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POST-VASHON WISCONSIN GLACIATION, FRASER LOWLAND, BRITISH COLUMBIA

J.E. Armstrong

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PREFACE

The Fraser Lowland is an area of intensive economic development, centring on diversified agricultural and industrial activities. The mild climate and the geographical location of the Lowland make it a highly attractive residential area and one of continuing population growth.

A wide variety of materials, deposited during post-Vashon Wisconsin time, underlies the Lowland. This bulletin presents a detailed account of the post-Vashon glacial history of the Fraser Lowland, together with a description of the sediments deposited. There has been considerable controversy as to the origin of these deposits, and through his insight the author has been able to relate the distribution, stratigraphic history, and origin of the materials and to fit the different deposits into the geological history of the area.

Because the materials below the surface here are diverse and the distribution vertically and laterally is complex, an understanding of their genesis and distribution is desirable for man's efficient use of the land and conservation of the area. The report provides basic information for urban and rural land use planning, engineering and agricultural studies pertaining to soils, environmental studies, and groundwater investigations.

D.J. McLaren
Director General
Geological Survey of Canada

Ottawa, September 1978

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Abstract

The late Wisconsin Fraser Glaciation in southwestern British Columbia commenced on the mainland between 23 000 and 26 000 radiocarbon years ago and terminated about 11 000 radiocarbon years ago. It reached its climax during the Vashon Stade about 15 000 to 15 500 years ago when it extended south to 47°N. The Vashon ice was more than 1800 m thick in the Fraser Lowland, and the weight of the ice isostatically depressed the area at least 350 m and possibly 400 m or more.

Withdrawal of Vashon ice was rapid, and from about 13 000 to 11 000 years BP most of the Fraser Lowland was invaded by the sea. During this interval the eastern part of the Fraser Lowland was occupied by a piedmont glacier or glaciers that at various times retreated, were stationary, or surged forward. The glacier or glaciers terminated in the sea for much of their history, probably in a manner similar to the glaciers of the Yakutat Bay area of Alaska. Throughout the period glaciomarine sediments were formed largely from dropstones and debris deposited into seafloor muds by floating pieces of ice (including bergs). During surges and standstills drift was deposited in places above sea level and on the seafloor. The deposits laid down during the occupation of the sea comprise the Fort Langley Formation and the Capilano Sediments.

Isostatic, eustatic and tectonic adjustments between the withdrawal of Vashon ice and withdrawal of the sea were not uniform for the whole area; however, at least two major submergences separated by unusually rapid emergences are indicated. The final withdrawal of the sea and disappearance of floating ice in the eastern part of the Fraser Lowland coincided with a final surge of piedmont ice. The deposits laid down during this last stade have been called Sumas. This ice apparently began to advance about 11 400 years ago when sea level was at least 50 m higher than at present. The date at which Sumas ice disappeared is indefinite but was probably about 11 000 years ago, at which time the sea no longer occupied the area.

Résumé

Dans le sud-ouest de la Colombie-Britannique, la glaciation de Fraser, qui a eu lieu au Wisconsin supérieur, a commencé sur le continent il y a 23 000 à 26 000 ans (datation au radiocarbone), et s'est terminée il y a environ 11 000 ans (datation au radiocarbone). Elle a atteint son maximum pendant le stade Vashon il y a environ 15 000 à 15 500 ans, alors qu'elle avait avancé vers le sud jusqu'à 47°N. Les glaces du stade Vashon atteignaient une épaisseur de plus de 1800 m dans les basses-terres du Fraser, et du fait de leur poids, ont déprimé le sol d'au moins 350 m et peut-être même 400 m.

Les glaces du stade Vashon se sont rapidement retirées, et il y a environ 13 000 à 11 000 ans (BP), la majeure partie des basses-terres du Fraser a été envahie par la mer. Pendant cet intervalle, la partie est des basses-terres du Fraser a été occupée par un glacier ou plusieurs glaciers de piémont qui ont plusieurs fois reculé, stationné, avancé. Le ou les glaciers ont, pendant la plus grande partie de leur existence, abouti à la mer, probablement de la même façon que les glaciers de la baie de Yakutat en Alaska. Pendant cette période, les sédiments glaciomarins ont principalement été amenés par des floes (et des icebergs) qui ont laissé échapper des pierres et des débris sur les fonds marins vaseux. Pendant les crues et stationnements, du drift s'est déposé par endroits au-dessus du niveau de la mer, et sur le fond marin. Les sédiments déposés pendant la période marine ont créé la formation de Fort Langley et les sédiments de Capilano.

Les compensations isostatiques, eustatiques et tectoniques entre le retrait des glaces du stade Vashon et le recul de la mer n'ont pas été uniformes dans toute la région; mais on observe au moins deux grandes phases de transgression séparées par des régressions exceptionnellement rapides. Le retrait final de la mer et la disparition des glaces dérivantes dans l'est des basses-terres du Fraser correspondent à une dernière crue des glaces de piémont. Les sédiments déposés pendant ce dernier stade ont été appelés sédiments de Sumas. La glace a apparemment commencé à avancer il y a environ 11 400 ans, alors que le niveau de la mer était au moins 50 m plus haut que le niveau actuel. La date à laquelle les glaces de Sumas ont disparu n'est pas bien définie, mais on estime que leur disparition date d'environ 11 000 ans, et qu'à ce moment-là, la mer s'était déjà complètement retirée.

INTRODUCTION

The Fraser Lowland forms the southwest corner of the mainland of the Pacific Coast of Canada and the adjoining northwest corner of the continental United States. It is a triangular-shaped area of Quaternary depositional origin and relatively low relief with its apex 105 km east of the Strait of Georgia. It is bounded on the north by the Coast Mountains, on the southeast by the Cascade and Chuckanut mountains, and on the west by the Strait of Georgia. Both the Coast and Cascade mountains are major systems and have many peaks above 1800 m elevation. The Fraser Lowland has an area of approximately 3500 km^2, of which approximately 2600 km^2 is north of the Canada - United States Boundary.

The dominant geomorphological feature of the Fraser Lowland is Fraser River, which occupies a late glacial and postglacial valley up to 5 km wide and 225 m deep. This river terminates in a growing delta 31 km long and 24 km wide. North and south of Fraser River valley the Fraser Lowland consists mainly of flat-topped and gently rolling low hills separated by wide, flat-bottomed valleys. Most of the hills consist of unconsolidated deposits and do not exceed 155 m, although three bedrock hills exceed 300 m. The hills range in area from 3 to 400 km^2.

The Quaternary history of the Fraser Lowland is controlled by several major factors, which must continually be evaluated: (1) The area is surrounded by high mountain ranges on two sides and the sea on the third side. (2) During part of Quaternary time the Lowland was covered by the sea. (3) The glaciers at their maxima filled the Strait of Georgia. (4) The mean annual temperatures during advance and retreat and at the termini of the glaciers were probably only about 5°C cooler than at present, suggesting that the climates were cryoboreal during glaciations. (5) The area was tectonically active, including volcanism, throughout Quaternary time. (6) Ancestral (pre-Wisconsin) rivers flowed into and through the area. These may include a pre-Wisconsin Fraser River, although evidence of one is missing.

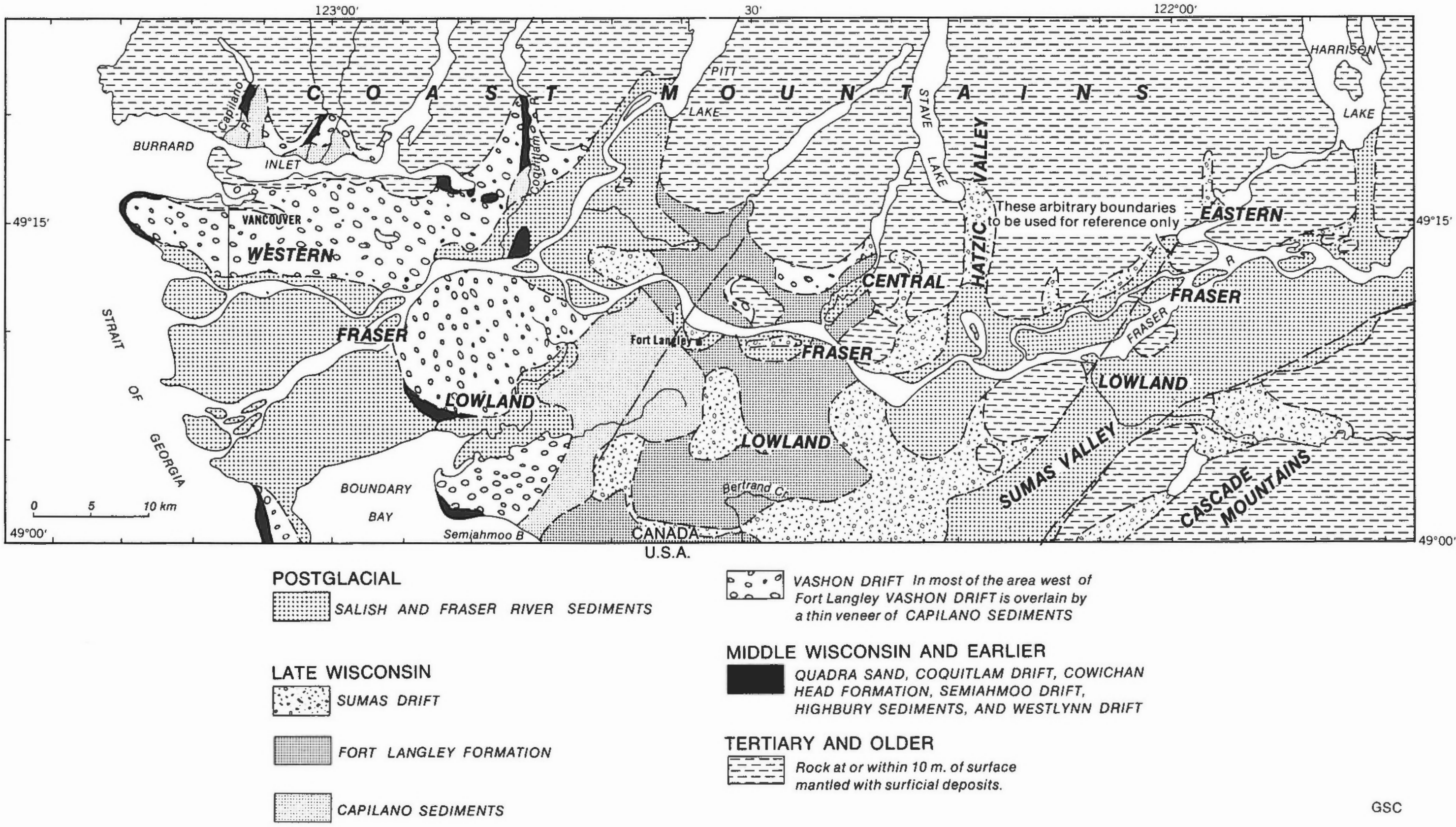


Figure 1. *Distribution of Quaternary deposits in the Fraser Lowland. (This map is compiled from information on surficial geology maps 1484A, 1485A, 1486A, and 1487A (Armstrong, 1980)).*

During Wisconsin and probably earlier time the Lowland was subjected to repeated glaciations separated by nonglacial intervals. Each major glaciation had three main stages: an advance stage characterized by coalescing piedmont glaciers; a maximum when the ice attained a thickness of 1800 m or more and overrode much of the adjoining mountainous areas; and a retreat or deglaciation stage when ice mainly occupied the valleys and arms of the sea once again and probably readvanced as surging glaciers. Each major glaciation was accompanied by isostatic, eustatic and probably tectonic adjustments, resulting in repeated relative sea level changes, each up to at least 200 m. As a result of this complex geological history thick (300 m plus) Quaternary deposits of widely diversified origin (Fig. 1), including marine, nonmarine and glacial, were laid down and a succession of landscapes was cut and buried.

The lithostratigraphic units identified in the Fraser Lowland are time transgressive and when the units are traced beyond the Fraser Lowland this time transgression is even more pronounced. The last major glaciation, the Fraser Glaciation, was defined as follows: "The last major glaciation during which the glaciers occupied the mountains and lowlands of southwestern British Columbia and western Washington is here named Fraser Glaciation from the Fraser Lowland of British Columbia where deposits attributed to this episode are typically exposed" (Armstrong et al., 1965). The Vashon Stade was defined as "the last major climatic episode during which drift was deposited by continental ice originating in the mountains of the mainland of British Columbia and occupying the lowlands of southwestern British Columbia and northwestern Washington. The Stade began with the advance of Cordilleran ice into these lowlands and ended with the beginning of marine and glaciomarine conditions within them" (Armstrong et al., 1965). Vashon Drift was deposited during the Vashon Stade.

This report deals primarily with post-Vashon deposits, particularly those included in the Fort Langley Formation and the Sumas Drift. Figure 1 shows the general surface distribution of Quaternary deposits, including Capilano Sediments, Fort Langley Formation and Sumas Drift (Armstrong, 1956, 1957, 1960a, b). For detailed maps of surficial geology see Armstrong (1980). Figure 2 shows the diachronous nature of the Quaternary deposits underlying the Fraser Lowland.

Fort Langley Formation

Fort Langley Formation consists of a thick succession of interbedded marine and glaciomarine sediments and of glacial drift. It is bounded by Vashon Drift at the bottom and Sumas Drift at the top. No one locality has been found in which all the units of the Fort Langley Formation, plus the bounding strata, may be observed. The variety of units and the bounding formations observed in stratigraphic sections are illustrated in Figures 3, 4, 5, 6 and 8. The name of the formation is derived from the village of Fort Langley on Fraser River, 2.5 km downstream from an outcrop on the south bank which has been designated the holostratotype (Figs. 3 and 6, sec. 1FL; Fig. 7).

The sediments comprising the Fort Langley Formation, which are more than 200 m thick in places, accumulated in the Fraser Lowland during the period of deglaciation that followed the maximum advance of Fraser ice as represented by Vashon Stade deposits (Vashon Drift). This deglaciation episode commenced with the invasion of the sea about 13 000 radiocarbon years ago and ended with the advance of Sumas ice less than 11 400 years ago (Fig. 2, Table 1). By the time Sumas ice had withdrawn completely from the area about 11 000 years BP, sea level was at or near the present level.

Table 1. Quaternary lithostratigraphic units in the Fraser Lowland

Lithostratigraphic Units (Mappable Units)	Probable Geologic-Climate Units and Radiocarbon Ages
FRASER RIVER SEDIMENTS Deltaic, distributary channel fill, and overbank deposits. Overlie postglacial estuarine and marine sediments in Fraser River delta.	POSTGLACIAL Present to 9000 years B.P.
SALISH SEDIMENTS Lowland and mountain stream sediments, lacustrine, eolian, colluvial, landslide, beach and bog deposits.	Present to 12 500 years B.P.
	FRASER GLACIATION (Late Wisconsin) 11 000-26 000 years B.P.
CAPILANO SEDIMENTS Raised deltas, intertidal and beach deposits, glaciomarine sediments. Found in the area west of Fort Langley beyond the area of Sumas Drift. Contain no recognized till diamictons.	Post-Vashon and Pre-Postglacial 11 000?-13 000 years B.P. the time interval covered by Sumas and Fort Langley units combined (see below)
SUMAS DRIFT Till, glaciofluvial, glaciolacustrine, and ice-contact deposits.	Sumas Stade 11 000?-14 000 years B.P.
FORT LANGLEY FORMATION Interbedded marine, glaciomarine, and glacial sediments. May include fluvial deposits. The glacial sediments consist of till diamictons, ice-contact deposits, and proglacial deltas.	Fort Langley Time Interval Probably represents more than one ice advance. Originally called Everson Interstade. 11 400-13 000 years B.P.
VASHON DRIFT At least three till diamictons, glaciofluvial and ice-contact deposits	Vashon Stade 13 000-18 000 years B.P.
QUADRA SAND Advance proglacial sediments of Fraser Glaciation, in part synchronous with, in part younger than, and in part older than Coquitlam Drift.	18 000-26 000 years B.P.
COQUITLAM DRIFT Till diamicton and till-like mixtures of possible glaciomarine origin.	Pre-Vashon Stade 19 000-23 000 years B.P. May be equivalent to Evans Creek Stade.
COWICHAN HEAD FORMATION Bog and swamp deposits interbedded with floodplain sediments overlying marine sediments.	OLYMPIA NONGLACIAL INTERVAL (Middle Wisconsin) 25 800-36 200 years B.P.
COWICHAN HEAD FORMATION (?) Organic colluvium, peat, silt, and sand.	40 200-<58 800 years B.P. (a minimum age)
SEMIAHMOO DRIFT At least two till diamictons, glaciomarine, glaciofluvial, and glaciolacustrine sediments.	MAJOR GLACIATION (Middle Wisconsin and earlier) >62 000 years B.P.
HIGHBURY SEDIMENTS Intertill fluvial, organic, and marine sediments.	MAJOR NONGLACIAL INTERVAL (pre-middle Wisconsin) Beyond the limit of radiocarbon dating
WESTLYNN DRIFT Till diamicton, glaciomarine, glaciofluvial, and glaciolacustrine sediments.	MAJOR GLACIATION (pre-Sangamon)

YEARS B.P. ($X10^3$) (scale varies)	TIME-STRATIGRAPHIC UNITS	GEOLOGIC-CLIMATE UNITS	RADIOCARBON DATES (years B.P.)	LITHOSTRATIGRAPHIC UNITS Deposited by ice flowing from N and E ←, N and W →	COMMENTS
5 10	HOLOCENE	POSTGLACIAL	Salish and Fraser River Sediments: more than forty dates from 12 350± 190 to 570± 100 Capilano Sediments: nine dates ranging from 12 800± 175 to 10 430± 150	SALISH SEDIMENTS AND FRASER RIVER SEDIMENTS SALISH SEDIMENTS	
11 12 13	LATE WISCONSIN	FRASER GLACIATION	Sumas Drift: six dates ranging from 11 700±150 to 11 300±100 Fort Langley Formation: five dates ranging from 12 900±170 to 11 680±180	CAPILANO SEDIMENTS ← SUMAS DRIFT ← FORT LANGLEY FORMATION	Capilano Sediments: glaciomarine and marine sediments deposited when the sea was at least 15m above present sea level. In contrast to similar sediments that comprise a large part of Fort Langley Formation, Capilano Sediments were not overridden by Sumas ice Sumas Drift: these glacial deposits are not overlain by glaciomarine or marine sediments Fort Langley Formation: records at least three local advances and retreats of a valley glacier into the sea
15 17			Vashon glaciolacustrine sediments: two dates 18 000±150 and 17 800±150	→ VASHON DRIFT	Includes at least three tills. Fluvial dissection occurred between deposition of Quadra Sand and Vashon Drift
18 20 26			Quadra Sand and Coquitlam Drift: three dates from Quadra Sand (?) ranging from 18 700±170 to 18 300±170 from sediments overlying Coquitlam Drift. Five dates from Coquitlam Drift ranging from 22 700± 320 to 21 600±200. Four dates from Quadra Sand ranging from 26 100±320 to 24 400±900	QUADRA SAND ← COQUITLAM DRIFT	Quadra proglacial deposits were formed during local advances and retreats, such as the Coquitlam, and during the main Vashon ice advance Coquitlam Drift: Coquitlam ice probably represents an advance and retreat that occurred in Coquitlam Valley before Vashon ice moved into the area
30 35 41	MIDDLE WISCONSIN	OLYMPIA NONGLACIAL INTERVAL	Fourteen dates ranging from 29 600±200 to 25 800±310. Five dates ranging from 36 200± 500 to 31 000±520 Two dates 40 500±1700 and 40 200±430. Three dates >39 000 to >36 800	COWICHAN HEAD FORMATION	Olympia nonglacial interval sediments consist of subaerial deposits marked by unconformities. One such unconformity, recognized at the Mary Hill gravel pit, separates sediments from 26 000 to 30 000 years old from sediments 40 000 years old
50 60 >62			One date at 58 800 $^{+2900}_{-2100}$ Five dates ranging from >37 000 to >43 000	COWICHAN HEAD FORMATION ?	Cowichan Head Formation? sediments are not seen in contact with sediments identified as Cowichan Head; however they appear to be part of the same lithostratigraphic unit
THE OLDEST UNITS PROBABLY ARE SEVERAL HUNDRED THOUSAND YEARS OLD	EARLY WISCONSIN AND PRE-WISCONSIN	SEMIAHMOO GLACIATION	Eight dates ranging from >31 000 to >62 000	→ SEMIAHMOO DRIFT	Believed to be Early Wisconsin. Includes at least two till units plus glaciofluvial and glaciomarine sediments. Semiahmoo Glaciation probably similar in complexity and duration to Fraser Glaciation
		HIGHBURY NONGLACIAL INTERVAL	Six dates ranging from >44 000 to >54 000	HIGHBURY SEDIMENTS	May be equivalent of Sangamon interglacial
		WESTLYNN GLACIATION	No dates have been obtained on materials known to be from this stratigraphic interval. Some of the above dates that are beyond the range of radiocarbon dating may be on materials that belong in this position	WESTLYNN DRIFT	Very poorly exposed. Westlynn Glaciation probably similar in complexity and duration to Fraser Glaciation
				OLDER SEDIMENTS	

Figure 2. *Quaternary stratigraphy, Fraser Lowland*

LATE WISCONSIN

POST-VASHON

SUMAS DRIFT

Sdi	*Diamictons, includes basal and flow tills*

FORT LANGLEY FORMATION

FLgm	*Glaciomarine sediments (poorly stratified);* a, *stony silty clay loam;* b, *silty clay loam with few stones;* c, *stony silty loam and silt, includes till-like mixtures with shear structures*
FLm	*Marine sediments (stratified); fine sand, silt, and clayey silt*
FLd	*Deltaic sediments (stratified), mostly proglacial;* a, *deltaic sandy gravel;* b, *deltaic gravelly sand and sand;* c, *silt, sand and gravel with ice collapse structures. Included are probably some nondeltaic fluvial deposits*
FLic	*Ice-contact deposits; sand and gravel with collapse structures and lenses of diamicton, probably flow tills*
FLdi	*Diamictons, basal and flow tills, and probably mudflows, all with a sandy loam matrix and characterized by clasts of glaciomarine sediments*

VASHON

VASHON DRIFT

V	*Glacial sediments;* Vt, *lodgment till;* Vgf, *glaciofluvial sand and gravel*

LOCATION OF SECTIONS

1FL South bank of Fraser River 2.5 km east of Fort Langley designated as the holostratotype, 49°09′50″ N, 122°32′10″ W

2FL Gravel pit in East Langley on 256th Street, 2.5 km south of Fraser River, 49°08′55″ N, 122°30′50″ W

3FL Roadcut on 272nd Street, 4 km south of Fraser River, 49°07′50″ N, 122°28′12″ W

4FL HMCS Aldergrove test hole on 272nd Street, 1.5 km north of Aldergrove (Halstead 1966), 49°04′20″ N, 122°28′15″ W

5FL Roadcut on 60th Avenue, 2 km east of 272nd Street, along Nathan Creek, 49°06′30″ N, 122°27′15″ W

6FL Bradner Road Hill (288th Street) south of Fraser River, 49°09′00″ N, 122°25′30″ W

7FL Roadcut north side of Bertrand Creek on 248th Street, 49°02′25″ N, 122°32′10″ W

8FL Boundary gravel pit, south end of 200th Street, 49°00′12″ N, 122°40′03″ W

9FL Gravel pit on south side Grant Hill, north of Fraser River, 49°10′35″ N, 122°31′45″ W

10FL Gravel pit 1.5 km north of Dewdney Trunk Road and 1.4 km east of 256th Street, 49°14′00″ N, 122°29′35″ W

11FL West side of Stave Lake, 0.5 km north of Dewdney Trunk Road, 49°13′50″ N, 122°21′20″ W

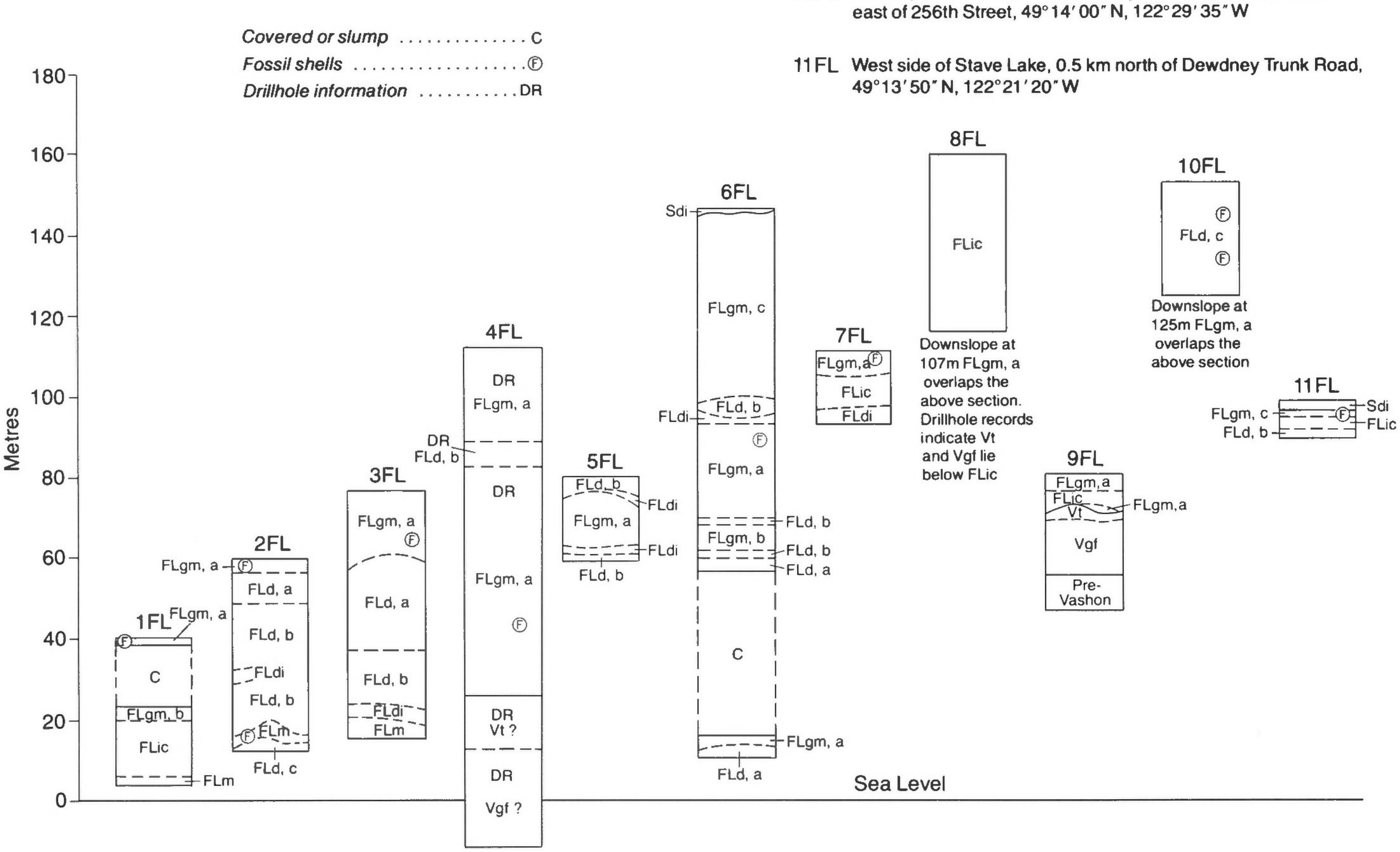


Figure 3. *Stratigraphic sections of Fort Langley Formation (see Fig. 7 for locations).*

Figure 4. *Fort Langley ice-contact delta, showing a fossiliferous silt and contorted gravel, exposed in section 10FL. GSC 202880-T*

Figure 5. *Fort Langley glaciomarine stony clayey silt, overlying Fort Langley glaciofluvial gravel exposed in section 7FL. GSC 202880-S*

Figure 6

Fort Langley till exposed in holostratotype, section 1FL. GSC 203193

The term 'glaciomarine sediments', rather than 'glaciomarine drift', is used for stony silty clay loam, silt loam and silt because the obviously ice-transported material they contain forms a relatively minor constituent, probably 5 per cent or less.

Many of the sediments comprising the Fort Langley Formation are stony to stoneless, fine-grained, glaciomarine and marine sediments. In places they are stratified, and some contain marine shells. Locally they appear to have been reshaped by tidewater glaciers and berg ice, destroying the original sedimentary structures and producing till-like mixtures. The marine and glaciomarine environment is the dominant characteristic of the Fort Langley Formation.

Stratigraphy. In the holostratotype section (Figs. 3 and 6, sec. 1FL) neither of the bounding formations may be observed; however, it does contain many of the units that characterize the formation. At this outcrop marine silty clay about 2 m thick is exposed at the base. This clay contains approximately one dropstone per cubic metre. Overlying the silty clay is about 15 m of ice-contact sediments. They consist of poorly sorted sandy gravel, lenses of sandy diamictons up to 3 m thick, and well stratified fine to medium sand. The diamictons, which are probaby flow tills, contain stones up to boulder size and clasts of stony glaciomarine silty loam up to more than 1 m in diameter. The gravel contains similar clasts of glaciomarine sediments. All the ice-contact deposits exhibit slump structures. At the top of the outcrop is approximately 2 m of fossiliferous glaciomarine silty clay loam with a few scattered stones.

The section exposed 2.5 km to the southeast (Fig. 3, sec. 2FL; Figs. 7, 8) has been designated as a parastratotype. Partly stratified marine silty clay with fossils also forms the base of this section. Overlying this unit is 35 m of sand grading upward into gravelly sand and sandy gravel. They form part of what is believed to be a proglacial delta formed in the sea. At the top of this section is 4 m of fossiliferous stony silt loam. A sandy diamicton with clasts of glaciomarine stony silt loam appears to overlie part of the deltaic sediments and may overlie all of them.

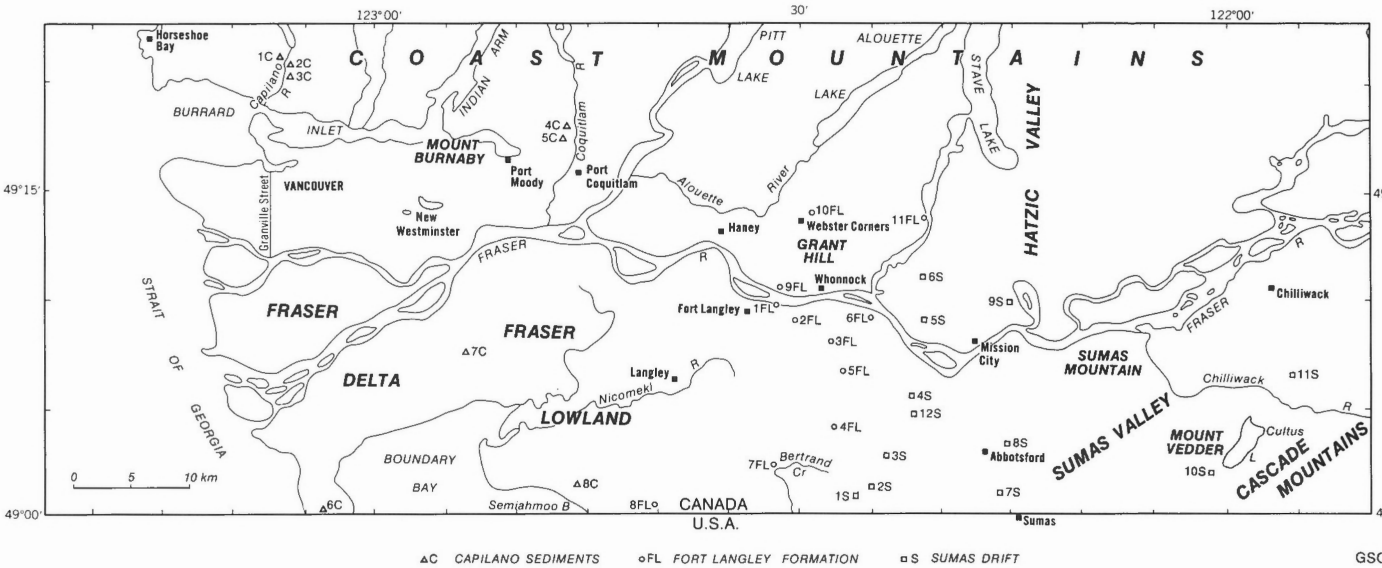


Figure 7. *Location of stratigraphic sections of post-Vashon Pleistocene sediments in Fraser Lowland. Detailed stratigraphic sections are illustrated in Figure 3 (1FL-11FL), Figure 9 (1C-8C), and Figure 12 (1S-12S).*

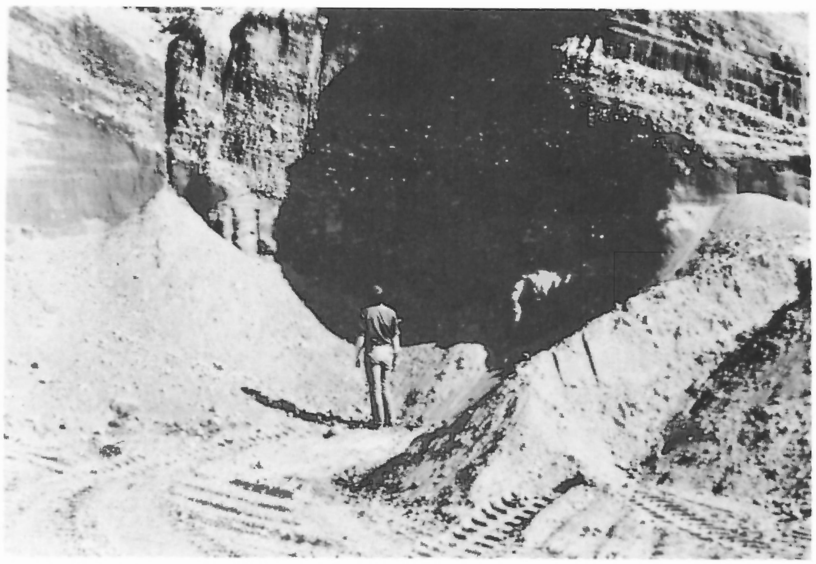


Figure 8

Fort Langley deltaic gravel exposed in parastratotype, section 2FL. GSC 203193-A

A second parastratotype has been designated on the south side of Grant Hill (Fig. 3, sec. 9FL; Fig. 7) where the underlying Vashon Drift may be seen. Sections 6FL and 11FL (Fig. 3) show the overlying Sumas Drift.

A composite section of the Fort Langley Formation is given in Table 2, which shows two ice-contact units, 2 and 5; two proglacial delta units, 4 and 7; and four glaciomarine and marine units, 1, 3, 6 and 8. Most likely this represents an oversimplification. The sequence of deposits formed by floating and grounded ice in a marine environment during a period of fluctuating sea levels cannot be unravelled on a regional scale but only locally; hence all are included in the single lithostratigraphic unit named Fort Langley Formation. The stones found in the sediments comprising the Fort Langley Formation appear to have their source largely in the mountains to the east and northeast rather than in the north and northwest (see section on provenance and direction of transport).

Capilano Sediments

Capilano Sediments consist of a thick succession of glaciofluvial, glaciomarine and marine sediments overlying Vashon Drift. In many places they are overlain by and grade into Salish Sediments. Capilano Sediments were deposited when relative sea levels were at least 15 m above present sea level.

No one section has been found in which all the units of the Capilano Sediments, plus the bounding formations, may be observed. Figures 9, 10 and 11 illustrate the variety of units and the lower bounding formation (Vashon Drift) observed in stratigraphic sections. The upper bounding formation, postglacial sediments, is not illustrated. Two sections (Figs. 7 and 9; secs. 2C, 3C) from the lower Capilano River basin, from which the name of the formation is derived, have been designated as the holostratotype.

Capilano Sediments consist of marine and glaciofluvial sediments containing diverse facies. These are seafloor muds with dropstones and fossil shells, raised deltas of sand

Table 2. Stratigraphy of Fort Langley Formation

Top of Section

SUMAS DRIFT

FORT LANGLEY FORMATION

Unit		Maximum thickness (m)
8	Glaciomarine and minor marine sediments, mainly stony silt loam and silt; shows stratification in places; probably includes diamictons formed by tidewater glaciers and grounded icebergs.	60
7	Proglacial deltaic sand and gravel, probably formed in the sea; the top beds appear to have formed above high tide.	30
6	Glaciomarine and minor marine sediments; similar to unit 8.	25
5	Sandy till-like diamicton, probably flow till in part, contains glaciomarine clasts of unit 3 or older; also contains ice-contact sand and gravel.	5
4	Proglacial deltaic sand and gravel; similar to unit 7.	30
3	Glaciomarine and till-like sediments, the latter probably deposited by tidewater glaciers and grounded icebergs.	25
2	Ice-contact sand and gravel, lenses of sandy till; similar to unit 5 except less till and more sand and gravel.	10
1	Marine sediments with scattered dropstones, mainly clayey silt.	30 +

and gravel, raised intertidal sand, and beach gravel. In contrast to Fort Langley glaciomarine sediments, Capilano glaciomarine sediments underlying uplands are normally less than 10 m thick and are not associated with ice-contact sediments and diamictons; in the lowlands these sediments may be more than 50 m thick.

Much of the upland areas mapped as Capilano glaciomarine sediments are mantled by intertidal and beach deposits (Fig. 10). In addition these areas have many well developed marine terraces and strandlines (see section on sea level changes). None of these features are associated with the Fort Langley Formation, and if they had developed on Fort Langley sediments they probably were obliterated by the advance of Sumas ice.

Stratigraphy The lower basin of Capilano River is a cone-shaped bedrock depression 4.8 km wide, extending from tidewater northward 5.6 km to its apex at Capilano dam. Exposed here are thick deposits of raised deltaic sand and gravel in places overlying, or containing thin beds of, glaciomarine and marine sediments. As a result of sea level changes during the post-Vashon, the area underwent extensive terrace development by wave and river action (Fig. 11).

The holostratotype sections (Figs. 7 and 9, secs. 2C, 3C) occur in the lower Capilano River basin. The sediments exposed in the holostratotype sections are characteristic of the raised deltas formed in the sea at the mouths of mountain streams during deglaciation and post-Vashon sea level adjustments. Section 2C consists of approximately 15 m of fossiliferous marine and glaciomarine sediments at the base, overlain by about 20 m of deltaic deposits, which in turn are overlain by approximately 5 m of marine shore deposits. Section 3C is similar, except that the marine and glaciomarine deposits are missing at the base and the deltaic sediments are thicker.

The most widespread Capilano Sediments are the relatively thin (1 to 12 m) deposits of glaciomarine sediments and marine shore deposits mantling Vashon Drift in much of the western part of the Fraser Lowland. They are not mappable at the scale used for Figure 1 and are included with the Vashon Drift unit. Two parastratotype sections (Figs. 7 and 9, secs. 6C, 8C) have been designated as typical of these widespread deposits. In both sections Vashon till is overlain unconformably by approximately 5 m of fossiliferous stony silt loam of glaciomarine origin. The shells from section 6C were radiocarbon dated at 12 600 ± 170 years (GSC-248) and those from section 8C at 12 625 ± 450 years (GSC-6). The glaciomarine sediments in section 6C are overlain by approximately 3 m of intertidal sand and in section 8C by 1 m of beach lag sand and gravel.

The Capilano Sediments are largely correlative with the Fort Langley Formation (Fig. 2). This correlation is supported by the fact that both formations were laid down in a post-Vashon period that began when the area was invaded by sea and ended, for the Fort Langley Formation, with the advance of Sumas ice and, for the Capilano Sediments, with the withdrawal of the sea. Radiocarbon dates also support this correlation.

Sumas Drift

Sumas Drift consists of diamictons (lodgment and flow tills), advance and recessional glaciofluvial deposits, and glaciolacustrine sediments that were deposited during the final occupation of the eastern part of the Fraser Lowland by a glacier. These sediments overlie strata of the Fort Langley Formation and underlie Salish Sediments.

The name of the formation is derived from the village of Sumas on the United States side of the Canada - United States Border. The village lies 1.7 km south of the holostratotype section (Figs. 7 and 12, sec. 7C).

Stratigraphy No one locality has been found to contain all the units of Sumas Drift plus the bounding strata. The sections illustrated in Figure 12 show the variety of facies found and the basal bounding strata. The upper bounding strata, Salish Sediments, are shown in only two sections.

In the holostratotype sections (Fig. 12, sec. 7S) the base of the Sumas Formation is not observable; however, nearby drillhole information indicates that the formation is underlain by Fort Langley glaciomarine and marine sediments. The lower 34 m of the section exposed is Sumas advance outwash sand and gravel. Overlying the sand and gravel unconformably is a lodgment till up to 4 m thick. At the top of the section is about 2 m of Salish windblown sand.

Two parastratotype sections (Fig. 12, secs. 11S, 12S) have been designated in which the lower bounding strata are observable. Section 12S, although only 5 to 8 m thick, is probably the most representative section of Sumas Drift in illustrating its relation to the underlying Fort Langley Formation (Fig. 13). The underlying Fort Langley glaciomarine stony silty clay loam has an undulating surface upon which Sumas Drift has been deposited. The latter consists of 0 to 5 m of glaciofluvial gravel and sand, and minor silt overlain unconformably by a sandy lodgment till 1 to 2 m thick. In places the till lies directly on Fort Langley glaciomarine sediments. The glaciofluvial gravel at this site indicates deposition by streams flowing north and northwest.

LATE WISCONSIN

POST-VASHON

CAPILANO SEDIMENTS

Cms	*Marine shore deposits (stratified); a, beach and lag sand and gravel; b, intertidal sand and minor gravel; c, longshore bar and spit deposits, mainly gravel*
Cd	*Deltaic sediments (stratified), at least in part proglacial; a, sand and gravel, mainly forset beds; b, gravel and sand, mainly topset and bottomset beds*
Cm	*Marine sediments (stratified); fine sand, silt, and clayey silt*
Cgm	*Glaciomarine sediments (poorly stratified); a, stony silt and silt loam; b, stony silty clay loam*

VASHON DRIFT

V	*Glacial sediments; Vt, lodgment till; Vgf, glaciofluvial sand and gravel; Vgl, glaciolacustrine clayey silt and silt*

QUADRA SAND

Q	*Proglacial sediments; sand, minor gravel*

Covered or slump c

Fossil shells .... Ⓕ

LOCATION OF SECTIONS

1C West side of Capilano River, 49°21'30"N, 123°07'00"W

2C East side of Capilano River in lower Capilano Valley; 2C and 3C are designated the holostratotype, 49°21'00"N, 123°06'11"W

3C East side of Capilano River in lower Capilano Valley; 2C and 3C are designated the holostratotype, 49°20'30"N, 123°06'08"W

4C Kask gravel pit, Coquitlam Valley; 49°18'05"N, 122°46'50"W

5C Allard gravel pit, Coquitlam Valley; 49°17'38"N, 122°47'14"W

6C Boundary gravel pit, Tsawwassen; 49°00'18"N, 123°04'08"W

7C Linton gravel pit, North Delta; 49°07'36"N, 122°54'10"W

8C Drainage ditch, Highway 99A, Surrey; 49°01'25"N, 122°45'50"W

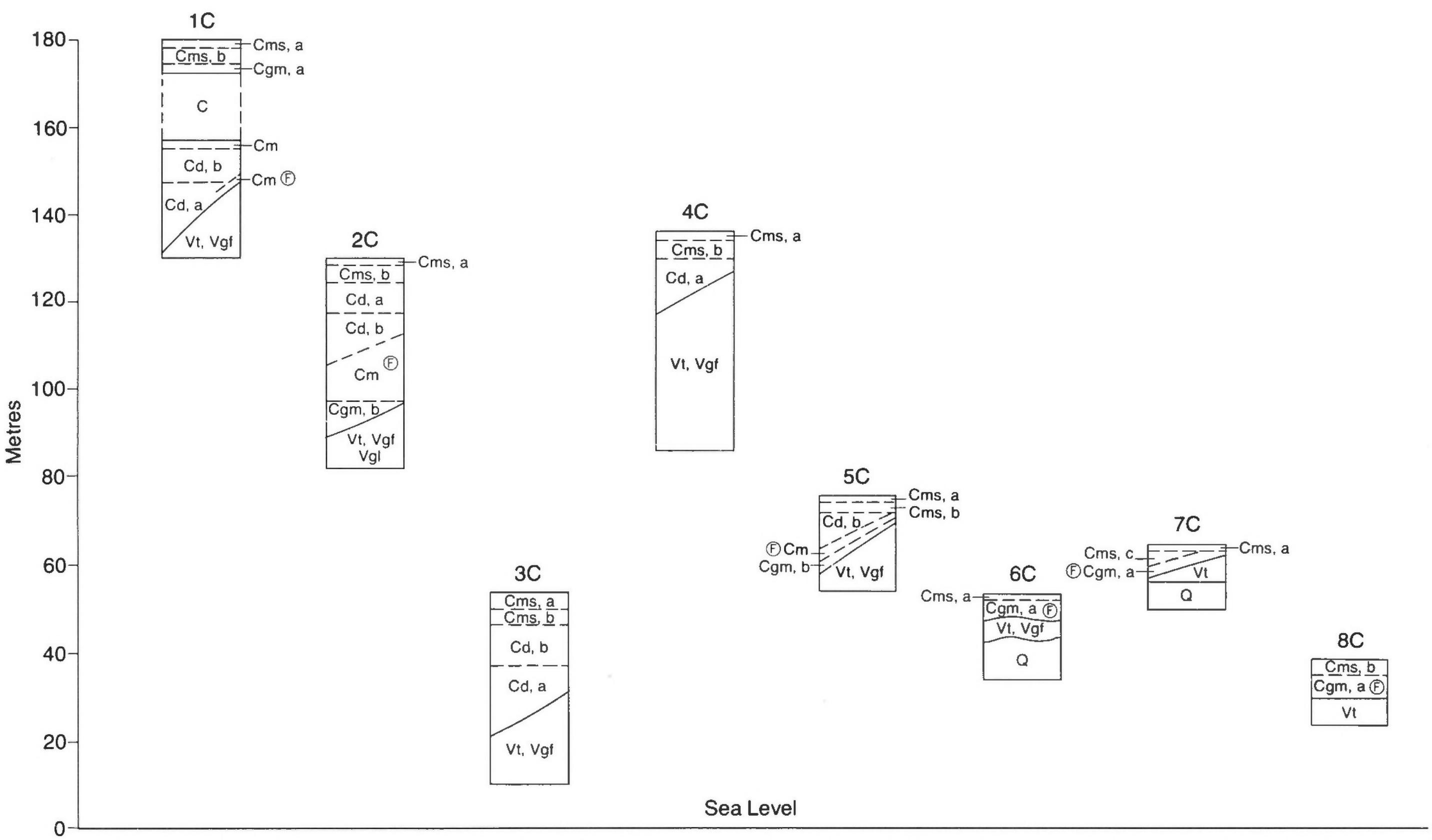


Figure 9. *Stratigraphic sections of Capilano Sediments (see Fig. 7 for locations).*

Section 11S consists of Semiahmoo marine clayey silts at the base. These contain fossil shells which have been dated at greater than 34 000 years (GSC-2230). The silts are overlain by approximately 15 m of sandy gravel and gravelly sand containing detrital organic material. These have been designated Sumas glaciofluvial sediments; however, some doubt has been cast on this correlation because a mammoth tusk lying at the contact of the underlying older clayey silts has been dated as 22 700 ± 320 years old (GSC-2232). If the mammoth was living at the time of deposition these gravels would belong to Quadra Sand or Coquitlam Drift (Fig. 2). I believe that the mammoth lived prior to the deposition of the gravel and that either the tusk was moved to its present position or the mammoth was moving across an old landscape developed on the marine silts (more than 34 000 years BP) and got bogged down during a wet period.

Overlying the sandy gravel and gravelly sand is approximately 30 m of lithologically typical Sumas glaciofluvial sediments. They grade upward through pebble, cobble and boulder gravel and probably originated as advance Sumas outwash. This outwash unconformably is overlain by a sandy loamy Sumas diamicton about 4 m thick, believed to be a basal till. The stones in the till and the underlying outwash indicate that the main source was probably the Cascade Mountains to the east and northeast. At the top of the section are postglacial Salish windblown sands, probably derived from recessional Sumas outwash plains to the west before they were revegetated.

Origin. Sumas Drift was deposited by a piedmont (valley) glacier that apparently advanced from the east and northeast into the Fraser Lowland during the final stages of deglaciation of the Lowland and the final emergence of the land above the sea. This last glacier advance extended for at least 50 km; supporting evidence for this conclusion follows.

Figure 10

Capilano raised beach on Highway 10 near Surrey-Langley district municipality boundary. GSC 202880-W

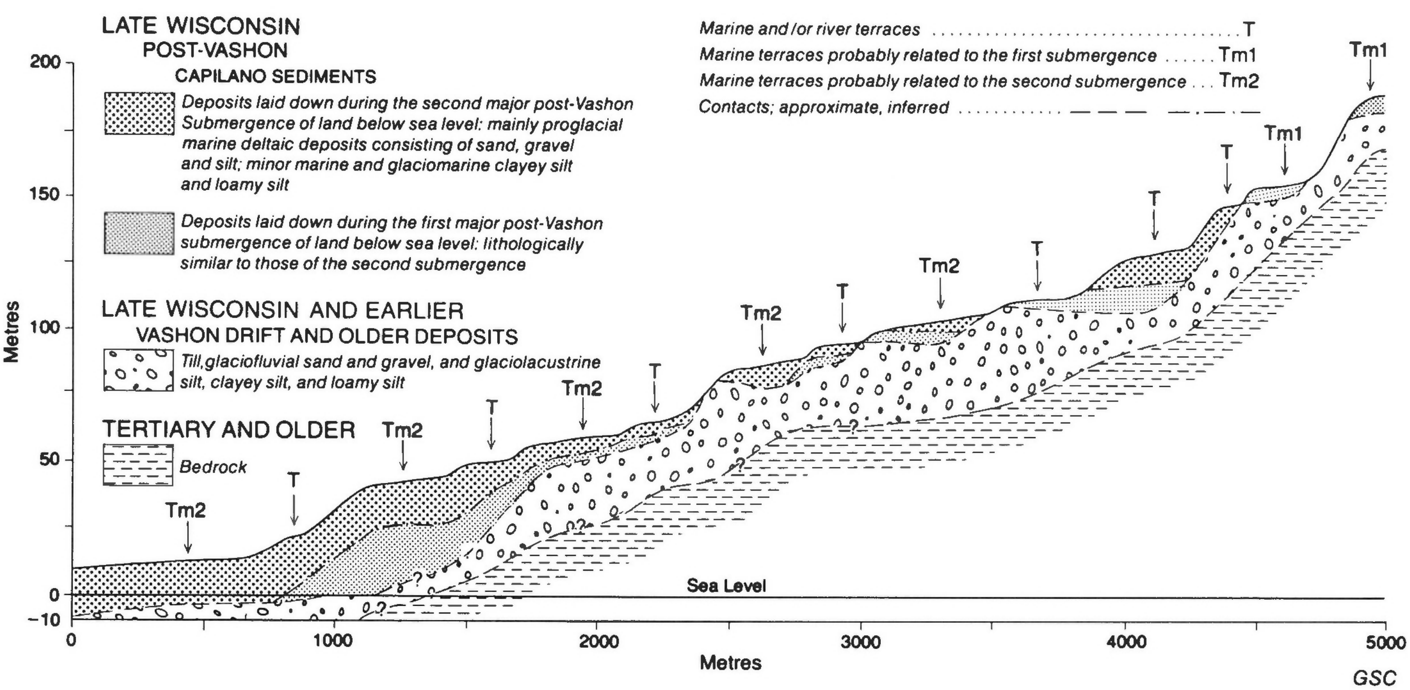


Figure 11. *Diagrammatic section of lower Capilano River area showing stratigraphic relations of Capilano Sediments and older formations.*

LATE WISCONSIN

POST-VASHON

SALISH SEDIMENTS

SAs — *Windblown sand*

SUMAS DRIFT

Sdi — *Diamictons; a, basal and flow tills; b, stony silty loam; c, interbedded thin diamictons, silt, and fine sand*

Sgf — *Glaciofluvial sediments; a, pebble to boulder gravel and sandy gravel containing scattered thin lenses of diamicton probably includes Sumas ablation till; b, gravelly sand; c, sand containing minor lenses of gravel and scattered stones*

Sic — *Ice-contact deposits; gravel and sand containing ice collapse structures and lenses of diamictons including fossiliferous glaciomarine stony silty clay, and probably flow and ablation till*

Sgl — *Glaciolacustrine laminated silt and sand*

FORT LANGLEY FORMATION

FLgm — *Glaciomarine stony silty clay loam (poorly stratified)*

FLd — *Deltaic sediments (stratified), in a large part proglacial; a, deltaic sandy gravel; b, deltaic gravelly sand and sand*

FLdi — *Diamicton; basal till containing a sandy loam matrix and characterized by clasts of glaciomarine sediments*

PRE-SUMAS

PSa — *Gravel and sand, in part proglacial Quadra and/or older sediments*

MID WISCONSIN

SEMIAHMOO ? DRIFT

Se — *Marine clayey silt (stratified)*

Fossil shells .... Ⓕ
Fossil wood .... Ⓦ
Drillhole information .... DR

LOCATION OF SECTIONS

1S Gravel pit 4.8 km south-southeast of Aldergrove, near intersection of 8th Avenue and 280th Street, Langley municipality, 49°00′55″N, 122°26′34″W

2S Gravel pit 5 km southeast of Aldergrove on 288th Street, 0.5 km north of 8th Avenue on southeast bank or meltwater channel, Langley municipality, 49°01′24″N, 122°25′24″W

3S Gravel pit 4.8 km east-southeast of Aldergrove at intersection of 296th Street and 24th Avenue, Matsqui municipality, 49°02′47″N, 122°24′13″W

4S Roadcut 7.2 km northeast of Aldergrove, at intersection of 304th Street and 48th Avenue, Matsqui municipality, 49°05′24″N, 122°22′50″W

5S Gravel pit 3.2 km northwest of Mission on north side of Silverdale Creek, 2.9 km north of Highway 7, 49°08′58″N, 122°21′40″W

6S Gravel pit 7.2 km northwest of Mission, 0.4 km of Hairsine Creek, 49°11′11″N, 122°21′40″W

7S Gravel pit 3.7 km south-southeast of Abbotsford on west side of Sumas Valley, 1.75 km north of International Boundary; designated as the holostratotype for Sumas Drift, 49°01′00″N, 122°16′30″W

8S Gravel pit 1.6 km northeast of Abbotsford on the northwest side of southwest trending ridge 2.4 km north of Highway 1, 49°03′16″N, 122°16′00″W

9S Roadcut 4.3 km northeast of Mission on north side of Draper Creek below monastery 1.7 km north of Fraser River, 49°09′40″N, 122°15′40″W

10S Gravel pit 1.3 km east-southeast of Cultus Lake, on east side of Frost Creek, 49°02′04″N, 122°01′30″W

11S Bailey sanitary land fill 4.8 km east-northeast of Vedder Crossing, on east side of Sumas Valley, 49°06′35″N, 121°55′20″W

12S Roadcut on Mount Lehman Road 2.9 km north of Fraser Way, 49°05′10″N, 122°22′50″W

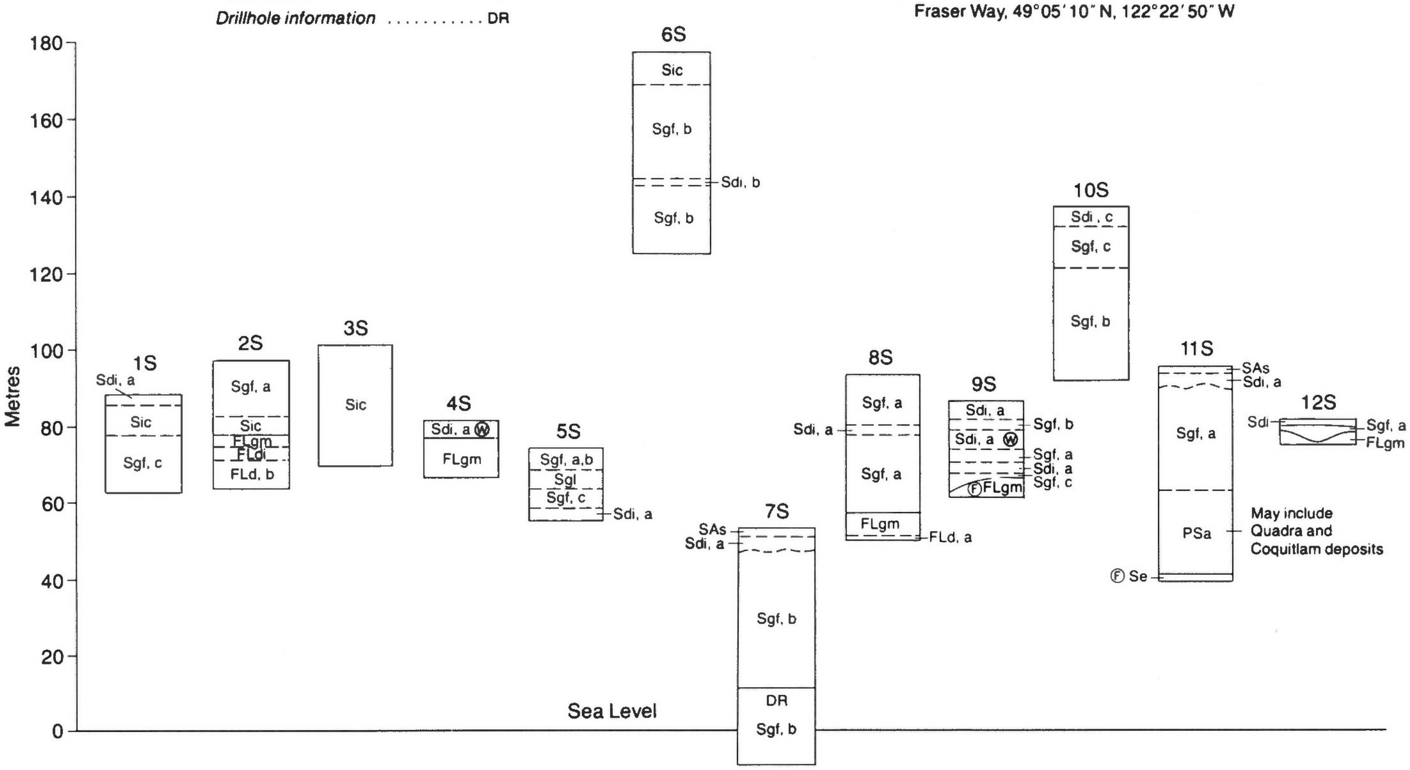


Figure 12. *Stratigraphic sections of Sumas Drift (see Fig. 7 for locations).*

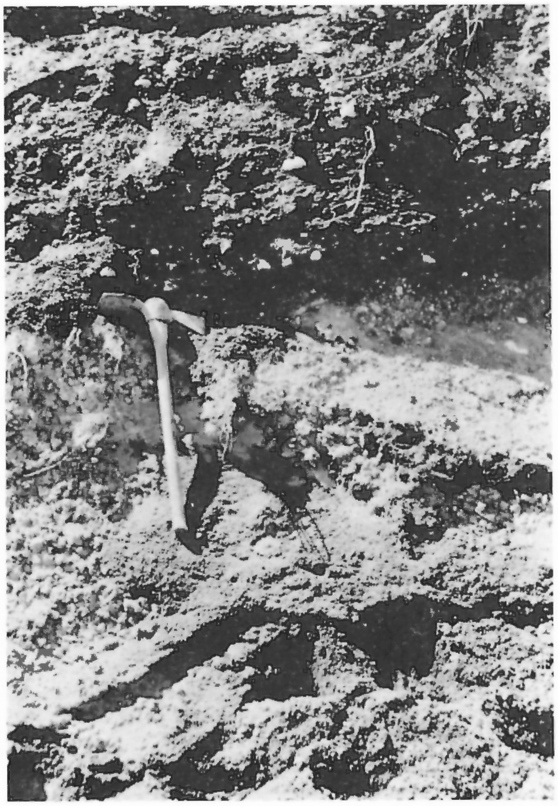


Figure 13. *Sumas till overlying Sumas glaciofluvial gravel, section 12S. Both overlie Fort Langley glaciomarine stony clayey silt. GSC 202880-Z*

Only those glacial deposits younger than the Fort Langley glaciomarine sediments have been mapped as Sumas Drift. Where drift deposits are overlain by glaciomarine sediments they have been mapped as part of the Fort Langley Formation.

HISTORY OF FRASER DEGLACIATION AND PALEOENVIRONMENTAL RECONSTRUCTION

The maximum advance of Fraser ice (Vashon Drift) occurred about 15 000 to 15 500 BP. Deglaciation of the Fraser Lowland commenced with the invasion of the area by the sea about 13 000 years BP. By this time the Cordilleran ice sheet had retreated back to the Coast and Cascade mountains; however, ice still occupied many valleys, and a large mass of glacier ice remained in the eastern part of the Fraser Lowland. This glacier terminated in the sea and provided floating ice over a wide area. During the deglaciation period represented by the Fort Langley Formation at least two local advances or standstills of this Fraser Lowland ice are recorded. Each advance was probably partly across land above sea level, partly across a tidewater area, and partly across the seafloor. Deglaciation came to a close with the advance and wasting of Sumas ice and final withdrawal of the sea from the area 11 000 years ago. These ice advances do not necessarily indicate climatic changes but may have resulted primarily from surging. During both ice buildup and wasting of post-Vashon glaciers, glaciomarine and marine sediments were deposited in front of the ice. These record several major changes in relative sea level, and at least two major invasions and withdrawals of the sea are believed to have occurred. The evidence to support the above synopsis follows.

Composition of glaciomarine and associated sediments

The term 'glaciomarine sediments' here refers to stony silty clay loam, stony silt loam, stony silt, and till-like mixtures that I believe are primarily seafloor muds into which ice-rafted stones and other rock debris have dropped. In places these materials were redeposited through slumping and sliding from the push of tidewater glaciers (see section on origin). A nongenetic term for these sediments is 'marine diamicton'. Similar sediments have been referred to by various authors as 'glaciomarine drift', 'glacial-marine drift', 'marine drift', and 'marine till'. The terminology used seems to depend largely on whether the writer considers the origin of the bulk of these sediments to be marine or glacial. All gradations between primarily glacial and primarily marine occur, especially when a glacier terminates in the sea. At the coast the environment would be mostly glacial and proglacial but would acquire normal marine characteristics as the distance from the land-anchored glaciers increased.

The glaciomarine sediments, exclusive of the till-like mixtures, generally consist of more than 95 per cent fine material smaller than 2 mm (-1ϕ unit). In further discussion the term 'fine' will be used for this material and constituents larger than 2 mm will be referred to as 'coarse'. The remaining 5 per cent or less of the constituents range from 2 mm to large boulders, a few of which are more than 2 m in diameter. In some till-like mixtures containing unbroken fossil shells and considered to be glaciomarine in origin, coarse constituents may comprise up to 20 per cent or more of the volume.

Particle size distribution Mechanical analyses of fine constituents of Fort Langley and Capilano glaciomarine sediments and Sumas till were made in order to compare sediments of similar origin with one another and with the closely associated Sumas till. Fractions coarser than 2 mm were not analyzed. The cumulative frequency curves illustrated in Figure 14 (Fort Langley glaciomarine sediments), Figure 15 (Capilano glaciomarine sediments) and Figure 16 (Sumas till) include results supplied by the Geological Survey and some material on the Fort Langley Formation obtained from Ahmad (1955). These curves illustrate that the proportions of clay (less than 0.004 mm), silt (0.004 to 0.063 mm) and sand (0.063 to 2 mm) vary greatly from place to place in each unit. Also the cumulative frequency curve field limits for the three units (Fig. 17) show that as a rule Fort Langley glaciomarine sediments contain the highest percentage of clay, and Sumas till the highest percentage of sand; this is observable in the field. Capilano glaciomarine sediments occupy the middle ground. The ternary diagram shown in Figure 18 illustrates the particle size field limits of each unit. Fort Langley glaciomarine sediments have been delineated as two fields in Figure 18 because samples 1 and 2, although within the same geographic area, varied greatly from the remaining eleven samples, which are felt to be more representative of the unit. Samples 1 and 2 may represent Fort Langley till-like diamictons; they were collected in 1954, and the section is no longer exposed.

No detailed mineralogical study has been made on the fine constituents comprising the larger part of the glaciomarine sediments. Believed to be mainly glacial rock flour transported to the sea by meltwater, they consist of feldspar, quartz and other common rock minerals. Results of pedological studies (Ahmad, 1955) indicate that the fine fraction must contain some minerals of high base exchange capacity such as montmorillonite, hydrous mica, illite and related minerals.

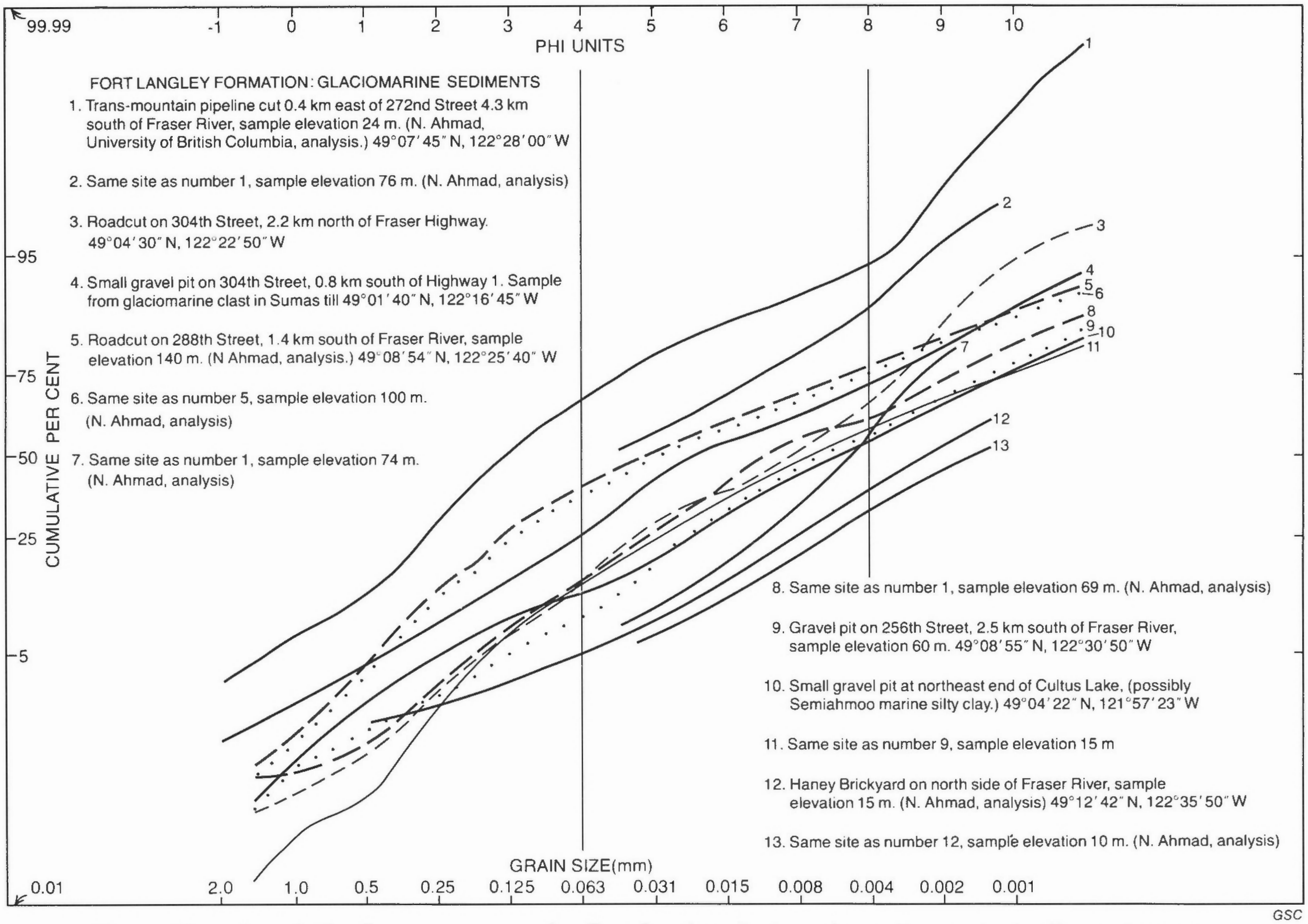


Figure 14. *Cumulative frequency curves for Fort Langley glaciomarine sediments in the Fraser Lowland.*

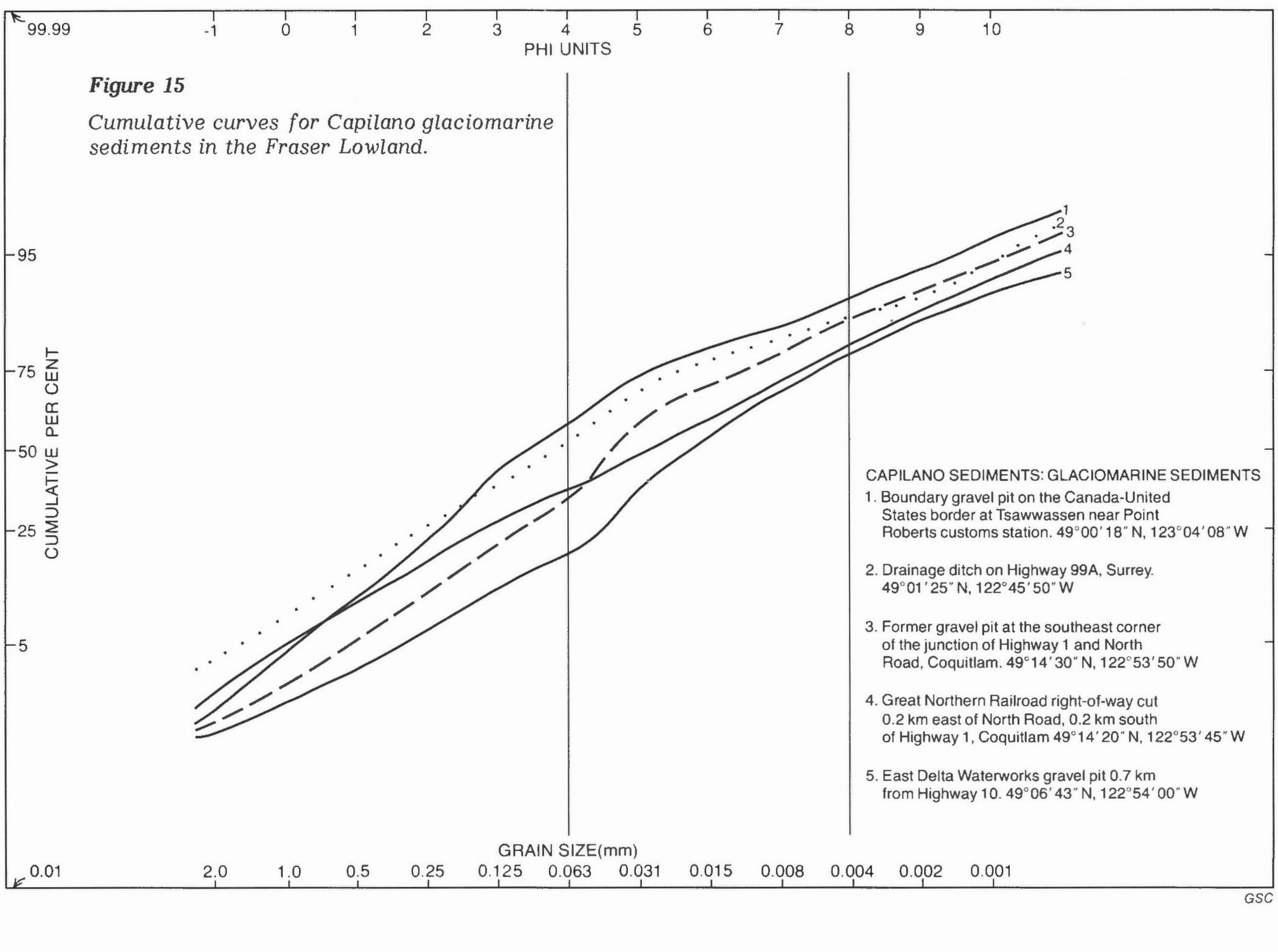


Figure 15

Cumulative curves for Capilano glaciomarine sediments in the Fraser Lowland.

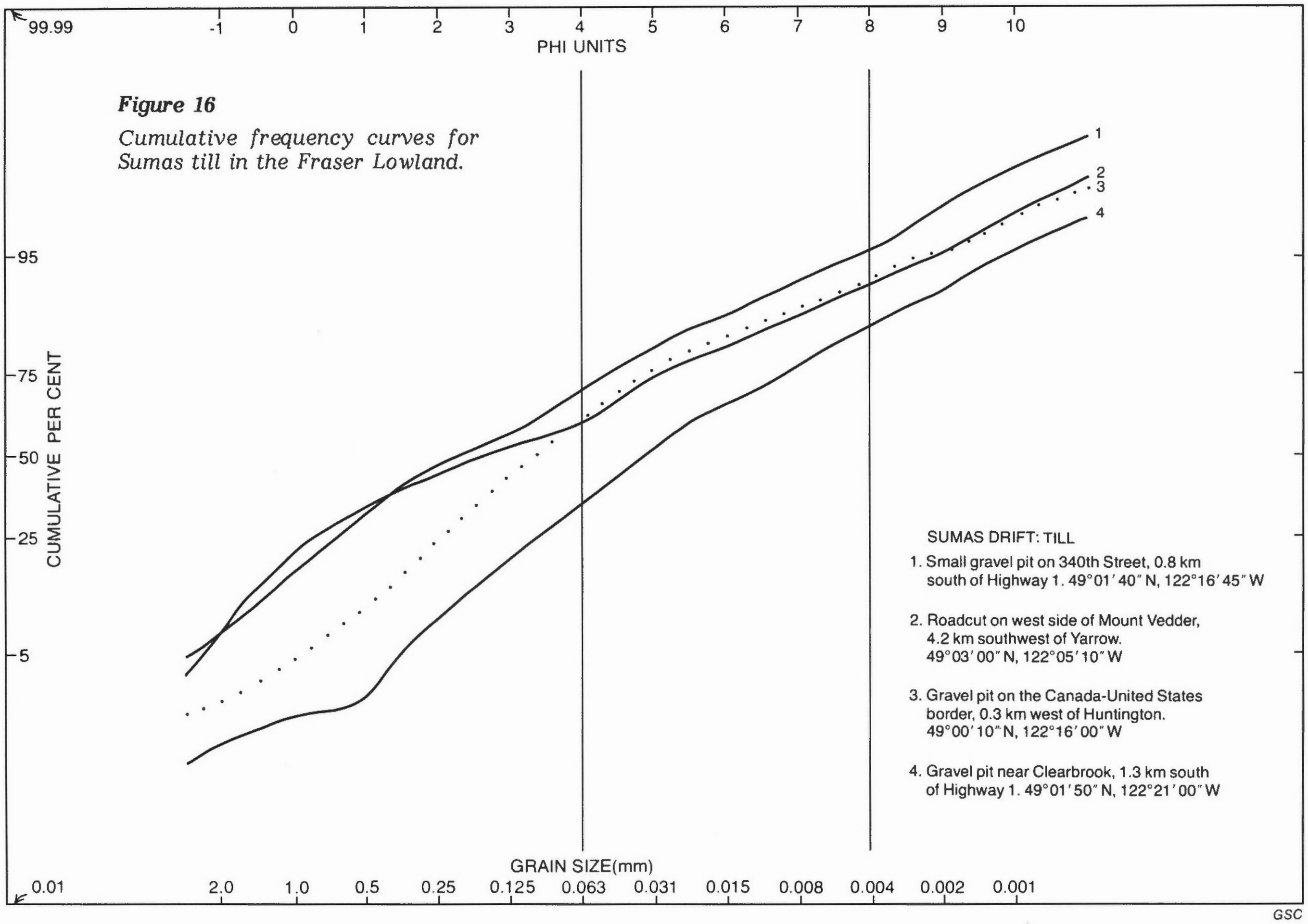


Figure 16

Cumulative frequency curves for Sumas till in the Fraser Lowland.

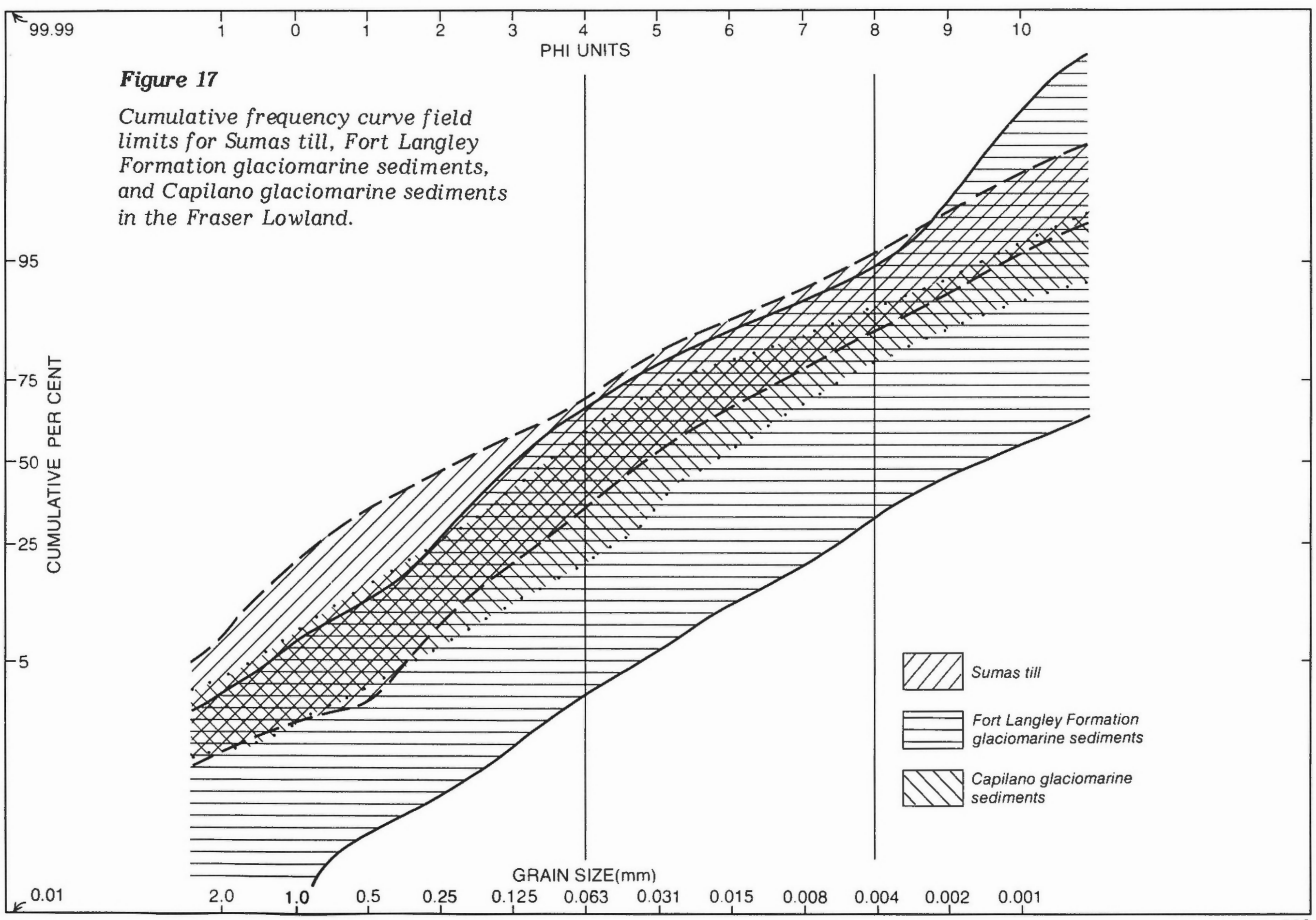


Figure 17

Cumulative frequency curve field limits for Sumas till, Fort Langley Formation glaciomarine sediments, and Capilano glaciomarine sediments in the Fraser Lowland.

Provenance and direction of transport of post-Vashon glacial sediments

Lithological identification of the pebbles found in post-Vashon glacial sediments was carried out to ascertain the bedrock type from which they were derived. The bedrock geology of the Fraser Lowland and part of the adjoining area was mapped by Armstrong (1953, 1960a, b), Armstrong and Roddick (1965), Roddick (1965) and Roddick and Armstrong (1965). It is my belief that in much of the Fraser Lowland the post-Vashon pebbles identified came from underlying older glacial and nonglacial sediments and not directly from the original bedrock source. Others may disagree with this conclusion. Vashon sediments were studied for comparison. Figure 19 shows the location of the 81 sample sites studied and the lithofacies unit that they represent. Each sample consisted of at least 100 stones ranging from 2 to 8 cm long (size arbitrarily chosen). Composite histograms (Fig. 20) illustrate the lithological similarities and differences of the coarse fraction (more than 2 mm) of each lithofacies if 2 to 8 cm is assumed to be representative of the coarse fraction.

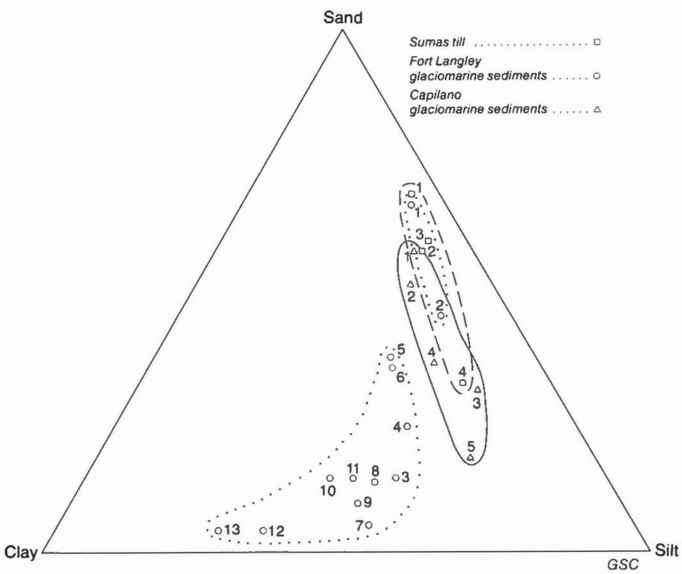


Figure 18. Grain size distribution of post-Vashon glacial diamicton matrixes, Fraser Lowland.

For the lithofacies studied the agents of transport that are partly responsible for supplying the different pebble lithologies are grounded ice (glaciers), floating ice (fragments of ice including icebergs and sea ice) and flowing water (glacial and nonglacial origins).

Bedrock geology A knowledge of the bedrock geology within the Fraser Lowland area and in the adjoining Coast Mountains to the north and northwest and Cascasde Mountains to the east and northeast is essential to evaluate the significance of the histograms (Fig. 20) for determining the direction of movement of the agents of transport that carried the pebbles. The greater part of the Fraser Lowland is underlain by thick Quaternary deposits (300+ m in places), which lie unconformably above poorly indurated Tertiary plant-bearing, freshwater sedimentary rocks, namely sandstones, siltstone, mudstone, shale and conglomerate. In places they are interlayered with or overlain by Tertiary basalts. These Tertiary rocks outcrop on both sides of Burrard Inlet, including Mount Burnaby; in the Haney-Mission area, including Grant Hill; in the Sumas Mountain area; and in scattered localities elsewhere, including Little Mountain, Vancouver. Since all of the Tertiary rock types disintegrate rapidly during transport, they rarely exceed 1 per cent of the pebbles and usually occur within 10 km of an outcrop. Where present, however, they are excellent indicator stones. The term 'indicator stone' is used to refer to pebbles that may be traced back to their original bedrock source.

Ninety-nine per cent or more of the pebbles were derived from pre-Tertiary rocks underlying the Coast and Cascade mountains. The Coast Mountains are underlain mainly by granitic plutonic rocks and associated metamorphic rocks. Mesozoic, Tertiary and Quaternary volcanic rocks, and Mesozoic sedimentary rocks compose the remaining rock types exposed in the Coast Mountains within 50 km of the Fraser Lowland. The only unique indicator stones are derived from these volcanic and sedimentary formations, particularly those from the Howe Sound and Harrison Lake areas. The Cascade Mountains are underlain by Upper Paleozoic and Mesozoic sedimentary and volcanic rocks, which are extensively interspersed with granitic plutonic and associated metamorphic rocks. The common sedimentary rocks are limestone, chert, cherty argillite, pelite and quartzite. Limestone disintegrates rapidly in transport; however, the other sedimentary types contribute

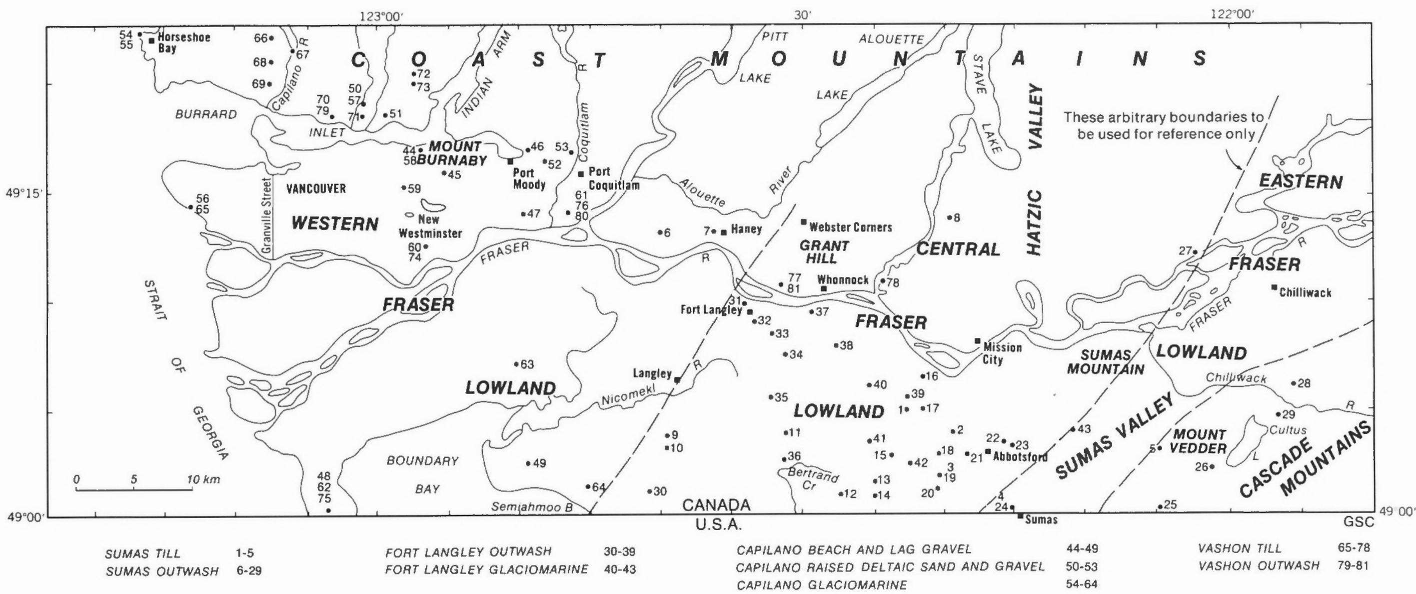


Figure 19. Distribution of Vashon and post-Vashon pebble provenance localities, Fraser Lowland.

good source indicator stones. The volcanic rocks in the Cascades are mainly porphyries and in places produce good indicator stones. Minor amounts of serpentine and granitic pebble conglomerate outcrop in the Cascades, and these yield some of the best source indicator stones.

Indicator pebbles. The following conclusions are drawn from the preceding paragraphs. Granitic and associated metamorphic stones, without regard to their geographic location, cannot be used as indicators; these stones form the largest percentage of stones in most samples. In some places, however, they obviously reflect the bedrock geology of the nearby area; this is especially true north of Fraser River. A few volcanic and sedimentary rock types exposed in the Coast Mountains may be good indicator source stones, especially Garibaldi and Gambier volcanics from the Howe Sound area and *Aucella*-bearing sedimentary rocks from Harrison Lake. Stones consisting of chert, cherty argillite, pelite, quartzite and some volcanic porphyry normally indicate a source in the Cascade Mountains. Locally Tertiary sediments and basalts, Cascade granitic pebble conglomerate, serpentine and limestone are excellent indicator stones.

Excluding the samples of Sumas outwash in the eastern part of the Fraser Lowland and the Fraser River gravel, the histograms illustrated in Figure 20 show that nonindicator stones of granitic and metamorphic lithologies make up the largest component of the samples. The remaining pebbles, which consist largely of indicator stones, provide a guide to the original source of the coarse material forming the lithofacies. To help interpret the direction of transport of the lithofacies this information on indicator stones is used in conjunction with geographic location of the sample locality. This latter item may be used in places to assign a direction of transport to nonindicator stones.

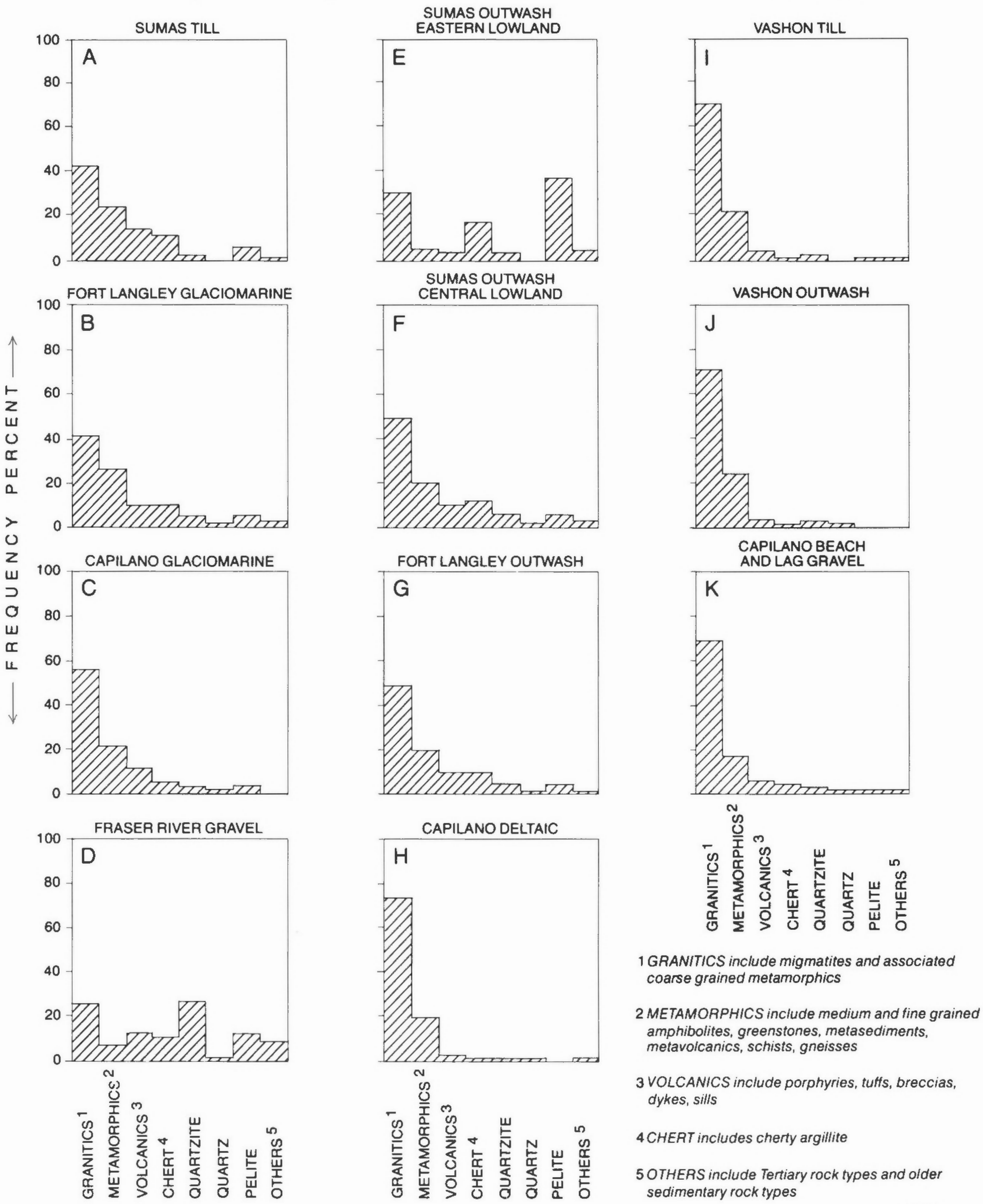


Figure 20. *Pebble provenance histograms, Fraser Lowland.*

Provenance of Vashon Drift and Sumas Drift. All the Vashon till samples (Fig. 20I) except sample 75 and all Vashon outwash samples (Fig. 20J) were collected near the flanks of the Coast Mountains; although they contain very few indicator stones, there is little doubt that most nonindicator granitic and metamorphic stones came from the north and northwest. This conclusion is supported by till fabric analyses, paleocurrent directions in outwash, and bedrock striae. In sharp contrast and using the same types of evidence and reasoning it is concluded that the stones in the Sumas till (Fig. 20A) and the Sumas outwash (Fig. 20E, F) were transported from the east and northeast.

Provenance of Fort Langley and Capilano sediments. The stones collected from glaciomarine sediments were transported by floating ice and indicate more diverse source areas than those from Vashon and Sumas tills. Both the Fort Langley glaciomarine sediments (Fig. 20B) and the Capilano glaciomarine sediments (Fig. 20C) contain up to more than 25 per cent of stones apparently derived from an eastern or northeastern provenance. In the case of the Capilano glaciomarine sediments the composite histogram (Fig. 20C) is somewhat misleading as the variation in per cent of lithological rock types between samples is much greater than in the Fort Langley glaciomarine sediments. A detailed study of the individual Capilano glaciomarine sediments indicates a strong northern and northwestern provenance for those samples near the Coast Mountains and near the western limit of the Fraser Lowland.

Fort Langley outwash (Fig. 20G) contains a significant percentage of indicator stones that have an eastern and northeastern provenance, which justifies the conclusion that the original source of these gravels, including the nonindicator stones, is primarily to the east and northeast. This conclusion is supported by the fact that many of these deposits have deltaic bedding that dips west, northwest and southwest. The Capilano deltaic gravels (Fig. 20H) are found on the flanks of the Coast Mountains and appear to have been derived from rocks exposed in these mountains; the deltaic beds dip primarily southward, providing no additional information. The Capilano beach and lag gravels (Fig. 20K), reflecting the underlying lithofacies from which they have been derived, are of no help in determining direction of transport. A histogram of postglacial Fraser River channel gravels (Fig. 20D) shows that they obviously came from the northeast. The high percentage of quartzite and relatively low percentage of granitic stones is characteristic of these gravels.

Conclusions on provenance and directions of transport. An attempt has been made to evaluate the pebble provenance, and the results have been plotted on a ternary diagram (Fig. 21a); one corner of the diagram represents stones from a north (and northwest) source, the second corner represents stones from an east (and northeast) source, and the third corner represents stones that could be derived from either source, that is, unassigned nonindicator stones. To plot all pebbles in a given sample, the percentage of nonindicator stones to be assigned to each of the three components was evaluated on the basis of geographic location of the sample. Figure 21b outlines the pebble provenance field limits and clearly demonstrates that the Fort Langley and Sumas lithofacies have an eastern and northeastern provenance and that the Vashon and Capilano lithofacies have a predominantly northern and northwestern provenance.

Sumas ice movement. Provenance alone does not necessarily portray correctly the direction of the ice movement, as many of the stones may have been picked up from older unconsolidated deposits in which the transport of the material was controlled by flowing water rather than by ice. Additional evidence is needed to determine the direction in which the glaciers moved. Limited studies of Sumas till fabrics by Roberts and Mark (1970) and reinterpreted by Armstrong et al. (1971) support the conclusion that Sumas ice moved westward from the Cascade Mountains and Fraser River valley east of the Fraser Lowland into and across part of the Lowland. The distribution of some large erratics further helps to substantiate this. For example a conglomerate boulder, estimated to weigh more than 3200 metric tons, lies near the Canada - United States Border about 3 km east of Highway 13. The nearest potential source of this boulder is a lithologically similar conglomerate that outcrops near Hope in the Fraser River valley 88 km northeast. Locally the Sumas ice apparently moved northwestward into Hatzic and Stave valleys and the area between. Scattered boulders of Tertiary sedimentary and volcanic rocks are found in Sumas Drift as much as 5 to 10 km north of outcrops of similar rock types.

Vashon ice movement. Till fabric analyses by Hicock (1976) shows that in the Coquitlam River area Vashon ice at its maximum moved southward off the Coast Mountains. Striae along Howe Sound and Indian Arm show that Vashon ice moved southward down these major valleys, and striae

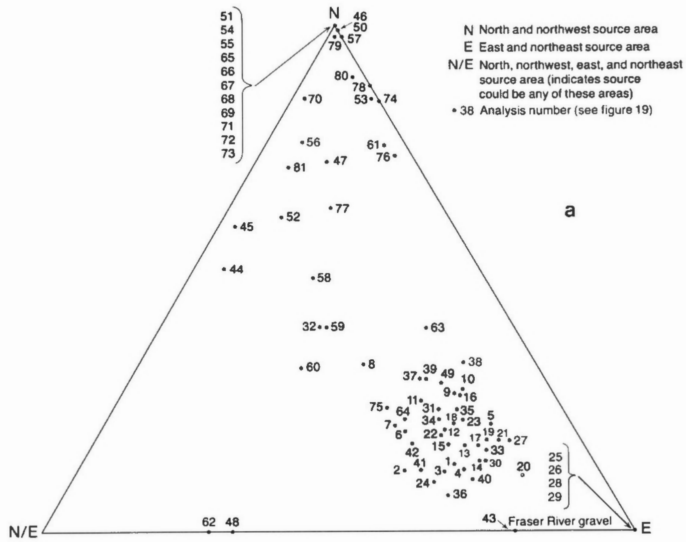


Figure 21a. *Pebble provenance analyses, Fraser Lowland.*

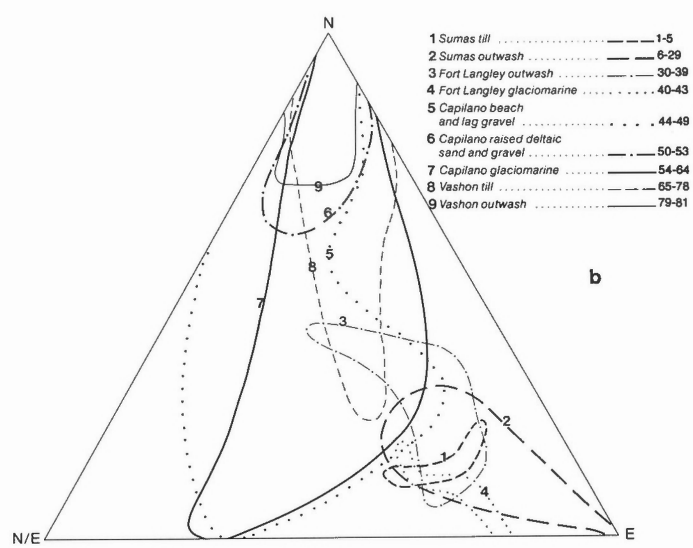


Figure 21b. *Pebble provenance field limits, Fraser Lowland.*

across the tops of the Coast Mountains also have a southward direction. During the buildup of ice to a maximum in the Vashon Stade the main ice movement was controlled by the valleys, and the provenance of stones from Vashon till near the Canada - United States Border indicates that some pre-maximum Vashon ice moved westward across the Fraser Lowland.

Origin of glaciomarine sediments

Previous work (1953, 1954). All geologists working in the Fraser Lowland prior to 1950 considered most of the deposits now referred to as glaciomarine sediments to be tills, particularly lodgment tills. Johnston (1923) referred to some of these sediments as shelly tills formed when glaciers were ploughing up the seafloor and incorporating fossiliferous mud in the lodgment. He referred to other glaciomarine sediments as a marine 'horizon' and suggested that some of the stones observed in this horizon may have been carried by floating ice. The hypothesis that these sediments were shelly lodgment tills was accepted in many parts of the world. Such tills do exist in places, probably including the Fraser Lowland. This theory, however, does not explain the presence of bivalves in growth position and unbroken barnacles and worm tubes attached to clasts. Similar late glacial and older sediments are exposed from south of the Canada - United States Border at the 49th Parallel northwest for more than 2000 km along the Pacific Coast to the Alaska Peninsula. In describing late Cenozoic sediments exposed on Middleton Island, Miller (1953) was the first modern geologist to suggest that the shelly pebbly mudstones in the area were probably glaciomarine deposits. Armstrong and Brown (1954), working independently 1900 km southeast of Middleton Island, had concluded that most of the so-called shelly tills in the Fraser Lowland were not tills but glaciomarine diamictons.

Armstrong and Brown (1954) listed many characteristics of these glaciomarine sediments that did not seem consistent with the interpretation of earlier workers who considered these sediments to be shelly lodgment tills. The more important of these differences are as follows:

1. They contain abundant marine fossil shells in places, and many unbroken shells are found in the growth position.
2. They never are found above the limits of marine invasion of the area.
3. The geomorphology of the areas in which they are found is not similar to the geomorphology of the areas overriden directly by ice.
4. In many places they exhibit recognizable bedding but are not varves.
5. Most clasts found within bedded glaciomarine sediments show evidence of having been dropped into the sediments; the beds are deformed around the clasts.
6. They contain a much higher percentage of silt and clay than the associated terrestrial tills.
7. They have higher void ratios and lower bulk densities than associated terrestial tills (Easterbrook, 1964).
8. The deposits are much thicker than the associated terrestrial tills. For example, some sections of the Fort Langley Formation that are more than 160 m thick consist of 10 to 15 m of tills and the remainder of glaciomarine and marine sediments.
9. They are interbedded with sorted and stratified marine sediments.

To explain these differences Armstrong and Brown (1954) proposed the following hypothesis for the origin of the glaciomarine sediments. The glaciomarine and associated sediments were deposited in the sea during and following the wasting of the last major Wisconsin Cordilleran ice sheet and during the subsequent uplift of the land above sea level. The agents of transportation of the clasts and some of the fine material probably were shelf, berg and sea ice, and for most of the fine materials, glacial meltwater and seawater. The fines were deposited in a marine environment as seafloor muds. Some of the sediments were redeposited as a result of sliding, slumping and turbidity currents. This interpretation was based on the hypothesis that when the Vashon ice left the Fraser Lowland and retreated into the mountains the sea invaded the area to a maximum of about 250 m. This was followed by a lowering of sea level over about 2000 years to the present.

Present work (1973 - 1977). The above interpretation now appears much too simplified, and the following modifications are proposed. About 13 000 years BP the Vashon ice apparently retreated from much and probably all of the Fraser Lowland into the Coast Mountains. Some uncertainty remains as to the position of the Vashon ice front in the eastern part of the Fraser Lowland. I believe that 13 000 years ago the Lowland was ice free from Agassiz west. The Vashon ice at its maximum isostatically depressed the Fraser Lowland at least 350 m and sea level had been lowered eustatically at least 100 m. Following the retreat of Vashon ice the sea invaded the lowland, covering areas up to 250 m above present sea level. From 13 000 to 11 000 years BP the eastern half of the Fraser Lowland became the site of a post-Vashon piedmont glacier that underwent several advances, standstills and retreats, and as a result terminated in the sea at various places in the Lowland. The piedmont ice front apparently moved east-west (see discussion on composition and provenance). The front of this glacier was calving into the sea, and the floating ice (in part icebergs) carried the clasts of ice-rafted material found in the glaciomarine sediments. Probably much of the meltwater that provided the fines making up these sediments was derived from this ice, although the streams flowing from the ice that still occupied some of the Coast Mountain valleys also must have provided some of the fines and possibly a limited amount of ice-rafted material. On the seaward side of the glacier front meltwater laid down thick deposits of coarse sediments (sand and coarser) as proglacial marine deltas and kames. The kame deposits contain lenses of flow till.

I no longer believe that shelf ice played a significant role as an agent of transportation for the clasts and some of the finer material that are found in the glaciomarine sediments. This conclusion is based on the following criteria:

1. The sea in which the sediments were deposited and in which the ice was floating was too shallow to permit the development of a large area of shelf ice. For example, a relatively thin ice shelf 25 m high would have its base about 200 m below sea level. At no place in the Fraser Lowland does the sea at the time appear to have exceeded 300 m, and as indicated by the marine fossils it apparently was shallower throughout much of its existence.
2. The widespread distribution of marine shells, especially the nonbuoyant forms such as *Serpula* and *Balanus*, in most of the glaciomarine sediments indicates that at the time they were living the sunlight could penetrate the water, which it could not do under an ice shelf.
3. The presence of marine shells indicates that the environment during deposition was comparable to that today in Cook Inlet off the coast of Alaska, where piedmont glaciers terminate in the sea and calve as bergs and smaller chunks of ice but do not float as ice shelves.
4. Heusser's (1972) palynological studies in the Kalaloch area of Washington 250 km southwest at the limit of glaciation indicate July temperatures 11 000 to 13 000 years ago of approximately 11°C, which seems too warm for ice shelf development.
5. The lithology of the glaciomarine sediments, their stratification in places, and the interbeds of extensive glaciofluvial deposits and to a lesser extent till diamictons indicate wet base glaciers as a source. These glaciers appear to have undergone surging at various times throughout their history.

Items 1, 2 and 5 are suggested by Carey and Ahmad (1961) as evidence for deposition in the iceberg zone.

Sea ice also may have acted as an agent of transport, especially in the narrow embayments that at times may have frozen over and may not have become ice free until after streams had debouched material on the sea ice.

Sea level changes were complicated; the simplified version of one submergence followed by an emergence must be modified to account for at least two major submergences and intervening emergences. The relative roles played by isostatic, eustatic and tectonic adjustments have not been unravelled, although the magnitude of the changes suggests that isostatic adjustments are probably much the largest.

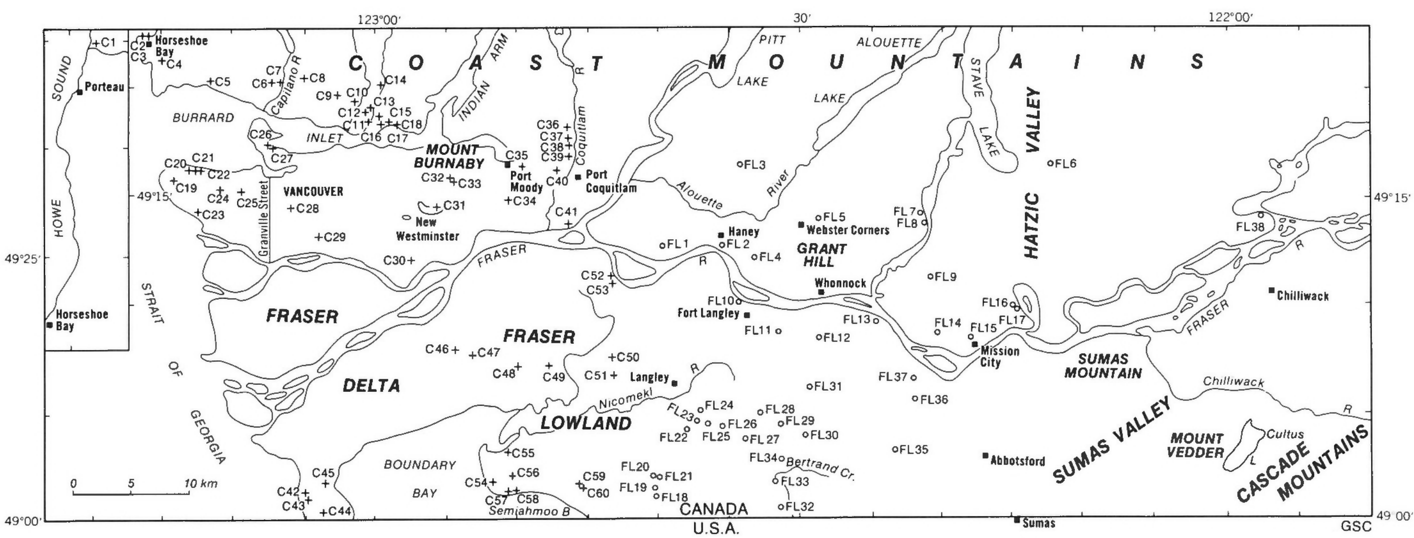
The deposits mapped as Fort Langley Formation and Sumas Drift indicate that at three or more intervals during Fraser deglaciation parts of the eastern and central portions of the Fraser Lowland were overriden by glaciers that in some places may have been subaerial and in others subaqueous, as indicated by a recent find of shells at Bertrand Creek in the ice contact unit (Fig. 3, sec. 7FL). The sandy loam lodgment or flow tills formed by the ice advances contain clasts of glaciomarine sediments. At other times the piedmont glaciers became, at their fronts, intertidal glaciers and as such reshaped and partly redeposited the glaciomarine sediments over which they moved. The resulting material resembles glaciomarine sediments but has a more till-like appearance and may be recognized by flow structures, geomorphology and complete lack of stratification.

Paleoecology of Capilano Sediments and Fort Langley Formation

Previous reports on Pleistocene marine fauna found in the Fraser Lowland include those by Johnston (1923), Crickmay (1925, 1929) and Draycot (1951). Wagner (1959) carried out a comprehensive study of the marine fauna found in both formations; Smith (1970) studied foraminifera from Capilano glaciomarine sediments. Figure 22 shows the location of these sites.

In addition to the above, palynological studies were made by Blunden (1971), who studied pollen found in Capilano Sediments in the Vancouver area, and Mathewes (1973), who examined pollen from Fort Langley Formation near Haney.

Macrofossil studies The faunal list of marine macrofossils as identified by Wagner (1959) is given in Table 3. Wagner did not discuss the variation in abundance of each species at



CAPILANO SEDIMENTS

SITE NO.	LATITUDE	LONGITUDE	ELEVATION (m.a.s.l.)
C1	49°35'	123°13'	41
C2	49°22.7'	123°16.9'	46
C3	49°22.6'	123°16.6'	9
C4	49°21.6'	123°15.8'	~61
C5	49°20.6'	123°12.5'	88
C6	49°20.5'	123°8.2'	~92
C7	49°20.6'	123°7.0'	~151
C8	49°20.7'	123°5.8'	114
C9	49°19.9'	123°3.6'	146
C10	49°19.5'	123°2.3'	~61
C11	49°18.7'	123°1.3'	15
C12	49°19.2'	123°1.3'	58
C13	49°19.3'	123°1.1'	65
C14	49°20.4'	123°0.4'	~127
C15	49°18.9'	123°0.5'	88
C16	49°18 6'	123°0.2'	~8
C17	49°18.6'	122°59.8'	~8
C18	49°18.5'	122°59.4'	~12
C19	49°16.0'	123°15.0'	~88
C20	49°16.6'	123°13.8'	~24
C21	49°16.6'	123°13.5'	~24
C22	49°16.6'	123°13.1'	~15
C23	49°14.5'	123°13.3'	~53
C24	49°15.5'	123°11.7'	~80
C25	49°15.5'	123°10.2'	~24
C26	49°17.6'	123°8.2'	~6
C27	49°17.5'	123°8.1'	~10
C28	49°14.7'	123'6.7'	99
C29	49°13.3'	123°4.9'	~61
C30	49°12.2'	122°57.3'	75

SITE NO.	LATITUDE	LONGITUDE	ELEVATION (m.a.s.l.)
C31	49°14.7'	122°56.4'	~12
C32	49°16.0'	122°55.4'	134
C33	49°15.8'	122°55.3'	114
C34	49°15.0'	122°51.3'	130
C35	49'16.5'	122°50.3'	~91
C36	49°18.3'	122°47.3'	~175
C37	49°17.7'	122°47.2'	69
C38	49°17.6'	122°47.1'	68
C39	49°16.9'	122°47.1'	~53
C40	49°16.3'	122°47.8'	14
C41	49°13.8'	122°47.1'	69
C42	49°1.2'	123°5.3'	~56
C43	49°1.0'	123°5.2'	53
C44	49°0.3'	123°4.2'	48
C45	49°1.7'	123°4.0'	52
C46	49°7.6'	122°54.2'	65
C47	49°7.7'	122°54.1'	70
C48	49°7.1'	122°50.7'	~58
C49	49°7.2'	122°48.5'	11
C50	49°7.6'	122°43.9'	~11
C51	49°6.7'	122°43.8'	~8
C52	49°11.3'	122°44.0'	23
C53	49°11.0'	122°44.0'	35
C54	49°1.7'	122°52.3'	15
C55	49°3.2'	122°51.1'	66
C56	49°2.0'	122'50.8'	93
C57	49°1.5'	122°51.0'	~11
C58	49°1.5'	122°50.5'	~38
C59	49°1.6'	122°46.1'	39
C60	49°1.6'	122°45.9'	40

FORT LANGLEY FORMATION

SITE NO.	LATITUDE	LONGITUDE	ELEVATION (m.a.s.l.)
FL1	49°12.7'	122°40.4'	15
FL2	49°12.8'	122°36.0'	~23
FL3	49°16.5'	122°35'	107
FL4	49°12.1'	122°34.1'	~27
FL5	49°14.0'	122°21.7'	95
FL6	49'17.1'	122°13.8'	140
FL7	49°13.9'	122°29.6'	154
FL8	49°13.6'	122'21.6'	~122
FL9	49°11.1'	122°21.6'	~122
FL10	49°10'	122°35'	12
FL11	49°8.6'	122°32.3'	27
FL12	49°8.4'	122°29.5'	~70
FL13	49°9.1'	122°25.5'	~90
FL14	49°8.6'	122°21.1'	~38
FL15	49°8.3'	122°18.9'	~60
FL16	49°9.7'	122°15.7'	~76
FL17	49°9.6'	122°15.6'	~80
FL18	49°1.0'	122°40.7'	~76
FL19	49°1.2'	122°40.7'	82
FL20	49°1.9'	122°40.7'	41
FL21	49°1.8'	122°40.6'	59
FL22	49°4.1'	122°38.7'	53
FL23	49°4.5'	122°37.9'	40
FL24	49°5.0'	122°37.7'	38
FL25	49°4.3'	122°37.5'	29
FL26	49°4.1'	122°36.1'	~55
FL27	49°3.5'	122°34.7'	~79
FL28	49°4.8'	122°33.6'	~85
FL29	49°4.2'	122°32.1'	99
FL30	49°3.8'	122°30.2'	~115
FL31	49°6'	122°30'	95
FL32	49°0.4'	122°32.1'	~61
FL33	49°1.8'	122°32.2'	~79
FL34	49°2.5'	122°32.1'	~99
FL35	49°2.9'	122°24.2'	114
FL36	49°5.4'	122°22.8'	79
FL37	49°6.3'	122°22.8'	78
FL38	49°6.3'	121°55.3'	46
FL39	49°13.8'	121°58.2'	~20
FL40	49°14.1'	122°33.9'	~38

Figure 22. *Post-Vashon fossil shell localities in the Fraser Lowland.*

Table 3. Marine macrofossils in Capilano Sediments and Fort Langley Formation

Species	Capilano Sediments (50 localities)				Fort Langley Formation (20 localities)
	1*	2	3	4	Glaciomarine and marine sediments
Annelida					
Serpula vermicularis Linné	x(18)**	x(3)	x(3)	x(1)	x(7)
Spirobis sp.					x(1)
Brachiopoda					
Hemithyris psittacea (Gmelin)	x(1)	x(1)			
Cirripedia					
Balanus crenatus Bruguière	x(1)	x(2)		x(1)	x(3)
Balanus sp.	x(11)		x(1)		x(4)
Decapoda					
Unidentifiable specimen	x(2)				
Diatoms					
Unidentifiable specimen	x(4)				
Echinoidea					
Strongylocentrotus drobachiensis Müller	x(7)	x(3)	x(1)		x(3)
Gastrapoda					
Acmaea digitalis Eschscholtz	x(1)	x(1)			
Acmaea pelta Eschscholtz	x(1)				
Acteocina culcitella (Gould)		x(1)			
Alvania compacta Carpenter		x(1)			
Buccinum plectrum Stimpson	x(3)				
Colus jordani (Dall)	x(2)				
Lacuna cf. *L. solidula* Lovén		x(1)			
Lepeta concentrica (Middendorff)	x(1)	x(1)			
Littorina scutulata Gould	x(1)				
Littorina sitkana Phillipi	x(1)				
Littorina cf. *L. scutulata* Gould		x(2)			
Margarites pupillus (Gould)	x(1)	x(2)		x(1)	
Natica aleutica Dall	x(2)	x(1)			x(2)
Natica clausa (Broderip and Sowerby)	x(6)				x(3)
Neptunea lyrata (Gmelin)	x(1)	x(1)			
Neptunea pribiloffensis Dall					x(1)
Odostomia (Evalea) barkleyensis Bartsch		x(1)			
Odostomia ("Amaura") sillana Dall and Bartsch		x(1)			
Oneopota pribilova (Dall)					x(2)
Polinices pallidus (Broderip and Sowerby)	x(2)				
Propebla quadra (Dall)	x(2)				x(2)
Trichotropis cancellata Hinds	x(6)	x(2)			x(4)
Turbonilla (Pyrgolampros) sp.	x(1)	x(1)			

*1,2,3,4 Capilano Sediments have been divided into four environmental types:

1 - Glaciomarine and marine sediments consisting primarily of stony and stoneless clayey silt, silty clay, and silt.
2 - Intertidal fine to medium sand
3 - Beach and lag gravel
4 - Raised marine deltaic deposits: gravel, sand and silt

**(18) Number of localities where species was found.

*** Total number of species identified, does not include those specimens identified by genus only.

Species	Capilano Sediments (50 localities)				Fort Langley Formation (20 localities)
	1*	2	3	4	Glaciomarine and marine sediments
Gastrapoda (Genus only identified)					
Buccinum sp.				x(1)	
?Cerithiopsis sp.		x(1)			
Lora sp.	x(4)				x(2)
Neptunea sp.					x(1)
Odostomia sp.		x(1)			x(4)
Oenopota sp.					
Policines sp.	x(2)	x(1)			
Turbonilla sp.					
Ostracoda					
Unidentifiable specimen	x(4)	x(1)			
Pelecypoda					
Astarte alaskensis Dall			x(1)		
Axinopsida serricata (Carpenter)					x(2)
Axinopsida viridis (Dall)		x(1)			
Chlamys berringianus (Middendorff)	x(1)				
Chlamys hericius (Gould)	x(7)	x(1)			x(3)
Chlamys hindsii (Carpenter)	x(21)	x(3)	x(3)		x(4)
Chlamys cf. C. jordani (Arnold)	x(1)				
Clinocardium blandum (Gould)	x(11)	x(2)			x(1)
Clinocardium ciliatum (Farbicius)	x(13)	x(1)	x(1)	x(1)	x(2)
Clinocardium fucanum (Dall)	x(4)	x(1)			
Clinocardium nuttallii (Conrad)	x(6)	x(2)	x(1)	x(3)	x(2)
Hiatella arctica (Linné)	x(15)	x(3)	x(4)	x(3)	x(9)
Leptonidae, close to Pseudophyina		x(1)			
Macoma calcarea (Gmelin)	x(21)	x(2)	x(1)	x(2)	x(5)
Macoma incongrua (Martens)	x(10)	x(3)	x(2)	x(2)	x(6)
Macoma inconspicua (Broderip and Sowerby)	x(2)			x(1)	
Macoma irus (Hanley)		x(2)			
Modiolus modiolus (Linné)	x(1)	x(1)			x(1)
Mya arenaria Linné	x(1)	x(1)			
Mya truncata Linné	x(15)	x(2)	x(2)	x(4)	x(10)
Mytilus edulis Linné	x(14)	x(3)		x(4)	x(7)
Nucula tenuis (Montagu)	x(4)			x(1)	x(4)
Nuculana fossa (Baird)	x(20)	x(1)	x(1)	x(1)	x(5)
Nuculana minuta (Fabricius)	x(16)	x(2)	x(1)		x(10)
Pandora grandis Dall	x(2)				x(1)
Propeamusium alaskense Dall	x(3)				x(3)
Protothaca staminea (Conrad)	x(1)	x(2)	x(1)	x(2)	x(1)
Saxidomus giganteus (Deshayes)	x(5)	x(3)		x(2)	x(1)
Schizothaerus capax Gould	x(1)	x(1)		x(1)	x(1)
Serripes groenlandicus (Bruguière)	x(17)	x(3)	x(1)	x(2)	x(6)
Spisula voyi (Gabb)		x(1)			x(1)
Yoldia (Yoldiella) keenae n. sp.		x(2)			
Pelecypoda (Genus only identified)					
Astarte sp.		x(1)			
Chlamys sp.	x(5)	x(1)	x(1)		
Clinocardium sp.	x(24)	x(2)	x(6)	x(7)	x(11)
Macoma sp.	x(9)	x(2)	x(2)	x(7)	x(6)
Mya sp.					x(1)
Mytilus sp.	x(2)		x(1)		x(1)
Nucula sp.	x(5)				
Nuculana sp.	x(6)				x(2)
Psephidia sp.	x(1)				
Scaphopoda					
Unidentifiable specimen	x(1)				
Porifera					
Unidentifiable sponge spicules (RKS)	x(1)				
Chordata					
Shark tooth		x(1)			
Fish remains	x(1)				
Number of species ***	(41)	(45)	(13)	(18)	(31)

the localities studied but stated that molluscs were the dominant group, forming roughly 90 per cent of the macrofossils. Table 3 shows which species and genera are the most widespread and how they vary in distribution among the environmental sedimentary units. My observations show that pelecypods constitute 95 to 98 per cent of the specimens in most localities and that 95 per cent of the specimens belong to between two and eight species.

All species, with the probable exception of *Yoldia (Yoldiella) keenae* n. sp., are still living in the waters along the west coast of North America. Also, since the macrofossil assemblages from the different sedimentary facies have many more similarities than differences, the general paleoclimate is probably common to all. Marine macrofossils obtained from both Capilano Sediments and Fort Langley Formation were compared to Holocene fauna, and the conclusions drawn by Wagner are summarized below.

1. To determine the corresponding present-day latitude, and hence the hydroclimate of each fossil assemblage, Wagner used the median-of-midpoints method devised by Schenk and Keen (1937) and revised by Schenk (1945). Wagner concluded that the temperature of the water in which the macrofossils lived compares with that found off the coast of Alaska from about 60.6° to 61.5°N, along the northern reaches of Cook Inlet and Prince William Sound. Malaspina Glacier is now found in this area.
2. Information regarding depth requirements of various species is most inadequate, and the total bathymetric range and the optimum zone within the range are known for only a few species.
3. Most macrofossils found within the area are known to be truly marine, but some are capable of making physiological adjustments for dilutions of up to 50 per cent of normal salinity.

Lack of the most important data, the modal point of depth range for each species, prevents the application of statistical methods in determining the depth for each assemblage. The median-of-midpoints method is not suitable because for some species where the optimum depth is known, the midpoint of depth is found to differ greatly from the optimum. This is true for the majority of macrofossils found in the area, except for species having a very limited depth range. Wagner estimated that all the sediments in which the assemblages are found represent shallow water deposition not exceeding 20 m, and generally the depth seems to have been less, suggesting a bay or estuarine habitat.

It is suggested that many of the species are free-swimming forms; this raises the possibility that some sank after death and were incorporated in sediments accumulating in water much deeper (up to 300 m+) than where the species preferred to live.

Microfossil studies The faunal list of marine microfossils identified by Smith (1970) is given in Table 4.

Table 4. Marine microfossils in Capilano Sediments and Fort Langley Formation

Species	Capilano Sediments	Fort Langley Formation
	(3 localities) glaciomarine and marine sediments	(1 locality) marine sediments
Foraminifera		
Angulogerina fluens (Todd)	0(2)	
Angulogerina hughesi (Galloway and Wissler)	0(2)	
Buccella frigida Cushman	*(1)x(1)0(1)	*
Buccella frigida Cushman(?)	0(1)	
Buccella tenerrima (Bandy)	*(1)0(2)	
Cassidulina barbara Buzas	*(1)0(1)	0
Cibicides lobatulus (Walker and Jacob)	**(1)x(1)	
Discorbis (?) spp.	0(1)	
Dyocibicides biserialis (Cushman and Valentine)	0(1)	
Elphidiella arctica (Parker and Jones)		0
Elphidiella nitida Cushman		0
Elphidium bartletti Cushman	0(2)	
Elphidium clavatum Cushman	**(3)	**
Elphidium spp.		
Epistominella vitrea Parker	0(2)	
Fissurina lucida (Williamson)	0(1)	
Fissurina cf. *F. marginata* (Montagu)	0(1)	
Fursenkoina fusiformis (Williamson)	0(1)	
Globigerina bulloides d'Orbigny	0(1)	
Islandiella teretis (Tappan)	**(1)*(1)0(1)	
Islandiella teretis (Tappan)(?)	x(1)	0
Lagena distoma Parker and Jones	0(1)	
Lagena gracillima (Seguenza)	0(2)	
Lagena mollis Cushman	0(2)	
Lagena parri Loeblich and Tappan	0(1)	
Lagena perulcida (Montagu)(?)	0(1)	
Lagena semilineata Wright	0(2)	
Lagena substriata Williamson	0(1)	
Lenticulina sp.	0(1)	
Nonionella auricula Heron-Allen and Erland	?	
Nonionella turgida digitata Nϕrvang	0(1)	
Nonionella (?) spp.	0(1)	
Nonionelliana labradorica (Dawson)	x(1)0(1)	
Oolina apiopleura (Loeblich and Tappan)	0(1)	
(?)*Protelphidium pauciloculum* (Cushman)	0(2)	
Protelphidium orbiculare (Brady)	0(1)	
Pyrgo lucernula (Schwager)	0(1)	
Pyrgo(?) cf. *P.lucernula* (Schwager)	0(2)	
Quinqueloculina akneriana bellatula Bandy	0(1)	
Quinqueloculina cf. *Q. stalkeri* Loeblich and Tappan	0(1)	
Quinqueloculina stalkeri Loeblich and Tappan	x(1)0(1)	
Rheophax longicollis (Wiesner)	0(1)	
Triloculina inornata d'Orbigny	0(1)	
Uvigerina cushmani Todd	x(1)0(1)	
Number of species	41	6

Smith denoted the abundance of a species as follows:
**Abundant *Common x Few 0 Rare

(2) Number of localities where species was found.

Following are the results of one example in which Smith counted the number of specimens of each species contained in an unwashed 60 cm^3 sample yielding the faunal collection listed under Fort Langley Formation (Table 4).

Elphidium clavatum Cushman	**(abundant)	1514
Buccella frigida Cushman	*(common)	630
Elphidiella nitida Cushman	0(rare)	3
Elphidiella arctica (Parker and Jones)	0(rare)	1
Islandiella teretis (Tappan)	0(rare)	1
Cassidulina barbara Buzas	0(rare)	1

Smith's conclusions can be summarized as follows: Forty-one species of foraminifera were identified from the three collections obtained from the Capilano Sediments and six species were identified from one collection from the Fort Langley Formation. *Elphidium clavatum* dominates in all four assemblages and constitutes approximately 35 to 75 per cent of the specimens. *Islandiella teretis* and *Cibicides lobatulus* are both abundant in one Capilano assemblage. *Buccella frigida*, *Buccella tenerrima* and *Islandiella teretis* are all common in one other Capilano assemblage, and *Buccella frigida* is common in the Fort Langley assemblage. The dominant species *Elphidium clavatum* thrives in salinities ranging from approximately 30 to 35 per cent (normal marine), to approximately 15 per cent. It is abundant through a limited depth range, reaches a maximum abundance above 15 m and decreases remarkably at about 30 m. The subdominant species *Buccella frigida* and *Buccella tenerrima* have ecological tolerances similar to *Elphidium clavatum*, but their present-day environment indicates that they normally do not live in waters with salinities below 20 per cent. Also they are usually found in water slightly deeper (20 to 50 m) than is *Elphidium clavatum* (less than 15 to 30 m). *Islandiella teretis*, a common subdominant species, is today most widespread and abundant in northern high-latitude, shallow waters (less than 15 m) but also may thrive in deeper water. The subdominant species live with *Elphidium clavatum* at salinities of approximately 20 per cent. Another subdominant species *Cibicides lobatulus* is abundant in one Capilano assemblage and is widely recorded from shallow water arctic Quaternary deposits. Its type locality today is the shore sands of southern England.

The three Capilano assemblages contain 9, 25 and 30 species. Characteristically very shallow, cold waters of normal marine salinities do not show relatively great diversity of species; 20 to 40 species is average in the Pacific Northwest today, and assemblages containing less than 20 species indicate a variation from the normal marine environment. The Fort Langley Formation assemblage of 6 species and the Capilano Sediments assemblage of 9 species indicate very shallow (perhaps less than 15 m) cold waters with reduced salinities. This conclusion is based on the fact that *Elphidium clavatum* dominates all the samples. Progressive decreases in diversity of species, in combination with continued abundance of *Elphidium clavatum*, indicate progressive decreases in salinity from normal marine down to about 15 per cent. The Capilano Sediments assemblages of 25 and 30 species indicate salinity was normal marine and the water probably less than 30 m and certainly less than 60 m deep.

It is suggested that the variations determined by Smith resulted from geomorphological and climatic changes during late Wisconsin deglaciation. The two low-diversity assemblages are approximately 25 km east of the two normal assemblages and were nearer the melting ice that probably caused reduced salinities.

The foraminifera collections studied by Smith are characteristic of the Quaternary foraminiferal fauna found around the world in very shallow water at high northern latitudes. The fauna extends in time from the beginning of the Pleistocene to the present. Depth limits are from approximately low tide to 100 m although the fauna is best developed above 60 m and more probably above 30 m depth. Salinities range from 30 to 35 per cent (normal marine) down to 15 per cent with progressive decrease in species diversity with salinity decrease. Water temperatures are variable for this fauna, with yearly extremes, and the only factor in common appears to be a temperature of about 0°C for part of the year.

Palynological studies

Fort Langley Formation near Haney. Mathewes (1973) recovered palynomorphs from Fort Langley marine silty clay outcropping at an elevation of 107 m in the University of British Columbia Research Forest north of Haney. Marine fauna from this clay gave a radiocarbon date of 12 690 ± 190 years (I-5959). The samples contained about 5000 pollen and spores per gram of wet sediment. The floral list of palynomorphs as identified by Mathewes is given in Table 5.

Rare pollen types encountered after the original count of 500 grains was completed include *Tsuga heterophylla*, *Shepherdia canadensis*, Gramineae, Compositae (Tubuliflora) and *Typha latifolia*.

Mathewes concluded that this assemblage seemed to indicate that pollen from the deposit reflected nearby successional vegetation, and he stated: "Reworking of older Pleistocene deposits is an unlikely source for these pollen and spores because grains observed in this study were both well preserved and abundant. Long-distance dispersal may account for some of the palynomorphs, but in view of their concentration of 5000 per cubic centimeter, a local origin is more plausible. Whether the observed pollen concentration reflects abundant or sparse terrestrial vegetation is unknown, and only a detailed study of modern marine deposits in the Fraser Lowland area could provide a means of comparison and interpretation."

Table 5. Palynomorphs in Fort Langley marine clay

	Per cent of total pollen and spores counted, 500 grains
Trees and shrubs	
Pinus contorta type	91.0
Abies	1.0
Picea	1.2
Tsuga mertensiana	0.4
Alnus	1.6
Angiosperms	
Artemisia	0.8
Polygonaceae	0.4
Onagraceae	0.2
Compositae (Liguliflorae)	0.2
unknown	0.4
Cryptograms	
Monolete Polypodiaceae	1.4
Polypodium vulgare type	0.8
Crytogramma	0.2
Lycopodium annotinum	0.2
Selaginella wallacei type	0.2

I believe that at the time the marine clay containing the palynomorphs was deposited, approximately 12 700 years BP, the Vashon continental ice had retreated well back into the Coast Mountains and the sea had invaded the area to elevations of 200 m or more. The extent of the retreat has not been documented but in the fiord valleys it is measurable in tens of kilometers, and on the southern slopes of the Coast Mountains between several hundred and several thousand meters elevation were free of ice and consequently available for vegetative growth.

Mathewes (1973) concluded: "The results of this investigation indicate that soon after the Vashon ice started to retreat from the Fraser Lowland about 13 000 years ago, vegetation quickly recolonized the deglaciated terrain in the area of the UBC Research Forest. By 12 690 ± 190 BP a fairly diverse palynomorph assemblage dominated by *Pinus contorta* type pollen was preserved in a marine clay. Whether these early immigrants to the Fraser Lowland existed only along a near-ocean strip or also in upland areas is unknown."

Marion and Surprise lakes. Mathewes (1973) also made comprehensive palynological studies of the sediments found in two small lakes, Marion Lake at 305 m elevation and Surprise Lake at 540 m, located respectively 4.7 km northeast and 5 km north of the marine clay site discussed above. The oldest dated material from Marion Lake is about 12 350 ± 190 years old (I-5097) and from Surprise Lake 11 230 ± 230 years old (I-5816).

His conclusions with regards to the Marion Lake and Surprise Lake palynomorphs are:

> Marion Lake at 305 m elevation was ice-free sometime before 12,350 ± 190 B.P., when pollen of lodgepole pine, *Shepherdia canadensis* (Buffalo berry), willow, and alder were deposited in clay underneath the first dateable organic sediment. The earliest organic sediments record abundant lodgepole pine pollen associated with fir, spruce, and mountain hemlock until about 10,370 ± 145 B.P. Cool and moist conditions are indicated for this interval, which seems to record the replacement of shade-intolerant lodgepole pine by more shade-tolerant conifers. High percentages (31% of total alder) of four-pored alder grains from this period suggest that mountain alder (*Alnus incana*) may have been present in the U.B.C. Research Forest at this time.

The sudden appearance of abundant Douglas fir pollen around 10,500 years ago at Marion and Surprise Lakes is associated with decreases in lodgepole pine, fir, spruce, and mountain hemlock. A trend toward warmer and perhaps somewhat drier conditions at this time may have favored Douglas fir, but high alder pollen with macrofossils of *Thuja* and *Isothecium stoloniferum* indicate abundant moisture.

Vancouver. Blunden (1971) reported palynomorphs in the "Gumboot" (Capilano Sediments) diamictons (in part bedded) and intercalated clays, silts, varved silts and seams of sand and gravel that overlie Vashon Drift deposits and underlie beach and lag gravel. I have grouped all late Wisconsin deposits above Vashon Drift with the Capilano Sediments, including beach and lag gravel. Blunden stated that Holocene type *Pinus*, *Picea* and *Tsuga* pollen were common in the diamictons although he does not define what he means by 'common'. He included the following quote in his report, although no source was given: "The 'Gumboot' diamictons appear to have been laid down in the midst of a forest not dissimilar from the present natural forest." He also paraphrased Heusser (1960) and stated, "At this time the indicated climate was both cooler and wetter than at present, but not frigid." Blunden also listed "rare" occurrences of *Pinus*, *Picea* and *Abies* pollen from the Sumas Drift north of Abbotsford Airport.

Fraser deglaciation sea level changes and geological interpretation

Previous work. Mathews et al. (1970) attempted to reconstruct the post-Vashon (as defined in this report) sea level changes in southwestern British Columbia and adjacent Washington State; Figure 23 is a modified version of the relative sea level curve drawn by them for the Fraser Lowland. Their curve was derived in part from my previous work and has been modified only to a minor extent as a better understanding of the post-Vashon geology has become available. Mathews et al. (1970) indicated the following history: A major submergence of 200 m or more occurred about 13 000 years ago following retreat of Vashon ice. This was followed by a rapid emergence of at least 150 m by about 12 000 years BP. The area apparently was submerged again more than 100 m during the next 500 years, that is up to about 11 500 years BP, when the Sumas ice commenced its advance. During and following this advance the land emerged again, and a sea level within 10 to 15 m of the present level was established about 11 000 years ago. Mathews et al. suggested as one possibility that the pre-Sumas submergence might be isostatic because of buildup of ice in the adjoining mountains prior to the Sumas climax.

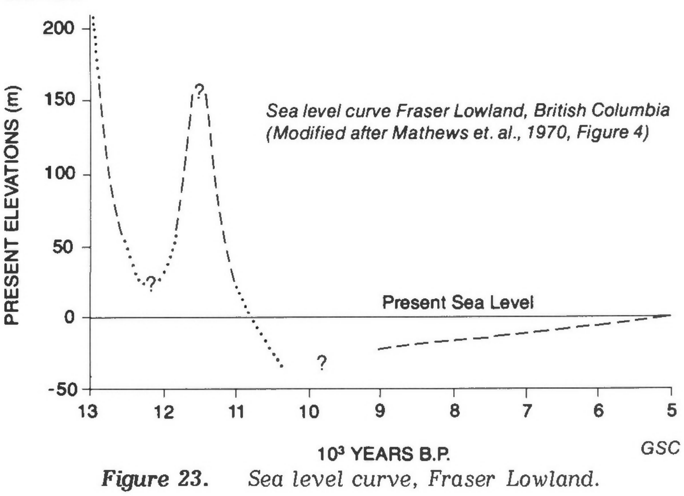


Figure 23. *Sea level curve, Fraser Lowland.*

Easterbrook (1963a) inferred a somewhat similar sequence of sea level changes in the Nooksack River area, a few kilometres south of the Canada - United States Border at Sumas.

Blunden (1975) published another curve showing the post-Vashon sea level changes in the western part of the Fraser Lowland and adjoining Coast Mountains. His curve varies considerably from the version produced by Mathews et al. He envisaged the first submergence in the Vancouver area about 12 500 years ago and a second submergence in the Coast Mountains of up to 330 m about 10 000 years ago. Blunden offered no substantial proof for his curve showing sea level changes nor is it stated why he did not accept, at least in principle, the prior interpretation.

Present work. In drawing the sea level shift curve for the post-Vashon deglaciation period the following criteria were used:

(1) the distribution of glaciomarine sediments containing relatively undisturbed fossil shells, some of which were found in living positions;
(2) the widespread occurrence of Capilano beach and lag gravel and littoral (intertidal) sand;
(3) radiocarbon dates on fossil shells;
(4) strandlines developed on Capilano Sediments and marked in many places by marine terraces; and
(5) strandlines found in Fort Langley raised marine deltas including those overlain by younger glaciomarine and marine sediments.

Fossils and radiocarbon dates. The distribution of glaciomarine and marine sediments (Fig. 1) and fossils (Fig. 22) is widespread. Many of the shell collections contain Annelida and Cirripedia, commonly unbroken and attached to dropstones, confirming that some lived in the area after the stones had been dropped. For example, 25 of the 50 fossil collections studied from the Capilano Sediments and 8 of the 20 fossil collections studied from the Fort Langley Formation contain Annelida; Cirripedia are also common and have been identified in 23 of the 70 fossil collections (Table 3).

Radiocarbon dates (Table 6), especially on shell collections, when studied in relation to the elevations at which the dated materials are found, definitely suggest more than one post-Vashon sea level submergence and subsequent emergence. The radiocarbon dates obtained from Capilano shell collections do not present a fully documented picture of sea level changes, but they do seem to indicate more than one submergence and subsequent emergence. Relative sea level was at its maximum height, more than 200 m, about 13 000 years BP immediately following the retreat of Vashon ice. With one submergence and emergence the oldest sediments should be at higher elevations and the younger sediments at lower elevations; however, a study of the radiocarbon dates from Capilano Sediments (Table 6) shows that this is not the case.

The second submergence or pre-Sumas submergence, as it was termed by Mathews et al. (1970), is not well documented in the Canadian part of the Fraser Lowland; however, the four radiocarbon dates on samples from the Fort Langley deposits seem to support this second submergence; the older dates, 12 900 ± 170 years at 154 m (GSC-2193) and 12 690 ± 190 years at 107 m (I-5959), appear to relate to the emergent stage of the first submergence; the two younger dates, 11 930 ± 190 years at 12 m (GSC-168) and 11 680 ± 180 years at 95 m (GSC-186), appear to relate to the submergent stage of second submergence. The younger and higher sample GSC-186 is stratigraphically above the older and lower sample GSC-168, as would be the case with a second submergence but would not be the case if only one post-Vashon submergence and emergence took place.

Strandlines. Fourteen well developed terraces have been mapped in the lower Capilano River basin (Fig. 11) in the raised delta deposits, and of these seven are definitely marine in origin and mark stands of the sea. The remaining seven likely have a marine origin; however, the possibility that they are terraced river floodplains cannot be excluded. Several more terraces occur in the upper Capilano River valley at higher elevations, although no proof has been found that they are marine. The seven terraces mark seven stands of the sea (strandlines) at elevations of 185, 155, 105, 90, 60, 40 and 25 m. These strandlines are at the back of the terraces at the contact of the true deltaic deposits with the overlying intradelta platform deposits. The platform surfaces of all the terraces are 5 to 10 m higher at the back than at the front.

The strandlines at 185 m and 155 m likely were formed during the emergence of the land following the first submergence by the sea, that is, from 13 000 to about 12 000 years BP. The strandlines at 105, 90, 60, 40 and 25 m probably were formed during the second submergence and emergence. The two higher strandlines are found along the flanks of the Coast Mountains from Howe Sound 50 km eastward as far as Webster Corners where a raised marine delta mapped as Fort Langley sediments has two well marked strandlines at 185 m and 155 m. Glaciomarine sediments have been found up to 155 m elevation as far east as the Hatzic Valley 75 km east of Howe Sound. Assuming deposition occurred in 30 m of sea water, these deposits could be related to the 185 m strandline. The lower strandlines, which were formed during the second submergence, are exposed not only in raised marine deltas along the Capilano, Seymour and Coquitlam rivers but throughout the western part of the Fraser Lowland where Capilano Sediments are at the surface. In some areas well defined terraces are associated with these former strandlines, but in others their trace is visible only on aerial photographs. Distinct marine terraces are found at the 40 m strandline on south Granville Street at 15th Avenue in Vancouver and also crossing Highways 99 and 99A, 1.5 km from the Border. Aerial photographs of the latter area show at least 20 strandlines, of which only a few are marked by terraces and most are difficult to identify on the surface.

In the area underlain by Fort Langley sediments buried strandlines are found at 105, 90 and 60 m. These strandline elevations were measured at the lower contact of the intradelta platform deposits, which overlie foreset deltaic sediments. The marine delta south of Langley probably represents the 40 m strandline although the surface of the platform is approximately 5 m higher. The 105, 90 and 60 m strandlines apparently were developed during the second submergence and the 40 m strandline during the second emergence. The 25 m strandline in the Capilano basin probably formed at this time.

The discussion and interpretation of strandlines is oversimplified, and the complete story may be more complex.

Conclusion. Figure 24, hypothetical geological section in the central Fraser Lowland, is an attempt to show the relationship of Sumas Drift, Fort Langley Formation and Vashon Drift based on two major post-Vashon submergences. The Fraser Lowland includes, in addition to Fraser River valley, several valleys about 5 km wide, 30 km long and more than 300 m deep, which were arms of the sea from pre-Vashon to post-Sumas time. The valley stretching from Fort Langley to Boundary Bay is one such example. Figure 24 shows the relationship of one such valley to the bordering hills. Possibly the valleys represent fiords formed by pre-Vashon glaciation and modified by Vashon glaciation. They acted as settling basins for pre- and post-Vashon marine and glaciomarine deposits.

I have attempted to show how my material fits into the modified curve of Mathews et al. (1970). Evidence exists, however, for several additional piedmont ice advances that are post-Vashon and pre-Sumas in age and for related submergences of unknown magnitude; therefore the curve (Fig. 23) is probably oversimplified. At present the relative significance and timing of isostatic, eustatic and tectonic movements is speculative only. Isostatic movements probably were the largest and were dominant at the beginning of deglaciation.

History of Fraser River

The post-Vashon history of Fraser River was controlled by deglaciation and subsequent sea level changes. In the past some writers assumed that all gravel and sand deposits found in the Fraser Lowland were carried to their present position by Fraser River. A study of pebble provenance, however, illustrates the invalidity of such an assumption. The pre-Vashon history of Fraser River is largely unknown.

Provenance of Fraser River gravel. A study was made of the pebble lithology of gravel bars found in Fraser River between Chilliwack and Hope. An examination of the pebble provenance histogram shows that Fraser River gravel lithology varies greatly from those of all the other lithologies illustrated in Figure 20. The contrast is most marked in the percentage of quartzite pebbles; the Fraser River gravel consists of about 25 per cent quartzite whereas the other deposits contain from 1 to 5 per cent quartzite. The quartzite probably came primarily from the Cariboo area, which lies several hundred kilometres north of Hope. In the Cariboo Mountains the Cambrian and late Precambrian formations are characterized by quartzite, and late Tertiary and Quaternary gravels in the Prince George - Quesnel area normally contain 50 to 90 per cent quartzite pebbles (personal observation).

No good source of quartzite is to be found in the Coast and Cascade mountains bordering the Fraser Lowland and the pebble lithologies of the Sumas, Fort Langley, Capilano and Vashon gravels reflect this (Fig. 20).

Pre-Vashon history of Fraser River. If the lithology of present-day Fraser River gravel is considered to be representative of pre-Vashon Fraser River gravel, no proof of a pre-Vashon Fraser River has been found in the Fraser Lowland.

At this stage in the geological studies of British Columbia the existence of an ancestral pre-Vashon Fraser River resembling the present-day river is strictly a subject of speculation. The Fraser Glaciation obviously rearranged much of the drainage pattern of British Columbia, although the large valleys, including that occupied by the present-day Fraser River, must have supplied the major control to the pre-Vashon drainage pattern. I believe that prior to Fraser Glaciation there was no ancestral Fraser River in the Fraser Lowland. For example, during part of Semiahmoo time (Fig. 2) the sea occupied parts or all of the Fraser Lowland as far east as Chilliwack.

Post-Vashon history of Fraser River. If present-day sea level were 10 m higher, Fraser River would enter the sea east of Chilliwack, which is 80 km east of Vancouver. A large arm of the sea would extend southwest down Sumas Valley and across the International Boundary to Bellingham Bay, 60 km from Chilliwack. The modern Fraser Delta would be found in this arm of the sea. No deltaic deposits underlie Sumas Valley. Apparently Fraser River never had such a scenario in post-Vashon time for two main reasons.

Table 6. Post-Vashon radiocarbon dates, Fraser Lowland

Locality of dated material (Fig. 25)	Laboratory dating number[1]	Radiocarbon years B.P.	Location		Elevation	Material	Collector[2]	Comments
				FORT LANGLEY FORMATION				
1	I-5959	12 690 ± 190	49°16.5'N	122°35'W	107	marine shells in glaciomarine sediments	RWM	sediments contain abundant pollen; sea level at time of deposition >107 m
2	GSC-168	11 930 ± 190	49°10'N	122°35'W	12	marine shells in marine sediments	JEA	sea level at time of deposition >12 m, probably less than 30 m
3	GSC-186	11 680 ± 180	49°06'N	122°30'W	95	marine shells in glaciomarine sediments	JEA	sea level at time of deposition > 95 m
4	GSC-2193	12 900 ± 170	49°13.9'N	122°29.6'W	154	marine shells in silt in proglacial delta	JEA	sea level at time of deposition >154 m
	GSC-2842	11 700 ± 120	49°03.8'N	122°28.2W	87	wood in glaciomarine sediments	ECH	sea level at time of deposition >87 m
				CAPILANO SEDIMENTS				
5	I(GSC)-248	12 800 ± 175	49°0.3'N	123°04.2'W	48	marine shells in glaciomarine sediments	JEA	sea level at time of deposition >48 m
6	I(GSC)-248 (rerun)	12 600 ± 170	49°0.3'N	123°04.2'W	48	marine shells in glaciomarine sediments	JEA	sea level at time of deposition >48 m
7	I(GSC)-6	12 625 ± 450	49°01'N	122°46'W	39	marine shells in glaciomarine sediments	JEA	sea level at time of deposition >39 m, probably less than 60 m
8	GSC-226	11 590 ± 280	49°02'N	122°47'W	58	wood in glacio-marine sediment	JEA	this date is approximately 1000 years younger than that obtained on shells believed to be living at the same time I(GSC)-248 rerun
9	GSC-64	12 460 ± 170	49°08'N	122°55'W	65	marine shells in a silt layer in offshore bar deposit	JEA	sea level at time of deposition 65-70 m

10	GSC-2177	12 000 ± 100	49°17.6'N	122°47.1'W	68	marine shells in a silt layer in a raised marine delta	JEA	sea level at time of deposition 70+m
11	L-391C	11 900 ± 300	49°16'N	122°56'W	134	marine shells in glaciomarine sediment	JEA	sea level at time of deposition >134 m
12	GSC-227	11 300 ± 190	49°35'N	123°13'W	41	marine shells in a stony silt layer in a marine ice-contact delta	JEA	sea level at time of deposition 41-46 m
13	GSC-185	10 690 ± 180	49°35'N	123°13'W	41	wood from same layer as GSC-227	JEA	this date is approximately 600 years younger than that obtained on shells in the same bed (GSC-227)
	GSC-2604	12 700 ± 150	49°07.7'N	122°54.1'W	70	marine shells in glaciomarine sediments	JEA	sea level at time of deposition >70 m
	GSC-2612	12 600 ± 120	49°16.3'N	122°48.7W	91	marine shells in glaciomarine sediments	JEA	sea level at time of deposition >91 m
	GSC-3124	13 500 ± 220	48°58.9'N	123°01.5'W	53	marine shells in sandy silty till-like mixture	SRH	sea level at time of deposition >53 m (first area to be clear of Vashon ice)
				SUMAS DRIFT				
14	L-331B	11 700 ± 150	49°11'N	122°9'W	35	wood from ice-contact deposits	JEA	maximum age, Sumas Drift
15	L-331A	11 450 ± 150	49°12'N	122°9.7'W	160	wood from ice-contact deposits	JEA	maximum age, Sumas Drift
16	GSC-1675	11 600 ± 275	49°06.3'N	122°22.8'W	78	wood from diamicton	WHM	maximum age, Sumas Drift
17	L-221E	11 000 ± 900	49°06.3'N	122°22.8'W	78	wood from same diamicton as GSC-1675	JEA	Maximum age, Sumas Drift
18	L-221D	11 500 ± 1100	49°04'N	122°11.5'W	91	wood from diamicton	JEA	Maximum age, Sumas Drift
19	GSC-1695	11 400 ± 170	49°09.8'N	112°16'W	98	wood from diamicton	WHM	Maximux age, Sumas Drift
20	L-339C	10 950 ± 200	49°09.8'N	122°16'W	98	wood from same diamicton as GSC-1695	JEA	Maximum age, Sumas Drift

Locality of dated material (Fig.25)	Laboratory dating number[1]	Radiocarbon years B.P.	Location		Elevation	Material	Collector[2]	Comments
			SALISH SEDIMENTS (Postglacial at site)					
			Salish radiocarbon dates pertaining to sea level changes and deglaciation					
21	I-5346	11 000 ± 170	49°29.5'N	121°26'W	317	gyttja in post-glacial lake	RWM	post-Sumas Drift in age
22	I-6057	11 430 ± 150	49°29.5'N	121°26'W	311	gyttja in post-glacial lake	RWM	Minimum age, Sumas Drift
23	I-6058	11 140 ± 260	49°29'N	121°24.3'W	194	gyttja in post-glacial lake	RWM	Minimum age, Sumas Drift
24	I-5097	12 350 ± 190	49°18.5'N	122°32.7'W	296	gyttja in post-glacial lake	RWM	Minimum age, Sumas Drift
25	I-6820	10 370 ± 145	49°18.5'N	122°32.7'W	298	gyttja in post-glacial lake	RWM	post-Sumas Drift
26	I-5816	11 230 ± 230	49°19.2'N	122°34.5'W	535	gyttja in post-glacial lake	RWM	Minimum age, Sumas Drift
27	I-6967	10 340 ± 155	49°19.2'N	122°34.5'W	536	gyttja in post-glacial lake	RWM	post-Sumas Drift
28	GX-904	11 780 ± 180	49°15.5'N	123°12'W	82	basal peat in postglacial bog	GER	Minimum age, Capilano Sediments
29	GSC-519	10 430 ± 150	49°05'N	122°47.5'W	-32	marine shells in fine grained sediment	ECH	probably postglacial estuarine deposits
30	GSC-228	9420 ± 180	49°15'N	122°56'W	10	peat in post-glacial bog	WHM	postglacial
31	GSC-225	8360 ± 170	49°02'N	122°16'W	-9	woody plants from postglacial silt	ECH	sea level at least 10 m lower than present
32	GSC-229	8290 ± 140	49°13'N	122°42'W	-10.4	postglacial peaty silt	JEA	sea level at least 11 m below present
33	S-99	7300 ± 120	49°13'N	122°48'W	-10.3	postglacial peaty silt	WHM	sea level at least 11 m below present
34	GSC-395	6790 ± 150	49°2.5'N	123°04'W	-14	marine shells in fine grained sediment	JEA	glaciomarine estuarine deposits

[1] Laboratories:
GSC - Geological Survey of Canada, Ottawa
GX - Geochron Laboratories, Boston, Mass.
I,I(GSC) - Teledyne Isotopes, Westwood, N.J.
L - Lamont-Doherty Geological Observatory, Palisades, N.Y.
S - Saskatchewan Research Council, Saskatchewan

[2] Collectors:
JEA - J.E. Armstrong, Geological Survey of Canada
ECH - E.C. Halstead, Department of Environment
GER - G.E. Rouse, University of British Columbia
RWM - R.W. Mathewes, Simon Fraser University
WHM - W.H. Mathews, University of British Columbia
SRH - S.R. Hicock, University of Western Ontario

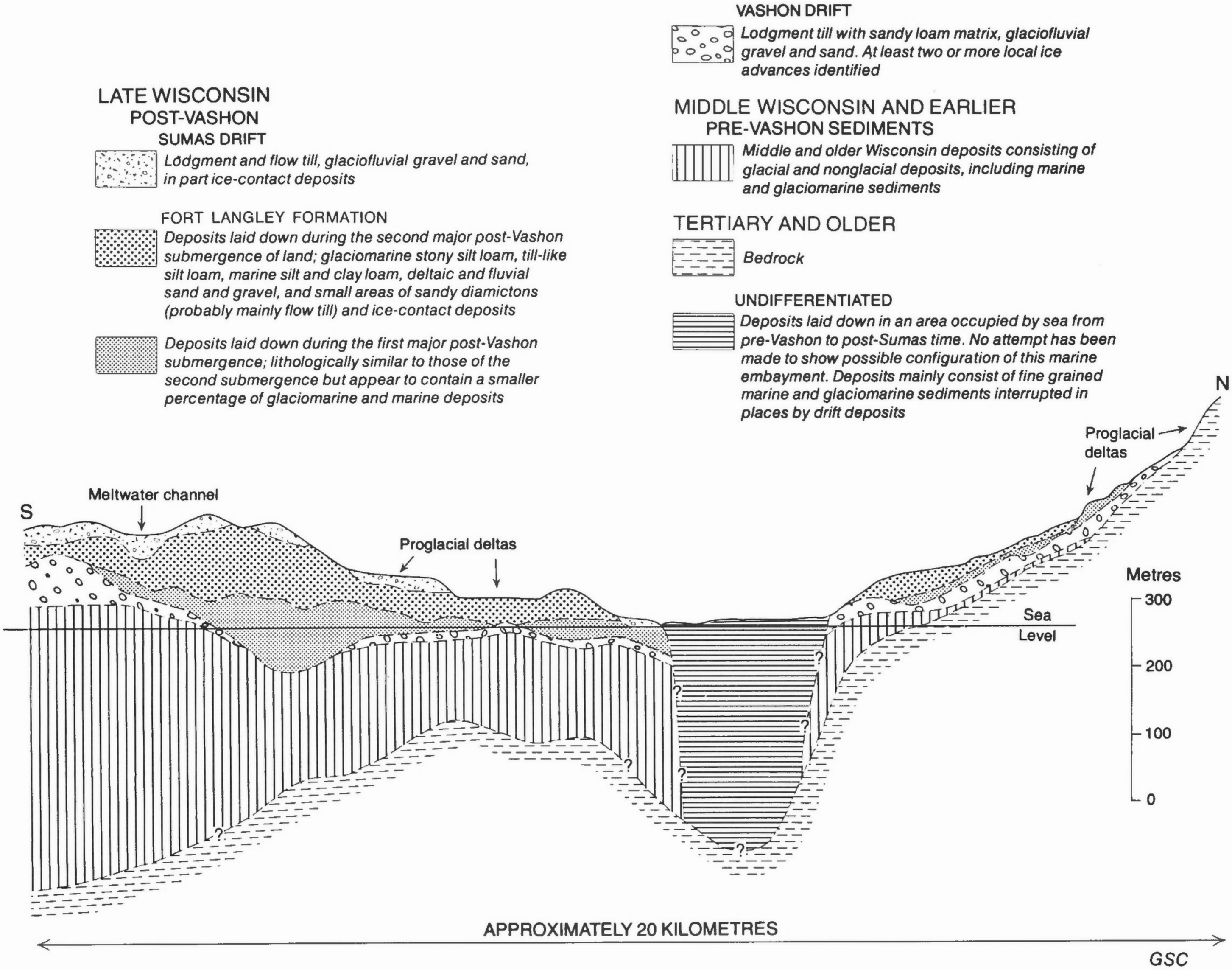


Figure 24. *Hypothetical section, central Fraser Lowland, showing stratigraphic relations of Sumas Drift, Fort Langley Formation, and Vashon Drift.*

First, when sea level was 10 m or more higher than that at present, that is from 11 000 to 13 000 BP, the eastern part of the Fraser Lowland was occupied by Sumas and Fort Langley ice and no Fraser River existed as such. Second, when the ice finally left the area, the land was as high as or higher than at present and meltwater rivers had established a channel to the north which later was occupied by Fraser River.

Fraser River did not enter the Fraser Lowland until the Sumas ice had disappeared completely. During its final stages of decay a block of Sumas ice occupied Sumas Valley after the main body of the Sumas glacier had retreated east of Chilliwack, and at this time, probably about 11 000 years ago, meltwater rivers flowing from the Sumas ice remaining east of Chilliwack formed the ancestral valley now occupied by Fraser River from Chilliwack to the Fraser Delta. If the Sumas Valley ice block had not existed, the natural course of the Sumas meltwater rivers would have been southwest down Sumas Valley.

From about 10 800 to 5000 years BP sea level was up to 12 m lower than at present, permitting Fraser River to establish itself in the old meltwater channel. From my evaluation of all the dates assigned to the commencement of the formation of the Fraser Delta, the period between 9000 and 10 000 years BP best fits the evidence.

Radiocarbon dates

Table 6 lists the radiocarbon dates obtained on shells and wood from the Fort Langley, Capilano and Sumas formations as well as dates obtained from postglacial peat bogs and gyttja deposits. (Locations of the samples used for radiocarbon dating are given in Figure 25.) Probably many of the dates on the latter are postglacial only at the sample site, and glacial ice was nearby. It is my belief that the deposition of sediments during Fraser deglaciation spanned about 2000 radiocarbon years, that is, approximately from 13 000 to 11 000 years BP. Although this conclusion seems reasonable, a study of the dates illustrates several major discrepancies and errors of more than 1000 years might exist. These errors could be due to laboratory procedures, contamination of specimens, the difficulty in obtaining reliable dates on shells and the discrepancy between radiocarbon dates obtained on shells and wood from the same section.

The major discrepancies are as follows:

1. Dates obtained on shells and wood from the same strata are incompatible. Samples GSC-227 (shells) and GSC-185 (wood), which yielded dates of 11 300 ± 190 and 10 690 ± 180 years, are from the same bed. Samples I(GSC)-6, 12 625 ± 450 years (shells) and GSC-226, 11 590 ± 280 years (wood) are from the same sediments. Because the shells are autochthonous and the wood allochthonous, the wood should be older.

2. Dates obtained on shell specimens from various elevations and thought to be of different stratigraphic ages give approximately the same radiocarbon age. For example, compare the following specimens: GSC-2177, elevation 68 m, 12 000 ± 100 years; L-391C, elevation 134 m, 11 900 ± 300 years; GSC-168, elevation 12 m, 11 930 ± 190 years. All three sites are believed to represent shallow waters of less than 40 m.

3. Some of the radiocarbon dates obtained on postglacial peat and gyttja samples are older than dates on samples from Fraser deglaciation sediments. For example, the oldest postglacial date on gyttja from a lake at 297 m is 12 350 ± 190 years (I-5097); shells in Fort Langley clayey silt on the same hillside at 107 m elevation dated 12 690 ± 190 years (I-5959). This anachronism may result from the inaccurate dates. However, ice apparently remained in the eastern part of the Fraser Lowland after most of the western part had risen above sea level and forests were growing on some mountain slopes above inundated areas (Mathewes, 1973; Blunden, 1971). These conditions might explain some of the anomalous dates.

Notwithstanding the above discrepancies the sample dates on which the ages of the stratigraphic units laid down during Fraser deglaciation (post-Vashon) are based are shown in Table 6. The post-Vashon stratigraphy and radiocarbon dates are summarized in Table 7.

Correlation. The correlations suggested in Table 8 between the Pacific Northwest and the Great Lakes regions may be illusory as a result of the difficulty encountered interpreting radiocarbon dates, the relatively short time span involved in the deglaciation, and the variations in local climate. An example of the climatic factor may be seen locally by contrasting the climate on the coastal side of the Coast Mountains with that 100 km northeast on the interior side of the same mountains. The Fraser Lowland, which has a maritime climate, averages about 1500 mm of precipitation a year and rarely has temperatures below minus 10°C; the interior averages 300 mm a year and frequently has temperatures below minus 20°C. Undoubtedly during deglaciation the contrasts were somewhat similar and even greater in the case of temperature. The contrasting climatic conditions would produce different deglaciation histories.

Consequently worldwide correlations would seem to be valid only if a broad time span is considered. The last major ice advance in the Pleistocene apparently falls between 29 000 to 10 000 years BP throughout the northern hemisphere. The maximum advance is thought to have been 18 000 years BP; however, in the Pacific Northwest of the United States the Vashon Stade reached its maximum between 15 000 and 13 500 years BP (Mullineaux et al., 1965). Porter (1976) concluded that the Vashon reached its maximum about 14 000 years ago in the Northern Cascade Range of the United States. It is my belief that the Vashon reached its maximum in the Fraser Lowland between 15 000 and 15 500 years BP (see Fig. 2).

Table 7. Post-Vashon stratigraphic units and their ages

Formation	Radiocarbon years BP
Salish Sediments	
basal peat bog and gyttja deposits	present to 12 350 ± 190
Sumas Drift	
wood in till (maximum age)	11 400 ± 170 to 11 700 ± 150
Fort Langley Formation	
shells in glaciomarine and marine sediments	11 680 ± 180 to 12 900 ± 170
Capilano Sediments (equivalent to Sumas plus Fort Langley Formation)	
shells in glaciomarine and marine sediments	11 300 ± 190 to 13 500 ± 200

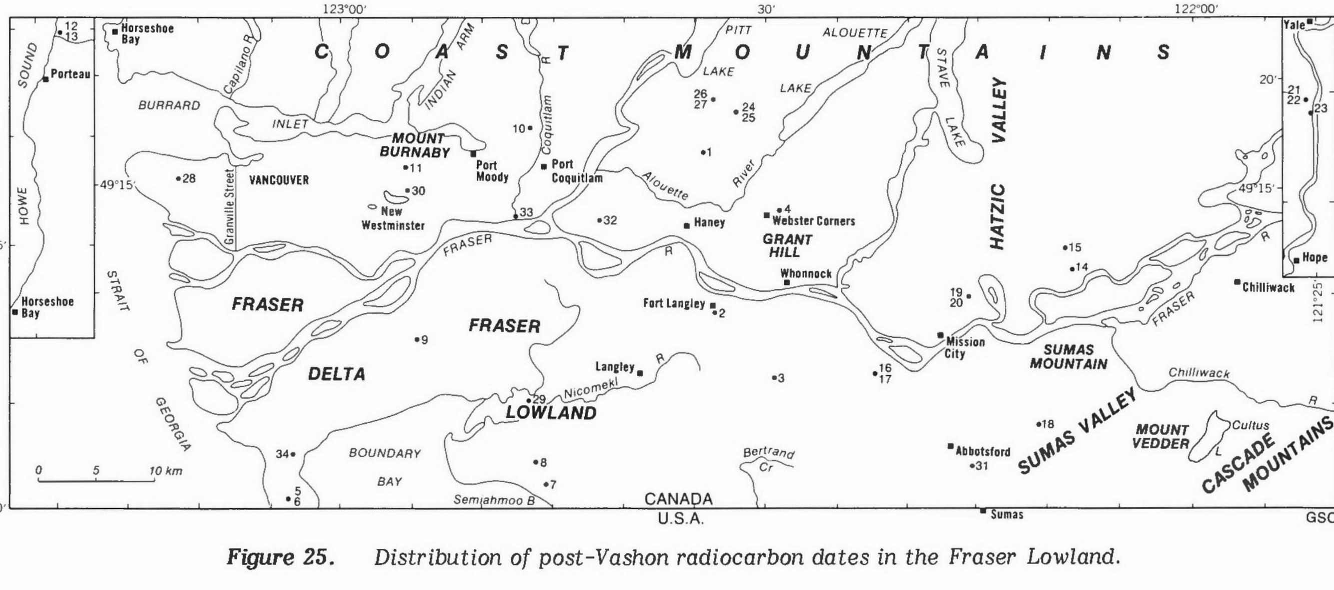


Figure 25. *Distribution of post-Vashon radiocarbon dates in the Fraser Lowland.*

Table 8. Suggested correlations of post-Vashon stratigraphic units

Years B.P. ($x10^3$)	Pacific Northwest: FRASER LOWLAND (This paper)		Pacific Northwest: PUGET LOWLAND (Hansen and Easterbrook, 1974)	Pacific Northwest: NORTHERN CASCADE Range, U.S.A. (Porter, 1976)	Great Lakes: EASTERN GREAT LAKES-ST. LAWRENCE REGION (Dreimanis and Karrow, 1972)		Great Lakes: LAKE MICHIGAN (Evenson and Dreimanis, 1967)
	HOLOCENE				NORTH BAY INTERSTADE	GREAT LAKEAN SUBSTAGE	
10	POSTGLACIAL		SUMAS TILL				
11	CAPILANO SEDIMENTS	SUMAS DRIFT	EVERSON INTERSTADE	HYAK MEMBER LAKE DALE DRIFT			STADE
12		FORT LANGLEY FORMATION (includes two or more stades)				TWO CREEKAN SUBSTAGE	INTERSTADE
					PORT HURON STADE	WOODFORDIAN SUBSTAGE	PORT HURON STADE
13	VASHON DRIFT		VASHON STADE		MACKINAW INTERSTADE		CARY-PORT HURON INTERSTADE
14				DOMERIE MEMBER LAKE DALE DRIFT c.f. VASON STADE (at Seattle)	PORT BRUCE STADE		CARY STADE
					ERIE INTERSTADE		
15	(extends to 18 000)						
16					NISSOURI STADE (extends to 23 000)		
17							
18							

CONCLUSIONS

The late Wisconsin Fraser Glaciation in southwestern British Columbia reached its climax about 15 000 years BP during the Vashon Stade, when the land was isostatically depressed at least 300 m and sea level had been eustatically lowered about 100 m. Vashon ice withdrew rapidly and by about 13 000 years BP most of the central and western Fraser Lowland was invaded by the sea; this occupation lasted until about 11 000 years BP. Isostatic, eustatic and tectonic adjustments between the withdrawal of Vashon ice and the withdrawal of the sea were not uniform for the whole of the Fraser Lowland. Also during this time interval the eastern part of the Fraser Lowland apparently was occupied by a piedmont glacier (or glaciers) that at various times advanced into the central part of the Fraser Lowland probably by surging; at other times it stood still or retreated. In some places the base of this glacier was subaqueous and in other places subareal.

The piedmont glacier (or glaciers) terminated in the sea for much of its history, probably in a manner similar to the glaciers of Yakutat Bay area of Alaska today. Throughout the period mainly glaciomarine, marine, glaciofluvial and glacial sediments were deposited.

These sediments comprise three post-Vashon stratotypes: Fort Langley Formation, Capilano Sediments and Sumas Drift. The Fort Langley Formation consists of interbedded glaciomarine, marine, glaciofluvial and glacial sediments bounded by Vashon Drift at the base and Sumas Drift at the top. They were deposited during the period of deglaciation that followed the maximum advance of Vashon ice. Deposition started about 13 000 years BP and ended with the advance of Sumas ice about 11 400 BP.

Capilano Sediments consist of a thick succession of glaciofluvial, glaciomarine and marine sediments lying to the west of the Fort Langley Formation and Sumas Drift. Capilano Sediments are bounded at the base by Vashon Drift and at the top by Salish Sediments. Capilano Sediments correlate generally with the Fort Langley Formation. This correlation is supported by the fact that both formations were laid down in a post-Vashon period that began when the area was invaded by the sea and ended, for the Fort Langley Formation, with the advance of Sumas ice and, for the Capilano Sediments, with the withdrawal of the sea to approximately its present position.

Sumas Drift consists of till diamictons, advance and recessional glaciofluvial deposits, and glaciolacustrine sediments that were deposited during the final glacial occupation of the eastern Fraser Lowland. Sumas Drift is bounded by Fort Langley Formation at the base and Salish Sediments at the top. It represents the last ice advance in the Fraser Lowland, commencing when sea level was within 50 m of present and ending with the withdrawal of the sea to approximately its present level.

The glaciomarine sediments that make up a large part of both the Fort Langley Formation and Capilano Sediments owe their origin to floating ice, mainly in the form of bergs and smaller pieces of glacier ice, and to a much lesser extent to sea ice dropping pebbles, large clasts and a minor quantity of sand and finer sediments into seafloor muds, which probably were deposited largely by meltwater streams. Macrofossil and microfossil shells found in the glaciomarine deposits indicate that the sea in which they lived was relatively shallow, probably less than 60 m at sites where the fossils were found. Other evidence suggests that at no time between 13 000 and 11 000 years BP was the sea more than 300 m deep and normally it was much less. The fossils also indicate that salinities were 15 to 35 per cent (normal is 30 to 35 per cent). Similar fossil assemblages are found today in the Cook Inlet area of Alaska (60° - 61°N) more than 1600 km northwest of the Fraser Lowland.

Palynological studies indicate that when the uplands of the Vancouver area were ice free and above sea level, piedmont ice and the sea occupied the Fraser Lowland east of Langley Valley. At the same time the mountain slopes adjoining the central and eastern Fraser Lowland were free of ice above 200 m elevation.

Between 13 000 and 11 000 years BP the Fraser Lowland underwent isostatic, eustatic and tectonic changes in relative sea level. A simplified version of these changes is as follows: A major submergence of more than 200 m followed the retreat of Vashon ice and the invasion of the land by the sea about 13 000 years BP. This was followed by a rapid emergence of at least 150 m by about 12 000 years BP. This emergence was followed by a second submergence of apparently more than 100 m during the next 500 years, that is up to about 11 500 years BP, when the Sumas ice advance commenced. During and following the Sumas advance the land again emerged and sea level was within 15 m of the present level. Based on the present state of knowledge, the relative significance and timing of isostatic, eustatic and tectonic movements are only speculative. Once these are understood fully, the postulated second major submergence may not be the most logical explanation of sea level changes.

No record of Fraser River is found in the Fraser Lowland in pre-Vashon time. The river apparently came into existence during post-Vashon time when Sumas ice finally melted and ice cleared out of the Fraser canyon. Apparently the Fraser established itself in a Sumas ice meltwater channel from Chilliwack west, probably about 11 000 years BP.

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