | 159 | 22 | 62 | 710 | 1.7 | 4.9 |
| 101 | KKT | 54°38.3' | 128°39.1' | 116 | 24 | 186 | 29 | 39 | 1280 | 0.7 | 4.8 |
| 102 | KKT | 54°38.5' | 128°43.8' | 97 | 26 | 165 | 26 | 73 | 1200 | 0.8 | 4.9 |
| 104 | KKT | 54°42.6' | 128°49.9' | 84 | 34 | 106 | 32 | 76 | 830 | 5.0 | 4.7 |
| 105 | KKT | 54°42.4' | 128°45.7' | 78 | 28 | 187 | 28 | 44 | 1130 | 3.3 | 5.5 |
| 106 | KKT | 54°45.6' | 128°49.4' | 79 | 20 | 111 | 14 | 32 | 250 | 0.8 | 3.0 |
| 107 | KKT | 54°46.2' | 128°45.8' | 157 | 22 | 147 | 26 | 34 | 1085 | 2.0 | 3.6 |
| 108 | KKT | 54°48.7' | 128°52.2' | 174 | 29 | 155 | 34 | 40 | 905 | 0.3 | 4.2 |

Appendix 2 (cont.)

| Site Fig. 48 | Region[1] | Location lat. | long. | Cu | Pb | Zn | Co | Ni | Mn | U | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Glaciomarine Sediments | | | | | | | | | | | |
| 109 | LSV | 54°28.5' | 128°45.5' | 80 | 25 | 171 | 28 | 62 | 1450 | 0.6 | 5.0 |
| 110 | LSV | 54°25.1' | 128°48.7' | 54 | 20 | 148 | 25 | 66 | 1125 | 1.3 | 4.7 |
| 112 | KKT | 54°14.9' | 128°39.5' | 86 | 20 | 149 | 20 | 58 | 845 | 0.8 | 4.5 |
| 113 | KKT | 54°15.8' | 128°34.6' | 85 | 25 | 189 | 26 | 60 | 1200 | 0.7 | 5.4 |
| 114 | KKT | 54°19.7' | 128°35.9' | 8 | 22 | 117 | 15 | 40 | 450 | 4.1 | 3.5 |
| 115 | KKT | 54°21.1' | 128°39.7' | 72 | 23 | 182 | 32 | 73 | 1120 | 1.5 | 5.4 |
| 116 | KKT | 54°22.2' | 128°35.9' | 62 | 23 | 170 | 27 | 64 | 945 | 1.0 | 5.3 |
| 92 | KKT | 54°22.6' | 128°31.2' | 91 | 23 | 187 | 24 | 64 | 1095 | 1.0 | 5.5 |
| 93 | KKT | 54°23.9' | 128°35.9' | 81 | 22 | 172 | 20 | 60 | 845 | 0.6 | 5.1 |
| 95 | KKT | 54°24.6' | 128°31.1' | 74 | 25 | 176 | 29 | 75 | 1435 | 0.7 | 6.0 |
| 117 | KKT | 54°25.3' | 128°42.8' | 92 | 24 | 133 | 21 | 56 | 770 | 1.1 | 6.0 |
| 97 | KKT | 54°26.5' | 128°28.6' | 86 | 25 | 182 | 30 | 67 | 1665 | 1.1 | 5.3 |
| 118 | KKT | 54°27.4' | 128°40.7' | 95 | 25 | 180 | 24 | 62 | 1035 | 0.8 | 6.6 |
| 119 | KKT | 54°32.2' | 128°37.8' | 76 | 21 | 171 | 24 | 68 | 1130 | 1.4 | 5.9 |
| 120 | KKT | 54°32.7' | 128°45.9' | 72 | 23 | 178 | 30 | 75 | 1430 | 1.0 | 5.1 |
| Glaciolacustrine Sediments | | | | | | | | | | | |
| 27[2] | BV | 54°56.5' | 127°18.7' | 89 | 30 | 186 | 33 | 86 | 1475 | 0.2 | 6.2 |
| 27[2] | BV | 54°56.5' | 127°18.7' | 147 | 37 | 204 | 29 | 79 | 1470 | 0.0 | 7.4 |
| 27[2] | BV | 54°56.5' | 127°18.7' | 77 | 24 | 138 | 22 | 42 | 960 | 0.1 | 5.7 |
| 123 | BV | 55°00.6' | 127°19.8' | 82 | 28 | 184 | 29 | 82 | 1470 | 0.0 | 6.2 |
| 124 | BV | 55°12.8' | 127°24.4' | 60 | 25 | 176 | 30 | 65 | 1655 | 0.2 | 5.7 |
| 126 | KKT | 54°43.2' | 128°49.7' | 63 | 23 | 190 | 30 | 71 | 1530 | 0.2 | 5.7 |

Notes: Analyses by Bondar-Clegg & Company Ltd. using Atomic Absorption Fluorimetric method ($HNO_3$-HCl extraction). All values are parts per million except Fe (per cent); nd = not determined.

[1] BV = Bulkley Valley; USV = upper Skeena Valley (Kispiox-Kitwanga); MSV = middle Skeena Valley (Kitwanga-Terrace); LSV = lower Skeena Valley (Terrace-Tyee); HL = Hecate Lowland; KKT = Kitsumkalum-Kitimat trough

[2] Three samples were collected from glaciolacustrine sediments at site 27: two from sediments below till (i.e., the first two sets of data) and one from sediments above till (the third set of data)

## Appendix 3

Clay mineral composition of sediments

| Site Fig. 48 | Region[1] | Location lat. | long. | Kaolinite (%) | Chlorite (%) | Illite (%) | Montmorillonite (%) |
|---|---|---|---|---|---|---|---|
| Till | | | | | | | |
| 1 | BV | 54°44.6' | 127°00.0' | 28 | 34 | 26 | 12 |
| 5 | BV | 54°45.1' | 127°09.4' | 13 | 48 | 22 | 17 |
| 8 | BV | 54°46.3' | 126°51.0' | 39 | 21 | 25 | 15 |
| 14 | BV | 54°48.7' | 126°58.2' | 46 | 12 | 17 | 25 |
| 16 | BV | 54°49.1' | 127°08.1' | 30 | 25 | 22 | 23 |
| 20 | BV | 54°52.0' | 127°14.1' | 5 | 43 | 24 | 28 |
| 21 | BV | 54°53.1' | 127°10.3' | 22 | 30 | 48 | |
| 22 | BV | 54°54.1' | 127°16.7' | 13 | 45 | 27 | 15 |
| 23 | BV | 54°54.6' | 127°12.0' | 31 | 41 | 28 | |
| 26 | BV | 54°55.4' | 127°21.1' | 29 | 30 | 26 | 15 |
| 28 | BV | 54°56.7' | 127°12.4' | 42 | 27 | 31 | |
| 29 | BV | 54°56.9' | 127°24.7' | 44 | 29 | 15 | 12 |
| 32 | BV | 54°59.3' | 127°20.7' | 9 | 43 | 28 | 20 |
| 33 | BV | 54°59.6' | 127°18.3' | 6 | 49 | 24 | 21 |
| 36 | BV | 55°02.8' | 127°17.8' | 43 | 29 | 28 | |
| 37 | BV | 55°03.3' | 127°20.7' | 6 | 46 | 28 | 20 |
| 39 | BV | 55°04.6' | 127°16.1' | 58 | 21 | 21 | |
| 40 | BV | 55°05.5' | 127°21.0' | 19 | 42 | 39 | |
| 45 | BV | 55°10.1' | 127°22.7' | 6 | 56 | 38 | |
| 46 | BV | 55°12.4' | 127°25.8' | 27 | 35 | 38 | |
| 47 | BV | 55°12.9' | 127°22.6' | 11 | 37 | 26 | 26 |
| 48 | BV | 55°13.8' | 127°30.1' | 8 | 35 | 57 | |
| 51 | BV | 55°15.1' | 127°23.9' | 5 | 36 | 59 | |
| 53 | BV | 55°16.4' | 127°29.9' | 2 | 34 | 64 | |
| 54 | USV | 55°20.6' | 127°42.0' | 9 | 57 | 30 | 4 |
| 55 | USV | 55°20.5' | 127°36.9' | 26 | 32 | 42 | |
| 57 | USV | 55°17.3' | 127°41.8' | 39 | 31 | 30 | |
| 58 | USV | 55°16.7' | 127°37.0' | 1 | 37 | 62 | |
| 60 | USV | 55°15.2' | 127°39.7' | 44 | 31 | 25 | |
| 62 | USV | 55°13.7' | 127°47.0' | 32 | 26 | 42 | |
| 64 | USV | 55°11.6' | 127°42.0' | 20 | 41 | 39 | |
| 67 | USV | 55°09.4' | 127°45.4' | 10 | 29 | 29 | 32 |
| 68 | USV | 55°07.7' | 127°57.0' | 12 | 45 | 43 | |
| 69 | USV | 55°07.6' | 127°50.9' | 15 | 35 | 50 | |
| 70 | USV | 55°05.7' | 127°48.5' | 37 | 29 | 27 | 7 |
| 71 | USV | 55°05.0' | 127°53.4' | 29 | 39 | 32 | |
| 72 | USV | 55°05.0' | 127°59.0' | 31 | 29 | 40 | |
| 73 | MSV | 55°06.1' | 128°08.6' | 22 | 38 | 40 | |
| 74 | MSV | 54°59.2' | 128°19.4' | 29 | 28 | 43 | |
| 75 | MSV | 54°53.5' | 128°22.7' | 28 | 30 | 42 | |
| 76 | HL | 54°13.7' | 130°01.7' | 28 | | 72 | |
| 77 | HL | 54°17.5' | 130°20.8' | 21 | 15 | 64 | |
| 78 | HL | 54°18.6' | 130°16.0' | 29 | 20 | 45 | 6 |
| 79 | KKT | 54°03.2' | 128°37.0' | 43 | 30 | 27 | |
| 80 | KKT | 54°06.4' | 128°30.9' | 36 | 40 | 24 | |
| 82 | KKT | 54°09.8' | 128°43.5' | 37 | 43 | 20 | |
| 84 | KKT | 54°12.9' | 128°37.6' | 9 | 59 | 32 | |
| 90 | KKT | 54°17.8' | 128°28.9' | 17 | 54 | 29 | |
| 91 | KKT | 54°19.7' | 128°29.6' | 33 | 42 | 25 | |
| 94 | KKT | 54°24.2' | 128°35.7' | 41 | 39 | 20 | |
| 95 | KKT | 54°24.5' | 128°31.0' | 32 | 36 | 32 | |
| 99 | KKT | 54°32.7' | 128°33.8' | 8 | 63 | 29 | |
| 100 | KKT | 54°34.4' | 128°40.7' | 12 | 42 | 35 | 11[2] |
| 101 | KKT | 54°38.3' | 128°39.1' | 5 | 28 | 51 | 16 |
| 102 | KKT | 54°38.5' | 128°43.8' | 21 | 31 | 48 | |
| 104 | KKT | 54°42.6' | 128°49.9' | 38 | 42 | 20 | |
| 105 | KKT | 54°42.4' | 128°45.7' | 16 | 24 | 36 | 24[2] |
| 106 | KKT | 54°45.6' | 128°49.4' | 46 | 27 | 27 | |
| 107 | KKT | 54°46.2' | 128°45.8' | 6 | 41 | 53 | |
| 108 | KKT | 54°48.7' | 128°52.2' | 27 | 38 | 35 | |

Appendix 3 (cont.)

| Site Fig. 48 | Region[1] | Location lat. | long. | Kaolinite (%) | Chlorite (%) | Illite (%) | Montmorillonite (%) |
|---|---|---|---|---|---|---|---|
| Glaciomarine Sediments | | | | | | | |
| 109 | LSV | 54°28.5' | 128°45.5' | 26 | 36 | 38 | |
| 110 | LSV | 54°25.1' | 128°48.7' | 34 | 33 | 33 | |
| 112 | KKT | 54°14.9' | 128°39.5' | 23 | 43 | 34 | |
| 113 | KKT | 54°15.8' | 128°34.6' | 1 | 45[3] | 54 | |
| 114 | KKT | 54°19.7' | 128°35.9' | 8 | 64 | 28 | |
| 115 | KKT | 54°21.1' | 128°39.7' | 35 | 35 | 30 | |
| 116 | KKT | 54°22.2' | 128°35.9' | 29 | 34 | 37 | |
| 92 | KKT | 54°22.6' | 128°31.2' | 21 | 35[3] | 23 | 21 |
| 93 | KKT | 54°23.9' | 128°35.9' | 9 | 43[3] | 48 | |
| 95 | KKT | 54°24.6' | 128°31.1' | 44 | 25 | 31 | |
| 117 | KKT | 54°25.3' | 128°42.8' | 17 | 52 | 31 | |
| 97 | KKT | 54°26.5' | 128°28.6' | 28 | 38 | 34 | |
| 118 | KKT | 54°27.4' | 128°40.7' | 22 | 41[3] | 37 | |
| 119 | KKT | 54°32.2' | 128°37.8' | 4 | 45[3] | 51 | |
| 120 | KKT | 54°32.7' | 128°45.9' | 42 | 27 | 31 | |
| Glaciolacustrine Sediments | | | | | | | |
| 27[4] | BV | 54°56.5' | 127°18.7' | 43 | 28 | 29 | |
| 27[4] | BV | 54°56.5' | 127°18.7' | 43 | 33 | 24 | |
| 27[4] | BV | 54°56.5' | 127°18.7' | 5 | 36 | 59 | |
| 123 | BV | 55°00.6' | 127°19.8' | 45 | 25 | 30 | |
| 124 | BV | 55°12.8' | 127°24.4' | 40 | 31 | 29 | |
| 126 | KKT | 54°43.2' | 128°49.7' | 23 | 24 | 53 | |

Notes: Analyses by R.N. Delabio using x-ray diffraction techniques (unpublished Geological Survey of Canada X-Ray Laboratory report).

[1] BV = Bulkley Valley; USV = upper Skeena Valley (Kispiox-Kitwanga); MSV = middle Skeena Valley (Kitwanga-Terrace); LSV = lower Skeena Valley (Terrace-Tyee); HL = Hecate Lowland; KKT = Kitsumkalum-Kitimat trough

[2] Sepiolite

[3] Includes chlorite

[4] Three samples were collected from glaciolacustrine sediments at site 27: two from sediments below till (i.e., the first two sets of data) and one from sediments above till (the third set of data)

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