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QUATERNARY SEDIMENTS, COLUMBIA RIVER VALLEY, REVELSTOKE TO THE ROCKY MOUNTAIN TRENCH, BRITISH COLUMBIA

R.J. FULTON
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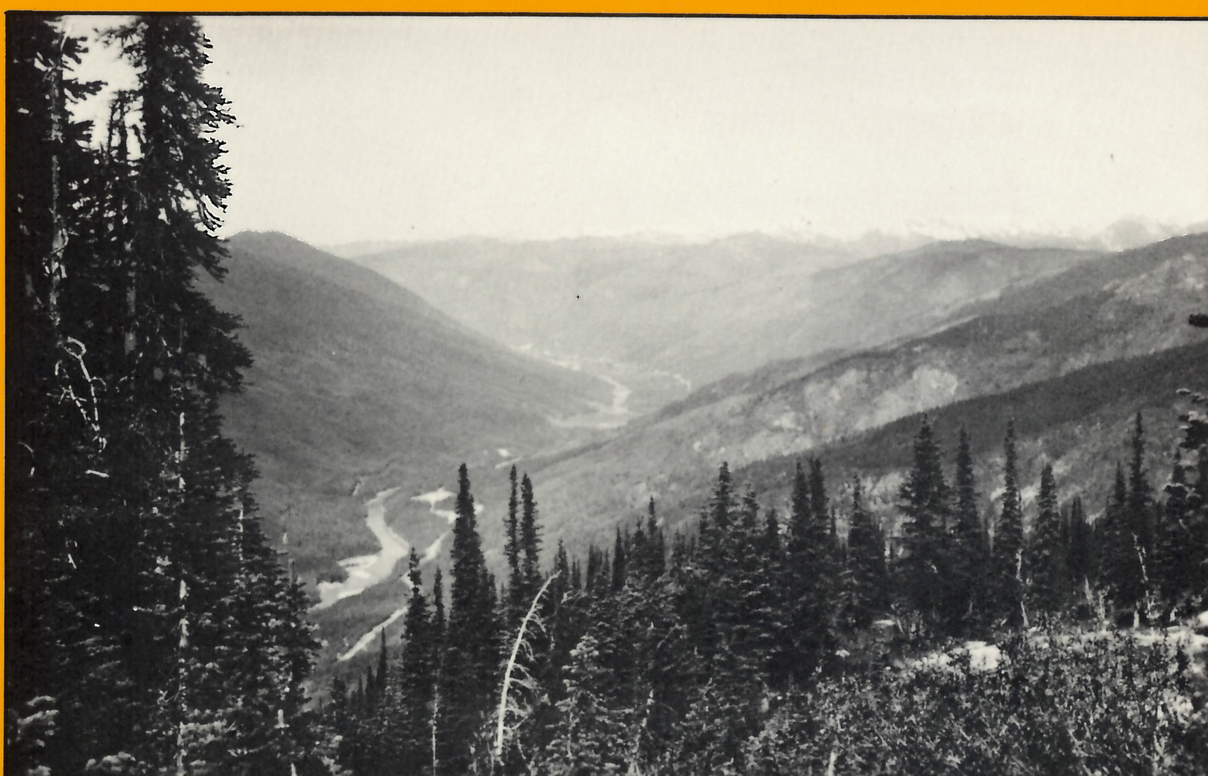

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Cover Illustration

Columbia River valley as seen looking north from Mount Revelstoke. The slopes of the valley are underlain by thin discontinuous glacial deposits and colluvium; the river channel in this reach is cut in a fill of glaciofluvial sediment up to 100 m thick. (GSC 202881-T)

Critical Reader

Dr. L.A. Dredge

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QUATERNARY SEDIMENTS, COLUMBIA RIVER VALLEY, REVELSTOKE TO THE ROCKY MOUNTAIN TRENCH, BRITISH COLUMBIA

Abstract

Columbia River valley between the Rocky Mountain Trench and Revelstoke is a large valley which separates the Monashee from the Selkirk mountains. It contains a succession of units which consists of remnants of pre-last glaciation valley fill, till of the last glaciation (Fraser Glaciation) plastered on the valley floor and walls, and late and postglacial sediments deposited on the valley floor.

The oldest Quaternary sediments are tills which were deposited before Olympia Interglaciation. These are overlain by nonglacial alluvial and lacustrine sediments deposited 25.2 to 21.5 ka and earlier. Fraser Glaciation ice completely covered the area and till and ice-contact stratified drift were deposited following 21.5 ka and before 10 ka. During deglaciation, lacustrine sediments were deposited in lakes caused by isostatic tilting and damming due to a plug of glaciofluvial sediment. Following deglaciation, aggradation occurred in the northern part of the valley and later degradation resulted in the formation of terraces up to 30 m above present river level. These events occurred before 6.6 ka and quasi-equilibrium conditions have prevailed since. In the southern part of the area, sandy alluvial deposits formed while the river was establishing a graded profile. Alluvial gravels sediments were laid down later.

Résumé

La vaste vallée du fleuve Columbia localisée entre le sillon des Rocheuses et Revelstoke sépare les monts Selkirk et Monashee. Elle contient une succession d'unités qui consistent en vestiges de dépôts de vallée de l'avant dernière glaciation, en till de la dernière glaciation (glaciation Fraser) recouvrant entièrement le fond et les versants et en sédiments de fond post-glaciaires et tardiglaciaires.

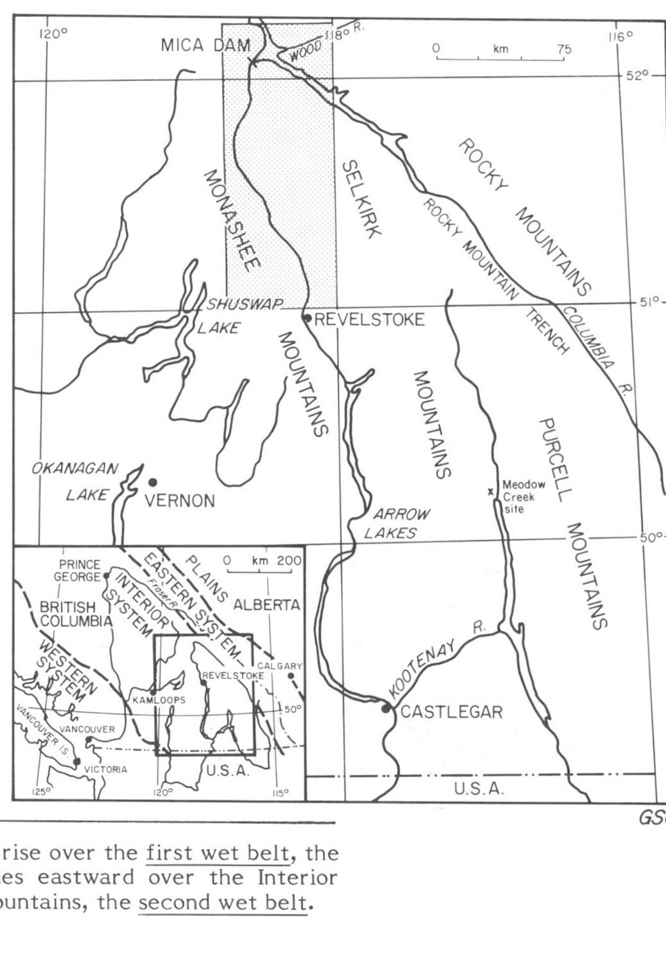
Les sédiments quaternaires les plus âgés sont les tills déposés avant l'interglaciaire Olympia. Ces sédiments ont été recouverts par des alluvions et par des dépôts lacustres datant de 25,2 à 21,5 ka et plus âgés. La glace de la glaciation Fraser a couvert complètement la région, dès lors, le till et les dépôts d'eaux de fonte glaciaires se sont déposés entre 21,5 ka et 10 ka. Au cours de la déglaciation, les sédiments lacustres se sont déposés dans des lacs formés à partir de mouvements de bascule isostatiques et d'endiguements dus à un bouchon constitué de sédiments fluvioglaciaires. À la suite de la déglaciation, l'alluvionnement est apparu dans la partie nord de la vallée, ce qui a donné lieu, plus tard, à des effets d'érosion aboutissant à la formation de terraces d'une hauteur allant jusqu'à 30 m par rapport au niveau actuel du fleuve. Ces évènements ont eu lieu avant 6,6 ka et un quasi équilibre s'est maintenu jusqu'à aujourd'hui. Dans la partie sud de la région, des alluvions sableuses se sont formées au moment où le fleuve a atteint un profil régularisé; par la suite, sont venues se superposer des alluvions plus grossières.

INTRODUCTION

The study area consists of a 160 km-long section of Columbia River valley between Revelstoke and the Rocky Mountain Trench (Fig. 1). The headwaters of Columbia River lie in the Rocky Mountain Trench at about 50°N; the river flows north for about 300 km to the mouth of Wood River where it turns 150° and flows back south through a relatively narrow valley separating the Monashee and Selkirk mountains. Monashee Mountains here are composed predominantly of metasedimentary gneiss and schist with local granitic and pegmatitic intrusions (Douglas et al., 1969, p. 425). Selkirk Mountains in this area consist predominantly of carbonaceous slate and phyllitic siltstone with minor intrusions and adjacent areas of high grade contact metamorphic rocks (Wheeler, 1965). Both mountain ranges are rugged, with relief of 1700 m within 4 km of the river and summits in the interior of the ranges reaching elevations of more than 3000 m. Several tributaries enter from the east side of the valley through dendritic patterned valleys; tributaries from the west, with the exception of Jordan River, occupy short, narrow, steep-gradient valleys (Fig. 2).

This part of the Interior System, the Columbia Mountains (Bostock, 1948) lies in the second wet belt[1] of British Columbia and is characterized by cool wet summers

Figure 1 (opposite). Regional and location maps; shaded area is shown in Figure 2.



GSC

[1] Eastward moving air masses are depleted of moisture as they rise over the first wet belt, the Coast Mountains. Moisture is picked up as the air continues eastward over the Interior Plateau and is removed again by passage over the Columbia Mountains, the second wet belt.

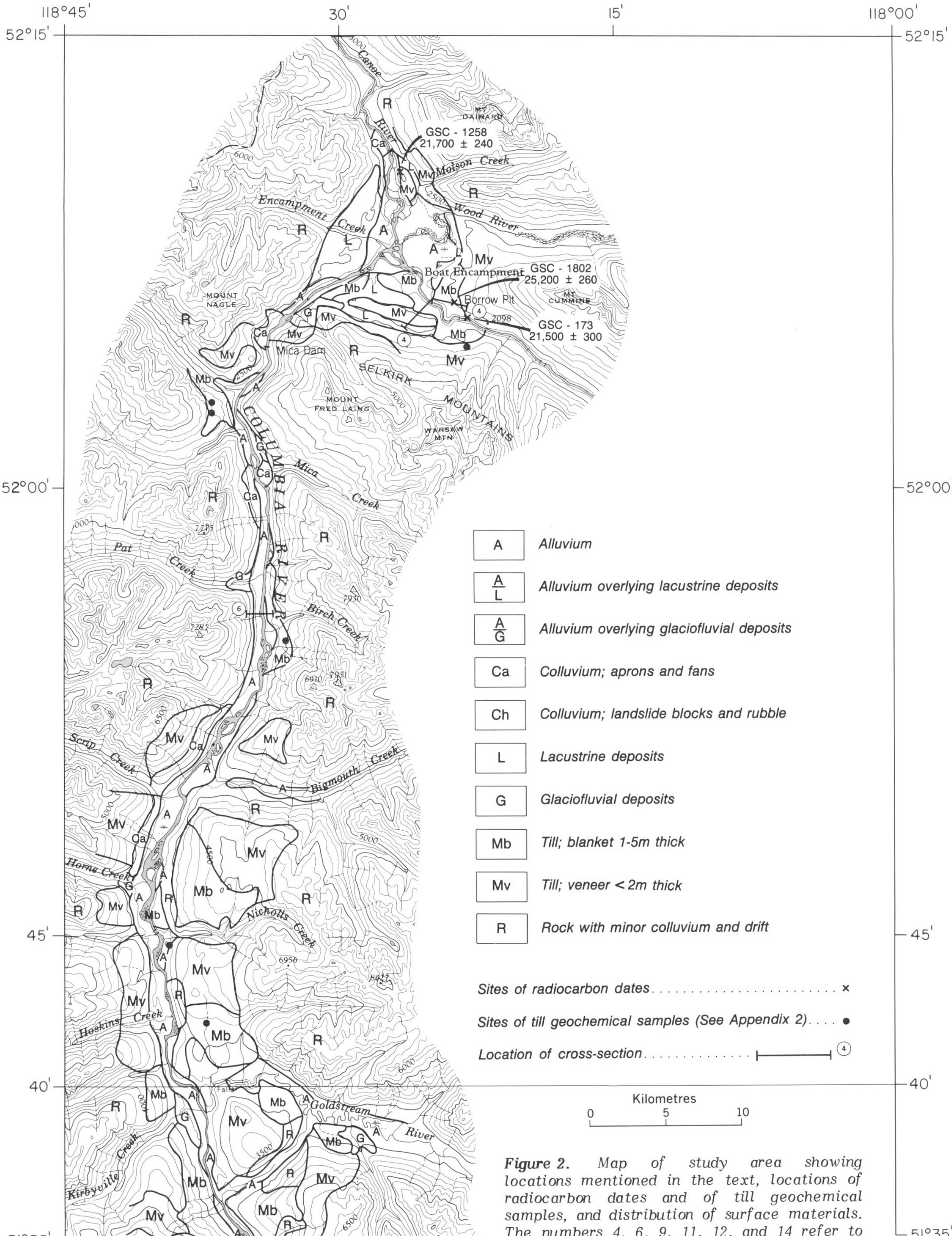


Figure 2. *Map of study area showing locations mentioned in the text, locations of radiocarbon dates and of till geochemical samples, and distribution of surface materials. The numbers 4, 6, 9, 11, 12, and 14 refer to figure numbers and indicate the locations of cross-sections.*

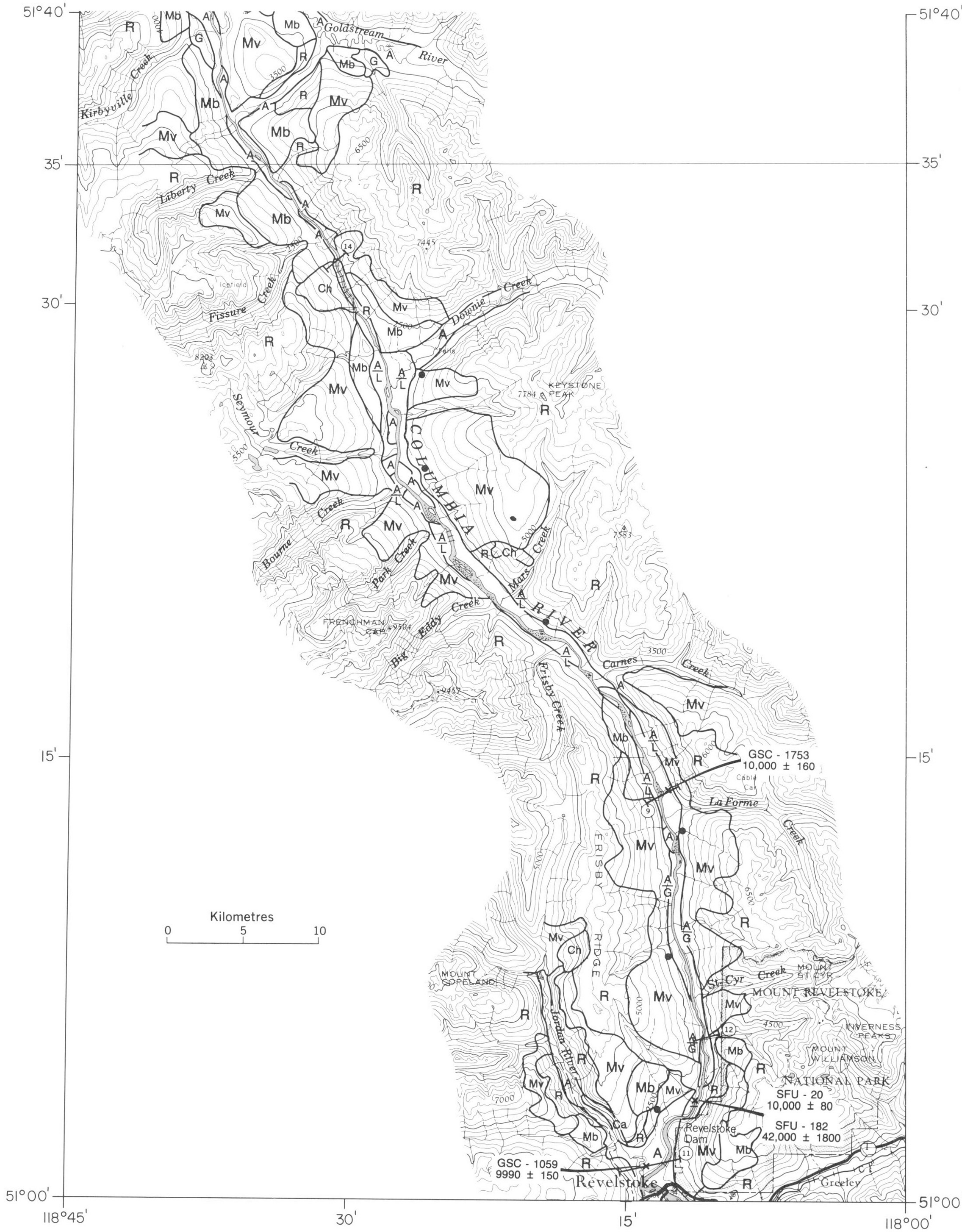

51°40'
35'
30'
15'
51°00'
118°45'
30'
15'
118°00'
Goldstream River
Kirbyville Creek
Liberty Creek
Fissure Creek
Downie Creek
Seymour Creek
Bourne Creek
Park Creek
Mars Creek
Big Eddy Creek
COLUMBIA RIVER
Carnes Creek
Frisby Creek
La Forme Creek
FRISBY RIDGE
St. Cyr Creek
Jordan River
KEYSTONE PEAK
FRENCHMAN CAP
MOUNT COPELAND
MOUNT ST CYR
MOUNT REVELSTOKE
INVERNESS PEAKS
MOUNT WILLIAMSON
NATIONAL PARK
Revelstoke Dam
Revelstoke
Greeley
Kilometres
0
5
10
GSC - 1753
10,000 ± 160
SFU - 20
10,000 ± 80
SFU - 182
42,000 ± 1800
GSC - 1059
9990 ± 150
GSC

Figure 2.

and winters. Under natural conditions the area was forested from the valley floor to treeline, which here lies between 1700 and 2000 m, and as a consequence exposures of Quaternary deposits were limited to a few river cutbanks. Logging during the past decade has, however, opened up the more accessible parts of the area and clearing in preparation for flooding by the Revelstoke Dam has accelerated erosion so that fresh exposures are common.

Information on Quaternary sediments for this segment of the valley cannot be readily displayed on a standard inventory map (scale 1:250 000 to 1:50 000). This is because of the small areal extent of most map units, access problems, and the difficulty of interpreting airphotos in heavily forested areas. In addition the narrow valley is occupied by a complex fill of pre-Fraser Glaciation sediments, Fraser glacial, ice-contact, and lacustrine deposits and postglacial alluvial, and colluvial sediments. The surface materials consist of modern alluvial and colluvial sediments so that standard presentation of map units would supply little information on the Quaternary succession. The emphasis in this report is on the stratigraphic subdivision of Quaternary sediments. Their horizontal distribution is discussed in a short section which describes the distribution of stratigraphic units in different segments of the valley and is portrayed by a highly generalized surficial materials map (Fig. 2). In discussing the Quaternary history of the area, the event terminology of Fulton and Smith (1978) is followed.

This report is based largely on field work by the senior author during 1972 with the assistance of D. Hall, data gathered during 1981 when clearing for the Revelstoke Dam reservoir was well advanced, and additional information from observations made by R.A. Achard during the summer of 1969. British Columbia Hydro provided unrestricted access to construction sites and consultants reports, supplied office and laboratory space at Mica Dam site to R.A. Achard, and permitted use of their radiocarbon dates.

STRATIGRAPHIC UNITS

Quaternary sediments of the study area are subdivided into five main stratigraphic units. These are referred to as: pre-Fraser (Glaciation) fill, till, glaciofluvial deposits, lacustrine deposits, and alluvium (Fig. 3).

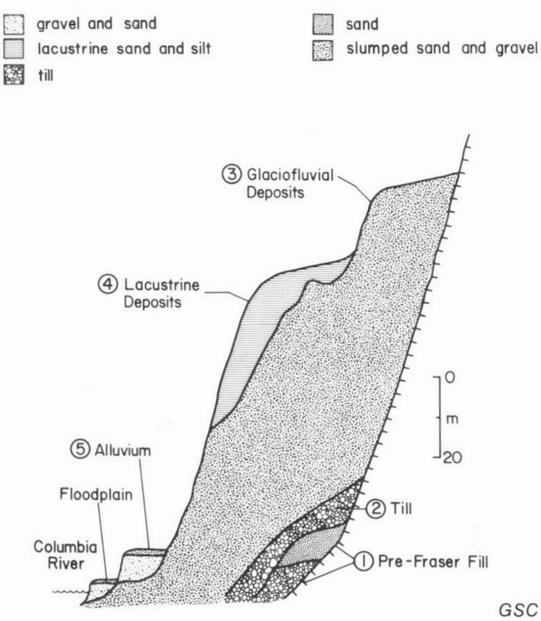


Figure 3. Standard Quaternary succession of Columbia River valley between Revelstoke and the Rocky Mountain Trench.

Pre-Fraser fill (1 of Fig. 3)

This unit consists of sand, gravel, silt, and till lying beneath the surface till or containing organic material dating older than 21 ka. Exposures of these materials have been recognized in only four areas: Rocky Mountain Trench north and south of Wood River, Mica Dam site, Columbia River valley between Birch and Mica creeks, and the site of the Revelstoke Dam (Fig. 2).

Pre-Fraser fill in the Rocky Mountain Trench (Fig. 4, 5) consists of at least three subunits. The oldest is a dark grey to olive silty, sandy, stony till at least 8 m thick, only exposed in the borrow pit for Mica Dam (Fig. 2), and is similar to the surface till of this area. The till is overlain by the second subunit, up to 7 m of sand and sandy silt with indistinct current bedding (apparently partly destroyed by bioturbation) containing lenses of gravel and abundant plant debris including roots, sticks, and logs up to 30 cm in diameter. One piece of wood identified as **Picea** sp. (unpublished Geological Survey of Canada Wood Identification Report 72-61 by L.D. Farley-Gill) was dated 25 200 ± 260 BP (GSC-1802, Lowdon and Blake, 1979, p. 20). Other pieces of wood were identified as **Populus balsamifera** based on

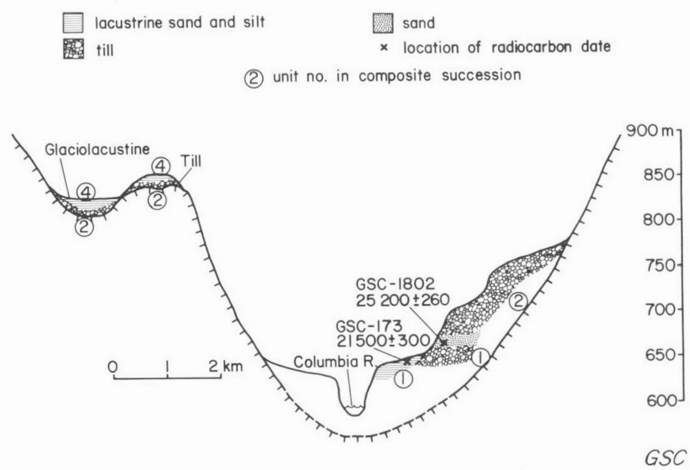


Figure 4. Generalized cross-section of Quaternary deposits in Columbia River valley south of the confluence of Columbia, Canoe, and Wood rivers.

Figure 5. Pre-Fraser fill exposed in Mica Dam borrow pit at the mouth of Wood River. Alluvial sediments containing wood (25 200 ± 260 BP, GSC-1802) underlie the surface till (Fraser Glaciation) and overlie a lower till of unknown age.

bark characteristics. This organic-rich alluvial deposit underlies about 30 m of till and was about 70 m above the level of Columbia River (Fig. 5). The third subunit consists of grey micaceous sandy silt and sand with parallel stratifications and ripple lamination. It contains small sticks and other plant detritus. Wood from this subunit was dated at 21 500 ± 300 BP (GSC-173, Dyck et al., 1965, p. 9). The micaceous sandy silt and sand unit was exposed in roadcuts adjacent to Columbia and Canoe rivers, 25-40 m lower than the floor of the Mica Dam borrow pit mentioned above. In places the unit is overlain by till but its relationship with the organic-rich unit exposed in the borrow pit is unknown.

Core trench excavations at the Mica Dam site exposed 18 m of "very dense" till which was overlain by 12 m of "heavily over consolidated" gravel, sand, silt, and clay which in turn was overlain by up to 15 m of silty fine to medium sand, river alluvium (Nasmith, 1972, p. 25). The overconsolidation of the gravel, sand, silt, and clay unit is thought to have resulted from the last glaciation. These overconsolidated sediments and the underlying "very dense" till are therefore considered to predate the last ice advance.

The pre-Fraser fill exposed between Birch and Mica creeks consists of at least 25 m of interbedded sand and gravel and 20 m of coarse gravel, overlain by up to 10 m of sandy till (Fig. 6). These materials underlie rounded, sloping benches north and south of the mouth of Birch Creek and elsewhere along the east wall of the valley. The lower unit of this fill consists of interbedded, well washed, and sorted sand and gravel with maximum clast size of about 10 cm. Clasts are largely subrounded to subangular, stratification is marked by abundant cut-and-fill structures, and there is no evidence of postdepositional disruption of bedding. The lower 4 m of the overlying unit consists of a layer of boulders with clasts as large as 1 m. Above this is approximately 15 m of variably sorted and washed bouldery gravel containing rounded to subrounded clasts up to 50 cm in diameter. There is little obvious stratification in this unit, but local sand lenses suggest that the bedding is subhorizontal. The contact with overlying till is graditional through about 4 m. No plant remains or other fossils were found in these two units.

According to H. Nasmith (Thurber Consultants Ltd., personal communication, 1981) there was 50 m of gravel and sand, which probably formed as advance outwash, at the site of the Revelstoke Dam. A piece of a log, radiocarbon dated at 42 000 ± 1800 BP (SFU-18a, Nelson and Hobson, 1982, p. 350), was obtained from near the base of gravel and sands

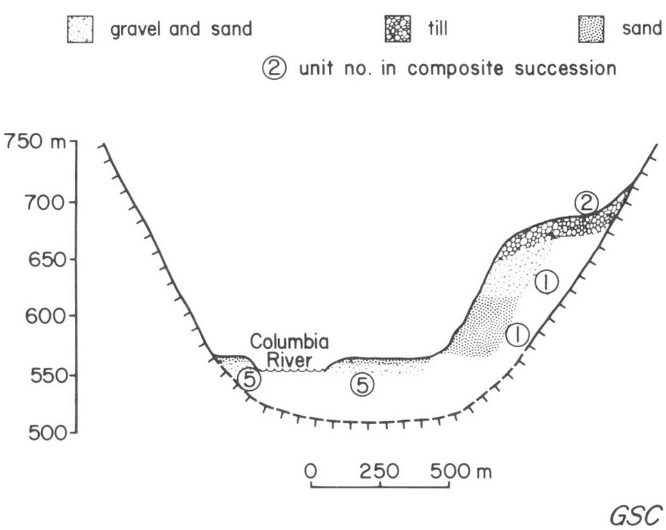


Figure 6. Generalized cross-section of Quaternary deposits found in Columbia River valley near Birch Creek.

in a buried channel at the damsite (H. Taylor, British Columbia Hydro, personal communication, 1983). The relationship between this gravel and that reported by Nasmith is unknown. Although till was not seen overlying stratified material in the excavations, if the observations and interpretations are correct, it is possible that two units of pre-Fraser fill occur in the Revelstoke area: a nonglacial alluvial fill in an old valley system and proglacial outwash.

The nonglacial sediments exposed in the borrow pit at the mouth of Wood River in the Rocky Mountain Trench are interpreted as overbank or floodbasin deposits of a large river. This is based on the relatively fine grain size, the presence but apparent later partial destruction of current structures, the high content of organic material which could not have been transported far, and the inclusion of lenses of gravel. These sediments suggest that nonglacial conditions prevailed in the area 25.2 ka ago and that the Rocky Mountain Trench was occupied by a river with a floodplain level 75 m above modern river level. The presence of younger, finer grained, horizontally stratified sediments adjacent to this site suggests that some incision took place after 25.2 ka and that ponding occurred by 21.5 ka. Possibly this ponding resulted when ice from one of the tributary valleys blocked drainage of the main valley or when isostatic downwarping and development of a forebulge in response to ice accumulation may have reduced the gradient of the main valley and caused general aggradation.

No direct correlation can be made between the pre-Fraser fill at Birch Creek and that at the mouth of Wood River. The coarse gravel at the top of the Birch Creek succession is similar in grain size to material on modern river bars in the area and it contains clasts of distinctive purple quartzite found only on the east side of the Rocky Mountain Trench. These suggest deposition by a river similar to the present Columbia at base levels up to at least 60 m above present river level. There is no modern analogue in the area for the finer grained alluvial fill at Birch Creek although it appears to be of nonglacial fluvial origin. Possibly it was deposited during a period of rapid aggradation rather than a period of relative stability or slow aggradation as is postulated for the present regime (R. Kellerhals, personal communication, 1966).

No evidence exists for correlating pre-Fraser deposits at Revelstoke Dam site with those farther north.

Till (2 of Fig. 3)

Till generally occurs in discontinuous patches and locally as a blanket above an elevation of about 550 m but is not common below 550 m. In most areas the till forms a discontinuous veneer but locally it forms benches up to 5 m thick. In several limited areas, such as north of the mouths of Downie Creek and Goldstream River, it occurs as a continuous blanket 3 m thick and south of the mouth of Wood River it occurs as a blanket up to 30 m thick.

The till matrix is dominantly sandy and silty (Fig. 7 and Appendix 1) and is especially sandy where ice overrode pre-Fraser sandy fill and especially silty adjacent to interbeds of fine grained, stratified sediments. Clast content is variable and although the till contains a number of large boulders, it is not particularly stony. Concentrations of 13 trace elements were determined for 20 samples (Appendix 2) and provide preliminary data on the geochemistry of till in this area.

Most till, apart from the pre-Fraser deposits described above, is assumed to have been deposited by the last glaciation. Fraser Glaciation till was deposited at the mouth of Wood River some time after 21.5 ka ago whereas ice had disappeared from the valley, at least as far north as La Forme Creek, by 10 ka (see *Lacustrine Deposits*).

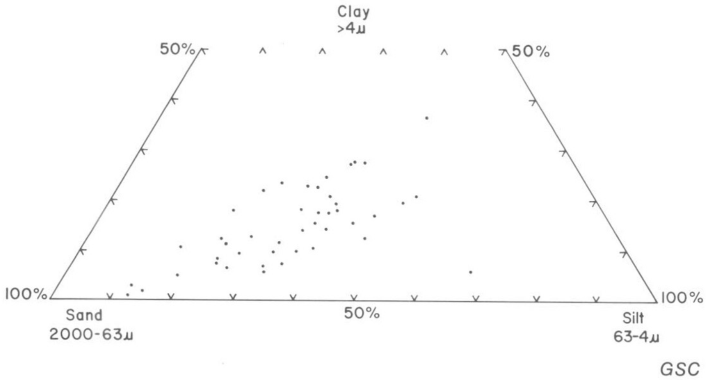


Figure 7. *Triangular diagram showing textures of Fraser Glaciation tills in Columbia River valley between Revelstoke and the Rocky Mountain Trench. Sample locations and analyses are listed in Appendix 1.*

Figure 8. *Glaciofluvial deposits and alluvium in an exposure on the west side of Columbia River about 7 km north of Revelstoke Dam site. Contorted sand of glaciofluvial origin is overlain by channel gravel and overbank silt which underlie a river terrace. Overbank sand is about 2 m thick.*

Glaciofluvial deposits (3 of Fig. 3)

This unit consists of up to 100 m of sand and minor gravel with disrupted bedding, and of sand and gravel benches along the valley walls and at the mouths of tributary valleys. It is most prominent between Revelstoke Dam and La Forme Creek (Fig. 2) but benches or terraces in other parts of the valley and scattered exposures of slumped sand and gravel may also belong to this unit.

Sand is the dominant facies of this unit, varying from fine to coarse grained and occurring in massive beds up to 2 m thick, or as ripple and horizontally laminated units. In many areas stratification is offset by small faults and contorted in such a way as to suggest slumping towards the centre of the valley (Fig. 8). Gravel is a minor component and occurs as discontinuous stringers, as massive "dump bedded" lenses, and as contorted infolded masses. In several places highly contorted units are overlain by less deformed units and both units further deformed by faulting. These unconformities suggest that periods of slumping and deformation were followed by stability and further deposition before subsequent slumping occurred. In all exposures the base of the unit was either covered or the unit extended below river level. The top of the unit is, in most places, overlain by alluvial deposits.

The valley fill of glaciofluvial deposits is considered to be sand and gravel which were deposited on a tongue of ice. The presence of unconformities in the deposit suggests that there was not a single period of deposition followed by melting of buried ice but that sedimentation continued as the ice melted. The top of this unit does not reach the same elevation in all parts of this segment of the valley. Possibly this variation is related to proximity to sediment sources or possibly to variations in thickness of buried ice. The occurrence of this unit as paired terraces, however, does suggest that the fill originally extended from one side of the valley to the other.

Benches of gravel and delta terraces are locally associated with and occur at higher elevations than the fill described above and are also found in other segments of the valley. The benches consist of well stratified gravel and sand and show little evidence of disruption of stratification. Despite this, their position on the valley wall above the ice-contact valley fill indicates that they are kame terraces. In the segment of the valley occupied by glaciofluvial valley fill they may have formed marginal to ice in the valley before the ice receded to the point where the tongue was completely buried by glaciofluvial debris. It is also possible that these benches were contiguous with the glaciofluvial fill but with melting of the ice tongue in the centre of the valley, only marginal parts of the deposits, which were supported directly by the valley wall, remained in their original position. The high delta terraces consist of well washed, well sorted and well stratified gravel and sand. At the mouths of larger tributaries these deposits consist predominantly of fine to medium grained gravel and sand; coarser, more poorly sorted sediments are the dominant component at the mouths of smaller valleys. The delta terraces probably bear the same relationship to the glaciofluvial valley fill as do the kame terraces.

Nothing has been found which would directly date the glaciofluvial valley fill or the sand and gravel benches but they are late glacial and stratigraphically underlie lacustrine deposits which contain organic sediments that are 10 ka old (see below).

Lacustrine deposits (4 of Fig. 3)

Lacustrine deposits consist of fine to medium grained sand, silt, and silty sand, commonly with parallel, horizontal stratification. They may be in isolated exposures but form a continuous unit between La Forme Creek and Downie Creek Slide (Fig. 2), where as much as 30 m is exposed. In exposures near the valley wall, stratification generally consists of undisturbed laminations or rhythmites but near the centre of the valley considerable contortion and disruption occur. This could be due either to slumping during melting of buried ice blocks or more likely to flow of the relatively mobile materials towards the center of the valley as a result of erosion by the Columbia River. The top of this unit has been planed off by river erosion in the center of the valley and is overlain by up to 4 m of medium to coarse sandy alluvium. Near the valley wall, wedges of local rubble (colluvium) are interstratified with the lacustrine deposits and fans and aprons of colluvial and talus deposits lap onto the deposit surface. Locally, lenses of organic detritus have been found in this unit. At one site, north of La Forme Creek (Fig. 2, 9), wood collected from 8 m below the top of this unit gave a radiocarbon date of 10 000 ± 160 BP (GSC-1753, Lowdon and Blake, 1979, p. 20). A pocket of glaciolacustrine material was excavated from the site of the Revelstoke Dam. Wood from "green silty clay" at an elevation of 500 m was dated 10 000 ± 80 BP (SFU-20; H. Taylor, British Columbia Hydro, personal communication, 1983; Nelson and Hobson, 1982, p. 350).

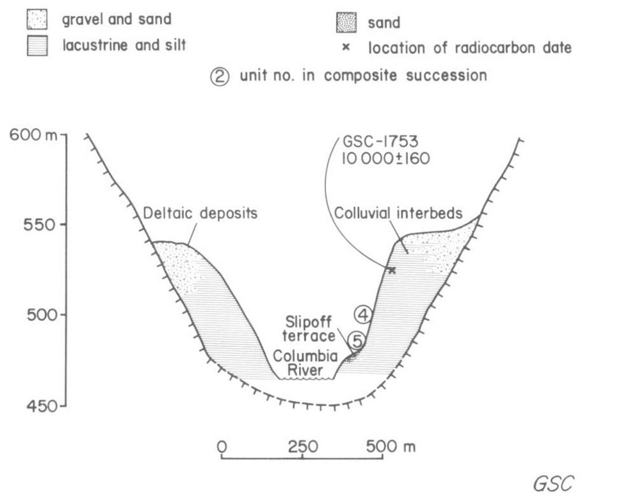


Figure 9. Generalized cross-section of Quaternary sediments occupying Columbia River Valley near La Forme Creek.

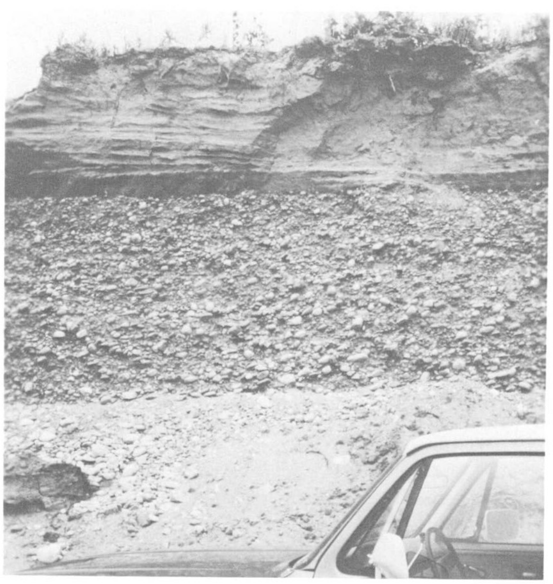


Figure 10. Gravelly alluvium underlying a terrace on the east side of Columbia River opposite the mouth of Bourne Creek. The lower unit consists of a pebble and cobble channel gravel, the upper of silty sand overbank material. GSC 203193-K

The actual extent of the lake is only poorly known, but lacustrine deposits between La Forme and Downie creeks extend up to elevations of about 550 m and similar sediments extend about 25 m higher in Downie Creek valley. A lake at this elevation would have extended at least from the Revelstoke Dam site north to Downie Creek Slide and east for 7 to 8 km up the valley of Downie Creek. A continuous terrace extending from the Downie Creek Slide to Bourne Creek is possibly a delta built into this lake by Columbia River. No evidence was found which requires the presence of glacier ice during deposition of the lacustrine deposits. Instead it appears that the lake owed its presence in part to the plug of glaciofluvial valley fill north of Revelstoke Dam site and in part to isostatic tilting.

Between La Forme Creek and Revelstoke Dam, the fill of glaciofluvial deposits reaches an elevation of 550 m. The water level north of this fill could only fall below this level as the river removed the dam of glaciofluvial deposits.

Alluvium (5 of Fig. 3)

Gravelly and sandy alluvium is common in Columbia River valley throughout the study area. These materials were deposited while the Columbia cut through the extensive pre-Holocene fill and achieved its present base level. The alluvium can be separated into two subunits: sandy alluvium and gravelly alluvium.

Sandy alluvium consists predominantly of coarse to medium grained micaceous sand. Ripple laminations are common and deposits commonly occur in graded beds, each apparently representing overbank deposition during a single flood. The alluvium is generally about 2 m thick but locally reaches 10 m. It is found on top of and inset into glaciofluvial and lacustrine units.

The gravelly alluvium consists predominantly of cobbly, well washed gravel with maximum clast size of 30 cm (Fig. 10). Stratification is not well marked but subhorizontal units with local areas of short planar crossbeds occur. The coarse sediment is in most places overlain by up to 2 m of silty, medium to fine grained overbank sand which locally shows ripple laminations but generally posses poorly developed parallel stratification. The thickest exposure of this subunit was 20 m. Gravelly alluvium is common near the valley floor north of La Forme Creek and is particularly well developed downstream from the mouths of tributaries. It was not possible to trace terrace levels throughout the system but 12, 25, and 30 m above river level were common positions for terraces. The sediment underlying the present floodplain (2-3 m above river level), and the sediments making up modern river bars have the same texture as the coarse facies of this deposit.

Fans at the mouths of many tributaries are graded to or built across terraces of gravelly alluvium. At the mouths of larger streams, fans generally are made of sandy gravel and have relatively low gradients; at the mouths of smaller tributaries they have steeper gradients and consist of poorly sorted bouldery sediment.

The sandy alluvial deposits are thought to have been formed during and shortly after emptying of the lake between Downie Creek Slide and La Forme Creek. At that time the southern segments of the valley contained an irregular fill of glacial and lacustrine deposits. Time would have been required for planing down high areas and filling in hollows before a graded profile capable of gravel transportation could have been established. The coarser, gravelly alluvium appears to have been deposited in the northern segments of the valley throughout postglacial time but farther south was deposited after Columbia River and its tributaries had re-established gradients capable of transporting coarse channel deposits.

The radiocarbon date mentioned above (GSC-1753, Lowdon and Blake, 1979, p. 20) indicates that alluvial deposition had not started before 10 ka in the segment of the valley between Downie and La Forme creeks. Mazama ash (6.6 ka, Lemke et al., 1975, p. 23) is locally present in floodplain overbank deposits within 3 m of present river level. This suggests that the coarse channel alluvium underlying the low terraces was deposited before the Mazama ash and that the level of the river has been relatively stable since that time. It also indicates that the river has been capable of flushing most of the sediments supplied to it through the system and into the Arrow Lakes for at least the past 6 ka.

REGIONAL SURFICIAL GEOLOGY

For ease of description, Columbia River valley between Revelstoke and Rocky Mountain Trench is subdivided into segments. Each segment is characterized by a broadly similar valley shape and each contains the same series of standard stratigraphic units (Fig. 3). A generalized representative cross-section has been drawn for each valley segment.

Revelstoke to Revelstoke Dam (Fig. 11)

This short, relatively broad segment of valley is the confluence area of the Jordan and Columbia rivers (Fig. 2). Till and rock slopes are dominant above 530 m; below this, gravel terraces and benches are dominant. Between 530 and 490 m the gravel underlying benches is relatively thin (a few metres) locally discontinuous, and the benches have been cut in lacustrine deposits. Below 490 m, only alluvial materials were seen in available exposures. The alluvial deposits consist mainly of coarse cobble gravel but in one cut on Jordan River, 4 m of coarse gravel overlies 16 m of interstratified sand and silt containing organic detritus (9900 ± 150 BP, GSC-1059, Lowdon and Blake, 1976, p. 12).

Revelstoke Dam to La Forme Creek (Fig. 12)

This segment of the valley is moderately narrow and the valley walls are not breached by major tributary valleys. Scattered kame terraces occur as high as elevation 665 m (215 m above river level). Above this level the bedrock valley wall has a patchy veneer of till with several restricted areas blanketed by several metres of till; constructional benches of till are present in two or three places. Discontinuous kame terraces are present at several levels between 665 and 550 m. Below 550 m the valley is largely occupied by glaciofluvial valley fill (unit 3 of Fig. 3) and the trench cut in this fill by the postglacial Columbia River (Fig. 13). Glaciofluvial deposits extend below present river level and locally are overlain by thin alluvial deposits.

La Forme Creek to Downie Creek Slide (Fig. 9)

La Forme Creek occupies the first large tributary valley north of Revelstoke. The size or shape of Columbia River valley changes little between La Forme Creek and the next main tributary valley (Carnes Creek), but between this point and Downie Creek Slide, the valley broadens and valley wall slopes become more gentle.

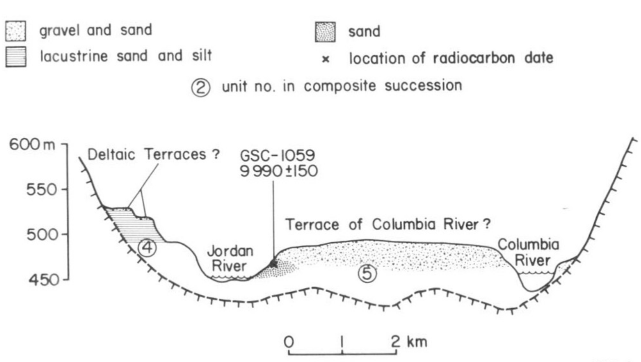


Figure 11. Generalized cross-section of Quaternary sediments occupying Columbia River valley near the mouth of Jordan River.

Above elevations of 550 m patchy till and scattered till benches occur. Below this elevation lacustrine deposits (unit 4 of Fig. 3) are the main unconsolidated materials but in many areas are masked by alluvial and colluvial deposits several metres thick. Alluvial terraces are prominent north of Carnes Creek, and continuous terraces north of Bourne Creek are considered to be remnants of deltas formed where Columbia River emptied into the lake in which the lacustrine deposits were laid down. Wood from the lacustrine sediments north of La Forme Creek has been radiocarbon dated 10 000 ± 160 BP (GSC-1753, Lowdon and Blake, 1979, p. 20) indicating that the lake was still present in the area at that time.

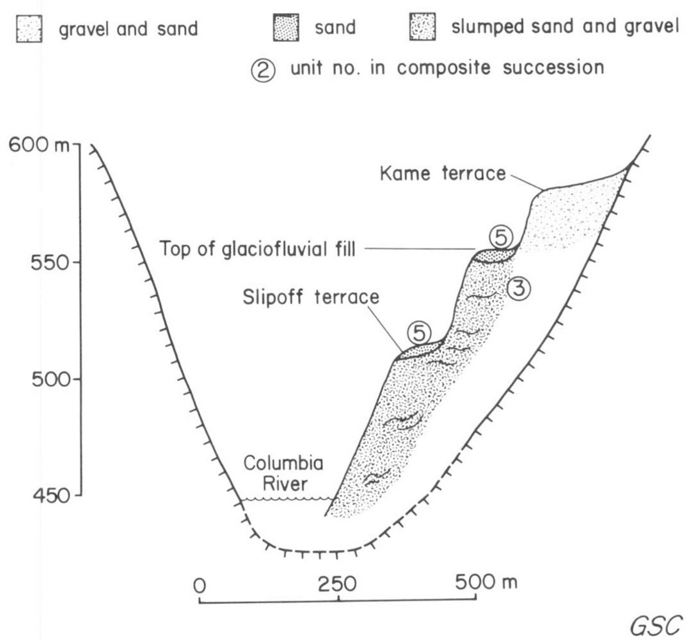


Figure 12. Generalized cross-section of Quaternary sediments occupying Columbia River valley near the mouth of St. Cyr Creek.

Figure 13. Fill of glaciofluvial deposits, west side of Columbia River about 7 km north of Revelstoke Dam. The glaciofluvial fill underlies terraces cut by the Columbia River and a raised fan built at the mouth of a local tributary valley. GSC 203193-M

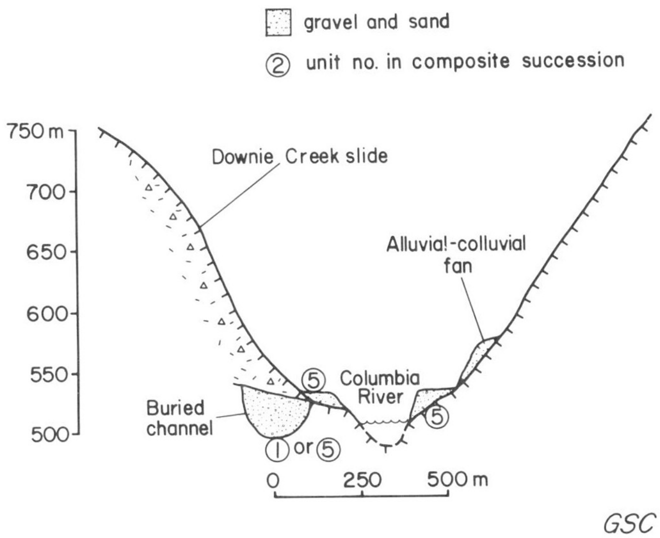


Figure 14. Generalized cross-section of Quaternary sediments occupying Columbia River valley at the upstream toe of Downie Creek Slide.

Downie Creek Slide to Nicholls Creek (Fig. 14)

Downie Creek Slide, a 1.5×10^9 m^3 rock slide (Brown and Psutka, 1980) on the west bank of the Columbia immediately north of Downie Creek (Fig. 2), pushes Columbia River towards its east bank and closes off the southern part of this valley segment. At the slide, Columbia River has cut a 200 m-deep canyon. North of the slide, the valley widens, valley walls are comparatively gentle and from Goldstream River north the Columbia occupies an inner trench excavated in the bottom of a broad valley. Possibly the valley is broad in this area because it is cut in relatively soft phyllites and schists (Wheeler, 1965).

In contrast with the valley segments to the south, this section of valley does not contain an extensive valley fill. The inner valley contains local alluvial and colluvial deposits and pockets of horizontally laminated sand and silt; the outer valley contains a relatively continuous blanket of till and scattered glaciofluvial sediments. Fans occur at the mouths of large streams and local terraces extend from these along the main valley. An extensive valley fill may be absent from this segment of valley because late glacial processes were not concentrated in a single narrow valley.

Little is known about the timing of the Downie Creek Slide. Slide movement does not appear to have occurred during a single failure but to have been progressive, occurred in pulses, or to have taken place in different sectors at different times. It is generally assumed that initial movement occurred 9-10 ka ago (Imrie and Bourne, 1981, p. 368) and certain parts of the slide are still active today (Nasmith, 1972, p. 22). During investigations, a channel, filled with gravel and sand, was discovered underlying the toe of the Downie Creek Slide (Brown and Psutka, 1980, p. 690; Fig. 14). This is probably a postglacial feature but it might be older.

Nicholls Creek to Mica Dam (Fig. 6)

From Nicholls Creek to Bigmouth Creek Columbia River valley remains broad but in contrast with the segment to the south, there is no well marked inner valley. North of Bigmouth Creek the valley narrows and valley walls become steeper.

Glacial sediments are not abundant in this segment of valley although a till blanket is locally present on the lower slopes and high fans at the mouths of some creeks may be kame-delta deposits. Alluvial terraces, however, are abundant and extend throughout this segment of the valley. These consist of bouldery gravel up to 20 m thick and are generally best developed immediately downstream from major tributaries.

From the mouth of Birch Creek north for several kilometres, sand and gravel underlie till along the east valley wall. The subtill sediments are as much as 50 m thick and consist of sand and gravel overlain by bouldery gravel. The bouldery gravel is similar to material seen on the modern bars of Columbia River; the underlying finer sediment does not have a modern analogue in the area. Isolated exposures of similar sediment north of the Birch Creek site suggest that this is a remnant of what was once an extensive valley fill.

Mica Dam to Rocky Mountain Trench (Fig. 4)

At the Mica Dam site and for several kilometres to the north, the valley is narrow and steep walled; north of this constriction the valley widens as the Rocky Mountain Trench is approached. Prior to dam construction the valley bottom was occupied largely by the Columbia River floodplain with scattered terrace remnants generally associated with fans built at the mouths of tributary valleys. Kame terraces are present at the mouths of several tributary valleys and a blanket of late glacial lacustrine sediments (up to elevations of 730 m) is present where Columbia River leaves the Rocky Mountain Trench. Sediments yielding wood dated at between 21.5 and 25.2 ka (GSC-173, 21 500 ± 300 BP, Dyck et al., 1965, p. 9; GSC-1258, 21 700 ± 240 BP, Lowdon et al., 1971, p. 294; I-773, 22 900 ± 1500 BP, Trautman and Willis, 1966, p. 175; and GSC-1802, 25 200 ± 260 BP, Lowdon and Blake, 1979, p. 20) were exposed in the vicinity of the confluence of the Columbia, Wood, and Canoe rivers prior to flooding by Mica Dam. Heavily overconsolidated silt and clay and sand overlying till (Nasmith, 1972, p. 25), exposed in the core trench for the Mica Dam, suggest that a pre-last glaciation valley, filled with older till and sediments may locally underlie the modern river channel.

QUATERNARY HISTORY

Early valley development

Most of this segment of Columbia River valley lies along the Columbia River Fault Zone (Read and Brown, 1981). The youngest rocks in which the valley is eroded are the Lardeau Group which is early Cambrian and younger (Wheeler, 1965). The prime structural elements of the area (Monashee Complex and Selkirk allochthon) were moved into their present positions before the end of the Jurassic, but there is evidence of Tertiary uplift and normal faulting. Eocene resetting of K-Ar dates implies anomalous thermal activity, rapid uplift, and accelerated erosion (Brown and Read, 1983, p. 167). Consequently it appears likely that development of a valley at this site may date back to Eocene.

The oldest Quaternary sediments occupying this part of the valley are a "very dense" till and overlying "over consolidated" silt and clay exposed at the Mica Dam site (Nasmith, 1972, p. 25). Although the age of these sediments is unknown, the till could correlate with the lower till exposed in the Mica Dam borrow pit, and the overlying stratified sediments with the deposits of Olympia Interglaciation age also exposed in the borrow pit. The two could equally well be older. The presence of pre-Fraser deposits indicates that Fraser Glaciation erosion was not vigorous enough to remove all pre-existing sediments and that much of the glacial erosion of the valley floor dates back to earlier glaciations.

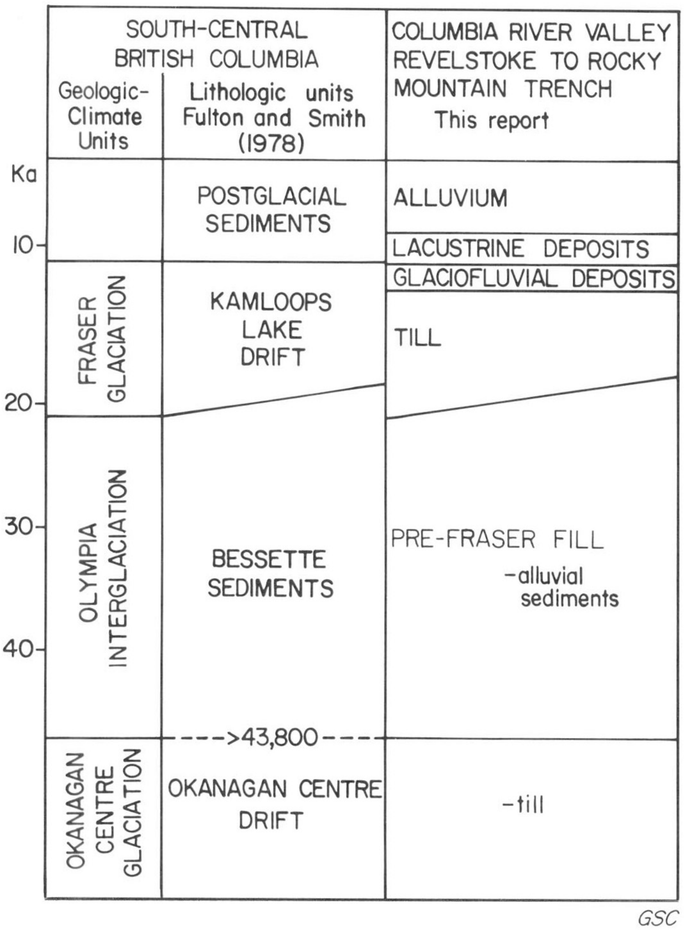


Figure 15. *Quaternary stratigraphic terminology used in the Southern Interior of British Columbia (Fulton and Smith, 1978) and units found in the study area.*

Olympia Interglaciation

The 42 ka age on wood from the Revelstoke Dam site indicates that at least part of the area was ice free and capable of supporting trees at that time. This agrees with conclusions based on evidence from the Meadow Creek site, 120 km southeast of Revelstoke (Fig. 1; Fulton, 1968).

The organic-rich floodplain sediments overlying the lower till in the Mica Dam borrow pit are 25.2-21.5 ka old and indicate that this area was not buried by ice during at least part of the Olympia Interglaciation (originally defined by Armstrong et al., 1965, p. 324; Fig. 15).

A river occupied the valley bottom 25.2 ka ago, and the level of the floodplain was about 75 m above the present river level. What little is known about the paleoenvironment at this time suggests that some of the trees growing in the area were similar to those in the area at present. At the time of deposition of the upper gravels of the subtill sediments near Birch Creek, a river comparable in size to the present Columbia and with a floodplain 60 m higher, occupied the valley between Birch Creek and the Rocky Mountain Trench. This might have been the same river that deposited the floodplain sediments 25.2 ka in the Rocky Mountain Trench.

The lacustrine sediments, dated as young as 21 500 ± 300 BP (GSC-173, Dyck et al., 1965, p. 9), at the mouth of Wood River, suggest blockage of Columbia River drainage or a decrease in valley gradient at about that time. It is logical to assume that this damming resulted from the growth of Fraser Glaciation ice and was caused by 1) an ice tongue blocking the valley, 2) glacially charged tributaries building alluvial fan-dams across the main valley, or 3) aggradation in response to isostatic downwarping caused by the advancing ice. The youngest age for pre-Fraser Glaciation sedimentation in the northern part of the study area is 21.5 ka.

Fraser Glaciation

During the Fraser Glaciation (defined by Armstrong et al., 1965, p. 326; Fig. 15) till was not deposited in the Rocky Mountain Trench at Wood River until after 21.5 ka. Fraser Glaciation till deposition had ended at least as far north as La Forme Creek before 10 ka. The 21.5 age is mentioned in the section above; 10 ka is the approximate age of late glacial lacustrine sediments north of La Forme Creek. These ages fit well with what is known about the timing of Fraser Glaciation in other parts of the southern Interior of British Columbia (Fulton, 1984).

Little data are available on the character of the glaciation in this part of British Columbia. It seems logical to assume, however, that with initial lowering of snowline, the alpine glaciers would have expanded into ice caps and engulfed the cores of mountain ranges. Eventually ice tongues would have coalesced to engulf the entire area, at which stage glacier flow would have become integrated into several ice streams moving southward along the trunk valleys. Although the maximum elevation of the Fraser Glaciation ice cover in this part of British Columbia is not known, Wilson et al. (1958) suggested that it was at least 2500 m. There are no lateral or end moraines, headless outwash trains, or other evidence that valleys tributary to the Columbia were occupied by upvalley retreating ice tongues during glacier recession. This suggests that snowline rose above the elevation of major accumulation areas during early deglaciation so that the ice stagnated instead of retreating back to the mountain source areas.

At the close of Fraser Glaciation, local ice-contact terraces were built at scattered localities throughout the valley and large volumes of glaciofluvial debris were deposited on the stagnant ice tongue in Columbia River valley between La Forme Creek and Revelstoke Dam. After ice had melted from the valley, the plug of glaciofluvial debris south of La Forme Creek played a prominent role in the later development of the valley.

Late glacial and postglacial Lakes

At the time when ice melted from the valley north of La Forme Creek, a regional lake occupied southern Columbia River valley (Fulton, 1975, p. 111). Sediment deposited in this lake reaches elevations of about 530 m at Revelstoke Dam, 550 m at Mars Creek, and 575 m at Downie Creek. Details of the extent, history, and origin of this regional lake are not known but it likely formed because of differential tilting between this section of the valley and the outlet at Castlegar, 200 km to the south (Fig. 1). It is possible that as the ice load disappeared from the area, the northern end of the basin rose relative to the southern and the level of the regional lake fell. A date of 10 000 ± 80 BP (SFU-20, H. Taylor, British Columbia Hydro, personal communication, 1983; Nelson and Hobson, 1982, p. 350) on wood in silty clay at an elevation of 500 m at the Revelstoke Dam site, indicates that the regional lake was at least this high at that time. A date of 9900 ± 150 BP (GSC-1059, Lowdon and Blake, 1976, p. 12) on wood from near the top of a deltaic sequence at an elevation of 450 m at the mouth of Jordan River, indicates that the regional lake was still above that level at that time.

Once the regional lake level had fallen below the level of the glaciofluvial fill north of Revelstoke Dam (about 550 m), this plug became a dam controlling the level of water in the basin north of La Forme Creek. Columbia River would have come into existence in this area at that time, flowing on top of the glaciofluvial fill, between the local lake north of La Forme Creek and the regional lake at Revelstoke. The level of the regional lake would have dropped steadily as the northern end of the basin rebounded but the lake north of La Forme Creek could only fall as quickly as Columbia River could remove the debris dam from a 17 km-long section of the valley.

The only date pertinent to the history of the local lake north of La Forme Creek is 10 000 ± 160 BP (GSC-1753, Lowdon et al., 1979, p. 20) on wood buried by at least 8 m of lacustrine sediment. This date indicates that Columbia River valley was ice free this far north by 10 ka, that the local lake level was above an elevation of 500 m at that time, and it remained above this elevation until after an additional 8 m of lake sediment had been deposited.

Postglacial alluvial history

Little detailed information pertinent to the alluvial history of Columbia River in the study area is available. A number of general conclusions however can be made based on the distribution and nature of alluvial deposits and shape of the postglacial valley.

The lack of well developed terraces or a floodplain in the segment of valley between Revelstoke Dam and La Forme Creek suggests that the postglacial history of this section of the valley has been characterized by nearly continuous downcutting. Prior to establishment of a graded river profile upstream from La Forme Creek, most of the sediment transported by the river in this area was eroded directly from the underlying glaciofluvial fill which consists dominantly of sand. Consequently alluvial deposits on high slipoff benches in this area are dominantly sand. After the lake upstream from La Forme Creek had drained, the river established a graded profile and transported coarser materials into the area and consequently alluvial deposits on the lower slipoff benches and underlying terraces consist predominantly of gravel.

During early postglacial development of Columbia River, while a lake occupied the valley between La Forme Creek and Downie Creek Slide, a delta was extended through a 10 km length of valley at the shallow northern end of this lake basin. During early stages of establishing a graded channel through the former lake basin, alluvial sediments consisted mainly of coarse sand. Once the river became established, it carried gravel into the area and consequently lower alluvial deposits consist of coarse gravel similar to what is currently being transported by the river. In the southern part of the lake basin, the river cut a channel without forming significant alluvial terraces; north of Mars Creek alluvial terraces at several levels occupy much of the valley bottom. This suggests that downcutting has been relatively continuous between La Forme and Mars creeks but that north of Mars Creek it might have occurred in pulses separated by periods of stability.

The constriction caused by Downie Creek Slide should have increased river downcutting downstream from the slide and decreased the gradient upstream. The slide has pushed the river against its east bank, created a series of rapids, and forced the river to cut a canyon up to 200 m deep. A detailed study of the effects of Downie Creek Slide on the alluvial history of the Columbia has not been made but it does not appear to have had a marked influence outside its immediate area.

The postglacial alluvial history of the segment of valley extending 25 km upstream from the Downie Creek Slide seems to have involved little deposition of floodplain materials. In this segment of valley the river occupies a trench up to 100 m deep developed mainly in rock; alluvial depsoits are restricted mainly to nonpaired terraces and terraced fans at the mouths of tributary valleys. Horizontally stratified sediments of possible lacustrine origin are exposed locally. These could have been deposited in local lakes formed as ice retreated or possibly in a lake or lakes dammed in the valley by Downie Creek Slide. As mentioned earlier, the toe of the slide does bury a channel of Columbia River but there is no evidence that movement of the slide had a signficant effect on the river gradient upstream.

Upstream from Goldstream River, thick alluvial deposits occupy most of the valley bottom. These are particularly prominent at and downstream from the mouths of major tributary valleys. Some of the deposits present may be glaciofluvial or kame terraces but most are alluvial deposits and underlie terraces less than 30 m above modern river level. Following deglaciation, the river established a graded channel through this part of the valley and the terraces at 30 m probably represent the level at which some measure of equilibrium was first achieved. This was followed by a period of gradual downcutting with terraces abandoned at several levels. The presence of Mazama ash on the modern floodplain indicates that this reach of the river has been in quasi-equilibrium for at least the past 6.6 ka.

CONCLUSIONS

The Quaternary sediments present in Columbia River valley between Revelstoke Dam and the Rocky Mountain Trench can be subdivided into five stratigraphic units, each representing a distinct phase in the Quaternary development of the valley:

1. Pre-Fraser fill – till and alluvial sediments deposited during Olympia Interglaciation and earlier.
2. Till – deposited during the Fraser Glaciation between 21.5 and 10.0 ka ago in this area.
3. Glaciofluvial deposits – sand and gravel deposited largely as ice-contact sediments during retreat of Fraser Glaciation ice.
4. Lacustrine deposits – horizontally laminated sand and silt deposited in lakes as Fraser Glaciation ice retreated from the area and nonglacial drainage was established.
5. Alluvium – sand and gravel underlying postglacial terraces and the present floodplain, deposited following retreat of Fraser Glaciation ice.

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APPENDIX 1

Mechanical Analyses of Tills

No	Location		% Sand	% Silt	% Clay
	Latitude	Longitude	2000-63μ	63-4μ	<4μ
1	51°06'00"	118°11'40"	68.3	23.2	8.5
2	51°00'10"	118°14'30"	83.9	14.3	1.8
3	51°10'20"	118°10'10"	64.3	26.1	9.6
4	51°05'50"	118°12'20"	45.4	37.4	17.2
5	51°05'10"	118°19'20"	58.6	31.7	9.7
6	51°16'10"	118°16'40"	51.1	34.7	14.2
7	51°25'00"	118°25'20"	51.6	38.0	10.4
8	51°42'30"	118°37'00"	27.0	66.9	6.1
9	51°03'00"	118°13'20"	37.0	35.9	27.1
10	51°03'00"	118°13'20"	34.0	38.4	27.6
11	51°03'00"	118°13'20"	36.6	36.1	27.3
12	51°03'00"	118°13'20"	41.8	33.4	24.8
13	51°03'00"	118°13'20"	46.0	31.0	23.0
14	51°03'00"	118°13'20"	48.4	35.9	15.7
15	51°08'10"	118°13'00"	19.6	43.9	36.5
16	51°12'20"	118°12'20"	54.5	35.5	10.0
17	51°19'30"	118°19'40"	62.1	32.1	5.8
18	51°24'40"	118°26'20"	47.0	38.6	14.4
19	51°27'40"	118°26'30"	43.1	37.4	19.5
20	51°27'40"	118°26'30"	58.1	34.6	7.3
21	51°42"40"	118°37'00"	42.0	45.4	12.6
22	51°42'40"	118°37'00"	31.9	48.6	19.5
23	51°42'40"	118°37'00"	29.2	50.0	20.8
24	51°44'50"	118°39'40"	46.9	35.5	17.6
25	51°55'00"	118°33'10"	72.1	17.0	10.9
26	52°03'00"	118°37'20"	60.7	21.2	18.1
27	52°02'40"	118°37'10"	67.6	25.7	6.7
28	52°04'40"	118°23'20"	54.0	24.1	21.9
E1	52°07'30"	118°28'50"	50.0	26.6	23.4
E2	52°07'30"	118°28'50"	49.5	38.5	18.0
E3	52°07'30"	118°28'50"	76.5	18.5	5.0
E4	52°07'30"	118°28'50"	65.7	22.0	12.3
9.1	52°06'30"	118°27'30"	38.0	45.0	17.0
9.2	52°06'30"	118°27'30"	60.5	26.8	12.7
9.3	52°06'30"	118°27'30"	65.5	23.0	11.5
9.4	52°06'30"	118°27'30"	85.0	12.0	3.0
P1	52°06'50"	118°28'30"	44.4	32.9	22.7
P2	52°06'50"	118°28'30"	69.0	23.5	7.5
P3	52°06'50"	118°28'30"	61.7	31.5	6.8
P4	52°06'50"	118°28'30"	85.5	12.5	2.0
W1	52°07'30"	118°22'10"	42.5	42.0	15.5
W2	52°07'30"	118°22'10"	43.3	35.8	20.9
W3	52°07'30"	118°22'10"	56.5	32.0	11.5
W4	52°07'30"	118°22'10"	49.6	32.3	18.1

APPENDIX 2

Trace Element Content of Tills*

SAMPLE NUMBER	Lat	Long	Cu ppm	Pb ppm	Zn ppm	Co ppm	Ni ppm	Ag ppm	Cr ppm	Mo ppm	Mn ppm	Fe %	Cd ppm	As ppm	Ufl ppm
9	51°03'00"	118°13'20"	58	39	158	27	58	<.1	108	2	1050	6.2	<.2	2	1.3
10	51°03'00"	118°03'00"	53	41	142	29	54	<.1	101	2	1010	6.2	<.2	3	1.4
11	51°03'00"	118°13'20"	59	55	172	27	56	<.1	108	2	1030	6.3	<.2	3	1.2
12	51°03'00"	118°13'20"	53	43	142	29	56	<.1	103	3	990	6.2	<.2	3	1.4
13	51°03'00"	118°13'20"	70	50	165	25	57	<.1	101	2	825	6.1	<.2	3	1.4
14	51°03'00"	118°13'20"	21	18	55	16	32	<.1	35	2	980	2.9	<.2	3	1.5
15	51°08'10"	118°13'00"	88	35	174	29	76	<.1	119	3	1065	7.2	<.2	9	2.0
16	51°12'20"	118°12'20"	57	22	130	26	32	<.1	51	2	1540	6.4	<.2	2	2.1
17	51°19'30"	118°19'40"	167	44	152	32	69	<.1	66	2	1430	6.4	<.2	8	3.3
18	51°24'40"	118°26'20"	112	40	198	26	102	0.2	92	2	735	7.3	<.2	17	1.4
19	51°27'40"	118°26'30"	172	33	189	26	41	0.2	40	3	1760	6.3	<.2	5	1.4
20	51°27'40"	118°26'30"	62	14	180	37	88	0.1	123	2	530	7.7	<.2	<2	0.7
21	51°42'40"	118°37'00"	132	40	167	33	134	0.2	77	2	845	8.8	<.2	10	0.7
22	51°42'40"	118°37'00"	44	26	99	26	57	<.1	59	3	815	5.4	<.2	3	5.3
23	51°42'40"	118°37'00"	46	21	99	31	70	0.1	70	2	850	5.7	<.2	4	2.4
24	51°44'50"	118°39'40"	145	25	176	29	154	0.1	75	3	915	6.8	<.2	3	0.5
25	51°55'00"	118°33'10"	128	22	142	23	73	<.1	101	3	570	5.7	<.2	7	1.9
26	52°03'00"	118°37'20"	154	21	200	31	64	<.1	114	2	670	8.1	<.2	<2	1.4
27	52°02'40"	118°37'10"	154	31	139	19	59	0.1	119	3	505	6.6	<.2	<2	3.0
28	52°04'40"	118°23'20"	216	57	202	33	66	0.1	55	3	1870	7.1	<.2	10	4.4
	Lower limit of detection		1	2	1	1	2	0.1	2	1	1	0.1	0.2	2	0.1

* Analyses were performed on the <2µ fraction which was obtained by centrifuging the silt-clay portion of the till matrix. All elements with the exception of arsenic and uranium were extracted by means of a hot LaFort aquaregia leach. Arsenic was extracted by means of a nitric acid perchloric leach, and uranium by a nitric acid leach. Element concentrations, with the exception of arsenic and uranium, were determined by atomic absorption. Arsenic concentrations were determined by colorimetric method, uranium by Fluorometric. Analyses were performed in the laboratories of Bondar-Clegg & Co. Ltd., 764 Belfast Road, Ottawa.