LATE QUATERNARY GEOLOGY AND GEOMORPHOLOGY OF THE CHILLIWACK RIVER VALLEY, BRITISH COLUMBIA

by

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Late Quaternary Geology and Geomorphology of the Chilliwack River Valley, British Columbia

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ABSTRACT

The aims of this research were threefold:
(i) to map the geomorphology and the surficial geology,
(ii) to interpret the sedimentary paleoenvironments, and
(iii) to establish a comprehensive geochronology.
Ten depositional terrain units were recognized, twelve measured sections were documented and three new radiocarbon dates were obtained.

The oldest dated feature in the valley is a sandur constructed by the Chilliwack Valley glacier at the onset of the Fraser Glaciation, at about 21-22,000 BP. Subsequently, the mouth of the valley was blocked by advancing ice in the Fraser Valley, and a glacial lake formed. Clays deposited in this lake have an age of 20,190±1000 BP (SFU-406). The Fraser Valley ice flowed into the lower Chilliwack Valley for much of the last glaciation, depositing a thick till unit which underlies the Ryder Upland. Wood from the centre of this unit was dated at 15,610±130 BP (BETA-11057).

During late Fraser times, ca. 11-12,000+ BP, another glacial lake formed, in a similar manner to the early-Fraser one. The receding Chilliwack Valley glacier deposited a sandur in the upper valley and a recessional moraine at Chilliwack Lake ("Chilliwack Lake Barrier"). Parts of the sandur were subaqueously deposited. Near the end of the glaciation, ca. 11,300 BP, floodwaters from the adjacent Silverhope-Klesilkwa basin, probably released catastrophically, drained into the

upper Chilliwack Valley and dissected the Barrier.

At about the same time in the lower valley, drainage from the glacial lake was diverted southwards into the Nooksack River by the Fraser Valley ice lobe. Ice-marginal rivers deposited a kame terrace and a hanging delta near Cultus Lake.

At the close of the Fraser Glaciation, the ice receded and the glacial lake drained. Stagnant ice masses lay in some parts of the region at this time. One of these caused the Chilliwack River to detour into the newly-formed Cultus Lake and construct a kame delta (Cultus Bench).

Once the valley was free of ice, vigourous paraglacial conditions ensued, during which the upper valley sandur was dissected. Many of the alluvial fans in the area probably originated at this time. Debris flow activity in the middle Holocene was responsible for depositing a localized valley fill (Tamihi Bench) which temporarily dammed the Chilliwack River. A date of 4270±60 BP (GSC-3961) was obtained from this landform. For the latter half of the Holocene, geomorphic activity has been relatively benign.

ACKNOWLEDGMENTS

I would like to acknowledge the support of my examining committee, all members of which have at various times contributed to my progress. Mark Pawson unearthed the wood sample from site CH3, and stimulated helpful discussion. Some of my fellow graduate students offered comments and advice. Despite this, I remain solely responsible for this lucubration.

Financial support for this research was provided by an SFU Open Graduate Scholarship and a President's Research Stipend. Radiocarbon dates attained through SFU (those from CH2 and CH3) were paid for by Michael Roberts. The wood sample from CH7 was dated by Wes Blake, Jr. of the Geological Survey of Canada.

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CHAPTER 1: INTRODUCTION

General Background

Recent geomorphological research has tended to concentrate on short-term process studies, but there has been mounting dissatisfaction with their applicability at a geomorphic timescale. For example, Church (1980) argued that such studies do not sample the complete variability of a process, and suggested that other approaches to the discipline could be employed to extend the knowledge of geomorphic processes through time. One of the alternative approaches recommended by him was followed in this thesis, that of interpreting recent sediments.

Interpretations of the Quaternary stratigraphic record have proved to be of great value in geomorphological research. The analysis of subsurface sediments enables the corresponding depositional environments to be inferred from them. The classification of landforms according to their morphology, distribution and origins, provides additional information to aid in elucidating the surficial geology and geochronology. The combination of the two approaches results in a powerful tool for geomorphology.

There are limitations to using the stratigraphic record. It is inherently imbalanced, for two reasons. Firstly, the stratigraphic column is incomplete: only the periods and environments of deposition are documented. Erosional intervals are represented by unconformities, and very limited amounts of information can be gleaned from these. This is a maxim of geology. Secondly, sedimentation is often spasmodic, such that a brief energetic event might be responsible for a major proportion of the stratigraphic record. In the Quaternary, this concept is exemplified by the paraglacial period (Church & Ryder, 1972), has been applied to British Columbia by Clague[1], and more broadly, was discussed in the context of stratigraphy and geomorphology by Ager (1973) and Schumm (1976).

Research Rationale and Objectives

In valleys of the British Columbian Coast and Cascade Mountains, the number of detailed Quaternary studies is quite limited. Only the Coquitlam River valley has received detailed attention (Hicock & Armstrong, 1981).

The Chilliwack River valley is only one example of the many possible montane valleys in which Quaternary research may be undertaken. It was chosen as the study area for several reasons. It is easily accessible from Vancouver, being only 100 km to the east. There are sufficient numbers of exposures to elucidate a major proportion of the surficial geology. Previous studies have already defined some aspects of the late Quaternary history and provide some basic data from which to build.

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[1]"The Character and Timing of Sedimentation and Erosion in British Columbia during the Quaternary", lecture presented at the Bill Mathews Symposium, Vancouver, October 1984

This study attempts to map the geomorphology and surficial geology of the Chilliwack River valley, and consequently establish a chronology of geomorphic events. So little detail is known about the geomorphology of the British Columbian Cascade and Coast Mountains that this contribution to knowledge represents a step forward in the comprehension of the last glaciation in the southwestern parts of the province. Also, it provides a stronger foundation on which future work can be built, and directly contributes to the understanding of the Quaternary in the adjacent eastern Fraser Lowland.

Briefly, the aims of the proposed research are as follows:

(i) to map the surficial geology and geomorphology,

(ii) to interpret the corresponding sedimentary environments, and

(iii) to establish a comprehensive geochronology.

The research concentrated on extending the presently limited understanding of the recent evolution of the valley. To this end, new data were sought to infill the gaps in previous knowledge.

The study area is that part of the Chilliwack River which lies on the Canadian side of the forty-ninth parallel, and downstream of Chilliwack Lake (Figure 1.1). The concentration of preserved unconsolidated deposits in the trunk valley, and sparsity of similar material in the tributary valleys, means that this study is necessarily concerned mainly with the valley fills of the trunk valley.

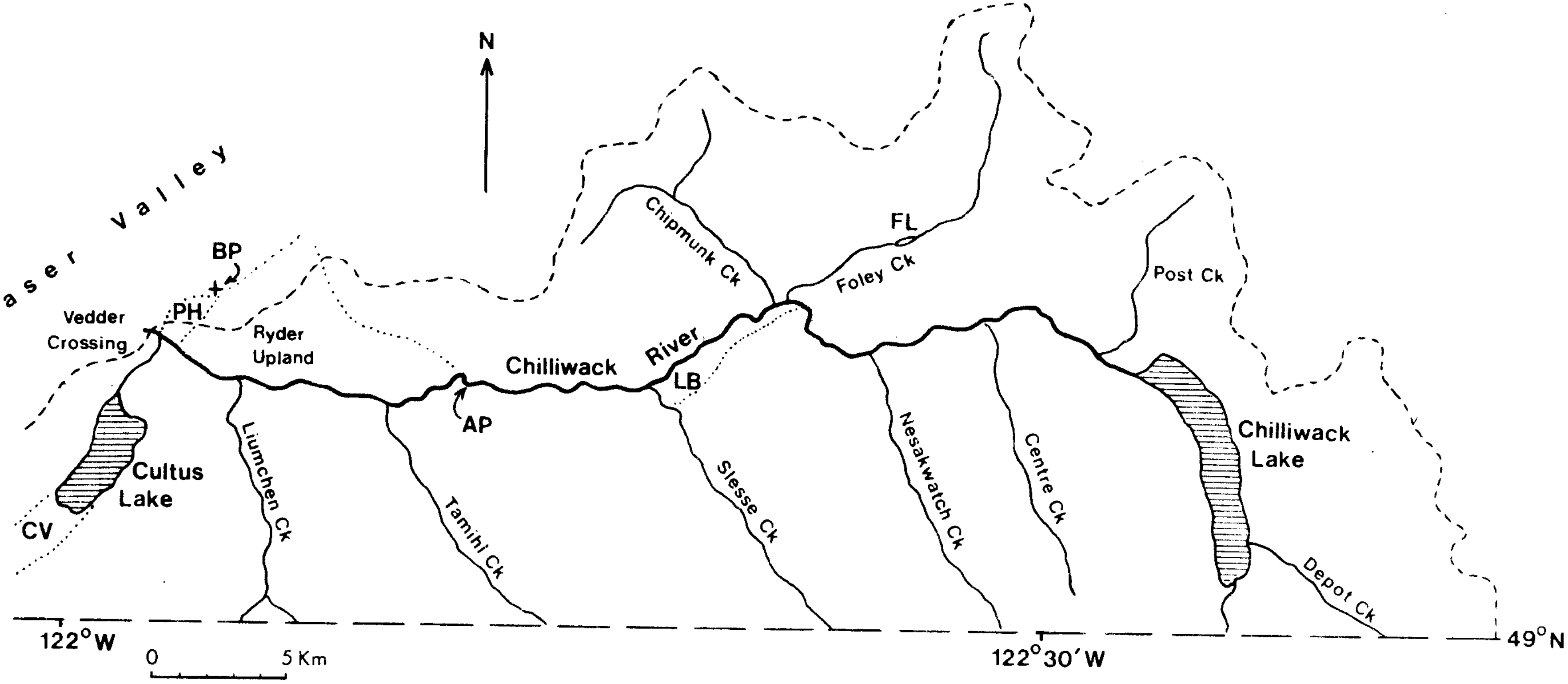

Figure 1.1 The Study Area

AP	Allison Pool
BP	Bailey Pit
CV	Columbia Valley
FL	Foley Lake
LB	Larsons Bench
PH	Promontory Heights

CHAPTER 2: THE RESEARCH AREA

This chapter reviews the physical characteristics of the Chilliwack River area, and includes discussions of the bedrock geology, erosional and depositional physiography, and aspects of the contemporary environment.

Bedrock Geology

The northern Cascade Mountains consist of a gneissic and granitic core flanked by sedimentary, metamorphic and volcanic rocks. The range as a whole is described in some detail by McKee (1972), and its context within the evolution of the Canadian Cordillera is set by Monger & Price (1979). The bedrock geology of the study area was mapped by Monger (1970), and is summarized below and in Figure 2.1. Lithostratigraphic names have been taken from Roddick et al. (1979) and from Monger's nomenclature.

The oldest rocks in the study area are probably early Paleozoic amphibolites and diorites correlative with the Yellow Aster Complex in Washington, but their exact age is unknown. The Chilliwack Group, from the late Paleozoic era, is composed of metamorphosed pelite and sandstone, with minor conglomerate, pyroclastic rocks, basic volcanic greenstone and limestone. The rocks exhibit complex folding and faulting. Unconformably overlying the Chilliwack Group are Triassic and Jurassic pelites with siltstones, sandstones and breccias, collectively termed the Cultus Formation. These too, are highly deformed.

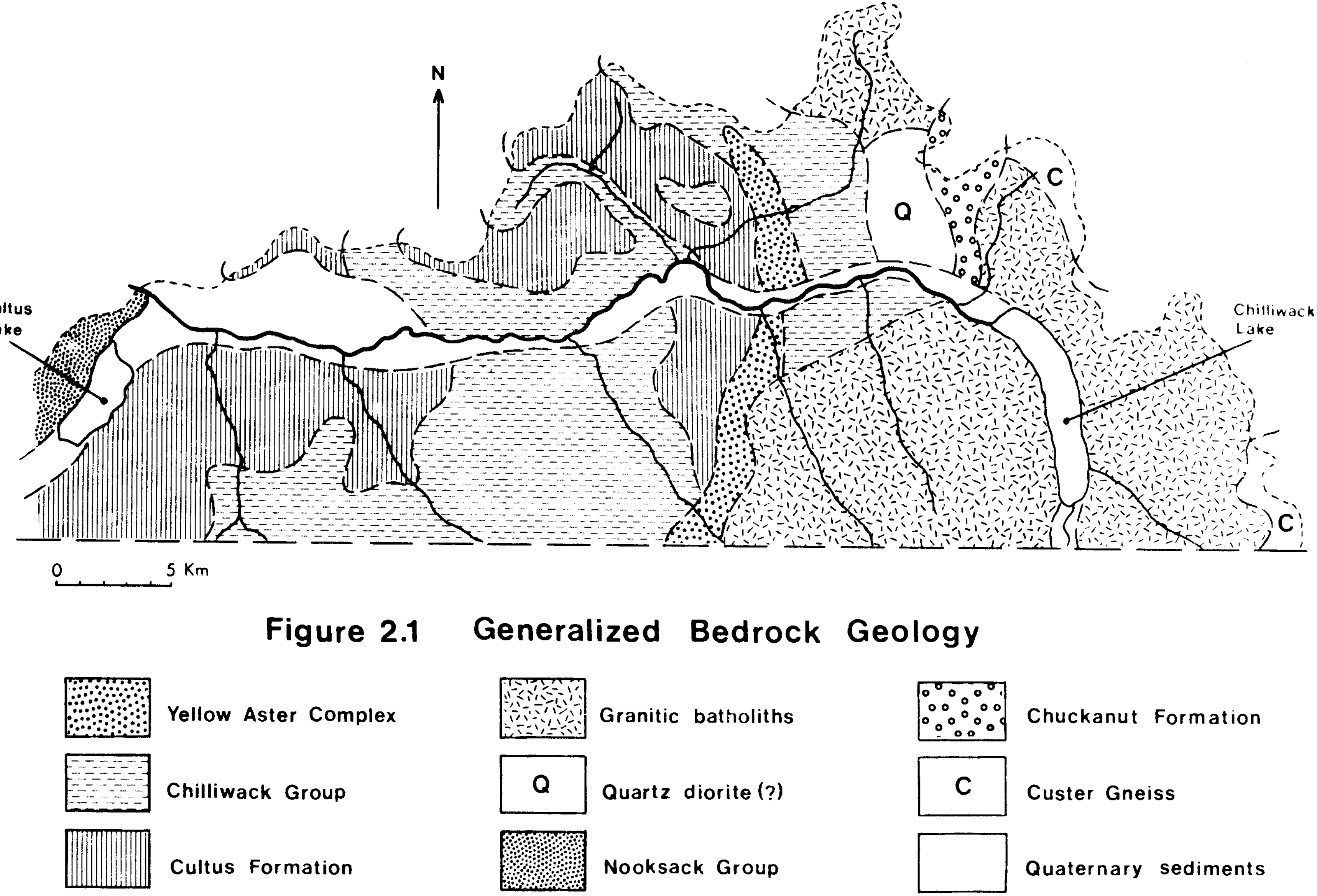

Figure 2.1 Generalized Bedrock Geology

The eastern part of the study area is underlain by the granitic Chilliwack and Mount Barr Batholiths, both having mid-Tertiary ages. The detailed composition of these were discussed by Richards & McTaggart (1976).

The granodiorite batholiths, the Chilliwack Group and the Cultus Formation make up most of the bedrock in the drainage basin (Figure 2.1). The localized occurence of conglomerates (Chuckanut Formation) and Custer gneiss in the vicinity of Chilliwack Lake, and Cretaceous/Early Tertiary graywackes and shales of the Nooksack Group at Vedder Mountain (Crickmay & Pocock, 1963) completes the bedrock geology of the drainage area.

Regional Physiography

The deeply dissected topography of the area is typical of the northern Cascades, and local relief may reach 2000 m. Peaks are usually clustered linearly along high ridges, and the highest tops in the area are generally of the order of 2100-2500 metres above sea level (masl). Daly (1912) argued for the former existence of an uplifted peneplain, that he called the Cascade Plateau, on the grounds of observed summit accordance. This discussion was expanded by Thompson (1962) to encompass multiple accordances, or gipfelfluren, in lieu of Daly's simplistic interpretation.

The drainage pattern of the area is structurally controlled, and exhibits a quasi-rectangular pattern (Figure 2.1). The Columbia Valley is the only other major valley in the study area in addition to that of the Chilliwack River. It slopes southward towards the International Boundary. All of the valleys display classic glacially-eroded cross sections; in the trunk valley of the Chilliwack River and the Columbia Valley, valley fills modify the smoothness of the profile.

There are numerous erosional features typical of alpine glaciation, such as hanging valleys, horns, aretes, truncated spurs and cirques. Daly (1912) applied the term "tandem cirque" to describe the compound cirques found in the area. Truncated spur elevations do not show any distinct accordance, but ice thicknesses of several hundred metres can invariably be inferred from them. Most of the land below about 2000 m has been rounded by ice, and even the sharp and rugged high peaks were probably submerged by ice for a very limited length of time during the Fraser Glaciation (Waitt, 1977).

Depositional Terrain Units

Unconsolidated Quaternary deposits occur throughout the valley and the associated landforms are mapped in Figure 2.2. The shading on these maps indicates the extent of each surface. In Figure 2.2c, two parts of the map are enlarged for greater clarity. Throughout this and subsequent chapters, the term "bench" is employed to describe landforms that are terrace-like in appearance.

Ten units were distinguished (Table 2.1).

Table 2.1 Depositional Terrain Units

Unit number	Reference name
L1	Ryder Upland
L2	Upper Bench
L3	Lower Bench
L4	Cultus Bench
L5	Tamihi Bench
L6	unnamed
L7	upper valley paleosandur
L8	unnamed
L9	unnamed
L10	Chilliwack Lake Barrier

In the lower valley[1], the Ryder Upland (L1 in Figures 2.2a,b) is underlain by a very thick unconsolidated deposit, whose surface expression is rolling or hummocky. Erratics litter parts of the Upland.

The south side of the lower valley supports two sets of benches, L2 and L3 in Figures 2.2a and 2.2b. The Upper Bench, L2, occurs in two places; the western segment (L2a) is poorly exposed but the eastern part (L2b) has been logged and so is better revealed. The broadest part of the latter slopes gently towards the valley centre with a concave profile. The edges of the Upper Bench show evidence of landsliding and gullying.

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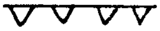
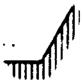
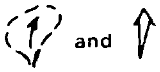
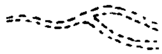
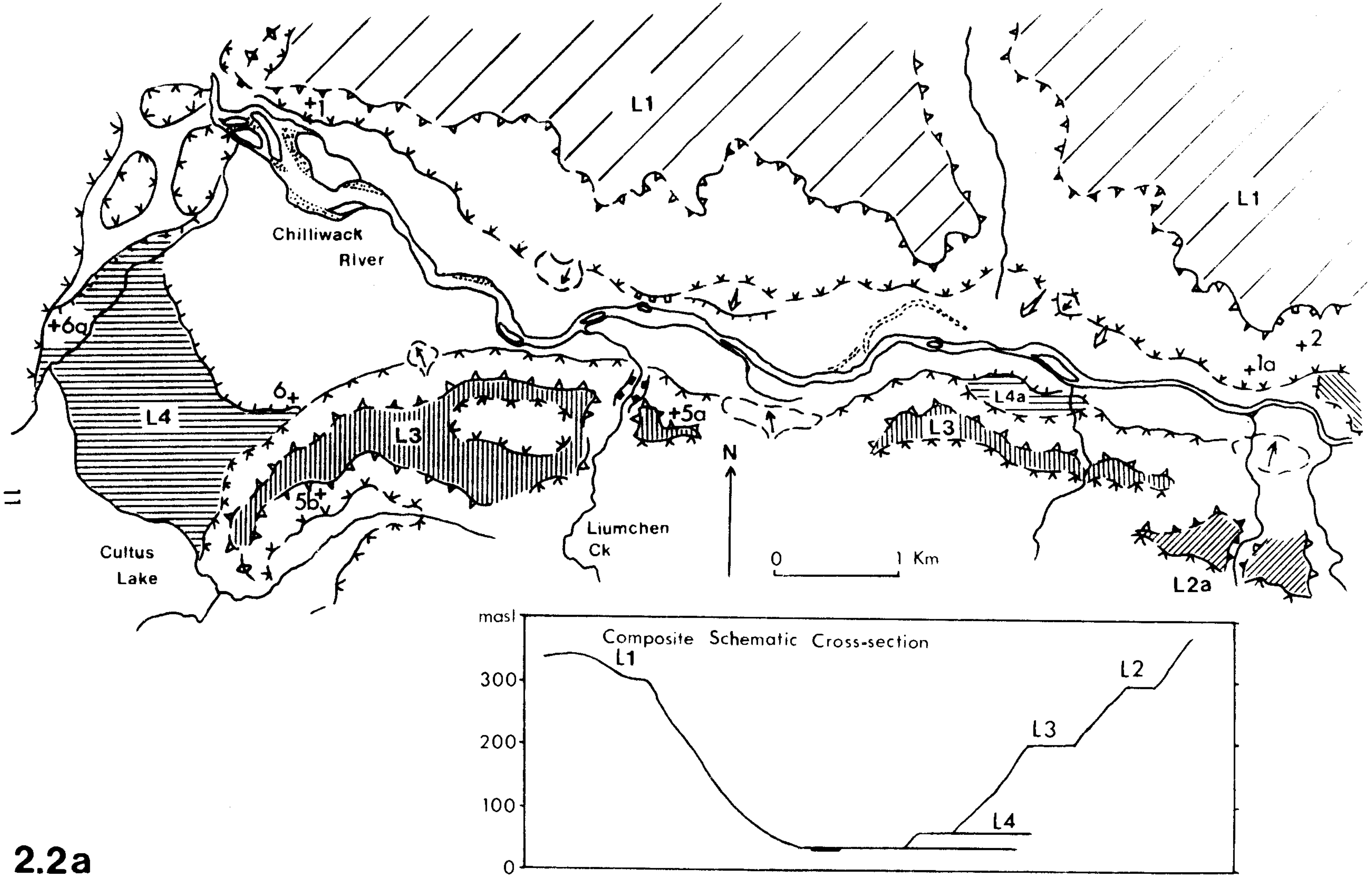
[1]"lower valley" refers to that half of the study area between Vedder Crossing and Slesse Creek.

Figure 2.2 Depositional Terrain Units

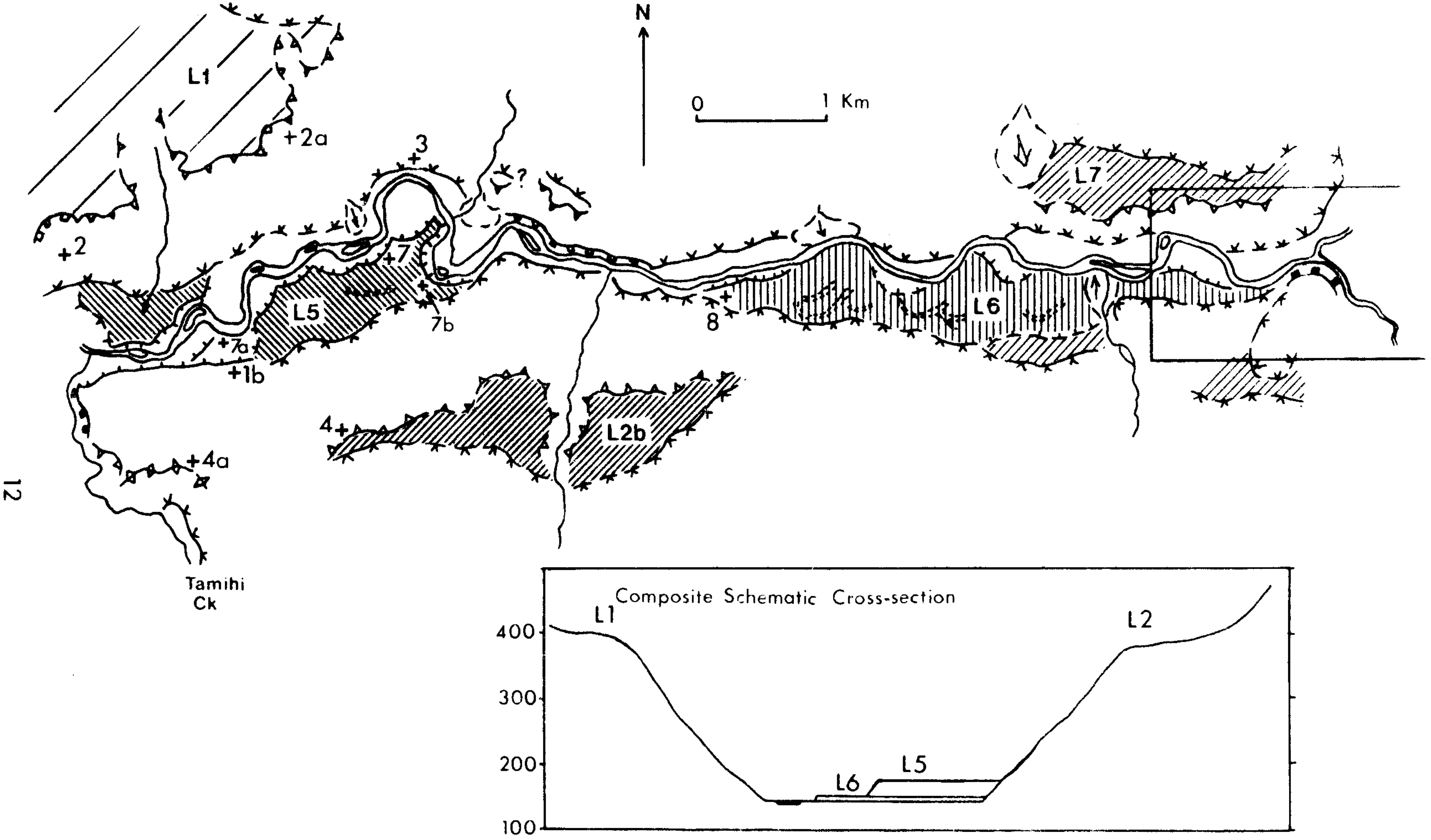
Legend

Map symbol	Feature
	convex break in slope[1] .... 
	concave break in slope[1] .... 
	adjacent breaks in slope[1] .... 
	cliff, unconsolidated deposits
	cliff, bedrock
	fans
	abandoned channels
L6	terrain unit
+6	location of measured section (CH6)

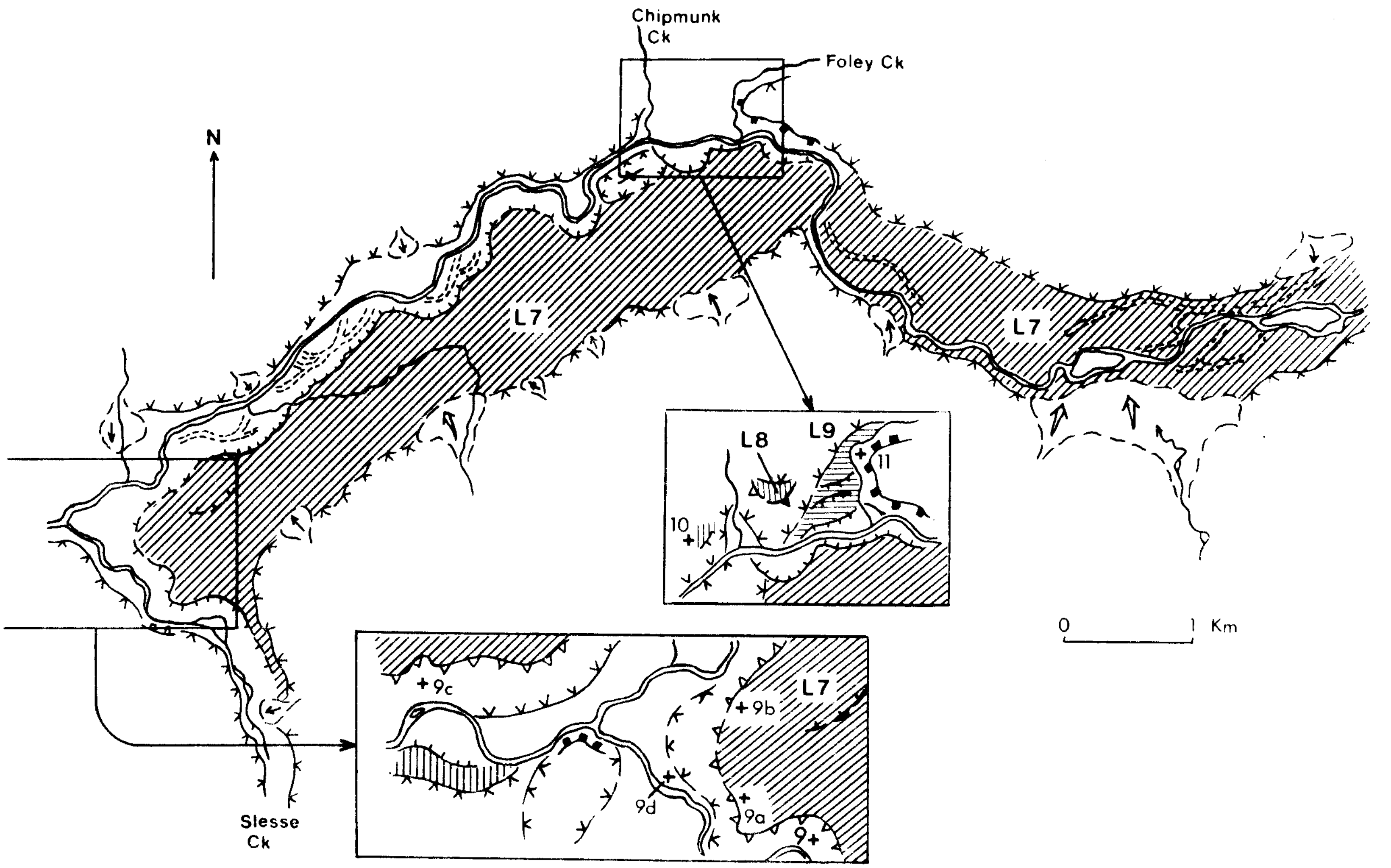
1. Broken-line symbols indicate indistinct features


L1
L1
Chilliwack River
+1
+1a
+2
+6a
6+
5b+
+5a
L4
L3
L3
L4a
L2a
Cultus Lake
Liumchen Ck
N
0
1 Km
masl
300
200
100
0
Composite Schematic Cross-section
L1
L2
L3
L4

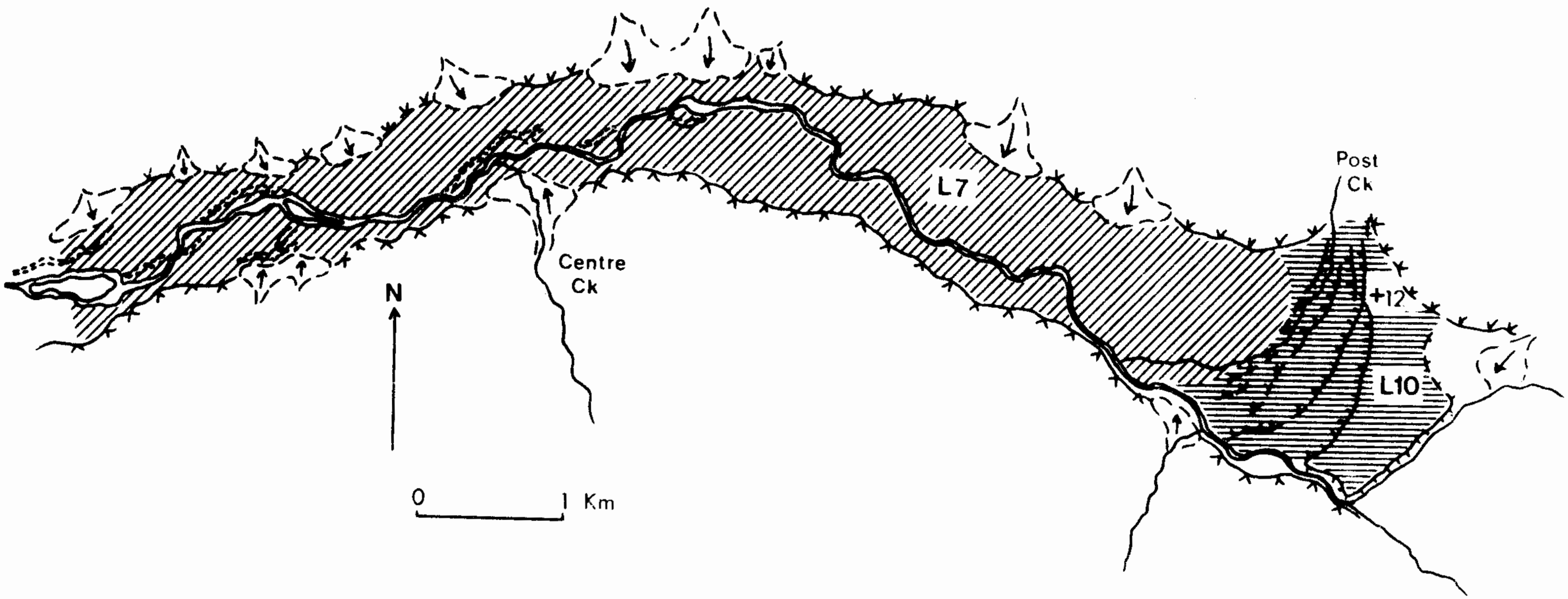
2.2a


N
0
1 Km
L1
+2a
+2
3
+7
7b
+7a
+1b
L5
L6
L7
L2b
8
4
+4a
Tamihi
Ck
Composite Schematic Cross-section
L1
L2
L5
L6
400
300
200
100

2.2b


Chipmunk Ck
Foley Ck
N
L7
L7
L8
L9
11
10
0
1 Km
+9c
L7
+9b
9d
9a
9+
Slesse Ck

2.2c



2.2d

The Lower Bench, L3, resembles a typical alluvial terrace. It possesses a flat top, and is clearly defined from the bedrock valley sides by sharp breaks of slope. Closer inspection reveals that in places the L3 surface is made up of several different bench remnants which lie within an elevation range of about 20 m, rather than having one single level. The Bench can be traced along the south side side of the valley from near Tamihi Creek to an abrupt terminus near the north end of Cultus Lake[2].

The Cultus Bench, L4, dams Cultus Lake and possesses a smooth, flat surface. Its northern edge is a distinct scarp adjoining the modern floodplain, whilst the southern one slopes gently into the lake. Due north of the Cultus Bench, and near Vedder Crossing, are two very narrow valleys, which may be ancient river courses. L4a is a very small arcuate bench, probably a river terrace, which is possibly correlative with L4.

Tamihi Bench, L5, has a surface which is hummocky in some places and relatively flat in others. Relict channels occur adjacent to the Chilliwack Lake Road where it crosses this surface. The Bench is being actively eroded by the Chilliwack River.

The L6 surface is a low alluvial terrace. It is a continuous surface (in contrast to L2, L3 and L5), possesses an undulating expression and is 5-10 m higher than the modern floodplain. The Chilliwack River has cut scarps up to 6 m high

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[2]"Cultus Lake" refers only to the lake itself, and not the settlement of the same name.

in places. The extent of incision is quite limited, however, and the river probably is constrained from further incision by the downstream control of a bedrock canyon (Figure 2.3). Several well-defined abandoned channels can be discerned in the aerial photographs; these appear to be of similar widths and planforms to the present Chilliwack River.

One of the largest surficial features in the study area is a valley fill in the upper valley[3], mapped as L7 in Figure 2.2. It extends unbroken for 18 km from near Chilliwack Lake to Slesse Creek, and remnants of the same surface can be identified for a further 3-4 km downstream. The lower part of the fill has been incised by the Chilliwack River to a depth of 130 m, but incision has been controlled by a bedrock outcrop at the Chipmunk Creek confluence. There is minimal incision upstream of this point. Abandoned channels are common in the middle reaches of this valley fill, but mostly are absent in the upper and lower parts.

The L8 and L9 landforms are small, indistinct benches. The L8 surface occurs at the mouth of Chipmunk Creek about 40 m above L7, and appears to be a dissected hanging delta. L9 is lower than L8 and is at the mouth of Foley CReek valley. Its topmost surface is of a similar elevation to that of L7 in the trunk valley. The L9 surface has been terraced by the Chilliwack River as part of the local incision of the L7 surface.

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[3]"upper valley" refers to that half of the study area between Slesse Creek and Chilliwack Lake.

Chilliwack Lake is dammed by a barrier, L10, whose form, except for an atypically flat surface, resembles that of a recessional moraine. It has been terraced on its north side by the minor tributary of Post Creek, and on its west side by the Chilliwack River.

Most of the landforms described here occur on or near to the floor of the trunk valley. The preservation potential of deposits higher on the steep valley sides and in the narrow confines of the tributary valleys probably is sufficiently low to ensure their rapid removal in postglacial times. It is therefore not surprising to find a lack of classic alpine glacial deposits such as terminal and lateral moraines which may normally be expected in an area of previously vigourous glaciation. Unlike other parts of the Cascades, such as the nearby Mount Shuksan area, prominent fresh-looking Holocene (usually from Neoglacial advances) moraines are also mostly absent. Only the Depot and Redoubt Glaciers in the extreme southeastern part of the drainage area have left such features. The scarcity of active glacier ice in the Chilliwack Valley has no doubt contributed to this state of affairs. Most contemporary glaciers in the area are small pockets of relatively inactive ice.

Contemporary Physical Geography

This section describes aspects of the physical geography of the study area which are not covered in the preceding discussions, namely geomorphic processes, hydrology, soils and vegetation.

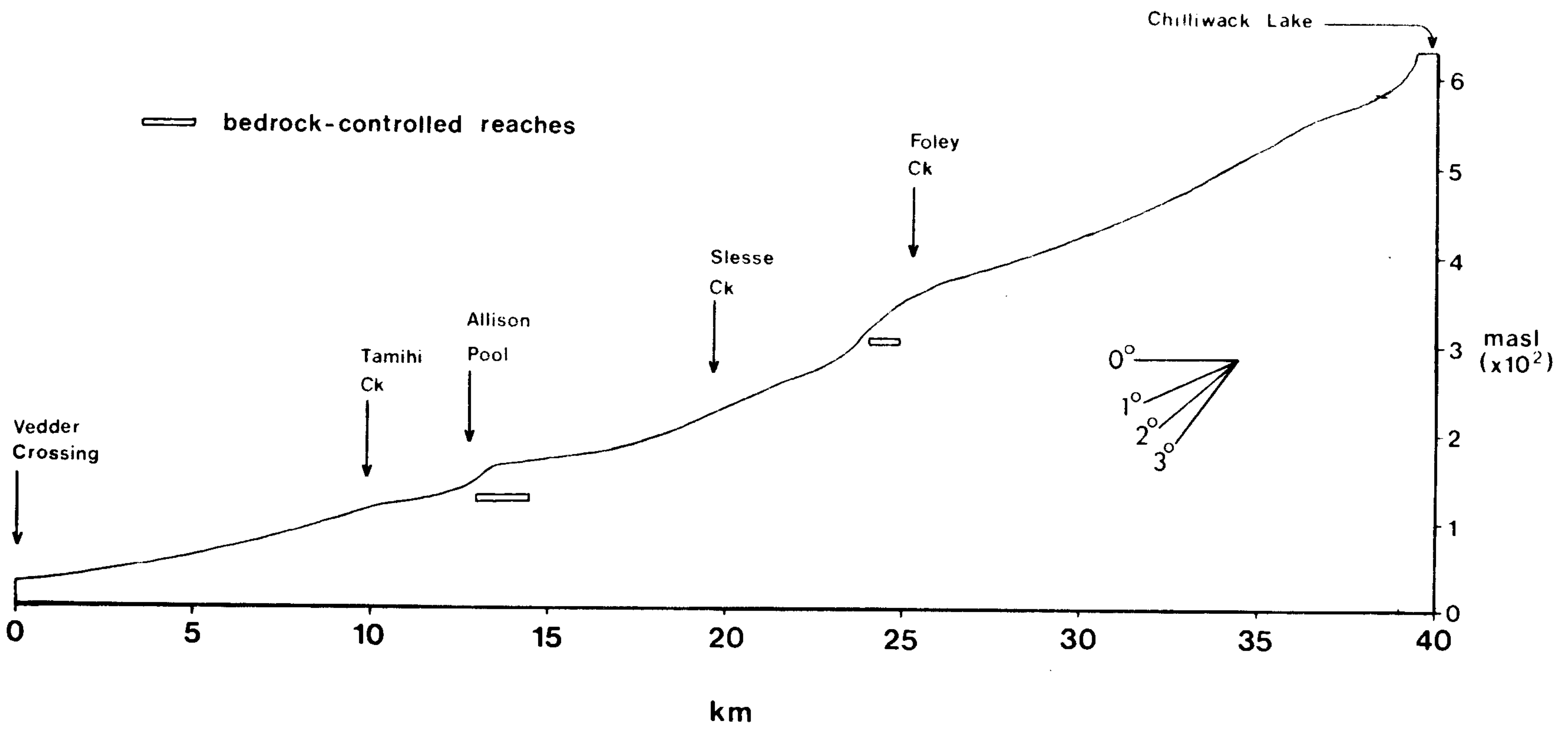
Geomorphic Processes

Active physical weathering is exemplified by the frost-shattered rock and talus accumulations in the alpine zone, while chemical weathering has also been found to be of significance in these mountains (Reynolds & Johnson, 1972; Bustin & Mathews, 1979). All types of mass movements, whether involving rock, unconsolidated deposits or snow, are active in the study area. Most are initiated at the higher elevations, but occasionally the catastrophic slides and mudflows reach the valley bottoms. Munshaw (1976) documented a major suite of such events, produced in December 1975 by failure of waterlogged slopes.

The drainage of the valley is characterized by steep and energetic mountain rivers throughout the study area, with abundant coarse clastic sediment lining the channels. The Chilliwack River falls nearly 600 m in the 40 km from Chilliwack Lake to Vedder Crossing, giving a mean gradient of 0.015. The longitudinal profile in this part of the river contains three roughly concave sections each about 14 km long, separated by bedrock-controlled knickpoints (Figure 2.3). The planform of the river is a single channel with straight and meandering reaches; the lowest 4 km are braided. Upstream of Allison Pool (Figure 1.1), the channel appears to be reasonably stable. Downstream from this point channel change occurs on a yearly timescale, and recent meander cut-offs, bank failures and shifting bars are readily apparent. The drainage area upstream of the Vedder Crossing bridge is 1230 km^2, of which 60-70% lies north of the International Boundary.

Tributary streams either possess poorly developed floodplains of limited extent or flow in very steep channels dominated by bedrock topography. Where there is a floodplain, these channels are generally unstable. Only two tributary channels, Slesse and Foley Creeks, are graded to the Chilliwack River. The remaining streams issue from hanging valleys. Of these, Liumchen, Tamihi and Chipmunk Creeks have cut narrow gorges in bedrock, and Nesakwatch and Centre Creeks have built fans onto the trunk valley floodplain. Fan growth has affected the course of the Chilliwack River in places by locally constricting the floodplain. Numerous small fans, mostly inactive, line the edges of the upper valley (Figures 2.2c,2.2d). Their position atop the late-glacial sandur surface implies that they are of postglacial age. It is probable that some were constructed under paraglacial conditions such as those described by Ryder (1971).

Figure 2.3 Longitudinal Profile, Chilliwack River



Hydrology

An examination of about 50 years of discharge rceords from the Chilliwack River revealed that the flow of the river exhibits typical alpine characterisics (Inland Waters Directorate, 1983). Monthly discharges are dominated by spring snowmelt. At the outlet of Chilliwack Lake (the upstream end of the study area), 92% of maximum monthly flows occur in either May or June. At Vedder Crossing (the downstream limit of the catchment), this figure is 77%. The majority of minimum monthly discharges occur in the four months of February, March, September and October. Superimposed upon this seasonal regime are short term fluctuations of daily discharges that reflect local climatic events. At Chilliwack Lake, 74% of maximum daily discharges occur in May and June, whereas low flows occur without preference throughout the months of October to April. Minimum daily discharges at Vedder Crossing are also spread throughout the same months, though October is a preferred time. In contrast to the regime at Chilliwack Lake, maximum daily flows at Vedder Crossing are divided equally between the May-June melt period and the October-February winter period, illustrating the importance of storm runoff in the short term regime of the lower Chilliwack River. Basic hydrological statistics for all gauging stations within the study area are summarized in Table 2.2.

Table 2.2. Discharges, Chilliwack River Valley.

Station	Annual Mean Flow (cumecs)	Minimum Monthly Flow (cumecs)	Maximum Monthly Flow (cumecs)	Number of years recorded
Slesse Creek	9.9	5.6	22.2	26
Chilliwack River: Chilliwack Lake	19.0	10.2	43.9	54
Chilliwack River above Slesse Ck.	36.5	20.9	85.7	20
Chilliwack River: Vedder Crossing	68.0	37.4	141.0	53

With the exception of Chilliwack Lake, standing water is scarce and is mainly confined to a few high tarns, thus providing only minor moderating effects on floods. The hydrological characteristics of the Chilliwack River were examined in more detail by Munshaw (1976).

Soils and Vegetation

The soils of the steep mountainous areas are derived from the thin colluvial and morainal veneers which cover the bedrock. In the extreme southwest part of the study area, these were labelled Cannell Soils by Luttmerding (1981). Soils developed on the glaciofluvial gravels in the Columbia Valley are mainly represented by Abbotsford Soils. Both the above were classified as Orthic Humo-Ferric Podzols. A thin capping of eolian silts was recorded by by Luttermerding in much of this area, and in fact is typical of the eastern Fraser Lowland. Vegetation is mostly closed coniferous forest containing hemlock, cedar and fir. Due to the steep nature of many valley sides, this often breaks directly into barren rock and snow ridges.

CHAPTER 3: LITERATURE REVIEW

This review first covers the recent evolution of the Fraser Lowland as a general setting. Focus is then given to the Quaternary research undertaken in the Chilliwack River area.

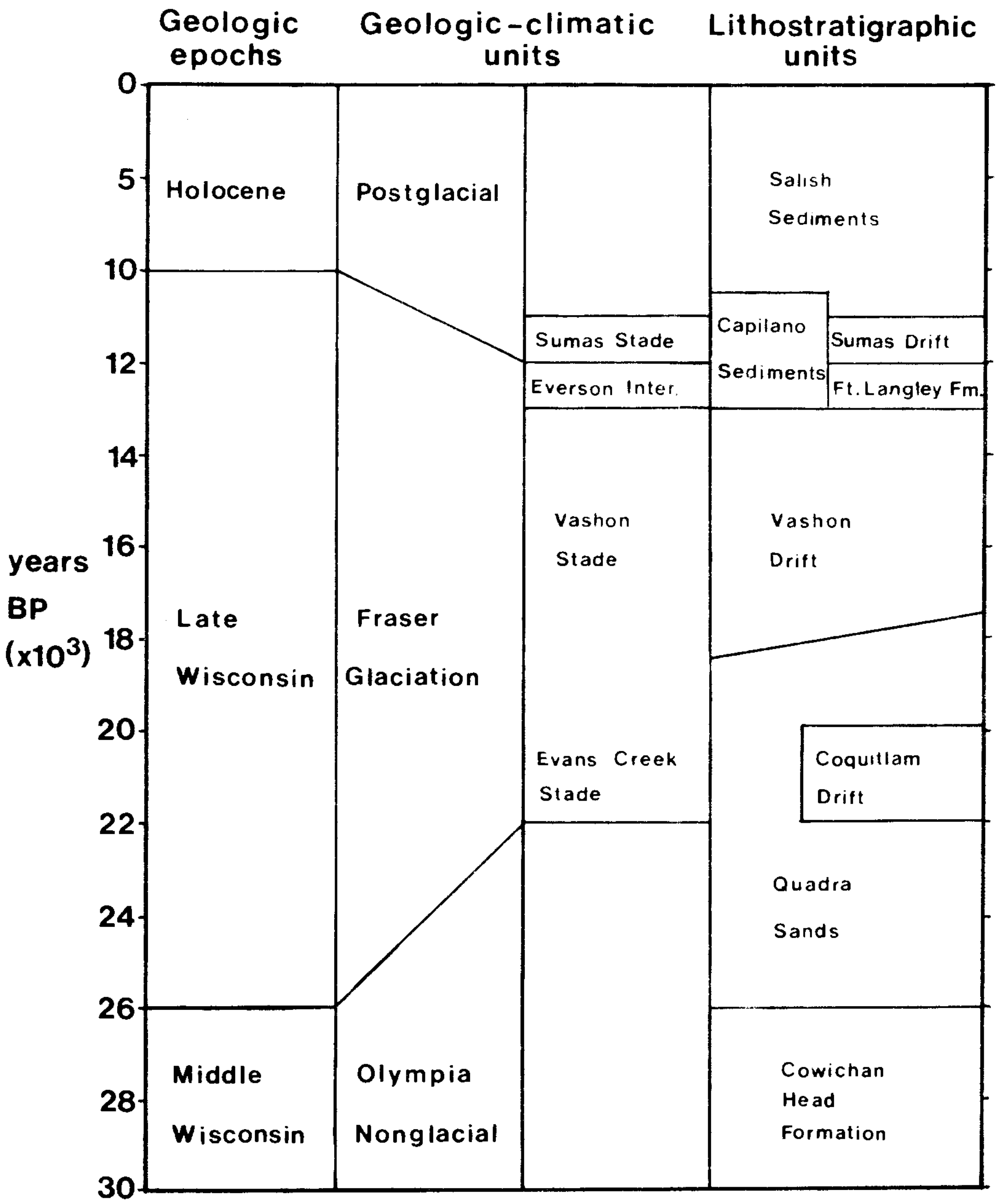
Late Quaternary History of the Fraser Lowland

The simplified history of the area, schematically presented in Figure 3.1, is adapted from Armstrong (1981) and Clague (1981), and is largely derived from dated deposits in the central and western parts of the Fraser Lowland. The use of these stadial and interstadial time divisions for the Fraser Glaciation outside this area is not necessarily valid (Clague (1981). Of the many studies of the Quaternary geology of the region, Armstrong et al. (1965), Armstrong (1981) and Clague (1981) are notable summaries.

Pre-Fraser Glaciation

Before the Fraser Glaciation, there was an interglacial period - the Olympia Nonglacial Interval. This is represented lithostratigraphically by the Cowichan Head Formation in the western part of the Fraser Lowland, and indicates conditions not unlike those of contemporary times.

Figure 3.1 Late Quaternary Stratigraphy, Fraser Lowland



Fluvial activity in lowlands, minor glacial activity in the mountains and deltaic and marine environments in the Georgia Depression were prevalent (Armstrong & Clague, 1977). A cooling climate in the latter part of this interval was a harbinger to the Fraser Glaciation.

The Fraser Glaciation - Advance Phase

The onset of the Fraser Glaciation is lithostratigraphically depicted by the Quadra Sand. This major unit consists of distal sandy outwash deposited on top of Olympian estuarine and marine sediments in the Georgia Strait-Puget Sound area in response to advancing glacier ice (Clague, 1977). Dated Quadra Sand outcrops record the advance of piedmont glaciers down the Georgia Depression: 29,000 years before present (BP) at the north end of the Georgia Strait to less than 15,000 BP in the Puget Sound.

The Evans Creek Stade, interpreted by Crandell (1963), occurred in early Fraser times at about 20-22,000 BP. Crandell's type section, at Evans Creek, Washington, showed moraine overlain by glaciolacustrine deposits, and marked an advance and retreat of alpine glaciers, with the subsequent formation of glacial lakes. Similar events were identified in the Coquitlam River valley, western Fraser Lowland, by Hicock & Armstrong (1981), and a local stratigraphic name, Coquitlam Drift, applied to the deposits. Here, outwash was deposited both prior and subsequent to Coquitlam Drift. The maximum extent of this local advance occured at 21,000 BP, when valley glaciers flowing out of the Coast Mountains into the Fraser Lowland coalesced into a piedmont lobe. The outwash was at least partly laid down in a glacial lake, formed by ice damming the mouth of the Coquitlam Valley. By about 18,500 BP, the Coast Mountain glaciers had receded into their valleys (Hicock & Armstrong, 1981), although the Cordilleran Ice Sheet maintained a slow but persistent advance southwards along the Georgia Depression. A millennium later, the Fraser Lowland was again inundated by ice, with the development of the Vashon Stade.

Some other mountain valleys fringing the coastal lowlands probably experienced advances of alpine glaciers at this time. Hicock et al. (1982b, reviewed in Chapter 5) and Crandell & Miller (1974) discuss similar behaviour of alpine glaciers, respectively in the Chilliwack River valley and on Mount Rainier.

At about 18,000 BP, much of southern British Columbia was free of ice. Subalpine forest grew in the northwestern Fraser Lowland, and existing ice probably underwent a period of standstill (Hicock et al. 1982a). After 18,000 BP the growth of the Cordilleran Ice Sheet intensified (Clague et al. 1980), fuelled by the northward shift of weather patterns that brought increased precipitation to the region (Hicock et al. 1982a). Then followed the most extensive episode of glaciation during the Fraser glacial period, referred to by some workers as the

Vashon Stade.

Cordilleran ice extended southwards and westwards from southwestern British Columbia to fill the Puget Sound and reach a maximum south of Olympia, Washington, between 14,500-15,000 BP (Heusser, 1973). At this time, ice filled the Fraser Lowland up to the 2100 masl level (Mathews et al. 1970). A reconstruction of the Puget Sound lobe as it stood at this time suggests that the ice was then in a near-equilibrium state (Thorson, 1980).

Glacial activity during this stade was predominantly erosional in the Lower Mainland region, and many of the fresh-looking erosional bedrock landforms that occur can be ascribed to this period. Thicknesses of Vashon sediments are often much less than those deposited in the shorter interstade which was to follow, and in some places where Vashon ice must have flowed, no Vashon sediments have been left behind (Armstrong, 1981).

The Fraser Glaciation - Recessional Phase

Retreat of the ice in the Georgia Depression allowed marine invasions into the low-lying areas, for example, as far as Deming at 75 masl on the Nooksack River (Easterbrook et al. 1975). This period, called the Everson Interstade, lasted for a little longer than a millenium. Radiocarbon dates indicate that the period 12,000-13,000 BP was largely ice-free in Fraser Lowland. Armstrong (1981) believes, however, that the eastern lowland was occupied by a piedmont lobe, whose margin fluctuated and was alternately subaerial and subaqueous. Sedimentation under marine, glaciomarine and deltaic conditions during this interstadial resulted in complex stratigraphic relationships; deposits are termed the Capilano Sediments and the Fort Langley Formation.

Late in the Fraser Glaciation, ice re-advanced into the eastern part of the Fraser Lowland, to terminate a few kilometres beyond Sumas, Washington. Ice reached a maximum extent at about 11,300 BP, and by 9920 BP recessional outwash had ceased to be deposited (Clague, 1981). The Fraser Canyon was clear of ice, or nearly so, after 11,000 BP (Mathewes et al. 1972). The possibility thus exists that ice was not fed by glaciers flowing down the canyon, but from another source. For example, Roberts & Mark (1970) suggested that a glacier in the Stave River valley fed Fraser Lowland ice, although Armstrong et al. (1971) argued against this in lieu of a Cascade source to the east. Clague (1981) also believed that ice in this area was fed from the Fraser Canyon, and underwent a very rapid retreat immediately following the climax of the advance. Clague also doubted that the last period of the Fraser Glaciation, labelled the Sumas Stade, may not in fact be defined as a stadial period. Instead, it represents a minor advance induced by the grounding of the ice lobe as sea level dropped, and so is not related to any significant climatic change.

Postglacial Events

Fluvial reworking of the abundant sediment left by the retreating glaciers caused rapid aggradation, leading to the development of floodplains and alluvial fans in the valleys (Ryder, 1971). These paraglacial conditions persisted for several thousand years after glaciation (Church & Ryder, 1972), with the glacial influence waning in strength during this time. For the remaining part of the Holocene, geomorphic activity has been relatively inert, although minor Neoglacial advances have occured in the high alpine cirques (Mathews, 1951).

Postglacial sea level changes in southwestern British Columbia were described in detail by Clague et al. (1982). The sea level was about 200 m above the present-day elevation at 13,000 BP. Following deglaciation it quickly stabilized to about 20 m below the contemporary level. Sea level began to rise at around 7000 BP, and attained the present-day elevation at about 5000 BP.

Quaternary Research in the Study Area

Early Work

The first pertinent research was undertaken by Daly (1912) during a geological survey along the forty-ninth parallel that concentrated on bedrock mapping. He described the obvious vigour of Cascade valley glaciers that created the alpine landforms, and estimated the ice thickness of major Skagit Range ice streams to be 1200-1500 m at the height of glaciation. In the Chilliwack Valley, two specific unconsolidated deposits attracted his attention. Firstly, he described the Chilliwack Lake Barrier as a bouldery recessional moraine. In the lower valley, Daly recorded a "thick deposit of glacial clay" forming a 90 m bench on the north side, from Slesse Creek to Vedder Crossing, much of this area now being called the Ryder Upland. Its origin was suggested to be from a Chilliwack Valley glacier, possibly assisted by ice from the Fraser Lowland.

Armstrong (1960a) presented the next study of the Quaternary geology of the area, mapping the deposits of Sumas map-area, which includes part of the Columbia Valley. In this latter area, Sumas recessional sand and gravel outwash was ubiquitous on the valley floor, except for limited Holocene stream deposits near Cultus Lake. The valley sides are mapped as being exclusively bedrock-dominated. Discussion of the Columbia Valley sediments was not included in the text. Armstrong also produced a preliminary survey map of part of the lower Chilliwack River valley, but without any accompanying discussion (Armstrong, 1960b). Three different types of deposit were recognized: (i) "Huntingdon" and "pre-Huntingdon" (pre-Sumas) gravel, sand and silt exposed in the north side of the lower valley, (ii) Sumas till on the Ryder Upland, and (iii) modern floodplain gravel in the valley bottom.

University of British Columbia Theses

Three University British Columbia undergraduates wrote theses on the Chilliwack Valley. The first of these, Chubb (1966) studied two exposures in the vicinity of the Slesse Creek-Chilliwack River confluence. Both sections were similar, and consisted of a 15 m basal unit of lacustrine clay, successively overlain by 15 m of well-stratified sand, up to 12 m of cobble gravel, and capped by 12 m of silty sand with clay lenses. The sandy units were interpreted as slack-water deposits and the gravel as channel fills. The depositional environment inferred was a glacial lake into which a sandur was built. The origin of this lake was not specified, but an ice dam in the lower valley was implied.

The second thesis was by Munshaw (1976), and included discussions of the surficial geology, geomorphology and hydrology of the area. The Chilliwack Lake Barrier was described in some detail. Landslide and recessional moraine origins were rejected. Munshaw suggested that either a glacier, or meltwater, from the Post Creek valley could have deposited this feature. Although catastrophic floods were inferred, the origins of these were not clearly explained.

Munshaw correlated the upper valley sandur with the Ryder Upland, and suggested that this was a continuous valley floor. No surficial deposits were dated older than the Everson

Interstade. He proposed that Sumas ice deposited till on the Ryder Upland, and outwash gravel in the Columbia Valley.

Munshaw's interpretations lack solid evidence, and in places contradict themselves. One of the major objections to his thesis is the problem of envisaging the thick Sumas-age valley fill that was removed by the postglacial Chilliwack River.

Gourlay (1977) wrote the third thesis, and concentrated on the upper valley sandur. This feature was described as being "constructed by a series of jokulhlaups issuing from Post Creek", the origin of which was the focus of the study. Maximum clast size of boulders on the valley surface were measured from Post Creek to Allison Pool (Figure 1.1), and graphed against downstream distance and valley slope. The results of this were interpreted somewhat subjectively. Gourlay estimated the paleodischarge required to transport the largest boulders at the mouth of Post Creek, and obtained results of the order of 10^5 m^3s^{-1}, which is probably a gross overestimate. The sources of the jokulhlaups were not clearly defined. Gourlay suggested that the Chilliwack Valley glacier ponded water in Post Creek, releasing it upon retreating. Although conceivable, this would not have allowed the Chilliwack Lake Barrier to be terraced (see Chapter 2) as ice would have covered this feature at the time.

Recent Publications

Armstrong (1980a,1980b,1981) produced revised maps of the surficial geology of the lower Chilliwack and Columbia Valleys. An obvious asymmetry of deposits was apparent along the Chilliwack River: on the south side, only bedrock and landslide debris were recorded, whereas the north side contains a variety of Sumas and pre-Sumas sediments, capped by Sumas till which forms the surface of the Ryder Upland. Minor amounts of eolian silt overlay much of the Upland. The valley bottom was mostly post-glacial alluvium. In the Columbia Valley, Sumas outwash was mapped as a low bench at the north end of Cultus Lake (the L4 surface), as well as the major valley fill beyond the south end.

Easterbrook et al. (1975) mapped the Columbia Valley outwash south of the border, to the Nooksack River. The outwash was believed to be of Sumas age in view of the freshness of the abandoned channels. The abrupt change in elevation of the valley just south of Cultus Lake was proposed as an ice-contact face; the ice would have been at least 100 m thick at the snout to form this feature. Till in this face was later dated at 11,300±100 BP (GSC-2523) (Clague & Luternauer, 1982).

Hicock et al. (1982b) conducted a detailed study of sediments at the Vedder Crossing Gravel Pit, and Clague & Luternauer (1982) also described this section. These works are summarized in Chapter 5, since this pit is site CH1 of this study. Clague & Luternauer also included a section from Slesse Creek (CH9) and the Chilliwack Lake Barrier (CH12).

D. M. Mark (1983, pers. comm.) attempted to depict the Quaternary history of the Chilliwack Valley by assuming that each set of benches (see Chapter 2) were alluvial terraces and so represented former valley floors.

Discussion

From this review, many questions emerge unanswered, or inadequately dealt with, by previous work. In particular, the composition, origins and correlations of the benches in the lower valley are not fully understood. The suggestion of a series of valley fills is not substantiated by field evidence. The composition of the thick deposit underlying the Ryder Upland has not been fully elucidated. There is a general lack of detail in the surficial geology throughout the valley. Armstrong's (1980a,1980b) maps do not cover the valley upstream of Allison Pool. Only the Vedder Crossing Gravel Pit, Slesse Creek section and Chilliwack Lake Barrier have been documented with any thoroughness, and there remains large gaps of poorly known territory in between.

CHAPTER 4: METHODOLOGY

This chapter describes the techniques used in field logging of sections, mapping the landforms and surficial geology, and the lithological coding used.

Field Logging

The ultimate aim of field measurement is to subdivide a section into definite units, which then form the basis for interpreting sequential events in the history of sedimentation at that site.

> "A stratigraphic unit is a stratum or assemblage of strata recognized as a unit...with respect to any of the many...attributes that rocks possess. Clear definition of a stratigraphic unit is of paramount importance." (Hedberg, 1976)

In this study, the basic parameters employed in defining units were the sedimentary texture and structure, and the lateral continuity exhibited in the exposure. The latter is important because individual lenses (which are not called units here) and extensive beds (which are described as such) can be separated.

The following information was recorded at each field site, wherever possible:

(i) thickness of beds,

(ii) textural characteristics,

(iii) types of contact,

(iv) sedimentary structures and fabric, and

(v) additional features.

These, if complete, enable the definition of a limited number (ideally, only one) of paleoenvironments for each unit.

Thickness of beds

Estimation of the thickness of beds was readily accomplished at a vertical or near-vertical face, by direct measurement using a 1 m rule or 30 m tape. With sloping faces, the use of a tape, inclinometer or Brunton compass, and simple trigonometry, enabled the calculation of the same quantity.

Texture

Textural properties of primary importance are an estimation of the dominant particle size or sizes present in a deposit, and the degree of sorting of those particles. The size divisions used here (Table 4.1) are those suggested by Wentworth (1922).

Table 4.1 Wentworth Particle Sizes

Terminology	Size range (mm)
Boulder gravel	>256
Cobble gravel	64-256
Pebble gravel	2-64
Coarse sand	0.5-2.0
Medium sand	0.25-0.5
Fine sand	0.063-0.25
Silt	0.002-0.063
Clay	less than 0.002

All observations of the sedimentary characteristics were qualitatively made. Field assessment of particle size was considered to be consistent and sufficiently accurate for interpretation procedures.

Although more objective in approach, quantitative analyses of texture were considered to be neither necessary nor practical. Several hundred samples would be needed to quantitatively assess the Chilliwack Valley sediments. The task of analysing such a large number of samples was considered to be beyond the point of diminishing returns in view of the limited time available for research. The time and energy expended in collecting and analysing textural samples would not be rewarded by signifcant returns in terms of enhanced appreciation of a deposit and the mode of deposition.

Types of Contact

Contacts may be conformable or unconformable. Conformable contacts may imply a continuum of deposition and an absence of an erosional interval. Unconformities represent a break in the sedimentary record. The implications for the interpretation of paleoenvironments are that only depositional environments can be specified in any detail. In the study area, unconformities are manifested in the form of erosional contacts, and are defined as such in the text. Without dating control, the length of the erosional period cannot be accurately defined.

Some contacts in the sections could not be adequately discerned, due to the poor or limited exposure. Unless other evidence suggested the contrary, a conformable contact was assumed for reasons of simplicity.

Sedimentary Structures and Fabric

The terminology used here to describe structure is mostly standard and self-explanatory. Two potential sources of ambiguity should be clarified, namely cross-bedding and loading structures.

(i) Cross-bedding may be manifested in a variety of ways (Reineck & Singh, 1980). Two main types can be defined: planar and trough. Where these are not specified in the text, planar cross-bedding should be inferred.

(ii) Loading stuctures can include flames, convoluted bedding, small-scale faulting and slumping, and dewatering structures (Reineck & Singh, 1980; Collinson & Thompson, 1982). In this study, the term is usually confined to the first two types listed above, unless otherwise stated. These structures are mostly of the order of tens of millimetres in size. In general, diapiric intrusion (invasion of an upper bed by sediment from the lower bed) is associated with flames. The causes of such features usually involve rapid loading of sediments which are still in a semi-plastic state, and may be assisted by subaqueous conditions.

Under some depositional conditions, clasts tend to show a preferred orientation, from which an estimation of the direction of flow of the depositing medium can be made. Glacial, fluvial and littoral environments may show such "primary fabric" (Reineck & Singh, 1980). Usually this is most obviously displayed in gravel-sized material, but finer grains may also possess this quality. Only gravel fabric was examined in this study.

Clast-supported gravel units were examined for imbrication, which indicates the paleoflow of the ancient river. Absence of imbrication need not, however, mean that a fluvial origin can be ruled out.

With some matrix-supported diamicts, a fabric analysis was performed to determine whether preferred clast orientation was present. The a-axis dip and dip direction was recorded for fifty elongate stones in a small part of the section, using a Brunton compass. Care was taken to execute the fabric analysis in undisturbed, in situ diamict.

The presentation of the directional data was in the form of rose diagrams, with the data grouped into 10° class sizes. Two statistical tests were performed in an attempt to ascertain whether there was a preferred clast orientation, and if so, in what direction. The former test used the Chi-square technique as outlined by Andrews (1971), comparing the observed distribution with a hypothetical omnidirectional distribution. To determine the preferred direction of clast orientation (the "resultant azimuth"), the two-dimensional vector analysis method used by Curray (1956) was employed. In both tests, a significance level of 90% was used.

Where clast orientation was significant, then the resultant azimuth was used to infer ice flow directions. Ice movement parallel to the preferred orientation, and in an up-dip direction, is the conventional interpretation of till fabrics.

Additional Features

Supplementary sediment properties, such as the presence of organic matter, colour and induration, were also recorded where applicable.

The presence of dateable material is of primary importance. Wood samples collected from the Chilliwack Valley underwent a minimum of handling and were stored in sealed polythene bags. To date, three samples have been submitted for radiocarbon assessment.

A radiocarbon age for wood within a deposit does not necessarily date that sediment. Potential sources of error include the possibility of a time lag between the death of the tree and the incorporation of the wood into a sedimentary deposit, and past variations in atmospheric radiocarbon activity. It is assumed here, however, that the errors in dating are acceptably small.

Colour was not considered to be of importance when recording the stratigraphy at a section, except when it was in some way unique. The problems of defining the colour of sediments were prohibitive: many sediments contain many different shades and tones, and colour can change with moisture content and the degree of weathering.

At a majority of Chilliwack Valley sections, sediments were not indurated. Matrix supported diamicts were the only deposits to exihibit solid compaction, and this quality was recorded with stratigraphic data.

Geomorphological Mapping

Two sets of vertical air photgraphs were used, details of which are in Appendix B. The breaks in slope that define the limits of the modern floodplain and benches in the study area were marked directly on 1:15,840-scale photographs. Terrain units were distinguished and labelled according to their elevation relative to the modern floodplain, surface microrelief, and apparent correlation to other similar units. A standard system of geomorphological mapping deposits does not exist in Canada (Occhietti, 1974), so coding based upon that used by Savigear (1965) was used. A base map was traced from the marked photographs and subsequently reduced to the 1:50,000 scale.

The elevations of the benches and field sites were determined using parallax bars on a stereoscope.

Surficial Geology Mapping

The surficial geology was compiled through the examination of sections and by inferrence from depositional landforms. Using the geomorphological base map and field observations of stratigraphy, a second base map was constructed using the provincial terrain classification system (BC Dept. Env. 1976). This system enables each individual landform-sediment unit to be uniquely and succinctly described by coding.

These units were re-classified according to their lithostratigraphic age (Figure 3.1) and then subdivided into depositional environments, such as glaciolacustrine, outwash, and so on. The resulting surficial geology map was reduced to a 1:50,000 scale in the same way as the geomorphological map.

Lithofacies Coding

Schematic classification and description of measured sections (used in Chapter 5) was accompilshed following the guidelines laid down by Miall (1978) and Eyles et al. (1983). Textures and contacts are illustrated diagramatically in Figure 4.1. Typical sedimentary structures encountered in this study are shown in Figure 4.2.

Figure 4.1 Textures and Contacts

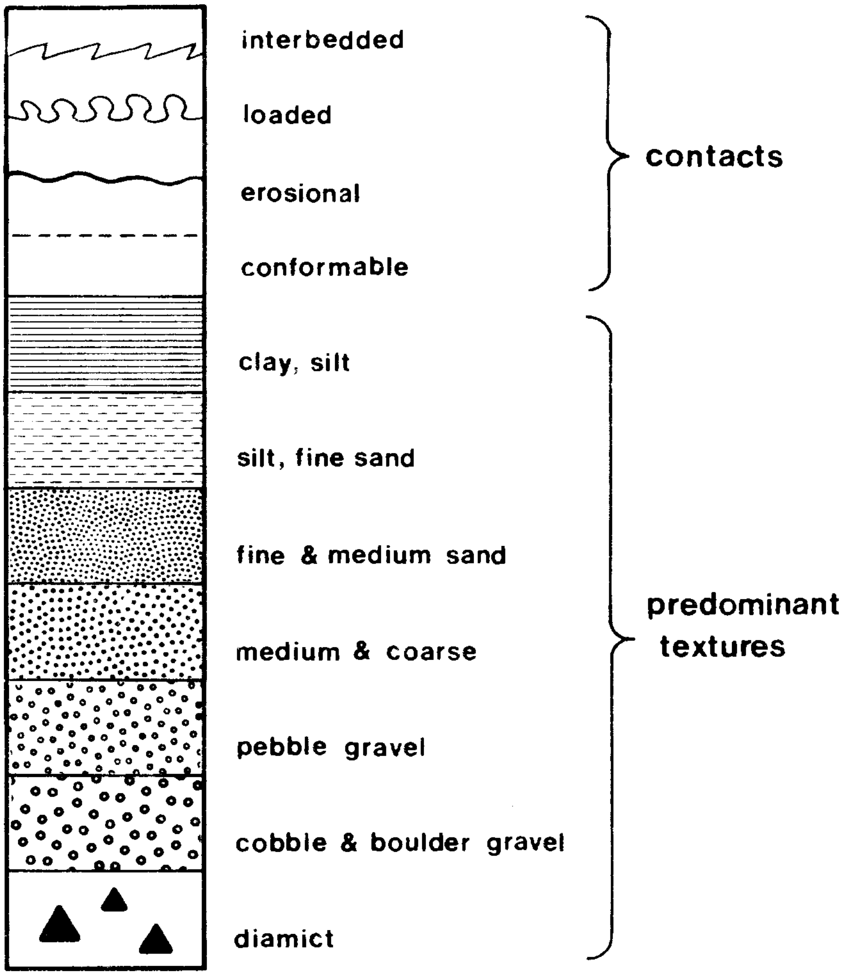
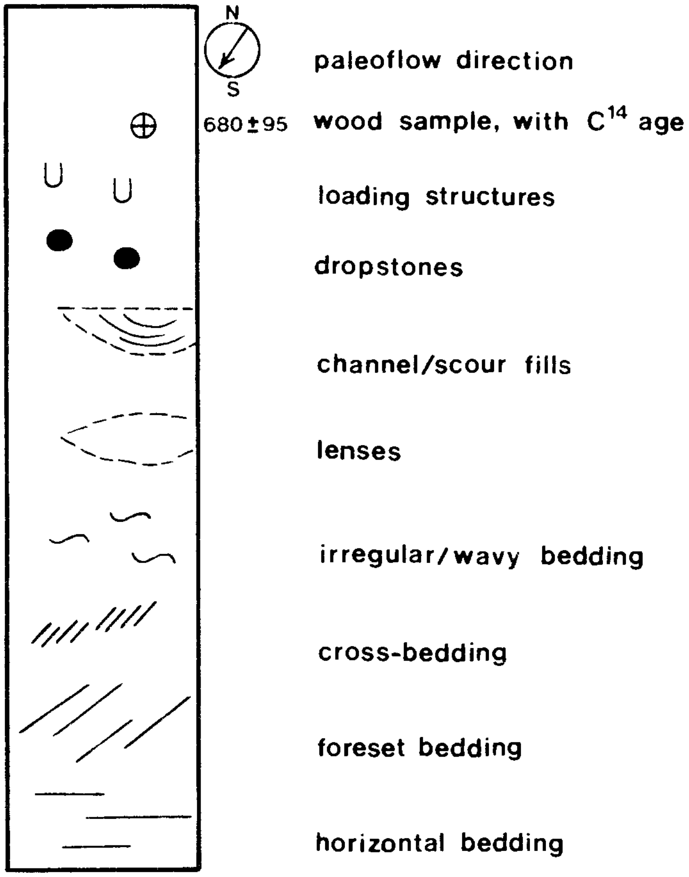


Figure 4.2 Sedimentary Structures



The abbreviations used in the measured sections are listed below (Table 4.2).

Table 4.2. Lithofacies Coding

General classification	
D	diamict
G	gravel
S	sand
F	fines (silt and clay)
IMB	imbrication
Coarse-sediment subscripts	
Dmm	matrix-supported massive diamict
Gcm	clast-supported massive gravel
Gcs	clast-supported stratified gravel
Gcp	clast-supported gravel, planar cross-stratification
Fine-sediment subscripts	
Sm/Fm	massive
Sh	horizontal stratification
Sp	planar cross-stratification
St	trough cross-stratification
Sr	ripples
Sc/Fc	channel/scour fills
S-d/F-d	containing dropstones
Fl	laminated
Sorting	
WS	well sorted
MS	moderately sorted
PS	poorly sorted
Rounding	
R	rounded
SR	subrounded
SA	subangular
A	angular

Minor amounts of a particular sediment type are indicated in parentheses. "Rounding" is used to indicate the degree of particle attrition. Putting aside lithological controls, the roundness of a clast approximately infers the amount of transportation and reworking that it has undergone.

CHAPTER 5: THE MEASURED SECTIONS

This chapter describes and discusses the major outcrops of Quaternary deposits in the Chilliwack Valley. The exact map locations of the sections are listed in Appendix A. Paleoenvironmental interpretations following the description of the stratigraphy usually resulted from the combined assessment of sediments and landforms. For the sake of clarity and brevity, much of the primary information about the surficial sediments is presented in schematic form in the figures, the key to which is defined in the previous chapter.

CH1. Vedder Crossing Gravel Pit.

This pit is 1 km east of the mouth of the Chilliwack River valley (Figure 2.2a), and is still actively worked in the upper parts. The stratigraphy here was described by Clague & Luternauer (1982) and Hicock et al. (1982b) and the measured section (Figure 5.1) is summarized from these sources. No attempt was made in this study to add further detail. This section shows the unconsolidated deposits which underlie Promontory Heights (Figure 1.1).

Stratigraphy

Unit 1 gravels rest on bedrock and account for half the exposed sediments. They are mostly horizontally stratified, with minor cross-bedding. Imbrication indicates a westward paleoflow. Three mammoth tusks have been dug from the upper parts of this unit, two of which gave radiocarbon dates of 21,600±240 and 21,400±240 BP (respectively SFU-65 and SFU-66, Hicock et al. 1982b).

Unit 2 clayey silts contain freshwater Pediastrum algae in its upper parts, and some sand and gravel lenses. The upper contact of shows evidence of catastrophic disturbance: blocks of silt from this unit have been pulled up and incorporated into the lower part of Unit 3.

The Unit 1-Unit 2 gravel-silt sequence can be traced upstream along the north side of the valley to the Tamihi Creek area, where it also outcrops on the south side; the best of these exposures are at CH1a and CH1b (Figure 2.2a,b).

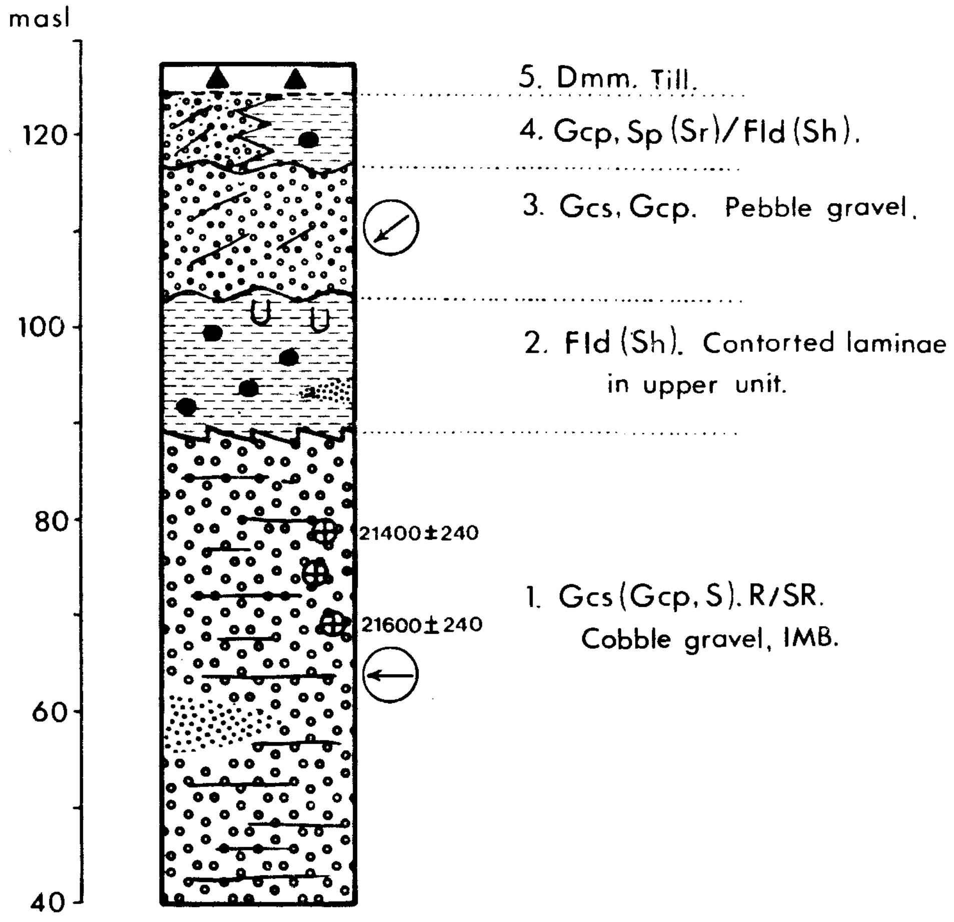
Unit 3 is finer than the lowest gravel (Unit 1), and has better defined cross-bedding and cut-and-fill structures. The paleoflow of these gravels suggest flow towards the Columbia Valley.

Unit 4 gravels are interbedded with sand. These grade eastward into horizontally-laminated silts. Unit 4 is unconformable with Unit 3.

Unit 5 is a mantle of till with a loess veneer.

FIGURE 5.1

CH1. VEDDER CROSSING GRAVEL PIT



Interpretations

The basal gravels are a typical coarse gravel-bed river facies and were deposited as outwash from an advancing Chilliwack Valley glacier. They are correlative in age with the Coquitlam Drift of Hicock & Armstrong (1981). The paleosurface of this unit shows a longitudinal profile that is characteristic of modern valley trains (Hicock et al. 1982b). The sandur gravels filled the entire width of the Chilliwack River valley in the Tamihi Creek area, and whilst no other outcrops of them occur on the south valley side, it is probable that a valley-wide fill extended downstream to Vedder Crossing, perhaps into the Columbia Valley as well, and was subsequently removed. An alternative interpretation of these gravels is that they are a kame terrace built alongside the advancing glacier.

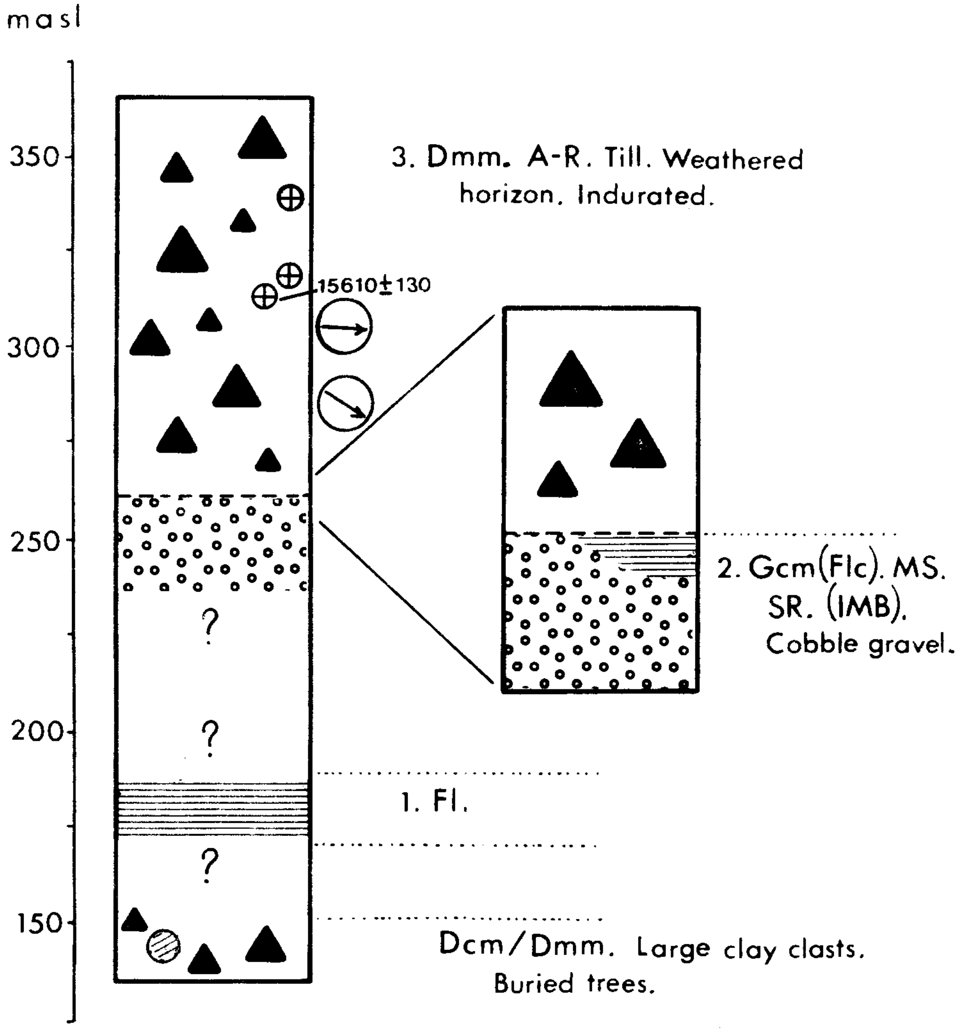
The lacustrine silts in Unit 2 were deposited in a lake probably dammed by advancing ice in the Fraser Valley, during the advance phase of the Fraser Glaciation (Hicock et al. 1982b; Clague & Luternauer, 1982). The sand and gravel lenses in this unit were possibly subaqueously deposited from the nearby ice margin or from floating ice blocks, or alternatively they may represent fluvial sediments from streams flowing into the glacial lake.

Hicock et al. (1982b) interpreted the gravels in Unit 3 as more outwash, intiated by a flood surge which disturbed and ripped up silt blocks from Unit 2. Such floods perhaps resulted from a sudden draining of the glacial lake. Clague & Luternauer (1982) suggested an alternative origin for these gravels, that of deposition from a subaqeous ice margin. The absence of till between Units 3 and 4, which would be expected from the advancing ice, was explained as a result of a floating ice margin or later removal. Glaciolacustrine conditions followed, and the presence of abundant coarse material within Unit 4 suggest that these conditions were ice-marginal, the gravel-silt grading perhaps representing a proximal-distal fining trend. Renewed ice growth deposited the till capping. Katabatic winds blowing off the receding ice masses would be responsible for the loess veneer.

CH2. Tamihi Scar

This is a major section. A landslide scar has exposed a thick accumulation of the sediments which underlie the Ryder Upland (Figures 2.2a,b). The scar, which pre-dates 1966, is still unstable in wet conditions. The most recent documented major failure at this site occured in December, 1975 (Munshaw, 1976). Most of the lower half of the section is buried under mass movement deposits but the upper half is still well-exposed. Due to the very poor or non-existent exposure in the lower section, the numbering of units in Figure 5.2 is necessarily tentative.

FIGURE 5.2
CH 2. TAMIHI SCAR



Stratigraphy

Immediately above the road, unsorted gravels are exposed in a road cut and in the stream bank; several mature trees in the road cut have been partially buried by this deposit. A few boulder-sized clasts of laminated silt are contained within this. This is a recent debris flow deposit.

Unit 1 displays laminated silts, at least 10 m thick, in a poor exposure in a tributary gully. The contacts are not visible.

Unit 2 is composed of massive gravels, with a 1.0 m lens of laminated silts occuring at the top contact. Localized crude imbrication indicates a westward paleoflow. The lower contact is buried.

Unit 3 is a diamict that lacks any kind of obvious structure or contacts and is apparently a single homogenous unit (Figure 5.3). The sediment is solidly compacted and contains occasional striated clasts. Most of the stones in the matrix are smaller than 1 m, although a few larger boulders (up to 4 m in size) do occur. Three small logs outcrop in this unit. The lowest one, which lies at approximately mid-section, was dated at 15,610$\pm$130 BP (BETA-11057).

Figure 5.3. Upper half of Unit 3, Tamihi Scar.

The Brunton compass rests on the lowest log found in this unit (dated at 15,610±130 BP). The surface of the Ryder Upland is visible at the top of the exposure.

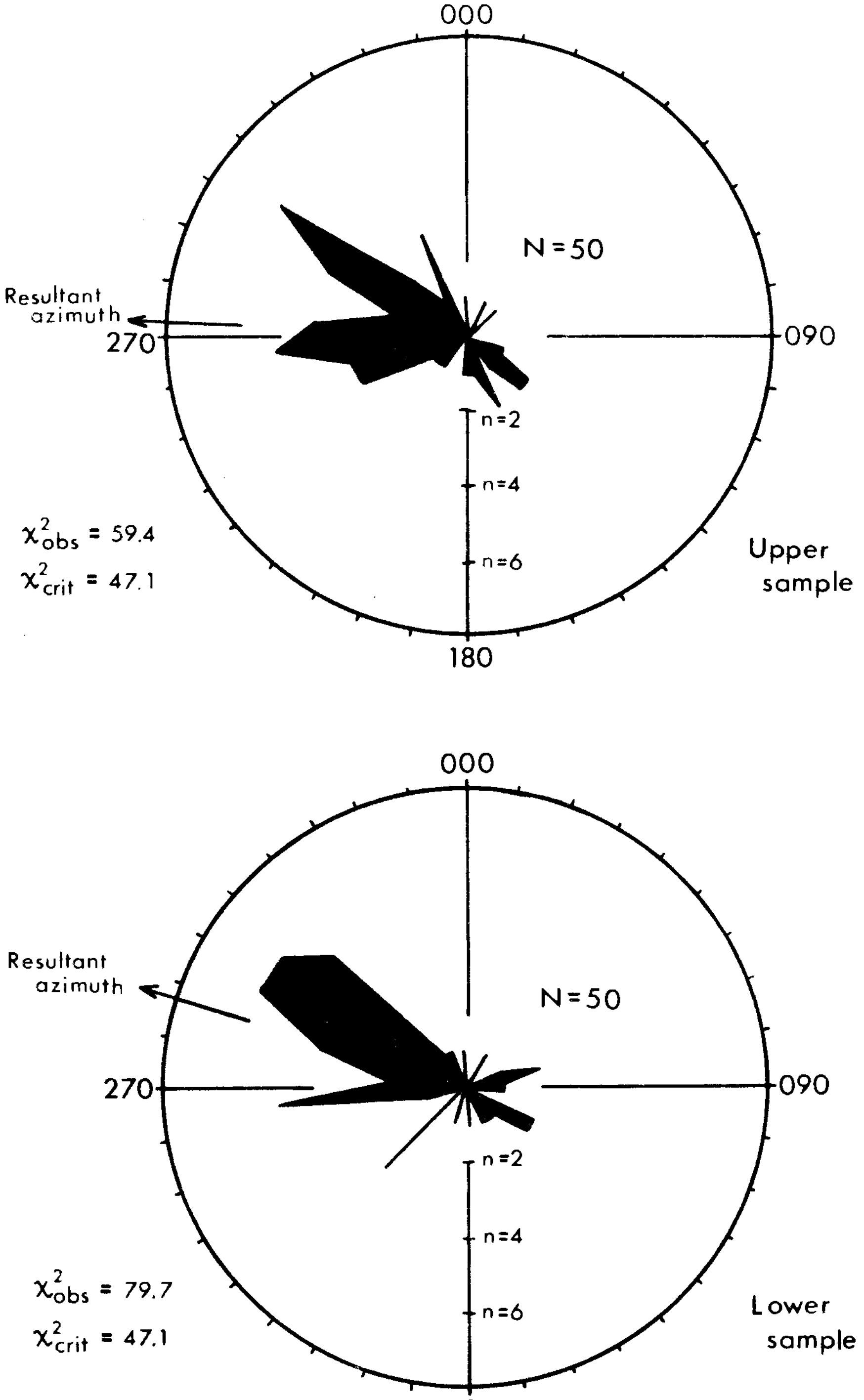
Figure 5.4. Log and ash, Unit 3, Tamihi Scar.

This photograph was taken about 2 m above the Brunton compass shown in Figure 5.3. The ash is probably derived from the log; it is not volcanic.

Scale is 0.15 m long.

FIGURE 5.5

CH2. FABRIC DIAGRAMS



The middle log rests upon a 0.1 m layer of white silty ash which appears to have been derived from the log (Figure 5.4). Two fabric analyses were performed in the lower half of the diamict; the results (Figure 5.5) show a strong, and statistically significant, preference for the clasts to dip westward.

Two small road cuts to the east of this site, collectively called CH2a (Figure 2.2b), lie within the elevation range occupied by Unit 3, at about 280 masl, and are included to provide further insight into the nature of this unit. One shows unsorted clast-supported gravels with few interstitial fines. The other exposes well-sorted fine and medium sand expressed in a variety of structures. The sand is generally bedded, with a low-angle dip toward the southwest. Local ripples and ripple-drifts indicate a downdip paleoflow direction. Some beds have been disturbed to produce faint wave-like flames up to 0.4 m high.

Interpretations

Unit 1 is most likely of glaciolacustrine origins and correlative with similar clays at CH1, CH1a and CH1b.

Unit 2 gravel is a fluvial facies; its coarseness, lack of well-defined bedding, and poor sorting imply a proximal or flood deposit or both. Its high elevation suggests that ice-marginal drainage was responsible; it is probably early Fraser outwash from the Chilliwack Valley glacier. Localized ponding by the ice would have enabled the clay lens to form.

Unit 3 is till. Ice apparently flowed from the Fraser Valley, from the west and northwest, for at least the first half of the depositional period. Given that the central part of Unit 3 is of mid-late Fraser age (15,610±130 BP), the depositional period represented by the till probably extended uninterrupted for the major part of the Fraser Glaciation.

The origin of the ash layer under the middle log in Unit 3 (Figure 5.4) is a curious problem. Deposition of this wood and ash was shortly after the lower log (dated at 15,610±130 BP), and at this time the Ryder Upland was covered by thick ice. A volcanic origin for the ash therefore seems most unlikely, and it is probably derived from the adjacent log.

The Ryder Upland represents a major depositional zone for the ice in the Fraser Valley. The exact cause of this anomaly (the thickness of Vashon till at CH2 is unmatched anywhere in this area) can only be speculated. Possibly, deposition was induced by interaction with the Chilliwack Valley glacier which would have been active at the same time. Ice flowing into the Chilliwack Valley from the Fraser Valley may have encountered this valley glacier and deposited its sediment as a response to the obstruction.

The sediments at CH2a must in some way be closely related to a glacial environment, since till occurs just west of this site. The gravels may merely be a locally stonier part of the till. The sands are undoubtedly waterlain, so the gravels may simply be moraine with the fines washed out at the time of deposition. The sands are current-deposited, and could be either subaerial or subaqueous. The lack of coarse material, in an environment rich with gravel-sized debris, suggests that the latter is more likely. The absence of similar deposits at the main section infers that localized ice-marginal lacustrine conditions existed at CH2a.

CH3. Allison Pool Scar

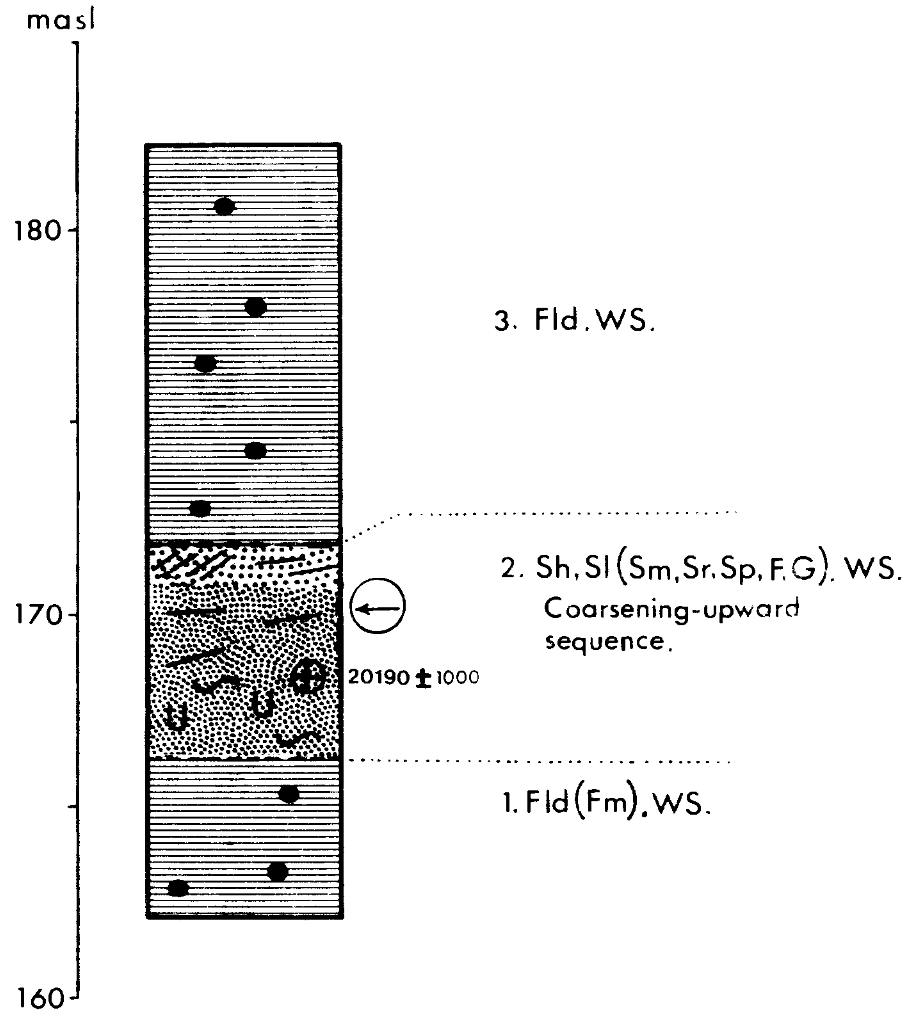
This section owes its origins to a landslide and is unstable when waterlogged. It is mostly covered by mudflow deposits. An abandoned road leads directly to the section. CH3 is not representative of any distinct landform; it merely occurs at the base of the valley-side slope, without an obvious surface expression (see Figure 2.2b for location).

Stratigraphy

Unit 1 mostly consists of horizontally laminated clay, with dropstones (Figure 5.6). In some parts, roots (from modern vegetation) have destroyed the laminae, and it appears massive.

Unit 2 contains well-sorted fine and medium sands with minor silt. The sand has massive parts, but is more commonly bedded, with some ripples and small-scale cross-beds. Many beds dip gently toward the west.

FIGURE 5.6
CH3. ALLISON POOL SCAR



Two 0.4 m silt flames occur in the lower parts of the unit, as do faults and slump structures. Occasional pebble-sized clay balls can also be found here.

Three small rounded pieces of wood within this unit were collectively dated (being individually of inadequate size for radiocarbon assessment). The samples were derived from a restricted area and were considered to be sufficiently close to each other to assume a single dateable sample, despite the possibility that they need not be derived from the same source. Two pieces were at the same level and about 0.3 m apart, and the third was less than 0.2 m below these. An age of 20,190±1000 BP (SFU-406) resulted.

The roundness of the wood pieces, and the lack of other wood here, suggest that a period of transportation and dispersion occured subsequent to the time when the sources log was eroded. The degree of fluvial attrition of wood pieces has been found to influence their radiocarbon age: Blong & Gillespie (1978) found that age was inversely proportional to the size of wood sample. The radiocarbon age is therefore a maximum for the Unit 2 sediments.

Unit 2 exhibits a general coarsening-upward sequence, and the upper metre contains mainly coarse sand with occasional pebbles; most of the pebbles are concentrated at or near the upper contact. Faint wavy bedding and planar cross-beds occur. The contact is sharp and irregularly horizontal with a rippled appearance.

Unit 3 is very similar to Unit 1, but contains fewer massive parts. Laminae are draped over individual clasts at the lower contact.

Interpretations

Extended glaciolacustrine conditions during the advance phase of the Fraser Glaciation are inferred from Units 1 and 3; the presence of dropstones throughout being indicative of such environments.

The complex variety of structures in Unit 2 probably results from rapid fluvial sedimentation, possibly accompanied by subaqueous conditions at times. The concentration of gravel at the topmost part of the unit suggests that energetic conditions existed in the latter stage of deposition. The dipping beds, coarsening-upward nature and the close association with lacustrine sediments, suggest that Unit 2 is a small delta.

The rate of deposition of the Unit 2 sands was probably much higher than that of the fines. In terms of the total length of time symbolized by the deposits at CH3, the sands likely represent a very brief depositional period.

The thickness of the clays at CH1 (Unit 2) is 14 m, and those at CH3 total more than 16 m. Both sets of clays can readily be interpreted as early Fraser; the latter were dated as such at 20,190±1000 (SFU-406). Both sets of clays probably are derived from the same lake.

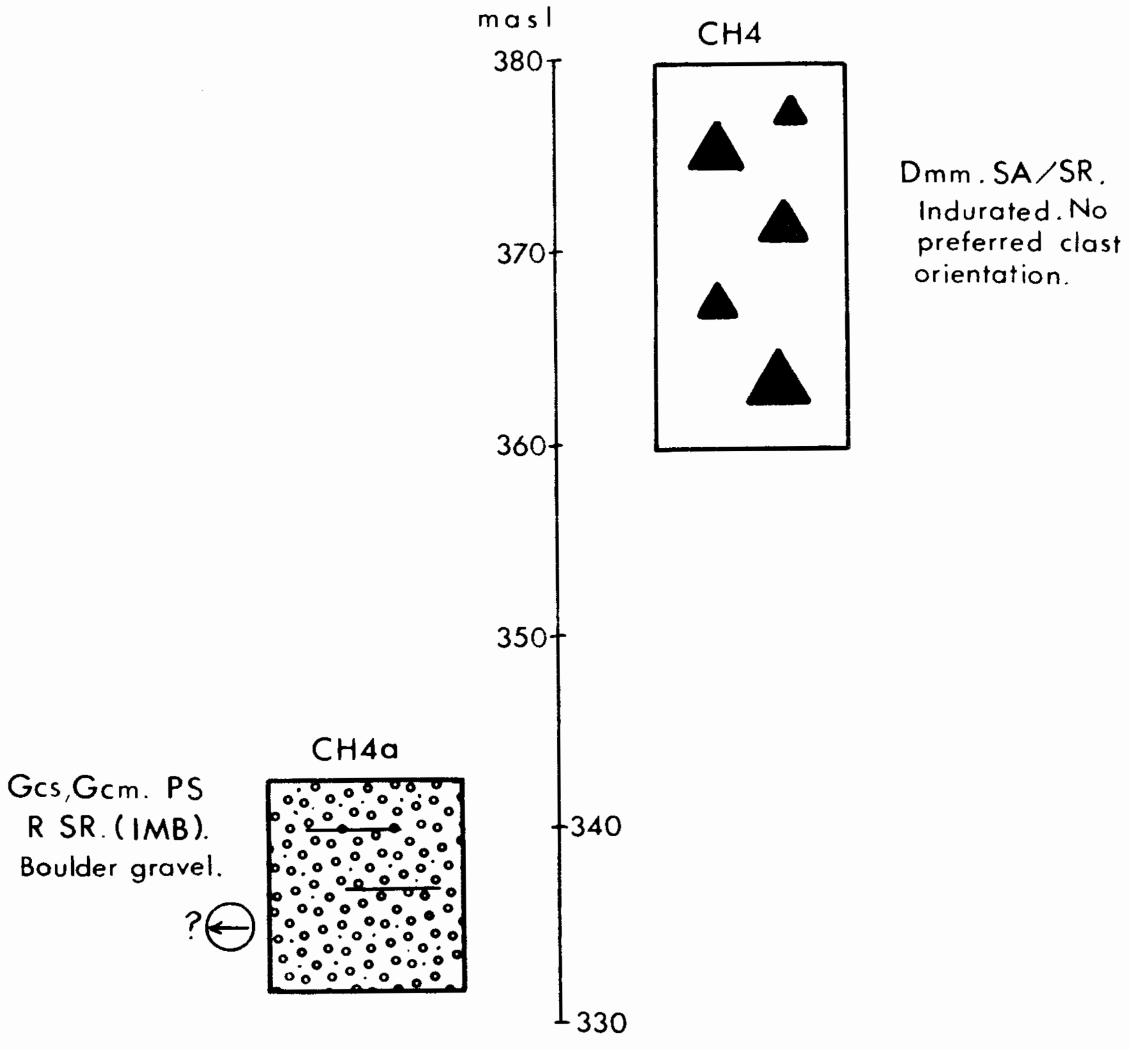
Two major glaciolacustrine events occurred in the Chiliiwack Valley, at ca. 20-21,000 BP and 11-12,000 BP (Clague & Luternauer, 1982). The date from CH3 places the deposits in the first event. Given the uncertainty of applying the radiocarbon date to Unit 2, however, the possibility that these sediments are significantly younger should be considered. Specifically, could the CH3 sediments have resulted from the 11-12,000 BP event?

The stratigraphy in this part of the valley suggests that this could not be the case. The deposits at CH3 lie at an elevation similar to glaciolacustrine sediments from the ca. 20-21,000 BP event (Unit 2, CH1; Hicock et al. 1982b), and which outcrop in two places 2-3 km away, at CH1a and CH1b (Figure 2.2a,2.2b). The morphology of the exposure at CH3, a landslide in the valley side, is also identical to those at CH1a and CH1b. If the CH3 units were late glacial (i.e. 11-12,000 BP), a more distinctive surface expression associated with these sediments might be expected.

CH4. Upper Bench

Only one usable section, a road cut, was found on the Upper Bench (Figure 2.2b). The exposure is reasonably clean; access is by a logging road branching off the Tamihi Creek Road.

FIGURE 5.7
CH4. UPPER BENCH



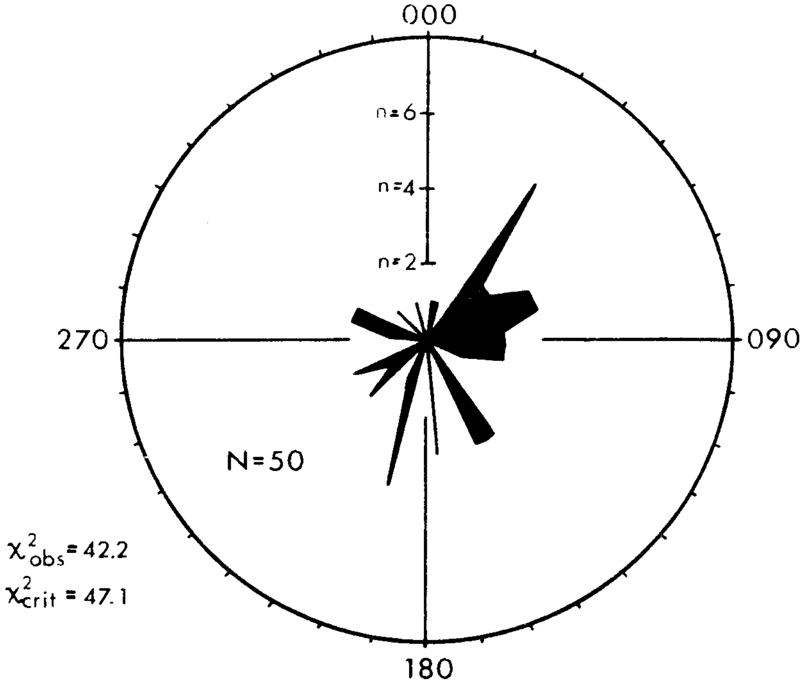


FIGURE 5.8
CH4. FABRIC DIAGRAM

Stratigraphy

The only sediment in the section is a dark grey, massive, matrix-supported compacted diamict (Figure 5.7). Clasts up to about 1 m in size occur, and are occasionally striated. Most are subrounded or subangular. A fabric analysis executed about 8 m below the bench surface showed no preferred orientation of clasts (Figure 5.8). The pebble orientations are not statistically different from an omnidirectional distribution.

Below the Upper Bench surface, and to the west, there is an arcuate ridge that blocks the mouth of Tamihi Creek valley (Figure 2.2b). A road cut in the uppermost part of this ridge, CH4a (Figure 5.7), reveals coarse gravels and sands, in places crudely stratified. Poorly defined localized imbrication gives a westward paleoflow direction.

No evidence was found to suggest that the diamict at CH4 directly overlies the gravels at CH4a: the landforms at each site are spatially discrete. It is therefore assumed here that the Upper Bench, as mapped in Figures 2.2a and 2.2b, contains only diamict.

Interpretations

There are three possible origins for the Upper Bench sediment. Firstly, it might be basal till similar to that at Unit 3, CH2, and thus is an extension of the Ryder Upland surface. But it lacks strong clast orientation; this could be explained as a result of different modes of glacial deposition (i.e. other than basal processes), or by post-depositional disturbance. The main objection to this suggestion are the problems of defining the spatial limits of such a thick valley fill, and the fate of the large volume of material that was subsequently removed. These problems are sufficiently great to make this origin unlikely. Secondly, it could be a lateral moraine. Although its form is not typical of such features (it lacks ridged topography), post-depositional modification may have occurred. Thirdly, it could result from a mass movement. If a landslide occured whilst ice filled the valley bottom, the debris would be left stranded on the valley side subsequent to the retreat of the ice. However, obvious source areas for the debris upslope of the bench remnants are absent.

The latter two suggestions require a valley glacier to be present at the time of deposition. The height of the Upper Bench above the valley floor demands that this glacier be of substantial size. Therefore, a mid-Fraser age is most probable. Of the options listed, the second one seems the most likely.

The sediments at CH4a must be glaciofluvial, given their location 200 m above the present-day Chilliwack River. The only reasonable explanation for their origin is ice-marginal drainage, which had to occur when ice masses existed in both the Chilliwack and Tamihi Valleys. The arcuate shape of the ridge may reflect the plan shape of a valley glacier in the Tamihi Creek valley. The ridge itself might be cored by a terminal or recessional moraine. However, without additional stratigraphic data, these suggestions are purely conjectural.

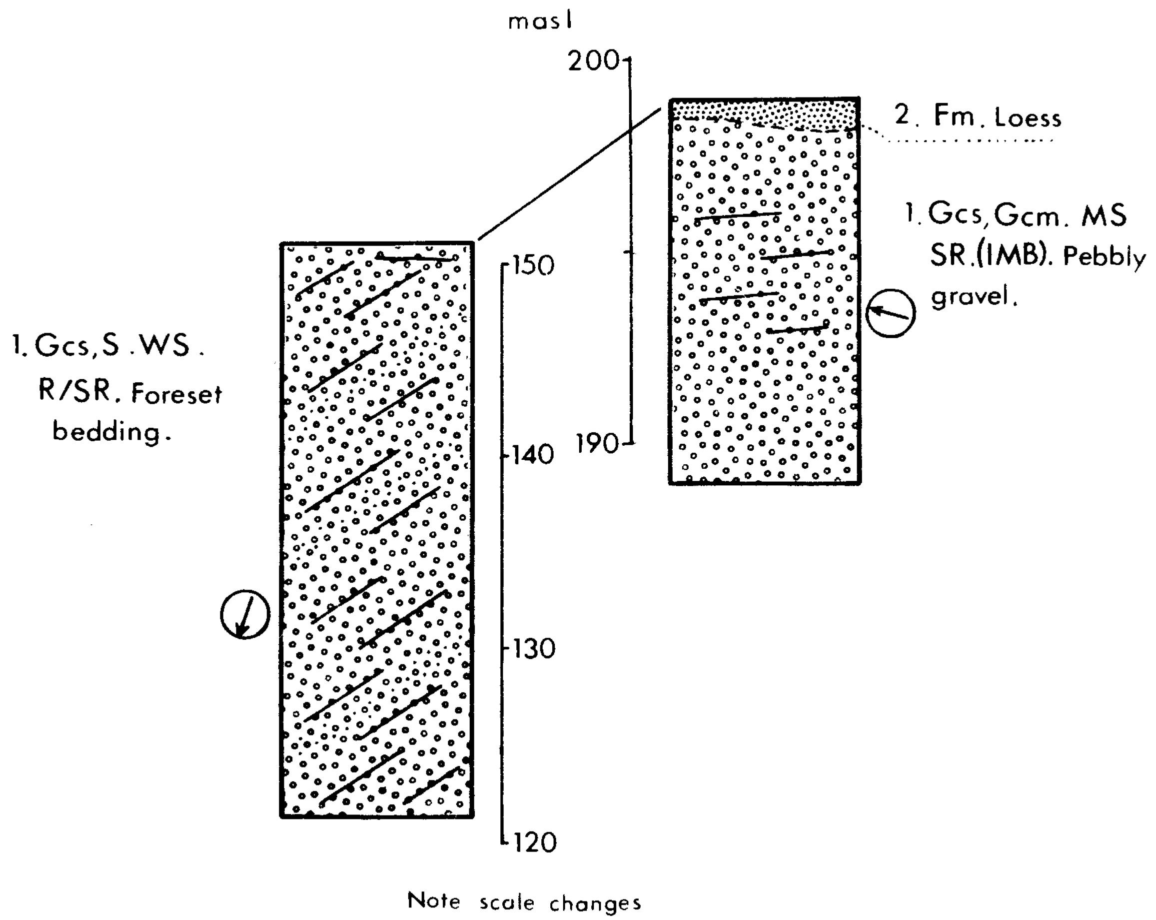
CH5. Lower Bench

Much of the western part of the bench surface has been disturbed, and there are few good exposures. Two sections (CH5a and CH5b), which are about 2.5 km apart, were measured (Figure 2.2a) and both are portrayed in Figure 5.9.

Stratigraphy

CH5a is a road cut. Pebbly gravels are exposed, some massive and some in low-angle dipping beds. The dip, and localized imbrication, exhibit a paleoflow toward 300°. The gravels rest on bedrock here but are obviously much thicker under the main bench segments.

FIGURE 5.9
CH 5. LOWER BENCH



Up to 1 m of reddish loess caps the gravel. Although this section is a few metres above the general level of the adjacent bench top, several small pits (now infilled) in the bench surface showed similar deposits. The loess capping outcrops in several places in the area.

The second exposure, CH5b, occurs at the westernmost end of the Lower Bench. This is a disused gravel pit, now regraded. The exposures are in gullies at the south end and are rapidly disappearing. Dipping foreset beds of coarse gravels and sands are exposed. Some of the gravel beds are open framework (no interstitial matrix). Topset bedding leading into foresets was briefly revealed in a backhoe excavation in the east side of the site, but is no longer exposed. A range of textures is present, from coarse sand to small boulders, but individual beds are well sorted. The gravels are locally open framework, but mostly contain interstitial sand.

Interpretations

The gravels at both sites are fluvially-deposited, and the lack of fines implies an energetic flow. The high elevation of the bench above the modern floodplain, and the absence of correlative landforms on the north side of the valley, suggest a kame terrace. Its freshness and loess veneer point to a late Pleistocene age.

The ice, against which this terrace was built, flowed into the lower valley from the Fraser Valley. Lobes of this ice dammed a lake that extended as far as Slesse Creek (Clague & Luternauer, 1982), and also filled the Cultus Lake basin. Drainage from the lake was confined to the south side of the ice lobe, leading to a delta built into an ice-marginal lake (Figure 5.10a), eventually connecting with the Nooksack River via the Columbia Valley. The present-day drainage route was covered by ice at the time. The ice-marginal lake was mostly confined to the valley of Smith Falls Creek, as evidenced by its unusually flat floor.

In places, the Lower Bench has smaller benches a few metres higher than the general level of this feature (see Chapter 2). This can be explained either as a result of a fluctuating glacier margin elevation, or possibly as fluvial terracing by the ice-marginal river.

Typically, kame terraces are supplied with sediment from upstream. In the case of the Lower Bench, however, there was a glacial lake immediately upvalley which would have trapped sediment being transported by the Chilliwack River (Figure 5.10a). Therefore, the gravels exposed in the CH5 sections must have been derived from elsewhere. Three possible sources exist. Firstly, material could have been transported from the surface of the ice lobe in the lower valley onto the kame terrace by supraglacial streams.

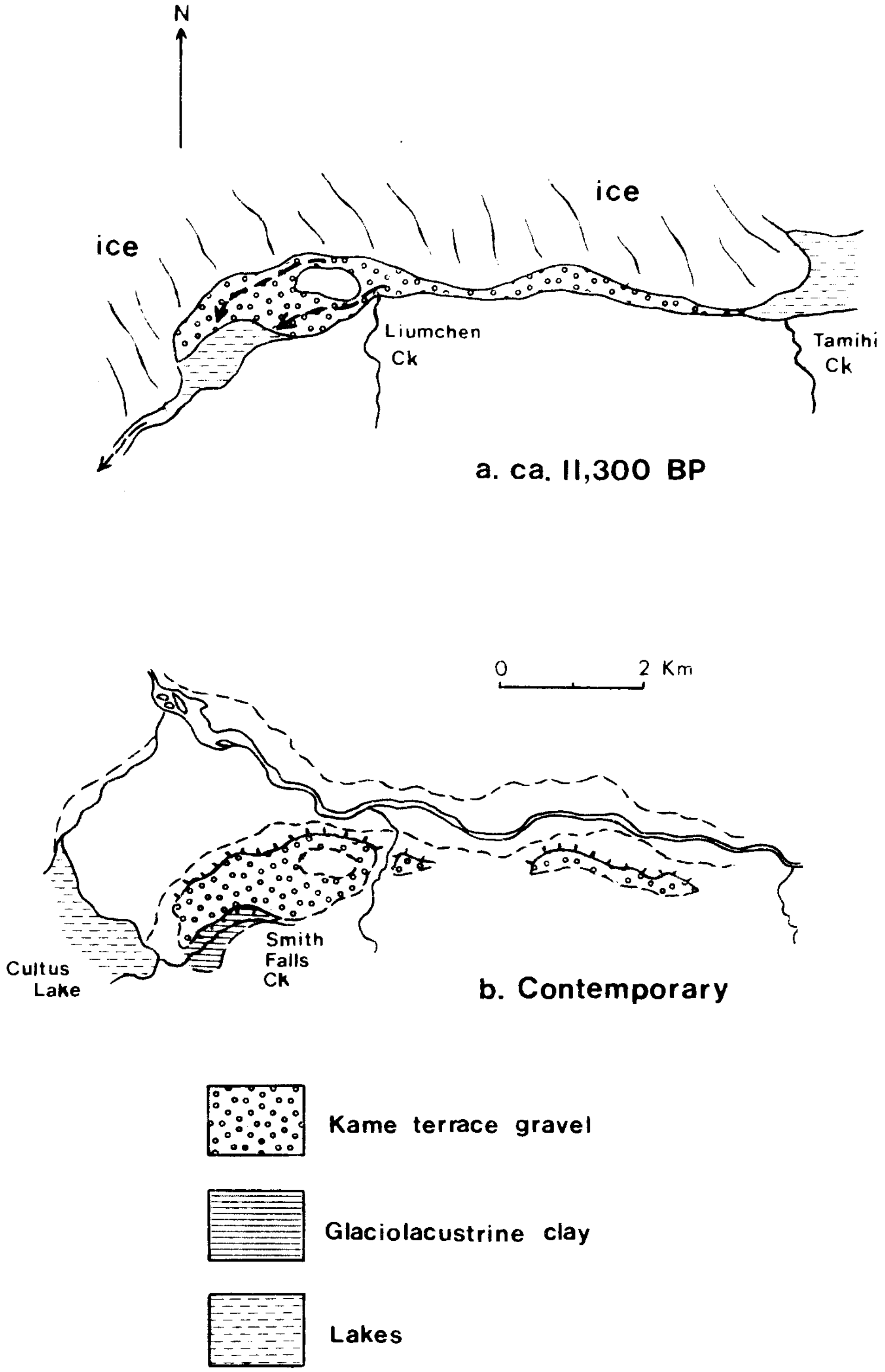


Figure 5.10 Evolution of Lower Bench

Secondly, tributary rivers from the south side of the valley, principally Liumchen Creek, would have fed into the ice-marginal drainage. Thirdly, debris may have been eroded from the valley side.

CH6. Cultus Bench

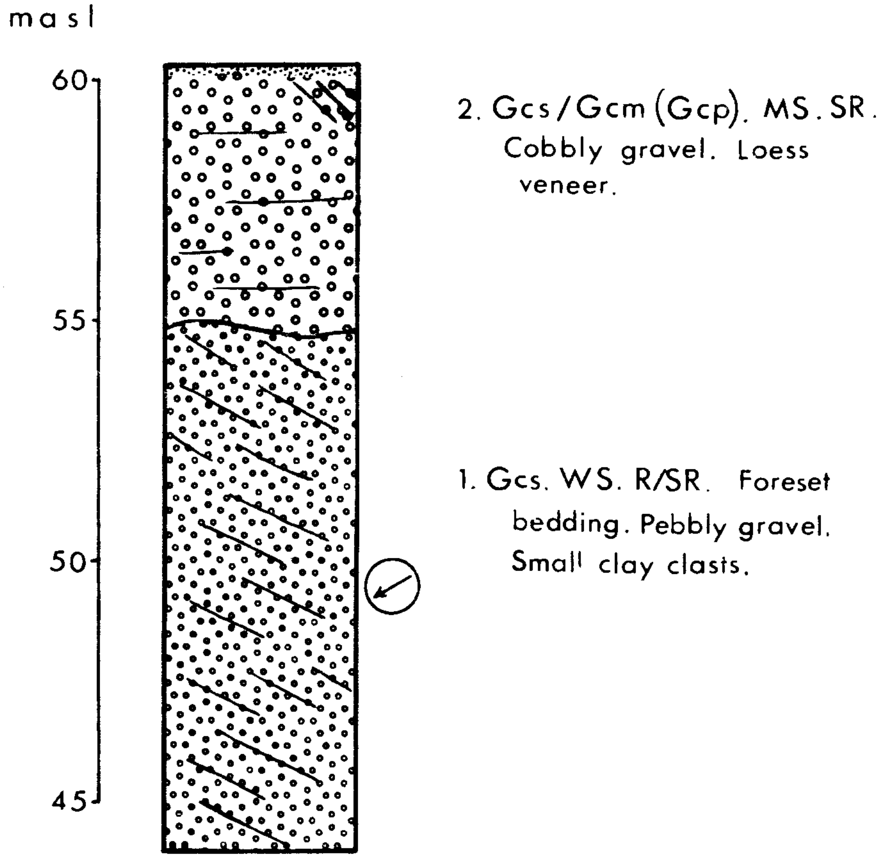
A recently reworked pit reveals the nature of the sediments underlying Cultus Bench (Figure 2.2a). The exposure is good, although talus is encroaching the lower parts.

Stratigraphy

Unit 1 contains gravel foresets with a paleoflow toward Cultus Lake (Figure 5.11). Textures from coarse sand to boulders are present, but individual beds are generally well sorted. Cobble-sized clasts of laminated clay can be found. The top contact is not distinct, but appears to be slightly wavy and is possibly erosional.

Unit 2 is composed of gravels that are coarser than those in Unit1, and are predominantly cobbles and boulders, weakly stratified. In the south end of the pit, cross beds occur. Up to 0.3 m of reddish loess rests conformably on Unit 2.

FIGURE 5.11
CH6. CULTUS BENCH



Interpretations

The Unit 1 gravels are deltaic. If the ancient lake level was close to the upper contact of this unit, then it would be about 10 m above the present-day level of Cultus Lake.

Gravels in Unit 2 result from more vigourous transport than the foreset gravels and may also have been more proximal. They are probably subaerial. At the time of deposition, the lake level may have been lower than it was when Unit 1 was deposited or further away from this site. The loess veneer was probably deposited at the close of the Pleistocene.

Lacking signs of major post-depositional disturbance, the sediments at CH6, and indeed the whole of Cultus Bench, are therefore probably of the same age. At this time, however, the Columbia Valley was filled with outwash deposits and so blocked southward drainage. The only other outlet for drainage is via Vedder Crossing, which requires a complete reversal of flow directions. It is possible that stagnant ice lay in the Chilliwack Valley and drainage was diverted around it, entering and leaving Cultus Lake as it did so (Figure 5.12a). Therefore, Cultus Bench formed as a kame delta.

Possible evidence for such a flow diversion lies in a disused pit at CH6a (Figures 2.2a, 5.12) on the west side of Columbia Valley, at an elevation only a few metres above CH6. Here, similar gravels to those in Unit 1 are exposed, horizontally stratified and not dipping. A channel fill is evident and gives a paleoflow direction of approximately 020'. If these gravels are time-correlative to those at CH6, then the reversal of flow, and the kame-delta, interpretations become more viable.

The abrupt scarp bounding the north side of the Cultus Bench may reflect the position of the stagnant ice (Figure 5.12). It may also have been eroded by the Chilliwack River and previously extended further than it does today. Extension of the bench to the north side of the valley (i.e. a valley fill) would mean that drainage via Vedder Crossing would be free of blockage, and paleoflows would be towards Cultus Lake. Therefore, some obstruction in the path of the Chilliwack River is the preferred interpretation, and this most likely was stagnant ice.

At some time, drainage at a higher elevation may also have ran due north from the Cultus Bench (Figure 5.12a) through the narrow valleys (now dry) near Vedder Crossing (shown in Figure 2.2a).

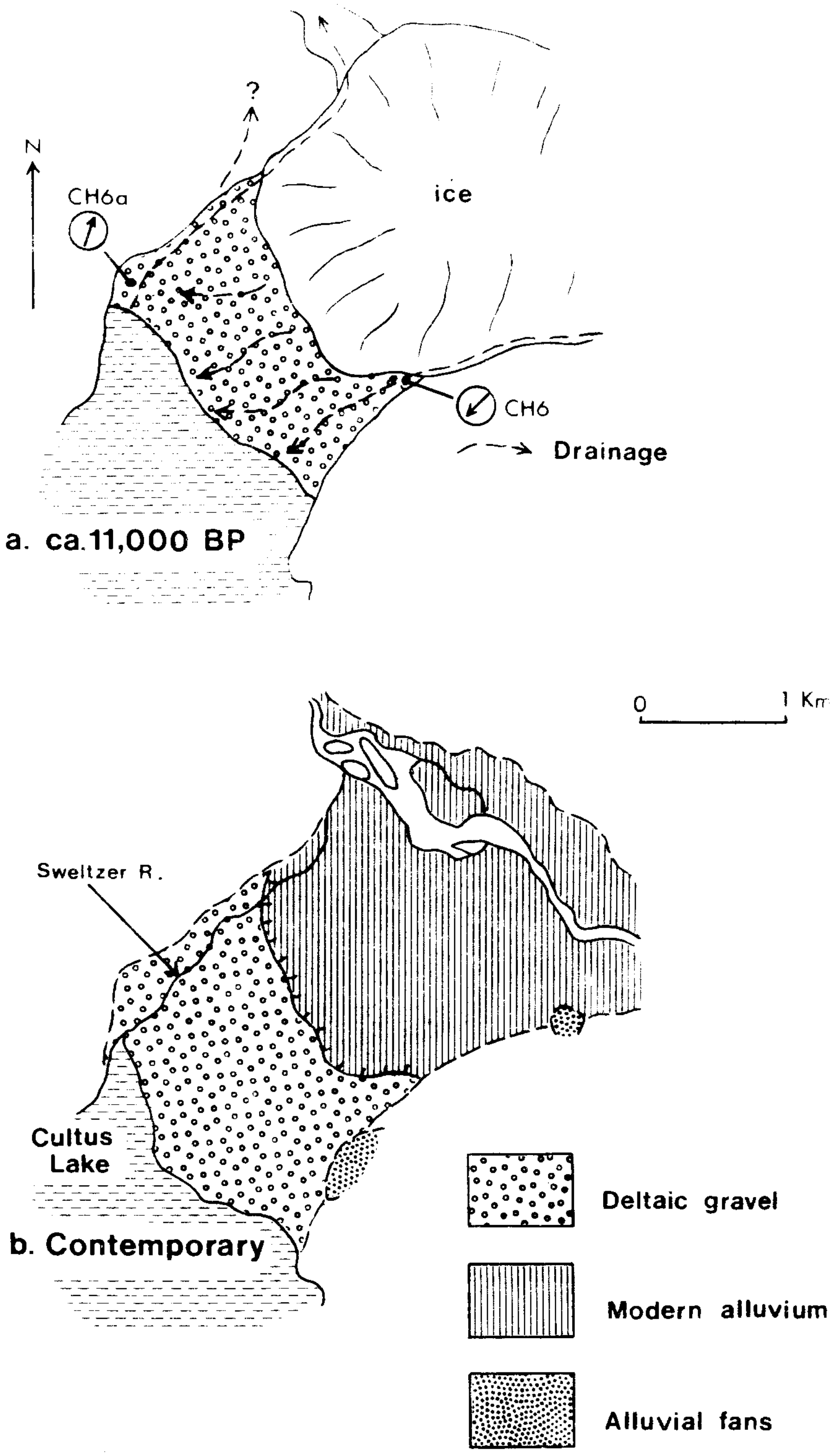


Figure 5.12 Evolution of Cultus Bench

CH7. Tamihi Bench

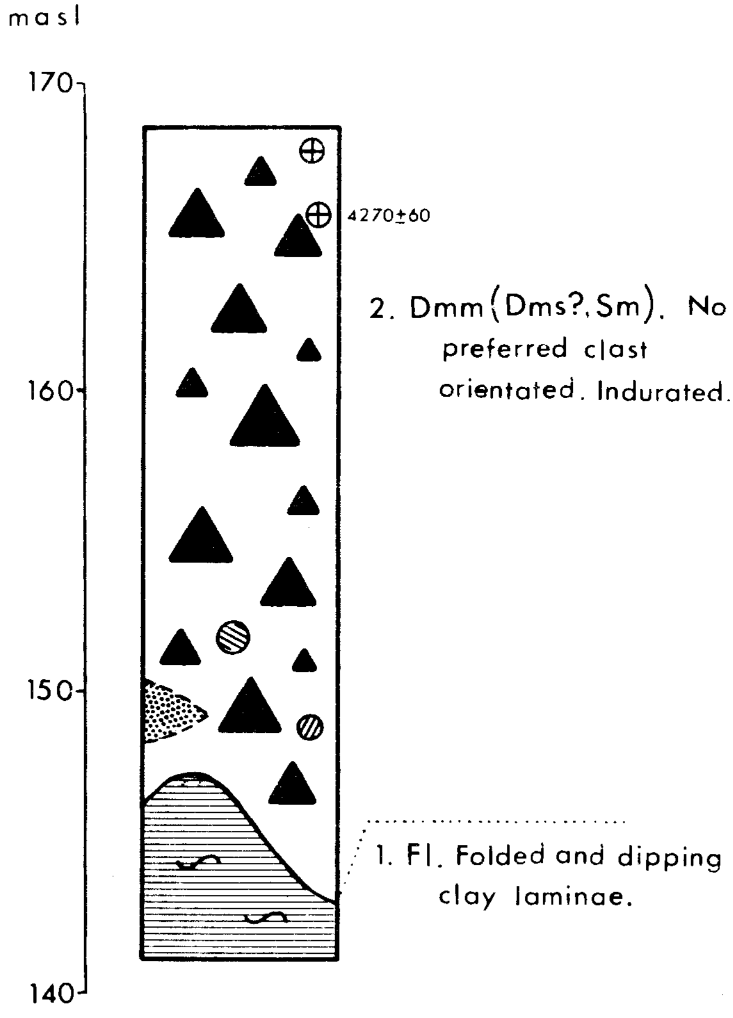
Bluffs up to 40 m high eroded by the Chilliwack River in this bench are generally covered by vegetation, mudflows and slump deposits. However, a fresh (August, 1984) slide at CH7 (Figure 2.2b) has produced a reasonable exposure.

Stratigraphy

Unit 1 occurs up to 5 m above river level, and exposes laminated clays (Figure 5.13). They are dipping, sometimes steeply. The clays are not exposed upstream of CH7. At their downstream end (CH7a on Figure 2.2b), the overlying diamict (Unit 2) has been eroded away, and the clays are capped instead by 2-3 m of coarse floodplain gravels. At the latter location, the laminae form a gentle anticline. The upper contact is not revealed; a disturbance is suggested by the distorted nature of the unit and the local variation in the maximum height at which the clay outcrops. It is probably erosional.

Unit 2 is a grey compacted diamict, with clasts up to 1-2 m in size. Faint stratification occurs in the centre of the exposure. A fabric analysis revealed that clast dips were nearly omnidirectional (Figure 5.14).

FIGURE 5.13
CH 7. TAMIHI BENCH



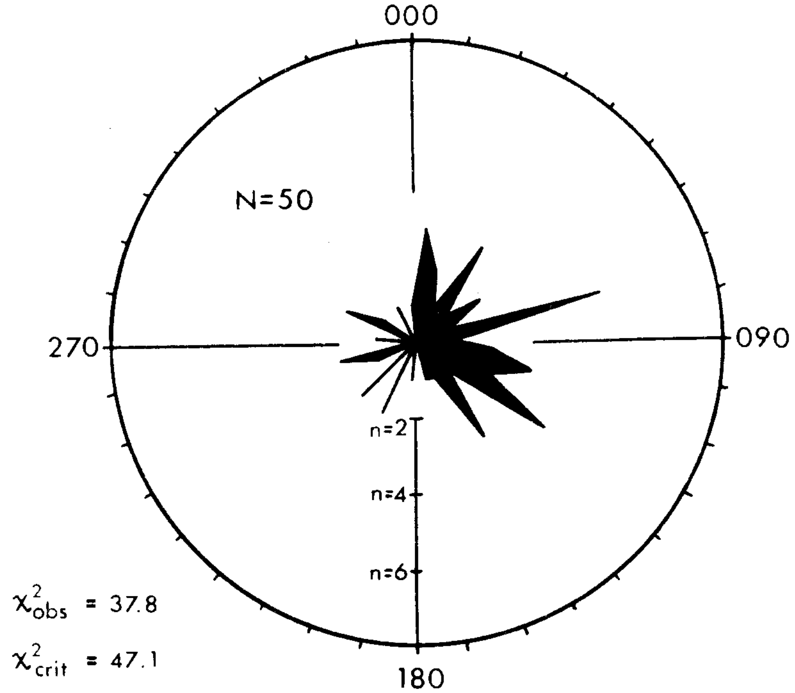


FIGURE 5.14
CH7. FABRIC DIAGRAM

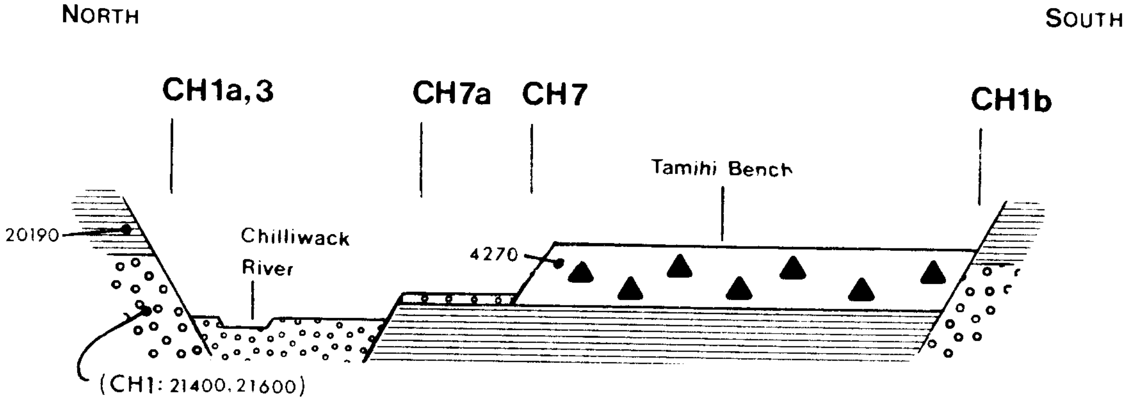
At CH7b (Figure 2.2b) an irregular pocket of massive well-sorted medium sand at least 3 m in size was observed; its contacts were sharp, but its true relation with the diamict was not revealed. Nearby, two boulder-sized laminated-clay clasts were seen in the same unit. Two logs are held in the bluff at CH7, about 2 and 6 m below the surface. A sample from the latter was dated at 4270±60 (GSC-3961).

Interpretations

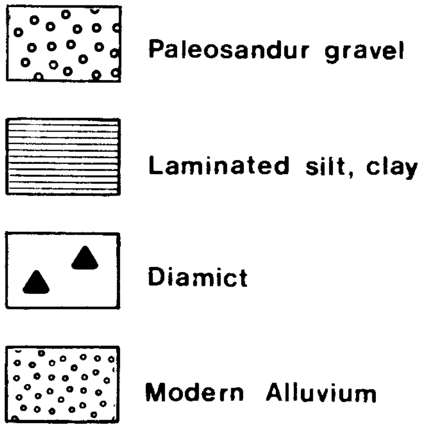
In both the north and south valley sides, early-Fraser sediments are exposed (at CH3 and CH1b) and the Tamihi Bench forms a valley fill within these. The probable relation of these sediments is shown in Figure 5.15.

The CH7 clays (Unit 1) are typically glaciolacustrine in appearance. Their stratigraphic relation to the valley-side clays implies that they are younger. The two major glaciolacustrine events in the valley have been dated at about 20,190 BP (from CH3) and 11,900 BP (from CH9, Clague & Luternauer, 1982). The latter age is therefore the only realistic option for the CH7 clays.

Figure 5.15 Schematic Cross-section, Tamihi Bench



Numbers refer to representative sections (see text)



The overlying diamict (Unit 2) has a mid-Holocene age, which indicates that a non-glacial origin must be sought for this deposit: a mass movement is the most likely mode of deposition. The mass movement was sufficiently energetic to rip up the underlying clay and incorporate blocks of it within the diamict. Water was also involved, as suggested by the presence of the sorted sand pocket and stratification. Based upon this evidence, a debris flow, or probably a series of flows, is the most appropriate interpretation of the diamict at CH7.

Although the radiocarbon date indicates a mid-Holocene age, it is quite probable that the steep slopes fronting the Upper Bench were unstable since late glacial times (as indeed they still are). Slope failures have likely occurred throughout the Holocene, perhaps decreasing in frequency as the slopes stabilized.

Before the deposition of the diamict, the surface expression of the clays was probably modified by the Chilliwack River, contributing to the apparently distorted upper contact. Debris flow activity deformed the laminae and doubtless furthered the disruption of the surface of the clays.

The flattish parts of the Tamihi Bench could have resulted from fluvial planation: assuming that the debris flow sediments were at one time continous across the valley floor, the Chilliwack River would have been ponded upstream by the freshly-deposited plug (Figure 5.16a).

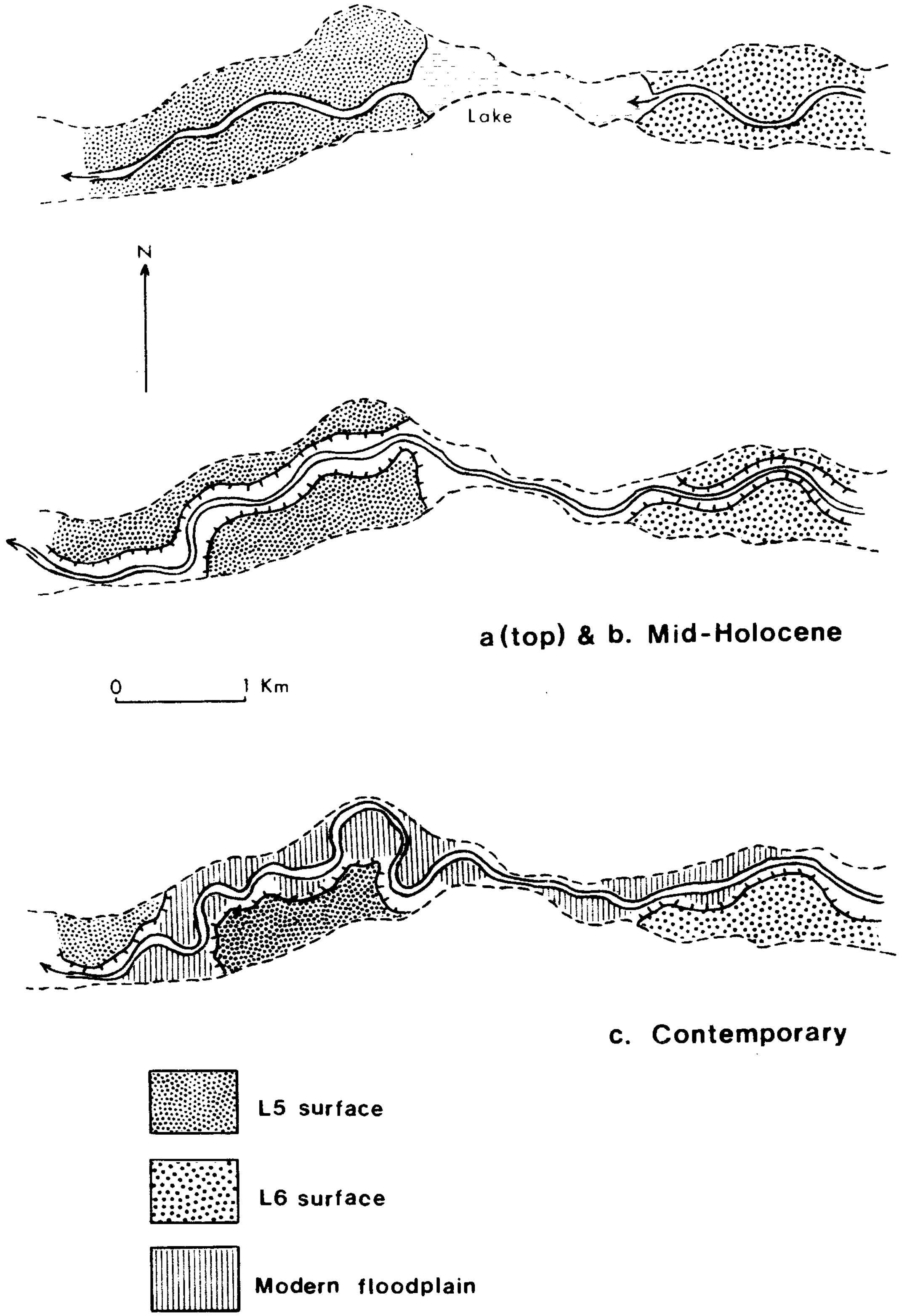


Figure 5.16 Evolution of Tamihi Bench

The surface of the plug may have been eroded when the river overtopped the dam. The abandoned channels on the surface of the Tamihi Bench support this, although the absence of a capping of alluvial sediments do not; fluvial gravels were probably trapped in the temporary lake upstream of the debris plug. Planation of the bench surface was not widespread, and hummocky parts still remain. Incision of the bench likely began soon after the debris flow event(s).

The local history of events as inferred from CH7 and its relation to adjacent sediments (Figure 5.15) is as follows. Firstly, deposition of sandur gravels formed a valley fill during the Fraser advance phase (see CH1, CH1a, CH1b), which was subsequently blanketed by laminated clay under glaciolacustrine conditions at about 20,190 BP (see CH3). These two units were subsequently dissected by the Chilliwack Valley glacier. Later, ca. 11,900 BP, glaciolacustrine conditions were responsible for depositing a unit of laminated clay (Unit 1, CH7) in the valley bottom. Upon deglaciation, the Chilliwack River flowed over, and modified, this surface. In early and mid-Holocene times, debris flows from the south side of the valley deposited a plug of material which temporarily dammed the river. Incision of this plug, and the underlying clays, followed, and erosion continues today. The Chilliwack River is currently flowing on a small gravel fill set within the lowest clay unit.

CH8. Thurston Gravel Pit

This site consists of a gravel pit and an adjacent river cut (Figure 2.2b). The pit exposure is very poor, but the river cut is fresh.

Stratigraphy

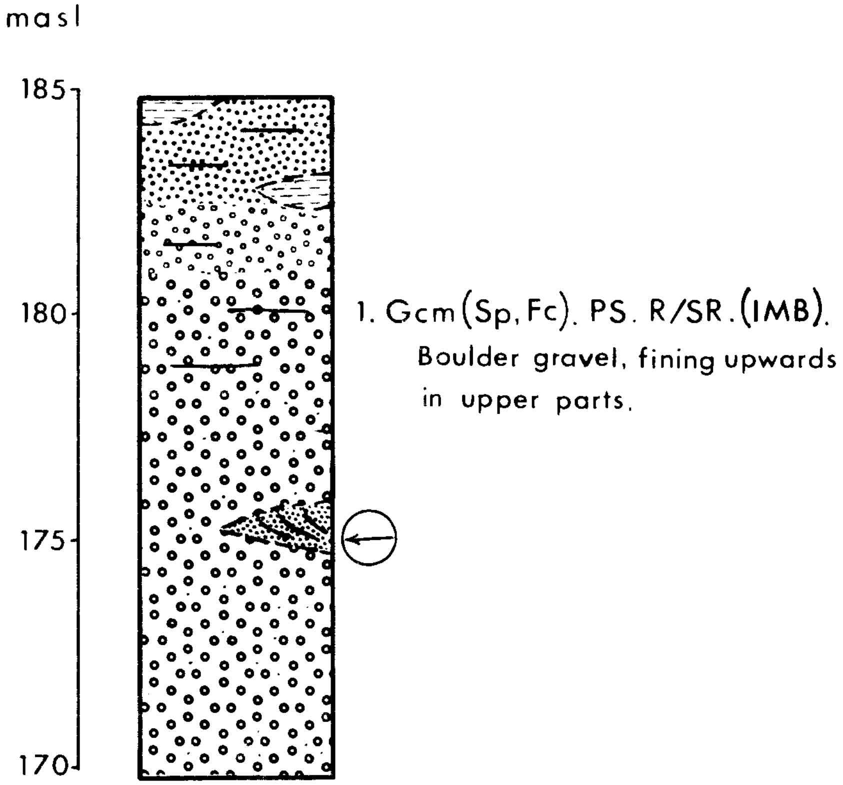
This section exhibits a general fining upwards trend, and no distinct beds were identified (Figure 5.17). Bouldery gravels dominate the section and are generally massive, but with crude stratification and imbrication in places. A coarse sand lens with planar cross-beds was observed within these. Both the imbrication and cross-bedding impart a westward paleoflow. The boulders fine upwards into cobbles and pebbles, and then sand in the uppermost 2 m. Two channel fills are visible in the topmost 1-2 m; one consists of horizontally laminated clay, the other of interbedded fine sand and silt.

Interpretations

The sediments, and their surface expression as a low terrace (the L6 surface, Figure 2.2b), point unequivocally to a fluvial origin.

FIGURE 5.17

CH8. THURSTON GRAVEL PIT



The freshness of the channeled topography (Figure 2.2b), suggests that deposition was either very late glacial or more probably postglacial. The draining of the late Fraser glacial lake have left the newly-formed upper valley sandur high and dry, with more than 100 m of relative relief between the upper and lower valley floors. At the same time, discharges were inflated by meltwater and fluvial activity was greatly enhanced: vigourous paraglacial conditions were prevalent. The sandur would have been rapidly incised creating large amounts of sediment, some of which was redeposited as the L4 valley fill and some of which is probably still in the contemporary fluvial system.

CH9. Slesse Creek

Several sections near the Slesse Creek-Chilliwack River confluence collectively expose the entire thickness of the upper valley paleosandur. The main section, CH9, is a large riverside slump face. Radiocarbon dates from this site are from Clague & Luternauer (1982). Other exposures of the upper parts of the sandur (CH9a,CH9b) occur in man-made pits: CH9a refers to several small exposures near the Slesse Creek Road, and CH9b is an exposure adjacent to the Chilliwack Lake Road. CH9c is equivalent to Section 1 of Chubb (1966), of which only the uppermost few metres remain exposed. CH9d is a minor exposure in the bank of Slesse Creek. In the section diagram (Figure 5.18), CH9d appears at a lower elevation than the other sections because it is further downvalley. Most exposures are relatively poor. Their locations are shown in Figure 2.2c.

Stratigraphy

Clague & Luternauer (1982) divided CH9 into six units, which from the base upwards were:

(1) up to 25 m of laminated silt and clay with dropstones, dated at 11,900±120 BP (GSC-3306). The laminae were folded and overturned. The upper contact was disturbed, and this unit diapirically intruded the overlying sediments.

(2) 10-30 m of stratified pebble-cobble gravel and sand, dipping gently westward. Possible foreset bedding was seen. Sand beds contained graded bedding.

(3) 0.5 m of laminated silt and fine sand, containing dropstones and organic debris dated at 11,700±100 BP (GSC-2966).

(4) 2.5 m of pebble-cobble gravel, poorly sorted.

(5) 6 m of stratified, locally graded, fine and medium sand.

(6) 9 m of interbedded silt, sand and gravel; the finer sediment was better sorted than the gravel. Buried forest litter and an *in situ* tree stump occured 5 m below the surface, and was dated at 11,400±140 BP (GSC-3308).

CH9 was reassessed in this study. The basic stratigraphy remains mostly unchanged, but further details were brought to light. The reinterpreted section is shown in Figure 5.18. Units 1-5 correspond to (1)-(5) above, but Clague & Luternauer's (1982) Unit (6) has been divided here into Units 6 and 7. The following information is supplementary to that of these authors.

Unit 1. A 1.5 m bed of boulder gravels dissects this unit at CH9d. These are clast-supported, rounded and imbricated with a paleoflow toward the northwest. The underlying and overlying clays dip in opposite directions, indicating that at least two separate disturbance episodes occured. The clays outcrop along the river upstream of this point to about 200 m south of the main section.

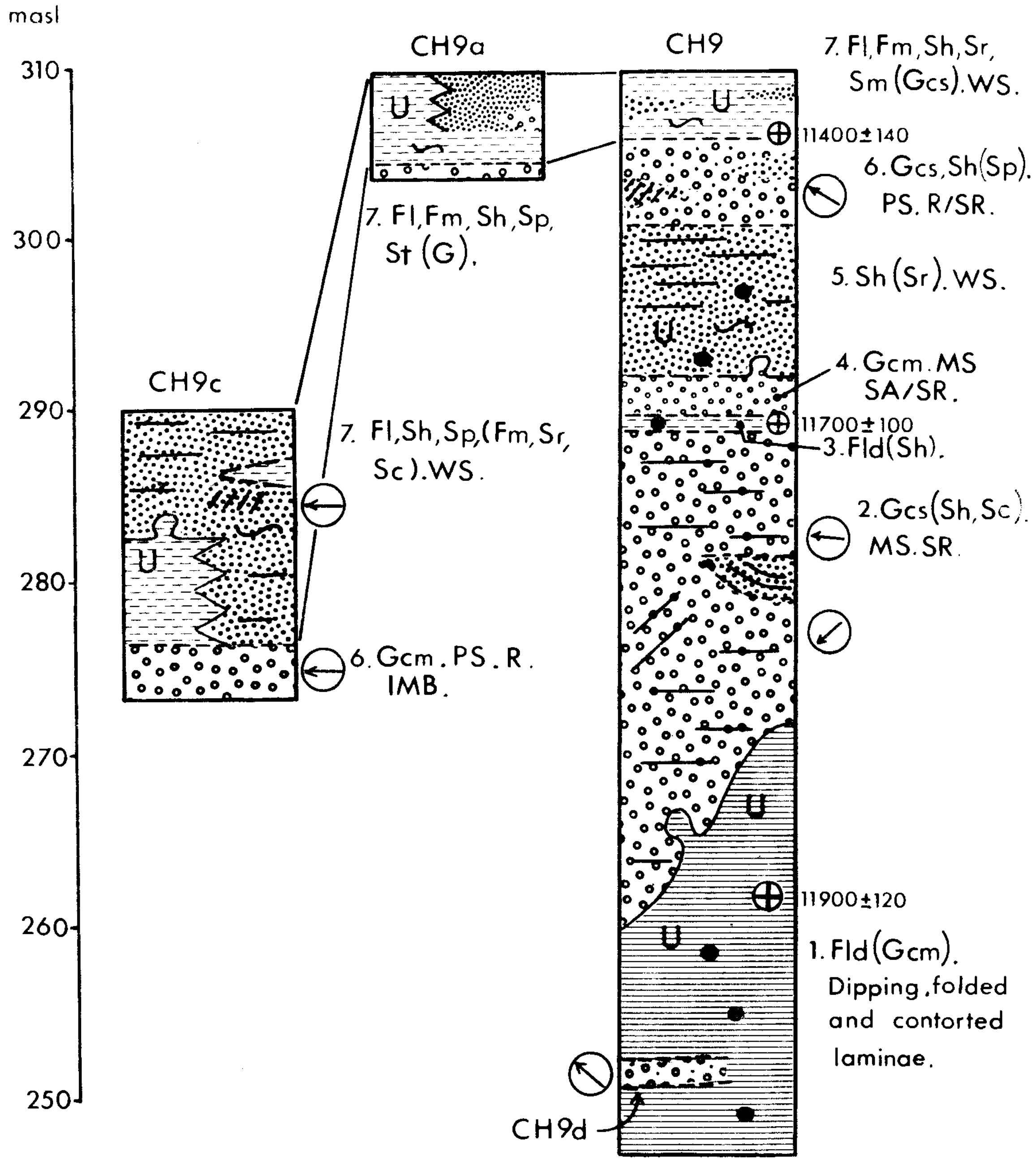
Unit 2 gravels are now almost completely buried, but parts of a large sandy channel fill can still be seen in the centre of the face; it gives a westward paleoflow. The foreset bedding can be seen in the gully at the north end of the face. A paleoflow direction could not be obtained, but a southerly component is evident.

Unit 3 silts are laterally continuous for the whole width of the face. In the aforementioned gully, a sand lens splits these silts.

Unit 4 gravels were found to diaprically intrude the overlying sands (Unit 5), exemplified by a 1.2 m flame (Figure 5.19).

Unit 5 sands are mostly horizontally laminated, and embrace occasional stones. They locally contain ripples and small loading structures in the lower part of the unit.

FIGURE 5.18
CH9. SLESSE CREEK

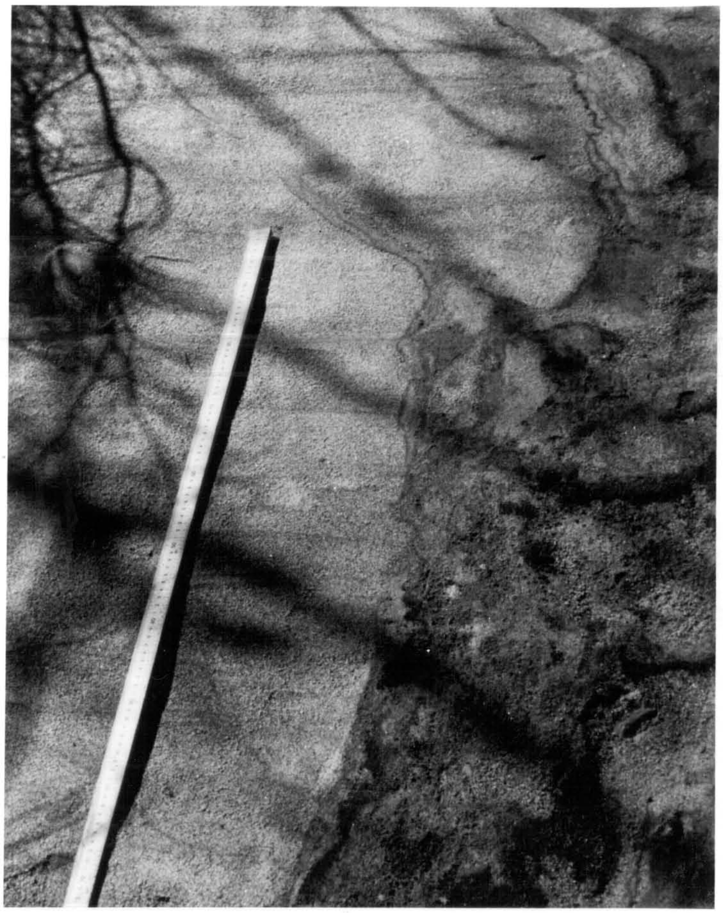


Unit 6 is composed of interlensing sand and gravel. The gravels tend to be cobbly or bouldery and poorly sorted; the sands are coarse with scattered pebbles throughout. A prominent yellow sand lens contains large planar cross beds with a northwesterly paleoflow. In the gully, these are stained black and red.

Unit 7 is characterized by alternating silts and fine sands. Its lower contact is marked in places by a distinct hard cemented layer about 5 mm thick. They vary in colour from a distinctive pale blue to brown and yellow, and contain ripples and loading strucures, as well as laminated and massive parts. A capping of pebble gravels occurs. The fines grade into coarser sands in the northern part of the face, and a gravel bed occurs within these. The buried forest floor dated at 11,400±140 (GSC-3308) by Clague & Luternauer (1982) is immediately above the lower contact of this unit, and can be found in the southern end of the face.

CH9a offers better, and more accessible, exposures of Unit 7 than the main site. The Unit 7 fine sands and laminated silts are displayed in a variety of structures (Figure 5.18). Many of the silt laminae show convolutions and deformations. Granitic boulders, some of them larger than 2 m in size, lie on the road below the section, originally derived from excavations at this site. Nearby, at CH9b, similar boulders can be seen in situ in Units 5 and 6.

Figure 5.19. Lower part of Unit 5, CH9. The laminated sands characteristic of this unit are seen on the left. The large flame structure on the right, which probably resulted from rapid loading, is derived from the Unit 4 gravels. The Unit 4-Unit 5 contact is at the bottom of the picture.
Scale is 1 m long.



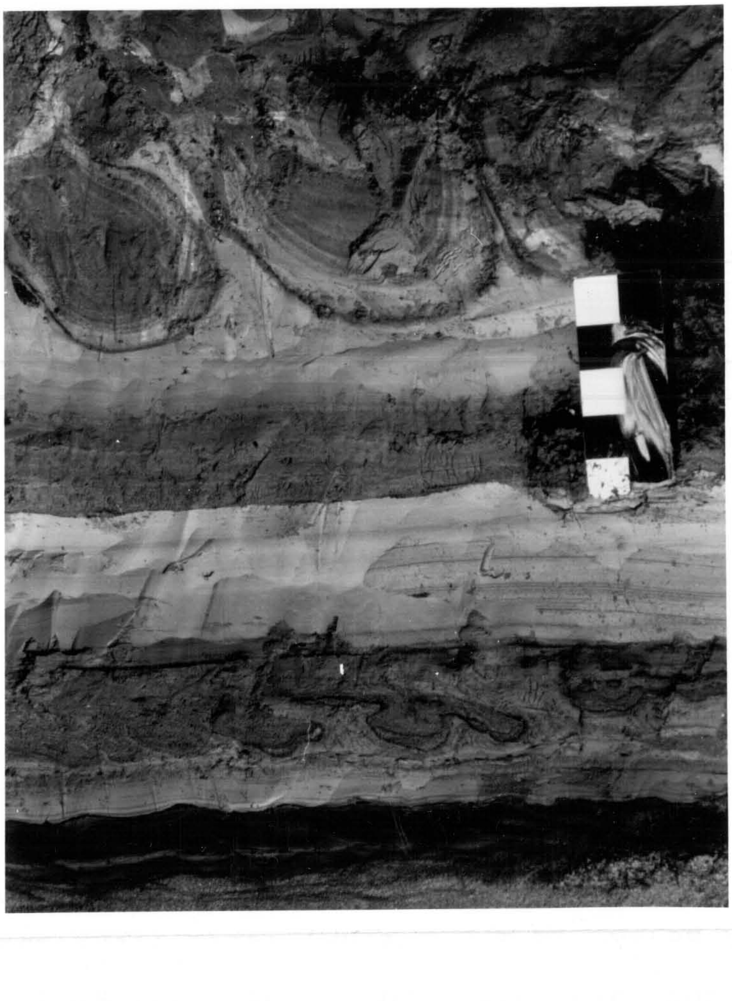
Clague & Luternauer (1982) described CH9b, but the stratigraphy here was not reassessed in this study. Units 5 and 6 outcrop, and possess similar characteristics to those at CH9, although the sands in Unit 6 are stained a variety of black and brown hues not common in the main section. This exposure reveals a number of isolated granitic boulders up to 3 m in diameter which occur in both units. Those in the Unit 5 are surrounded by apparently undisturbed sand laminae. Those in Unit 6 have beds which dip under and drape over them (Figure 5.20). There is a significant break in the particle size distribution in these units: the exotic boulders are several times larger than the stratified boulder gravels in Unit 6, and three orders of magnitude larger than the Unit 5 sands.

CH9c exposes Unit 7 sands, silts and clays and the upper part of Unit 6 gravels (Figure 5.18). Unit 6 gravels are different from those at the other sections in that they are not lensed, but apparently massive. Chubb (1966), however, described a "lenticular body of ... gravel" here when the exposure was fresh. Unit 7 here is generally coarser than at CH9 and CH9a, there is a major proportion of sand, some of which is medium sand. Most of the sandy parts of the unit show horizontal and planar cross bedding. The clays and silts that are exposed are predominantly laminated and in places display convolutions and striking flame structures (Figure 5.21). There are also minor quantities of gravel in Unit 7.

Figure 5.20. Part of Unit 6, CH9b. Several large granitic boulders occur within this unit, and also in Unit 5. Some do not appear to have disturbed the surrounding sediments. Other boulders, like those portrayed here, seem to have caused deformation of the beds. They were probably ice-rafted. The boulder on the left is approximately 2 m in diameter.

Figure 5.21. Loading structures, Unit 7, CH9c. Convoluted bedding and flames in laminated silts and clays are seen here. Fine sand ripples occur beneath these, at the bottom of the picture.

Scale is 0.15 m long.



The CH9c Unit 7 was correlated to Unit 7 at CH9 on the grounds of similar deposits, and stratigraphic position relative to the sandur surface.

Interpretations

Clague & Luternauer (1982) considered that Unit 1 was glaciolacustrine in origin, as were other laminated silts in the section. The major unit at CH9, Unit 2, was thought to be deltaic. The disturbed contact between Units 1 and 2 was suggested to result from an unstable lake level or from shifting braided river channels or from loading of the lake floor muds by the overlying gravels. The upper units (4 to 6) indicated a general fluvial setting, but the presence of laminated silts and graded sand bedding within these led Clague & Luternauer to believe that some of these sediments were deposited subaqueously, probably in a deltaic environment. All the units were deposited within the closing millennium of the Fraser Glaciation, ca. 11-12,000 BP.

Further details have now been added to the interpretations of CH9. In Unit 1, deposition of glaciolacustrine clays was interrupted by at least one fluvial event, and perhaps more. Although apparently brief (only 1.5 m of coarse gravels were deposited), this indicates an unstable lake, and supports Clague & Luternauer's (1982) conclusions.

Unit 2 shows that rapid deposition of gravels by a westward-flowing braided river followed, and probably was outwash from retreating glaciers in the Chilliwack and Slesse Creek Valleys.

The Unit 3 silts indicate a less active, glaciolacustrine, period, possibly including a subaerial interval which gave rise to the organic debris and the sandy lens in the middle of the unit.

Unit 4 could be either a fluvial or deltaic deposit; it contains nothing which unequivocally points to one of these depositional modes.

The Unit 5 sands are glaciolacustrine; the sediment is very well sorted, and graded bedding and dropstones occur. The production of the large flame which intrudes this unit from Unit 4 would also be assisted by glaciolacustrine conditions. Lacking laminated silt or clay, they are probably proximal to the lake/delta margin.

The gravels in Unit 6 are at least partly fluvial in origin, and the bouldery nature of some beds (e.g. at CH9a, CH9b) indicate very energetic conditions. Some of the gravel lenses could be interpreted as discrete subaqueous sediment gravity flows. These could have been either mass movements from the delta front or debris released from icebergs. Upon deposition of an unsorted gravel "parcel", some material was reworked and became better sorted and structured, but some was left untouched. This resulted in the different degrees of sorting noted in the stratigraphy.

Unit 7 indicates that renewed deposition of glaciolacustrine fines and fluvial sands continue to the end of the sedimentation period. The buried forest floor at the lower contact of this unit may represent a period of local stability: Clague & Luternauer's dated stump was at least 100 years old. Possibly this part of the section was a bar or island that was unaffected by the geomorphic activity occuring on other parts of the sandur. The forest floor was drowned by the glacial lake as it rose to deposit Unit 7.

At CH9b, the exotic boulders in Units 5 and 6 were suggested by Clague & Luternauer (1982) either to have been transported from the Chilliwack Lake Barrier by catastrophic floods, or by icebergs from a calving glacier. They did not elaborate on the latter possibility. Although these boulders are reasonably well rounded, normal fluvial processes seem inadequate to explain the problem of grossly incompatable competences between them and the finer sands and gravels which compose the major part of the section.

Ice rafting seems the only plausible explanation. Rounding of the boulders, either by water or ice, probably occured before rafting. Deposition of these great stones would have certainly entailed disturbance of the lake bed sediments, but the sand laminae in Unit 5 show no signs of disruption. This anomaly can be explained by assuming that the sand adjacent to the freshly-deposited boulder was reworked by wave or current activity and horizontal lamination restored. Continued sedimentation of sand eventually buried the boulder.

In Unit 6, the story is a little different. Bedding may have been deformed by the large boulders dropping into them. But some of the deformed beds beneath the boulders in Unit 6 are akin in appearance to fluvial scour holes and associated lag gravels, and so offer an alternative interpretation. A fluvial scour explanation was given for similar phenomena observed in an intratill sand layer by Shaw (1982). Shaw proposed that the boulder was held in basal ice and the scour fill was deposited subglacially around it. It is conceivable that a grounded iceberg could have behaved in a similar fashion at CH9b.

The source of the exotic granitic boulders was not specified by Clague & Luternauer (1982), although they implied the Chilliwack Batholith at Chilliwack Lake (Figure 2.1). Another possible source is the Mount Barr Batholith in the Foley Creek sub-catchment. A valley glacier may have existed in the lower Foley Creek valley when the sandur/delta in the trunk valley was being constructed. If the glacial lake extended as far as the mouth of the valley (requiring a lake level of ±380 masl), then this glacier could have supplied icebergs, some of which rafted the boulders in question a few kilometres downvalley to Slesse Creek. Evidence that might support this supposition is found at CH10 and CH11.

If fluvial transport of some of the boulders did occur, then the Foley Creek supply is still a viable source area for coarse sediments at the Slesse Creek sites. The longitudinal slope of this valley is steeper than that of the Chilliwack River, and would be more beneficial to the fluvial transport of large boulders.

Sediments at CH9c can be similarly interpreted to those at CH9 and CH9a. The generally coarser nature of Unit 7 at this site suggests that geomorphic activity was a little more energetic on this part of the sandur/delta front.

Throughout the section, alternate periods of glaciofluvial, deltaic and glaciolacustrine conditions are evident. The topmost unit, containing extensive laminated silts and sands, shows that this lake persisted until very late in the Sumas stade, by which time the water surface elevation was of the order of 300 masl.

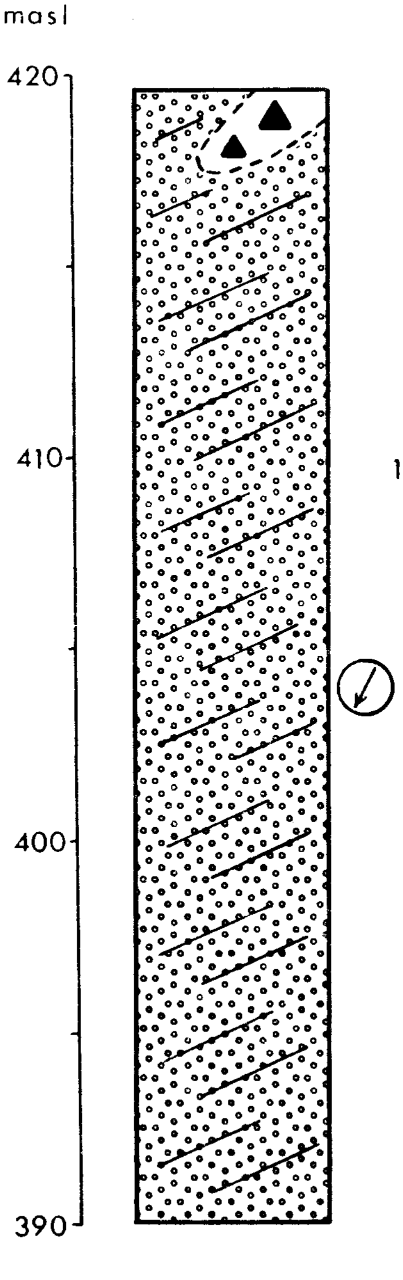
CH10. Chipmunk Creek Gravel Pit

This pit is near the confluence of Chipmunk Creek and Chilliwack River (Figure 2.2c). Much of the face is buried by talus, but those sediments that do outcrop are cleanly exposed.

Stratigraphy

The section consists almost entirely of one unit of dipping (dip 25°, towards 210°) gravel foreset beds (Figure 5.22).

FIGURE 5.22
CH10. CHIPMUNK CREEK GRAVEL PIT



1. Gcs (Dmm). WS. SR. Pebbly gravel. Foreset bedding.

Textures range from coarse sand to occasional boulders, but as with similar outcrops in the study area, individual beds are generally well sorted. Some have open framework gravels. Paleoflows inferred from the dip indicate flows emanating from the Chipmunk Creek valley. In the upper few metres of the section, minor pockets of gravelly diamict occur within the dipping beds.

Interpretations

The sediments typify deltaic foresets. The elevation of the lake level would be ±430 masl if it was close to the upper limit of the exposed foresets, so glacial damming must have been involved. Possibly localized ice-marginal ponding was responsible, or it may have been built into the late Fraser lake that was interpreted from CH9b. The diamict lenses in the top part of the section are probably small sediment gravity flows into the lake from the nearby valley side.

<u>CH11. Foley Creek</u>

A few hundred metres upstream of it's confluence with the Chilliwack River, Foley Creek has dissected a small bench (L9 in Figure 2.2c) and exposed the sediments underlying the surface. The section is approached from the Foley Creek logging road. Most of the deposits are poorly exposed. Figure 5.23 divides the

100 m wide section into two halves for the sake of clarity, and the two columns shown are only 50 m apart. The south half of the exposure has a lower surface elevation due to terracing (see discussion of this landform in Chapter 2). Units 1 and 2 are not laterally continuous, but have been truncated in the centre of the face.

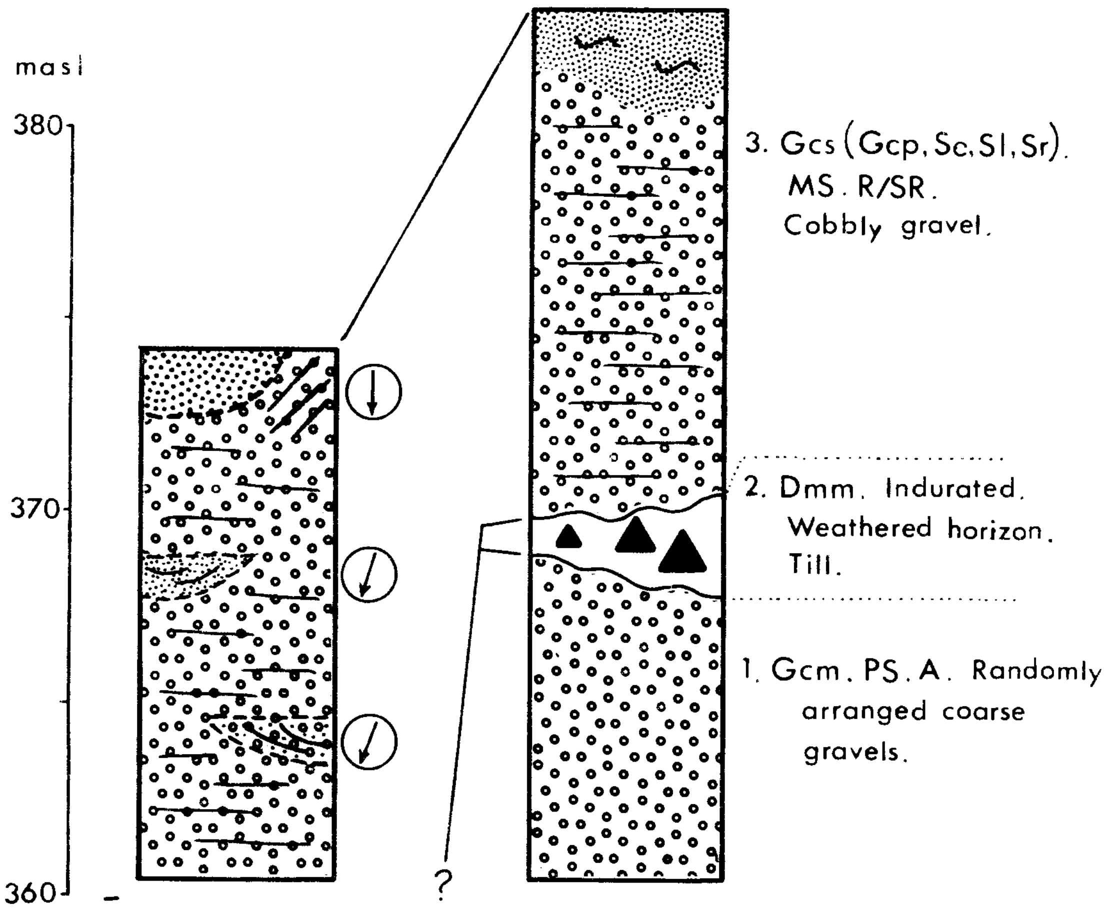
Stratigraphy

Unit 1 gravels are entirely composed of randomly arranged angular material. The gravels are predominantly from the local pelitic bedrock (the Cultus Formation). The upper contact of this unit is probably erosional.

Unit 2 is a grey diamict that is well compacted, and also outcrops to the northeast of this site. The upper 0.5 m or so are texturally similar but are pale brown, and probably result from weathering. The upper contact is irregular, dips southward and appears to be eroded.

Unit 3 is composed of gravels which are horizontally bedded, with two channel fills. Pockets of well-sorted sand occur in the topmost parts of this unit, and may be further channel fills. This sand also outcrops in a road cut immediately above the section, where it displays ripples and loading structures. Large granitic boulders, rounded and subrounded, are contained within this unit. Some are concentrated in a layer resting on the lower contact.

FIGURE 5.23
CHII. FOLEY CREEK



Interpretations

Unit 1 gravels were probably deposited by an advancing glacier in the Foley Creek valley during the Fraser Glaciation. The same glacier then deposited till: Unit 2. The weathered horizon of the till implies a time interval between retreat of the glacier and deposition of Unit 3. The truncation of Units 1 an 2 must have occured within this interval. Fluvial terracing is the most probable cause of this erosive event.

Unit 3 was deposited by flows issuing from the Foley Creek valley. The abundance of rounded material and stratification suggest reworking of sediment as the river mobilized freshly deposited morainal sediments left by the receding Foley Creek glacier. The granitic boulders were derived from the headwaters of this valley, where the Mount Barr Batholith outcrops; similar boulders can be seen still held within till on the slopes above Foley Lake. Large granitic stones at Slesse Creek were probably derived from the Foley Creek glacier (see discussion of CH9b). Unit 3 gravels were likely deposited at the same time as the uppermost parts of the trunk valley sandur, during late Fraser times, ca. 11,300 BP.

Subsequent incision of the sandur surface by the Chilliwack River, probably under paraglacial conditions (see discussion under CH8), terraced the Unit 3 sediments, whilst Foley Creek incised a small canyon in them. Incision has been checked by the downstream bedrock control at the Chipmunk Creek confluence (Figure 2.3).

CH12. Chilliwack Lake Barrier

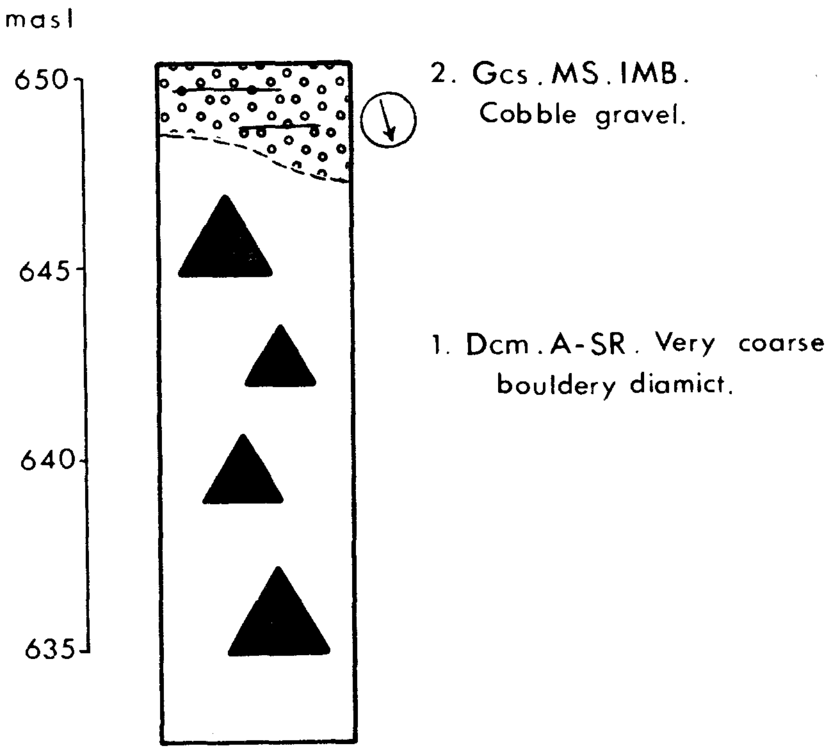
A road cut adjacent to the Chilliwack Lake Road partially reveals the internal composition of the Chilliwack Lake barrier (L10, Figure 2.2d). Gourlay (1977) and Clague & Luternauer (1982) recorded the stratigraphy at this section, which is mostly obscured now. A summary of their results is presented here.

Stratigraphy

Unit 1 is a very coarse diamict (Figure 5.24). Boulders up to 8 m in diameter occur, though most are less than 1 m in size. Both angular and rounded stones can be found.

Unit 2 caps the section with 1-4 m of cobbly gravel, which is better sorted, bedded and imbricated than the rest of the section. Paleoflows from Post Creek are inferred from these topmost gravels. Granitic rocks make up the vast majority of lithologies.

FIGURE 5.24
CH12. CHILLIWACK LAKE BARRIER



Interpretations

The core of the barrier is probably a recessional moraine left by a late Fraser glacier which filled the basin presently occupied by Chilliwack Lake (Daly, 1912; Clague & Luternauer, 1982). It is in lateral contact with the upper valley paleosandur. The coarse diamict most likely results from glacial deposition or rockfall or both, in a similar manner to the bouldery ridge damming Moraine Lake in the Rocky Mountains of Alberta (Baird, 1977). Discharges from Post Creek briefly deposited a gravel capping on the barrier and subsequently incised and terraced it, carrying boulders eroded from the moraine for a few kilometres downvalley.

Jokulhlaups draining a glacial lake in the Silverhope Klesilkwa basin have been suggested as the cause for this action (Gourlay, 1976; Clague & Luternauer, 1982). But no unequivocal supporting evidence has been fowarded. The primary reason for citing catastrophic discharges is the fact that boulders, some 2-3 m in size, have apparently been transported downvalley from the Chilliwack Lake Barrier across a gently sloping unconfined valley floor about 1 km wide. The downstream decrease of maximum boulder size is very rapid (Gourlay, 1976): it is less than 2 m at 2 km from the barrier, 1.5 m at 3.2 km, and 1 m at 6 km. The jokulhlaup therefore seems to have been of very short duration.

Caution is needed, however, in accepting the catastrophic flood hypothesis. The proposed meltwater channel (the Post Creek valley) is underlain by granite, conglomerate and gneiss. It could therefore be expected that discharges of catastrophic magnitude would have transported boulders of all lithologies into the Chilliwack River valley. But only granitic boulders are in evidence, some of which have obviously undergone virtually no attrition, and cannot have been subjected to much fluvial transport, if any. It is possible that the terraces in the Chilliwack Lake Barrier were not cut by catastrophic floods, but by enhanced meltwater flows. Perhaps a short-lived jokulhlaup was assisted by such flows in dispersing the bouldery debris from the Chilliwack Lake Barrier.

CHAPTER 6: SURFICIAL GEOLOGY AND GEOCHRONOLOGY

This chapter presents the surficial geology map and chronology of geomorphic events for the Chilliwack Valley, as compiled from the data and interpretations presented in the previous chapter.

Surficial Geology

The combined assessment of surface deposits and associated landforms was utilized to identify the type and extent of the surficial geology. The resultant maps are shown in Figure 6.1. A few additional minor qualifying comments are necessary.

In Figure 6.1a, the sediments underlying the meltwater channels (?) mentioned in the discussion of landforms (Chapter 2) are unknown. Armstrong (1980b) correlated them to pre-Sumas sediments at CH1, but they might conceivably be younger.

The early Fraser drift mapped at the base of the Ryder Upland (Figures 6.1a,b) is probably largely covered by mass movement and fan deposits, and its upper boundary is uncertain.

The composition of the Upper Bench (Figures 6.1a,b) has been tentatively mapped as mid-Fraser till, but as discussed in Chapter 5, this has yet to be confirmed.

The Chilliwack Lake Barrier (Figure 6.1d) has been mapped as a combination of recessional moraine and outwash. This is an attempt to distinguish this feature from the sandur surface immediately downvalley.

Figure 6.1. Surficial Geology

Legend

Salish Sediments

- Alluvium (modern)
- Alluvium (paraglacial)
- Fans, landslides

Late Fraser Drift

- Recessional moraine
- Outwash/deltaic
- Kame terrace
- Kame delta
- Glaciolacustrine

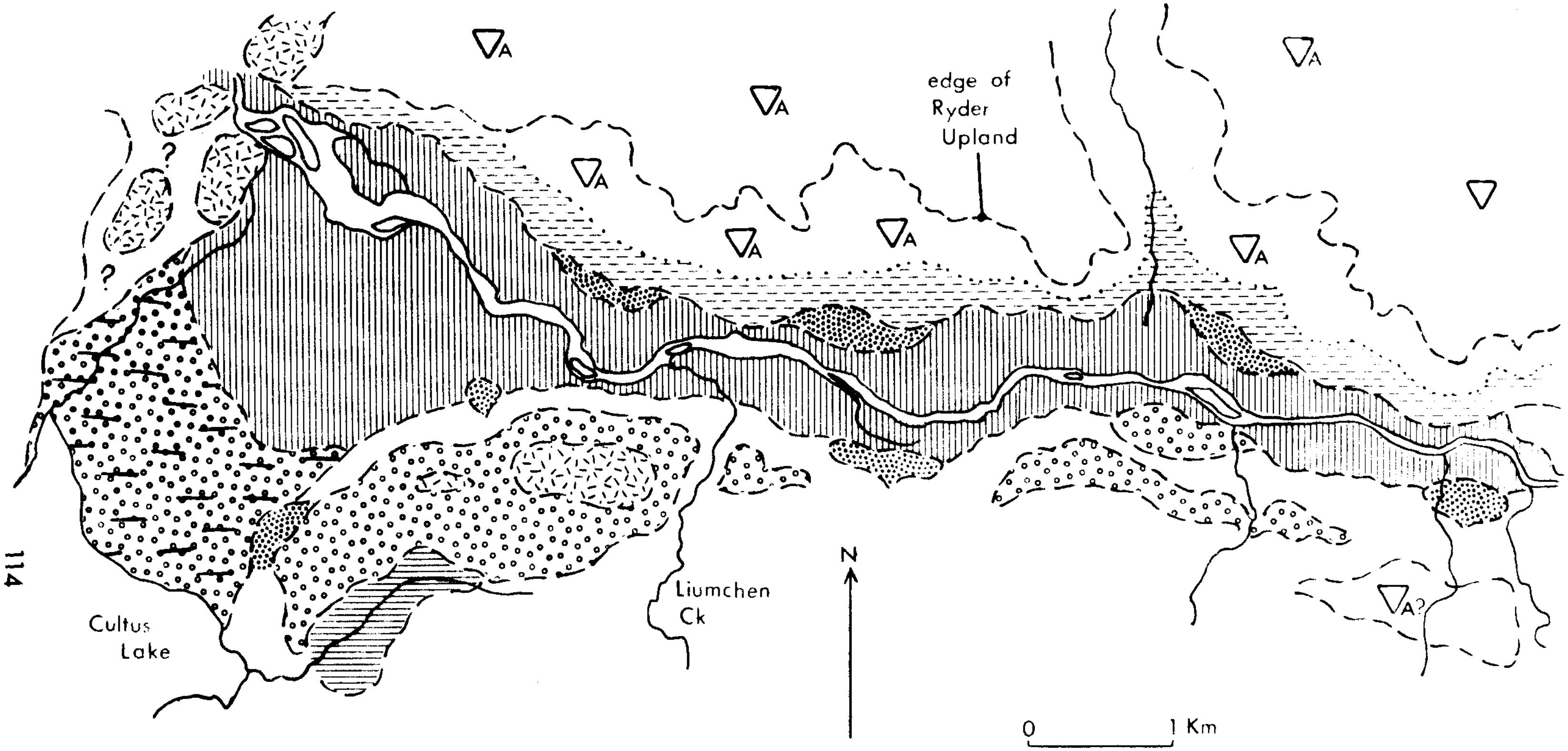
Fraser Drift

- Basal till
- Kame terrace

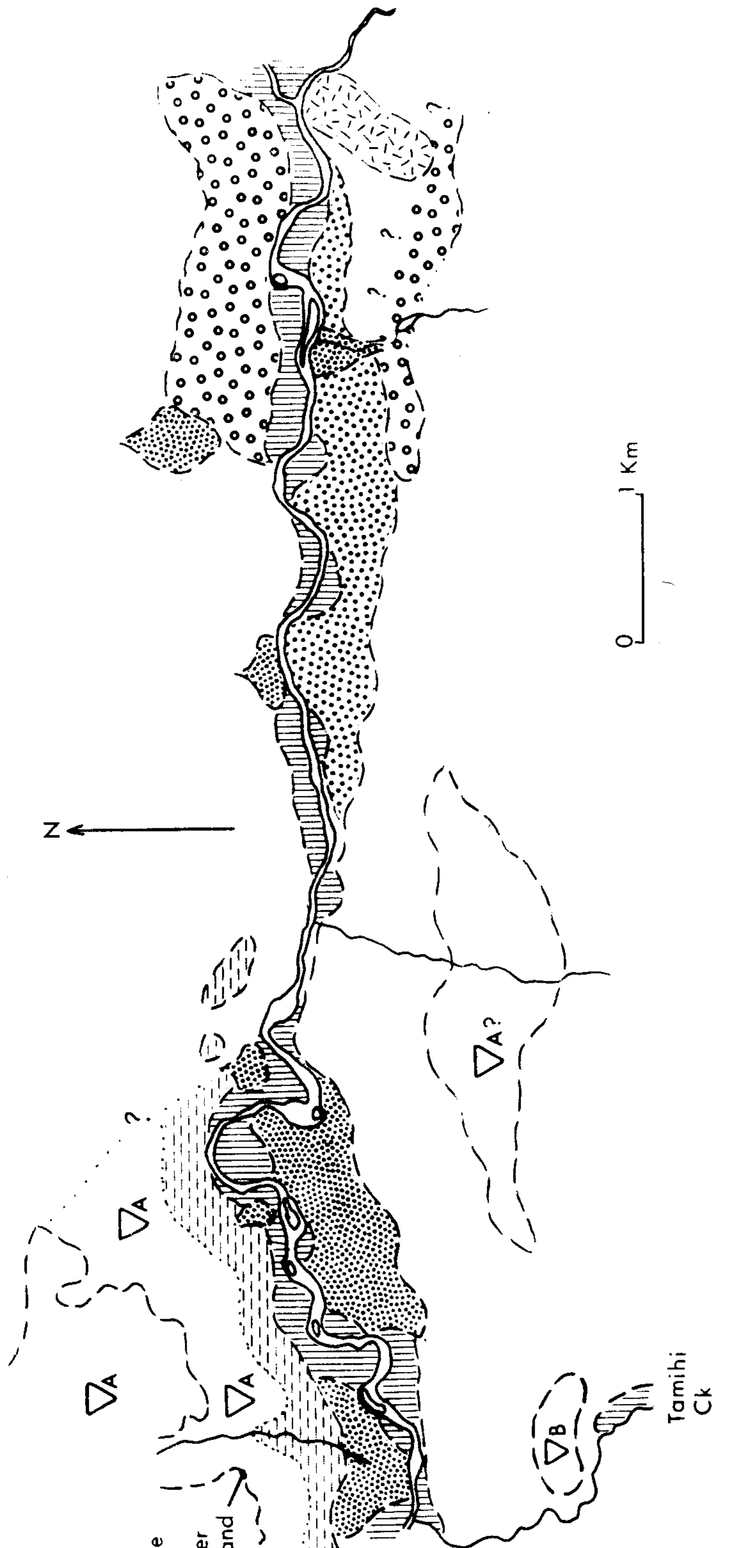
Early Fraser Drift

- Outwash, glaciolacustrine

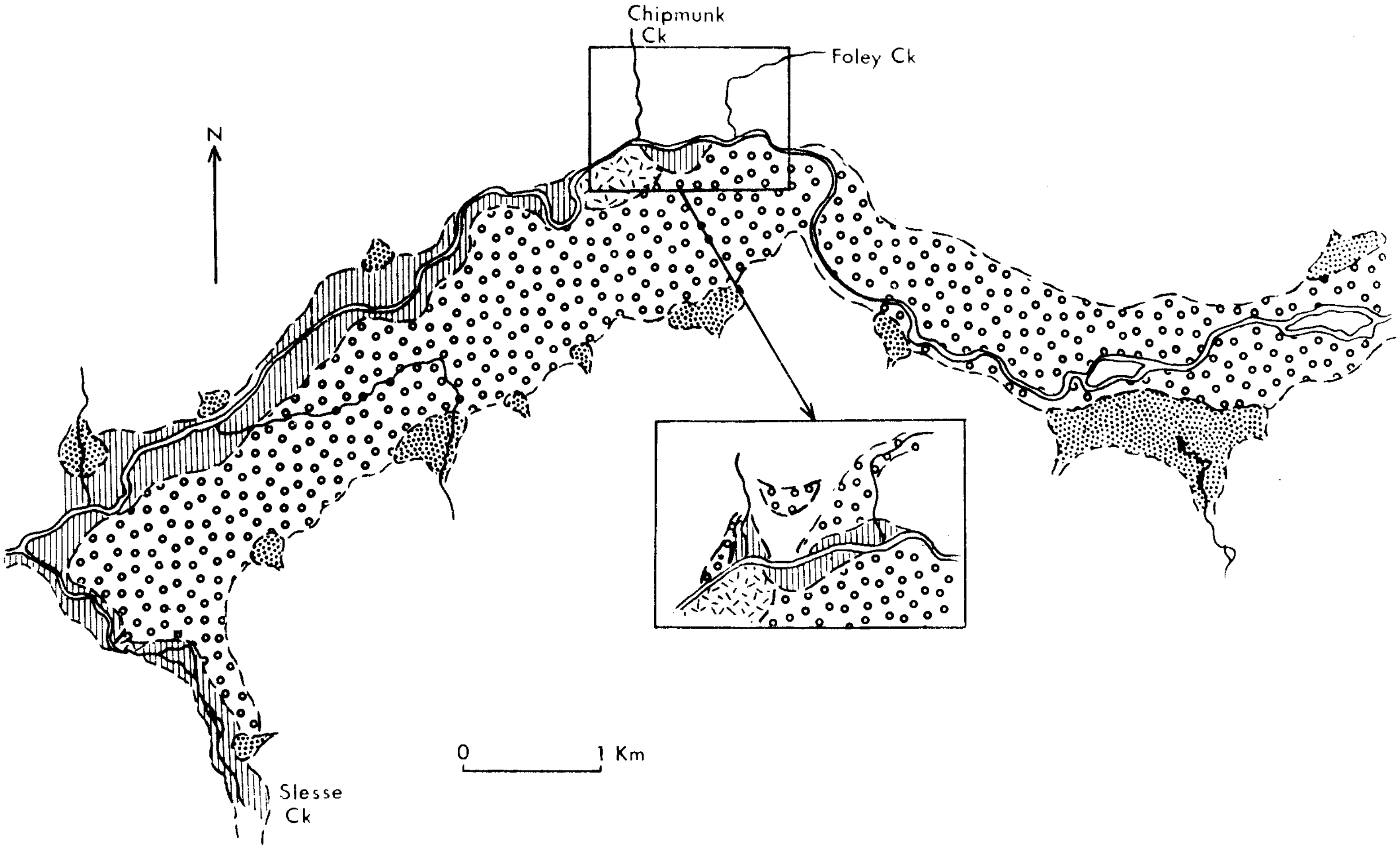
- Bedrock



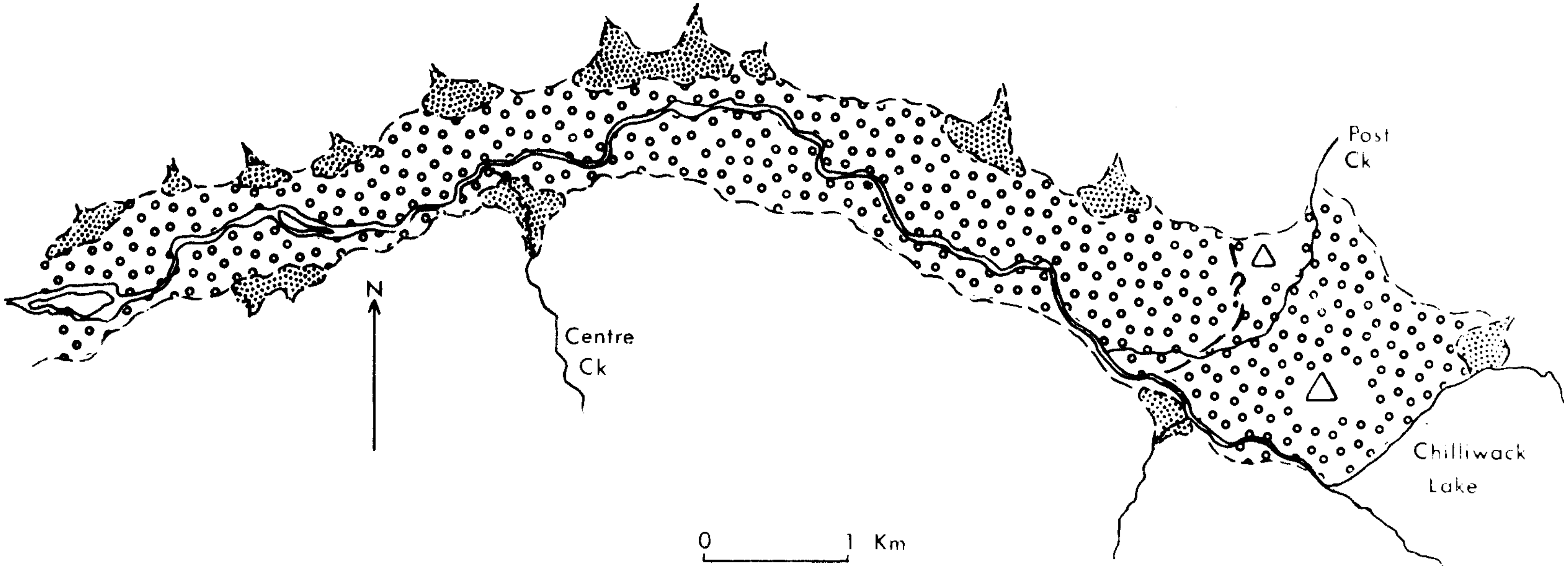
6.1a



6.1b



6.1c



6.1d

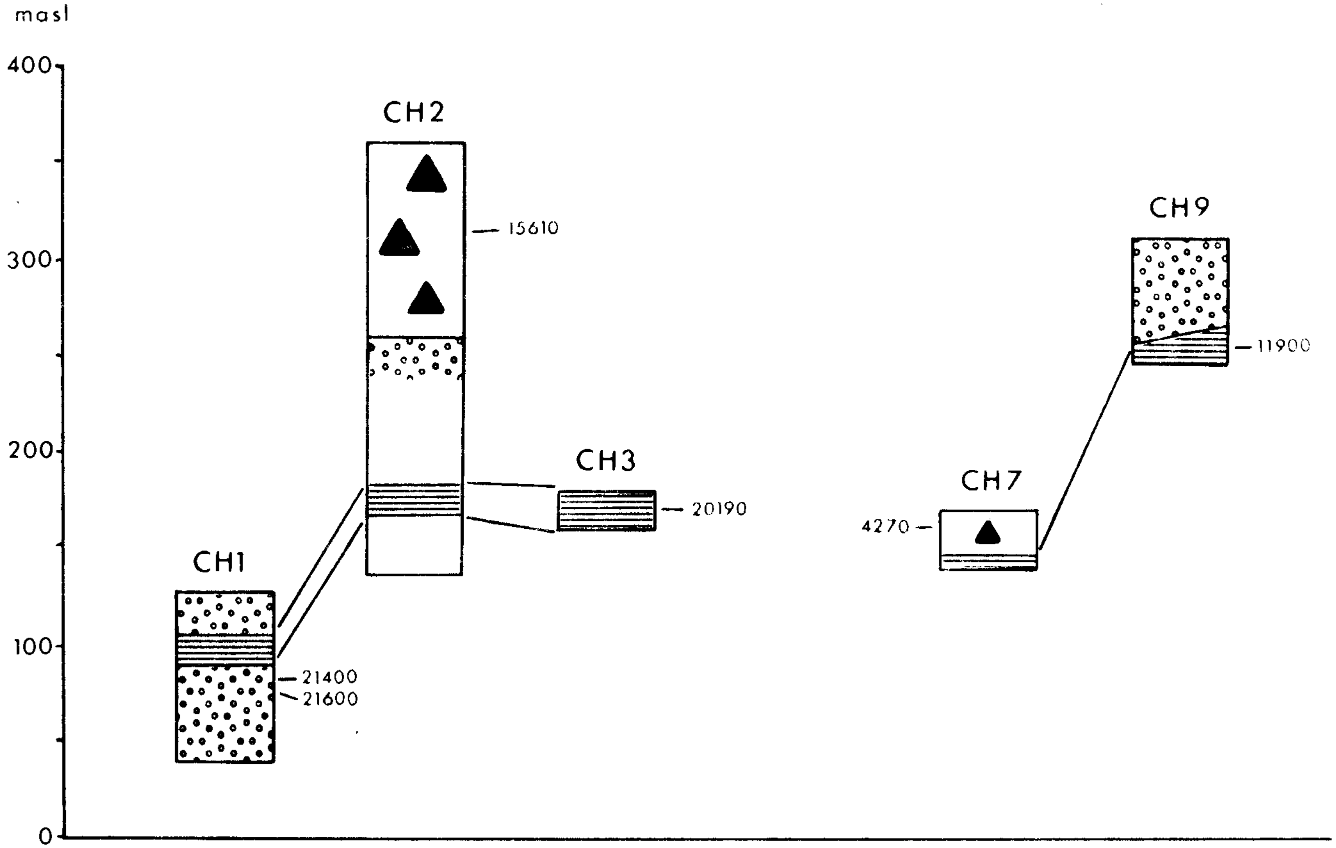
Most of the sections in the study area are representative of limited areas, and few can be correlated with each other. Figure 6.2 shows those which can readily be related. The early Fraser drift, composing glaciofluvial and glaciolacustrine sediments, can be traced along the north side of the lower valley, underlying the Ryder Upland. Sections CH1 to CH3 illustrate this.

Figure 6.2 also shows the possible correlation between the glaciolacustrine clays at CH7 and CH9. The CH9 deposit was dated by Clague & Luternauer (1982) at 11,900±120 BP (GSC-3306). The CH7 clays are not dated, but were interpreted as probably belonging to the same period, and therefore are correlative with those at CH9.

Geomorphological Chronology

There is not a complete record of the late Pleistocene glacial activity in the valley. The problems of the intrinsic imbalance in paleoenvironmental chronologies was noted at the beginning of this thesis, and deserve reiteration here. The stratigraphic record is inherently incomplete, especially in a high energy mountain environment. Only the surficial geology which is revealed can be interpreted, Only depositional environments can be specified in detail.

Figure 6.2 Schematic Correlations



The Fraser Glaciation - Advance Phase

The paleosandur underlying the Ryder Upland is the oldest dated feature in the valley. It was being formed between 21,400 and 21,600 BP, and undoubtedly existed for longer than this. It probably filled the whole width of the valley, and drainage was westward to Vedder Crossing. Sediment was derived from local advances of valley glaciers. No evidence for a pre-Wisconsin Fraser River has been unearthed (Armstrong, 1981) and so at that time the Chilliwack River may have emptied into a marine estuary. Alternatively, if sea levels were dropping at this time in response to the expanding ice sheets in the Coast Mountains, the river would have flowed a greater distance before reaching the sea.

The growth of ice into the eastern Fraser Lowland created a glacial lake in the lower Chilliwack Valley by blocking the westward drainage. The position of the ice margin was assumed to have been proximal to the Vedder Crossing Gravel Pit as shown by the presence of sand and gravel lenses in Unit 2 at this site. It is pssible that it flowed into the Columbia Valley.

Glaciolacustrine conditions prevailed until at least 20,190$\pm$1000 BP (SFU-406), and probably for a considerable period after this, as inferred from CH3.

Intense glaciation was undoubtedly the norm for this phase, and erosion played a dominant role. Many erosional features typical of alpine glaciation were left, but there is a dearth of deposits. The major exception to this in the research area is the thick bench of unconsolidated sediments which make up the Ryder Upland, some of which (e.g. Unit 2 at CH2) probably result from outwash alongside an advancing Chilliwack Valley glacier. Nearly half of the Upland is composed of till, with a radiocarbon age of 15,610±130 BP (BETA-11057) from CH2, which was deposited from ice flowing into the lower Chilliwack Valley from the Fraser Valley. A confrontation between this ice mass and the Chilliwack Valley glacier may have been the catalyst leading to localized, though intense, deposition of morainal material forming the bench.

Accepting the arguments against the deposition of a continuous valley floor between the Ryder Upland and the Upper Bench (discussed under CH4), it is conceivable that the Chilliwack Valley glacier lay along the south side of the lower valley when sedimentation was active in the Ryder Upland area, thus preventing valley-wide deposition.

The Fraser Glaciation - Recessional Phase

Although the Everson Interstade is represented in the sediments of the central and western Fraser Lowland, it is apparent that the eastern parts of the area, and the Cascades, were occupied by ice at this time (Armstrong, 1981). No deposits that indicate interstadial conditions have been identified in the Chilliwack Valley. The homogeneity of the thick till unit at CH2 (Unit 3) suggests that there was no break in deposition from the Vashon to the Sumas Stade. It seems likely that during this period ice was at a standstill or underwent a slow retreat up the valley. Alternatively, the Chilliwack Valley glacier could have retreated rapidly, as suggested by Crandell (1965) for Washington glaciers. It is quite possible that the large Fraser Valley ice mass remained stationary whilst the valley glacier retreated.

Separation of the Fraser Valley and Chilliwack Valley ice masses allowed a lake to form between them. The lake extended upvalley to at least Slesse Creek by 11,900±130 BP, and its presence in the lower valley prevented a late-glacial valley fill from being deposited (Clague & Luternauer, 1982). Laminated clays at CH7 and CH9 were derived from this lake. Glaciolacustrine sediments at the Slesse Creek sites suggest that the lake level was at least 300 masl, but CH10 and CH11 interpretations require a lake of 380-430 masl. Ice, in the lower valley, of sufficient thickness to dam a lake at this elevation would have flowed over the Ryder Upland. Given the suggestion of uninterrupted till deposition inferred from Unit 3 at CH2, ice probably persisted on the Upland throughout most of the Fraser Glaciation.

Drainage along the south side of the lower valley ice lobe deposited the Lower Bench kame terrace, and flowed into an ice-marginal lake at Smith Falls Creek (Figure 5.10). The lake extended to the snout of the Columbia Valley ice lobe, at the south end of Cultus Lake. Drainage from here was southward, down the Columbia Valley to join the Nooksack River.

Coeval with these events in the lower valley, a receding Chilliwack Valley glacier deposited a sandur in the upper valley which terminated in the glacial lake. No evidence of a re-advance of the Chilliwack Valley glacier has been found, and it was probably in a state of general retreat during late Fraser times. It was stationary at Chilliwack Lake for a while, and deposited a bouldery moraine there.

Tributary valleys discharging onto the sandur surface undoubtedly contributed meltwater at this time. Only Foley Creek shows evidence of providing a significant sediment supply in addition to the trunk valley outwash material. Boulders littering the sandur surface have been assumed by Gourlay (1976) and Clague & Luternauer (1982) to be solely derived from the Chilliwack Lake area (specifically the Chillwiack Batholith), but in fact those at the downstream end of the sandur were probably derived from the Mount Barr Batholith at the head of Foley Creek.

Towards the close of the Pleistocene, water from the Silverhope-Klesilkwa drainage area crossed the drainage divide into the Chilliwack River, via Post Creek, briefly depositing a gravel capping on the Chilliwack Lake Barrier. This feature was subsequently dissected and terraced, probably by a brief catastrophic flood, and bouldery debris tranported a few kilometres downvalley. The disposition of ice masses needed to precipitate catastrophic discharges were not fully clarified by Gourlay (1976) and Clague & Luternauer (1982).

The arrangements of ice necessary for the creation of a glacial lake in the Silverhope-Klesilkwa valley which would drain via Post Creek are as follows. Two glaciers are necessary, one flowing south down the Silverhope Creek valley from the Fraser Canyon, and the other flowing northwest up the Klesilkwa River valley from ice in the Skagit drainage area (as portrayed by Waitt, 1977, for early Fraser glaciers). These two ice lobes would have impounded a glacial lake between them upon separation (Figure 6.3a). Putting aside the possibility of ice-marginal drainage from this lake, the lowest outlet available is through the Post Creek valley, which was most likely ice-free during late Fraser times. The immediate precursor to the situation in Figure 6.3a is for one of the ice lobes to block the eastern end of the Post Creek valley, thereby raising the water level above the elevation of the drainage divide. Upon retreat of the lobe, the lake would drain into the Chilliwack Valley via Post Creek.

Detailed supporting evidence for this scenario is not available. However, exposures of deltaic(?) gravels north and south of the Silverhope-Klesilkwa drainage divide show paleoflow directions convergent on the Post Creek valley. If these gravels were deposited at similar times, then the presence of the two glaciers is proved, and the possibilty of a lake held between them becomes much greater.

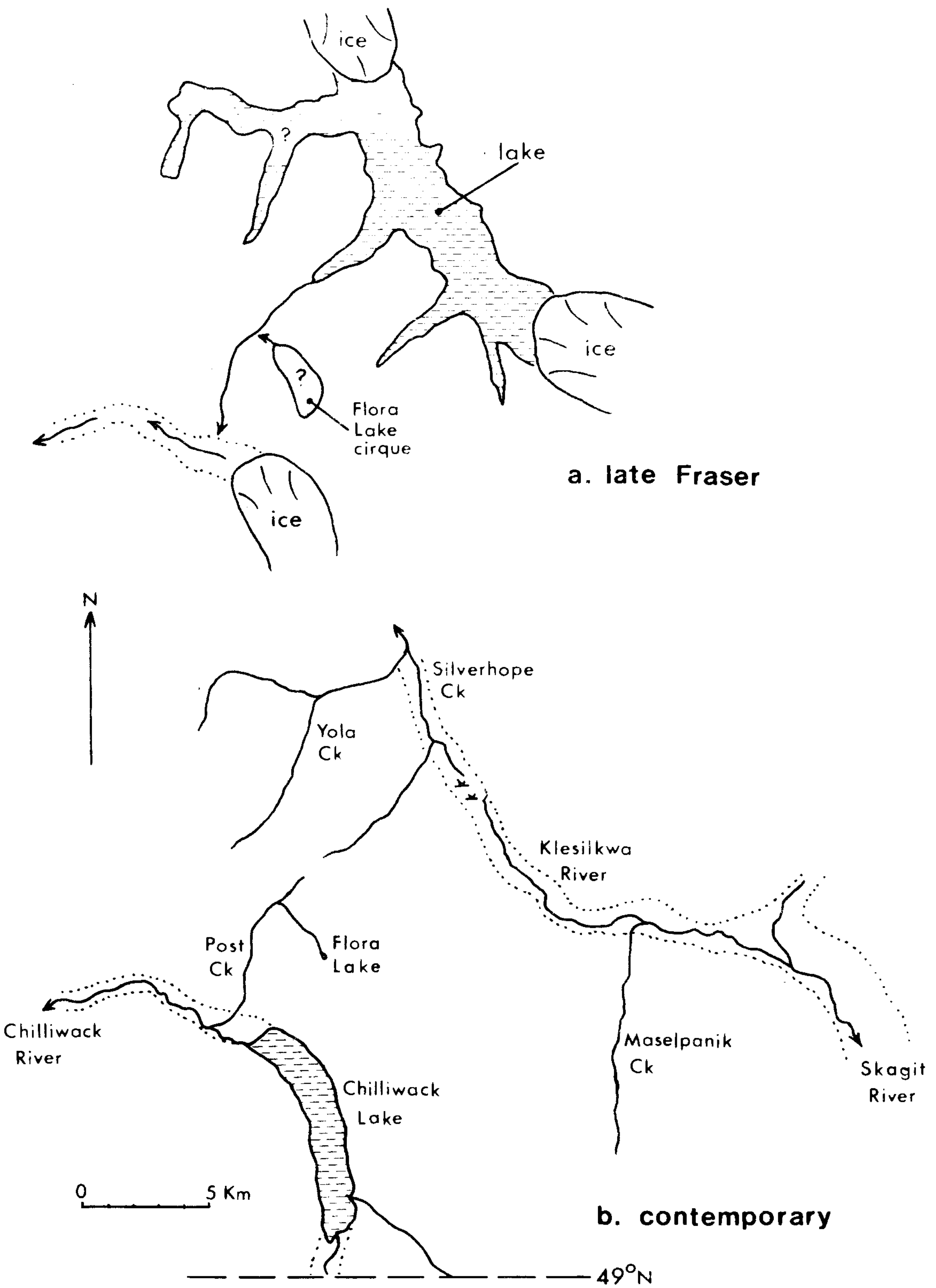


Figure 6.3 Post Creek Drainage

Until further research is undertaken in this area the proposals for the generation of flows through Post Creek valley must remain tentative.

At the end of the glaciation, the glacial lake in the lower valley drained. Since the Columbia Valley was infilled, drainage had to be into the Fraser Valley, perhaps via the narrow dry valleys near Vedder Crossing. Stagnant ice lay in the lower valley, diverting drainage and causing Cultus Bench, a kame delta, to be deposited (Figure 5.12a). Once this ice had melted, the Chilliwack River was able to leave the valley via Vedder Crossing, as it does at the present day. Cultus Bench remained in place and held back Cultus Lake.

Postglacial Events

With the draining of the glacial lake in the lower valley, the Chilliwack River incised the upper valley paleosandur in response to the lowered base level, leaving high terraces in the vicinity of the Slesse Creek-Chilliwack River confluence.

The L4 surface was deposited by paraglacial fluvial activity as a result of the dissection of the upper valley sandur. Its downstream extent may have been limited by the temporary lake dammed by the Tamihi Bench (see Figure 5.16a). The lake level would have stood at $\pm$165 masl, and extended upstream as far as the vicinity of CH8, which coincidentally is the terminus of the L4 terrace. Putting aside the lack of stratigraphic evidence for a delta here (no foresets), a possible evolutionary sequence for this part of the valley was illustrated in Figure 5.16.

Debris flow activity on the slopes of the Upper Bench deposited sediment in the valley bottom and temporarily dammed the Chilliwack River, so forming the Tamihi Bench. Slope failures probably began in late glacial or paraglacial times. Incision of the Tamihi Bench commenced soon after its formation, and it is still being actively eroded today.

Many of the fans in the valley probably originated during paraglacial times. Some fans are inactive today, but those that are fed by creeks remain active.

Once the glacial influence had waned, the intensity of geomorphic activity was reduced, and for or at least the second half of the Holocene, was probably very much as it is today.

Neoglacial advances were apparently not of widespread importance in the study area: moraines from such events are limited to the glaciers in the Depot Creek valley. Advances of other glaciers in the Chilliwack Valley probably did occur, but their moraines (if any were deposited) must either have been quickly destroyed, or were very small and so are not apparent in the contemporary landscape.

CHAPTER 7: CONCLUSIONS

This chapter outlines the implications of the present study for the Fraser Lowland Quaternary history, and for future research in the area.

Implications for the Fraser Valley Chronology

Some of the early Fraser drift identified in the Chilliwack Valley was deposited at the same time as the Coquitlam Drift in the western Fraser Lowland. Specifically, the lower valley paleosandur discussed by Hicock et al. (1982b) shows that the Chilliwack Valley glacier was active at that time. Similar activity has been reported from Washington by Crandell (1963) and Crandell & Miller (1974). Advances of alpine glaciers in the Evans Creek Stade were probably the norm in the Cascades and southern Coast Mountains at that time.

The glaciolacustrine clays dated at CH3 as 20,190±1000 BP (SFU-406) infer that Fraser Valley ice was in place at the mouth of the Chilliwack Valley at this time, and so confirms Hicock & Armstrong's (1981) tentative 21,000 BP reconstruction of the eastern Fraser Lowland. Subsequently, both these clays and the underlying sandur gravels (exposed at CH1, CH1a, CH1b) were eroded by the advance of the Chilliwack valley glacier.

Vashon till is scarce in the Fraser Lowland (Armstrong, 1984). In the Chilliwack Valley a major till unit of this age was found to underlie the Ryder Upland. This is Unit 3 at CH2.

It is several times thicker than any similar units reported by the above author. The date of 15,610±130 BP (BETA-11057), and the paucity of dates available to mid-Fraser times (Clague, 1980), makes CH2 an important section. The Ryder Upland was apparently a principal deposition site for the Fraser valley ice lobe. The exact reasons why this should have been could not be fully ascertained (see interpretation of CH2, Chapter 5).

No sediments relating to the Everson Interstade were identified in the study area. Instead, ice in the Chilliwack Valley probably underwent a slow retreat or standstill during this time, without significant deglaciation. This study supports the suggestion that interstadial conditions (deglaciation) did not occur in this area at this time, and that ice persisted in the eastern Fraser Lowland (Armstrong, 1981).

A broad suite of deposits has been ascribed to the late Pleistocene in this study: the kame terrace deposits at CH5, the kame delta (Cultus Bench) and glaciolacustrine and deltaic sediments at CH9. All these depend upon a lobe of the Fraser Valley glacier existing in the lower Chillwack Valley. Glaciolacustrine clays at CH9 dated at 11,900±120 BP (GSC-3306) mean that Fraser Valley ice existed in the lower Chilliwack and Columbia Valleys at this time. A till date of 11,300±100 BP (GSC-2523) from the Cultus Lake ice-contact face suggests that this ice, and consequently the Chilliwack Valley glacial lake, persisted until then.

While Clague (1981) argued for a rapid retreat of ice in the Fraser Valley at the end of this stade, it is possible that some stagnant ice masses persisted in the eastern Fraser Lowland. This was suggested in the interpretation of CH6, and thus supports Armstrong's (1960a) argument for stagnant ice in the Sumas Valley at the same time.

Implications for Chilliwack Valley Research

The Quaternary evolution of the Chilliwack River Valley is now understood in more detail and broader scope as a result of this research. The implications for past and future research are discussed here.

Assessment of Previous Research

The previous works can now be reviewed against the new findings of this study.

Two sections from Slesse Creek were well documented and competently interpreted by Chubb (1966), but his stratigraphy was not as detailed as his petrologic work. His four-unit section was an oversimplification of the complexities documented later by Clague & Luternauer (1982) and by this author.

Munshaw's (1976) work was broad in scope, but his coverage of geomorphology and geology was uneven. Munshaw was the only previous author who described the exposure at CH2, the Tamihi

Scar, and then when it was fresh, but he failed to realise its significance. His correlation between the upper valley paleosandur (L7 surface) and the Ryder Upland (L1) can now be positively discounted.

Armstrong's (1980b) map has been updated in this study, but it remains axiomatic. This work deviates from his in two respects. Firstly, he mapped the Tamihi Bench as outwash sand and gravel, whereas it was found to be composed largely of diamict (see CH7). Secondly, he omitted the Lower and Upper Benches. This study has expanded upon Armstrong's work by extending the mapping into previously uncharted parts of the valley.

Clague & Luternauer's (1982) field guidebook remains a valuable study of the valley. Of their work at CH1, CH9 and CH12, that from the latter two sites was expanded upon in this thesis.

Future Research

The major problem site in the research area is the Upper Bench. Further studies of the surficial geology of this feature might reveal a more detailed story, although at the time of this author's visits, this site was notable for its reluctance to reveal good exposures of the subsurface sediments.

Detailed reassessments of the remaining Chilliwack Valley sections would probably also be worthwhile. In particular, the lithological aspects, given a secondary role in this study, could provide a basis for provenance studies. Palynological research would be well worth pursuing to enrich paleoenvironmental interpretations, and indeed was used to advantage by Hicock et al. (1982b) at CH1. The thick till unit at CH2 presents possibilities for a well-focussed diamict study.

A seismic study of some of the terrain units could prove interesting. The Ryder Upland, Tamihi Bench and the upper valley paleosandur might be productively examined in this manner.

Lastly, the surficial geology of the Silverhope-Skagit area has not yet received any attention. The late Sumas chronology of the upper Chilliwack River valley will not be complete until this gap in knowledge is infilled.

APPENDIX A. SITE LOCATIONS

All but one of the following six-figure coordinates are taken from the 1:50,000 topographic map sheet 92H/4 (Chilliwack). The exception, CH12, is from sheet 92H/3 (Skagit River).

Site	Grid reference
CH1	766383
CH1a	838366
CH1b	862358
CH2	845368
CH2a	864374
CH3	874374
CH4	867352
CH5a	787358
CH5b	766354
CH6	764358
CH6a	745368
CH7	871366
CH7a	858360
CH8	898355
CH9	956362
CH9a	952364
CH9b	952370
CH9c	933372
CH9d	948364
CH10	989400
CH11	996404
CH12	127392

APPENDIX B. AERIAL PHOTOGRAPHS

The following are all vertical air photographs. The flight-lines in Set 1 run north-south, whilst those in Set 2 are east-west. These lists include only those photographs used by the author; there are many other photographs available for this area.

Set 1

August-September, 1966. Average scale, 1:31,680.

Flight line	Photograph numbers	Location
BC5168	212-214	Silverhope-Skagit divide
BC5169	209-216	Post Creek, Chilliwack Lake
BC5212	181-185	Post Creek, L10
	194-199	upper Foley Creek, L7, Centre Creek
BC5213	088-092	lower Foley Creek, L7, L8, L9, Nesakwatch Creek
	099-102	L8, L9, Larsons Bench (17), Slesse Creek
BC5214	192-195	Vedder Crossing, L4, Cultus Lake
BC5215	122-125	L6, lower Larsons Bench (L7)
BC5217	022-024	L2, L5, L6, Tamihi Creek
	031-033	L1, L2, L3, L5, Tamihi Creek
	196-198	L1, L3

Set 2

July, 1973. Average scale, 1;15,840.

Flight line	Photograph numbers	Location
BC7472	074-076	Cultus Lake.
	087-101	Cultus Lake, L4, L3, part of L1, L2, L5, L6, part of L7.
	087-101	Vedder Crossing, L1, L5, L6, whole of L7, L8, L9, L10.
	205-207	L8, L9.
	216-217	Post Creek.

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