THE LATE QUATERNARY SURFICIAL GEOLOGY AND GEOMORPHOLOGY OF THE LOWER SEYMOUR VALLEY, NORTH VANCOUVER, BRITISH COLUMBIA

by

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B.Sc. (physics), Simon Fraser University, 1988

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

in the Department
of
Geography

Simon Fraser University
December, 1991

APPROVAL

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Degree: Master of Science

Title of Thesis: The Late Quaternary Surficial Geology And Geomorphology Of The Lower Seymour Valley, North Vancouver, British Columbia

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Date Approved: December 2, 1991

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ABSTRACT

A detailed study of the surficial sediments and landforms in the lower Seymour Valley shows an almost continuous stratigraphic record spanning the last glacial cycle. Based on lithostratigraphy, extensive radiocarbon dating, and limited supportive thermoluminescence dating, a comprehensive geochronological history beginning more than 37 ka BP, during the Olympia Nonglacial Interval, has been developed for Seymour Valley. This study shows that the valley was slowly aggrading before 29 ka BP followed by rapid aggradation after 29 ka BP. The pre 29 ka BP aggradation was possibly a result of climatic fluctuations during the Olympia Nonglacial Interval, while the post 29 ka BP aggradation was likely a result of ice advancing during the onset of the Fraser Glaciation. Ice of the Fraser Glaciation reached the mouth of the valley by about 22 ka BP, and had retreated before 18 ka BP. The valley was subsequently vegetated. Ice once again advanced and occupied the valley between about 17 ka BP and 12 ka BP. After about 12 ka BP ice had finally retreated and the valley once again became vegetated. During and after deglaciation, glacial sediments were rapidly being eroded from the valley sides and deposited in the valley bottom. An apparent hiatus occurred during this time of rapid reworking of valley-side glacial sediments. The hiatus was possibly climatically induced, beginning about 10 to 11 ka BP during an interval of dryer and warmer climatic conditions (the early Holocene xerothermic interval) and ending sometime before 5 ka BP. By about 5 ka BP, incision of Seymour River into the valley fill was approximately 85% complete.

This research supports and refines the known mid- to late-Wisconsinan lithostratigraphy and geochronology of the Fraser Lowland. Six of the twelve lithostratigraphic units defined for the Fraser Lowland occur in the Seymour Valley, including Coquitlam Drift, which until now, had only been positively identified in the Coquitlam-Port Moody area.

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

The Geomorphic and geologic processes that have led to the present character of the landscape are diastrophism, volcanism, subaerial erosion and deposition, and glaciation (Mathews, 1989). Although all of these processes were ongoing throughout the Quaternary, most of the change to the landscape, during that time, has been due to repeated glaciation.

Potassium-argon dating of lava flows interbedded with tillite in Alaska, has shown that the first glaciation in the Cordilleran occurred at least 9 Ma ago (Denton and Armstrong, 1969). Isotopic and magnetic data from deep-sea cores have shown the presence of eight major climatic cycles over the last 800 ka, many coinciding with growth and decay of major ice sheets (Clague, 1986).

Each glacial cycle, in its simplest form, can be characterized by advance, climax and retreat phases. During the advance phase, glaciers move down valleys scouring and shaping bedrock, depositing fluvial outwash material, invading proglacial lakes, and altering the drainage systems. During the climax, valley glaciers move into low-lying areas and coalesce as a piedmont glacier, till is deposited and the underlying crust is isostatically depressed. The retreat phase is characterized by intense glaciofluvial erosion and deposition, marine incursion and glaciomarine deposition. The glacial cycle is finally terminated by isostatic rebound and fluvial downcutting into valley and deltaic fills (see Davis and Mathews (1944) or Fulton (1989) for a discussion of the glacial cycle). Because of these erosional characteristics, each glaciation virtually destroys any sign of preceding glaciations and makes our understanding of them exceedingly difficult. Most of the surficial geology of British Columbia is therefore a product of the last glaciation and post-glacial time.

The study of past glacial environments is done primarily by mapping and interpreting sedimentary exposures and drillhole logs. The certainty of past-environment interpretation is therefore directly proportional to the number of exposures studied. In British Columbia, as elsewhere, past glacial histories are developed by correlating spatially diverse sedimentary exposures. Complete stratigraphic columns, exposed at one location, representing even the last glacial cycle, are sparse.

Mountain valleys may provide ideal sites for studying glacial history. As ice advanced and retreated into the Fraser Lowland, valleys in the Coast and Cascade ranges were filled with associated sediments. Post-glacial fluvial down-cutting and subsequent slumping has, in many cases, provided numerous exposures. Despite these favourable characteristics, few detailed Quaternary studies of mountain valleys in southwestern British Columbia have been undertaken. Two exceptions are the Coquitlam (Hicock, 1976), the Chilliwack (Saunders, 1985) valleys.

Preliminary field reconnaissance had shown that the Seymour Valley contains some of the best exposures of Quaternary sediments in the Fraser Lowland - sediments that appeared to represent at least one glacial cycle. It was thought that the documentation and understanding of the stratigraphy in this valley would not only add to the existing body of knowledge concerning the late Quaternary in southwestern British Columbia, but open up a new laboratory for a diversity of future Quaternary research.

1.2 The Objectives

The primary objectives of this study, therefore, were as follows:

(1) To map and interpret the surficial geology and geomorphology of the study area.

(2) To establish a comprehensive geochronology for the study area possibly spanning the Wisconsinan.

(3) To set the results of this study in the context of existing knowledge for southwestern British Columbia and northwestern Washington.

1.3 The Study Area

1.3.1 A Brief History

Seymour Valley has been of great interest to both loggers and miners since the mid-nineteeth century. It is known that placer miners occupied the valley in the 1860's and that gold was discovered in 1888. The Moodyville Sawmill opened operations in 1875 and selective logging in the valley occurred to about 1936. The Seymour Valley had also been of great interest as an alternate transportation route to the interior, and in 1877 the Lillooet Trail from the mouth of the Seymour River to Pemberton Meadows was completed. The trail eventually only served miners and trappers. In 1890 homesteaders occupied the lower valley, and in 1908 the first pipeline carrying water to the city below was completed. In 1928 the first dam at Seymour Falls was completed and in 1936 the Seymour Valley was designated a closed watershed; in 1961 a new larger dam was constructed. In 1987, after some 50 years of closure, the area south of Seymour Falls Dam was opened to the public as the Seymour Demonstration Forest (Kahrer, 1989). No detailed study of the Quaternary deposits in Seymour Valley has been completed (Lewis, 1985); likely a consequence of the long period of closure.

1.3.2 Location

Seymour Valley (Figs. 1.1, 1.2, and 1.3) is located on the north shore of Vancouver within the Pacific Range of the Western System of the Canadian Cordillera, known as the Coast Mountains. The physiography of the area has been described by Holland (1976). Seymour Valley is one of several major valleys running north-south opening into the Fraser Lowland; others are Capilano, Lynn, and Coquitlam valleys. Seymour Valley is ~35 km long and lies roughly along 123°00' W, and falls between 49°15.2' N and 49°30.3' N. The study area comprised the section of the valley between the Seymour Falls Dam and Burrard Inlet. At the time of this research the remainder of the valley was closed to public access by the Greater Vancouver Regional District (GVRD).

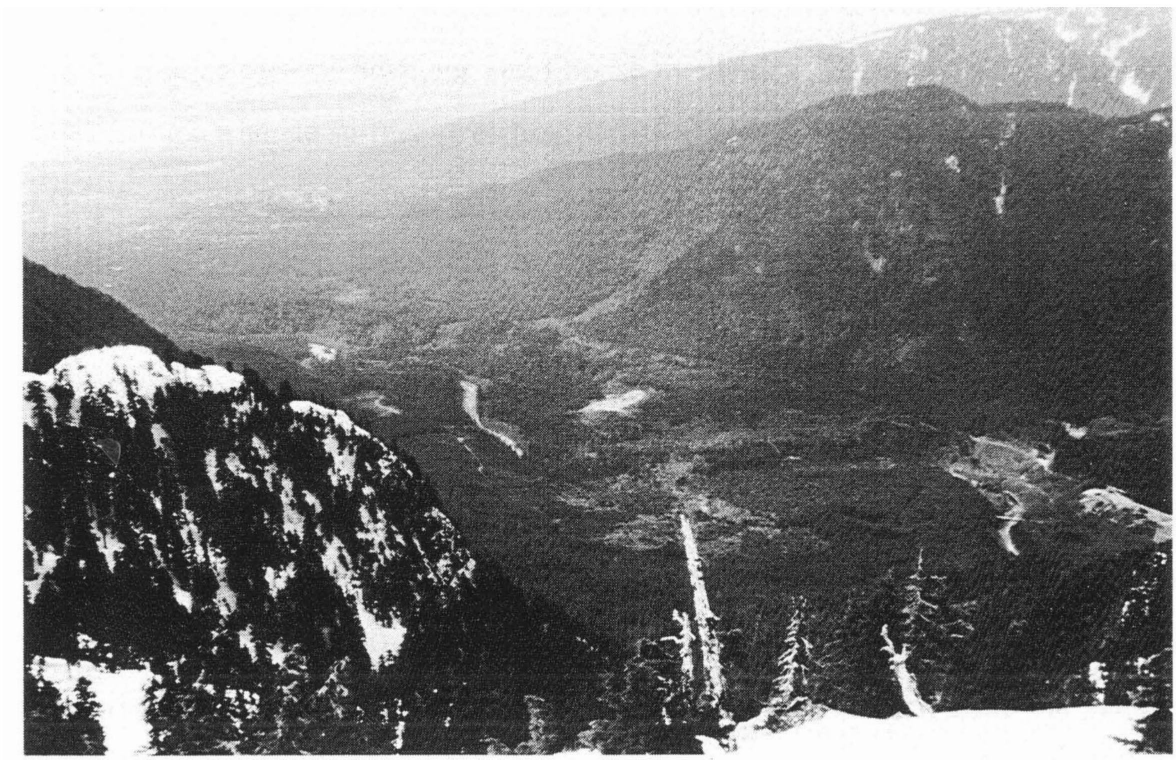


Figure 1.1 Mouth of Seymour Valley opening into the Fraser Lowland. The photograph was taken from Mount Seymour in the Spring of 1991.

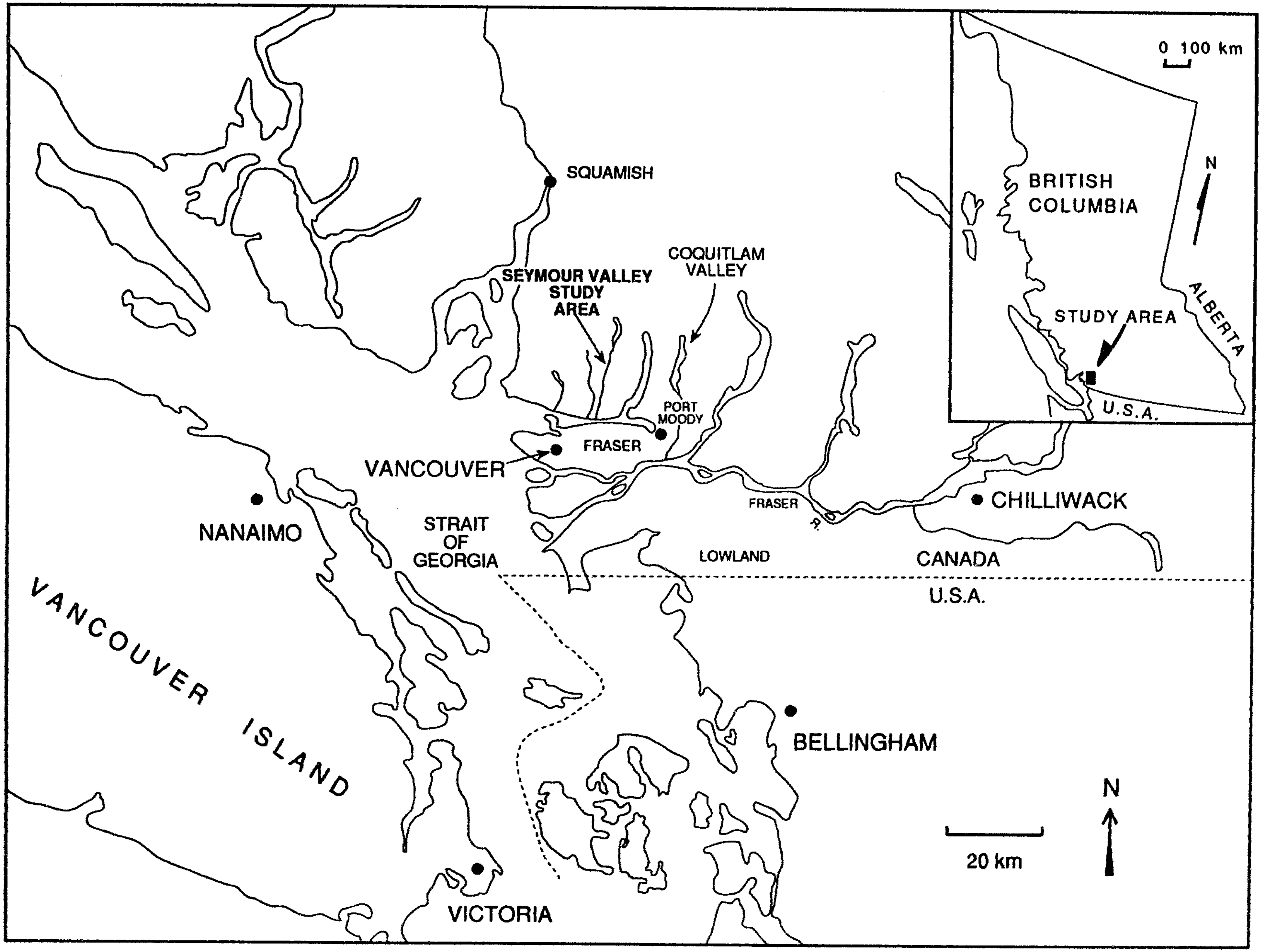


Figure 1.2 Maps showing general location of the study area.

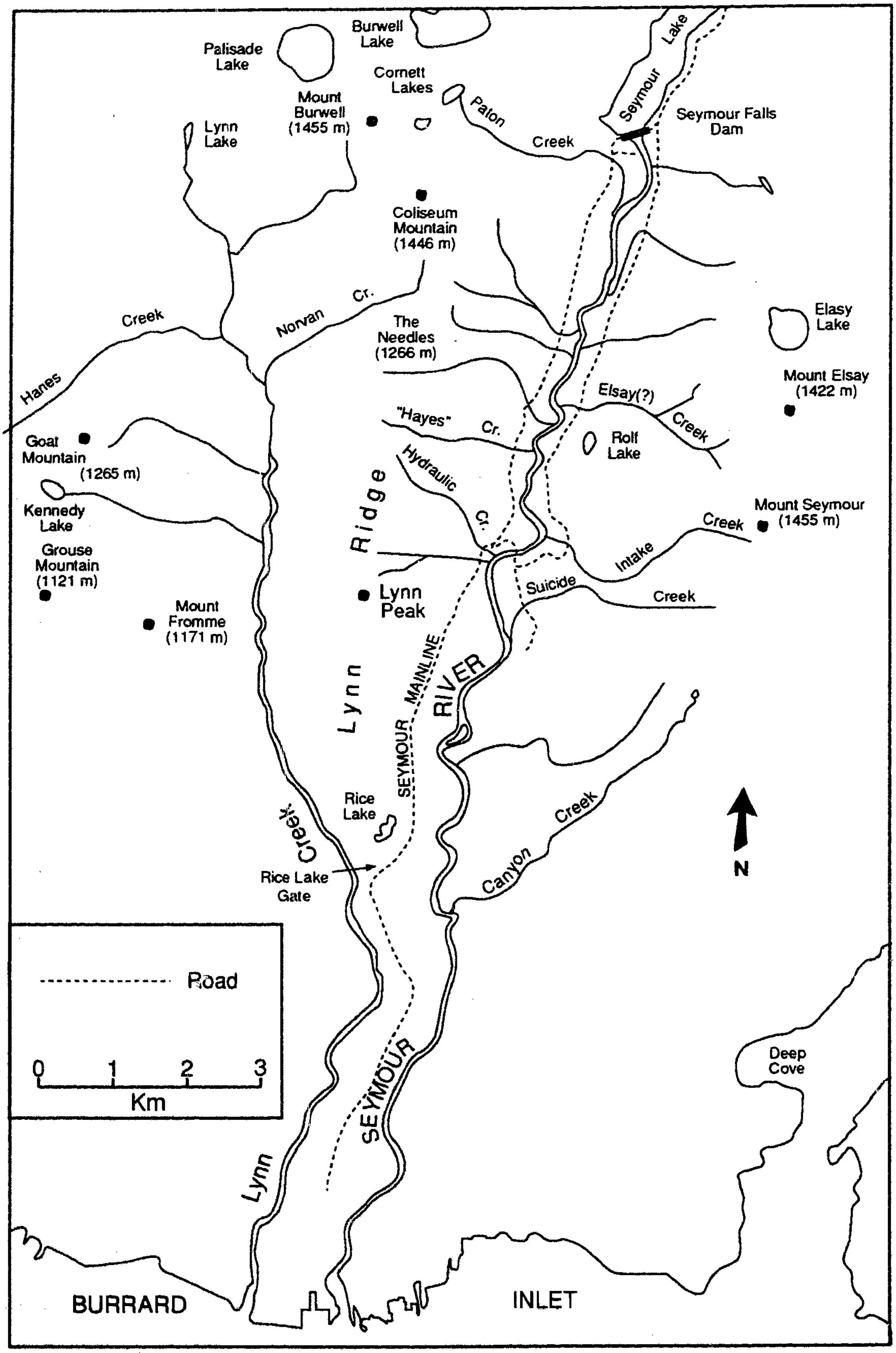


Figure 1.3 Location of the Seymour Valley study area. The study area comprised the section of the valley between Seymour Falls Dam and Burrard Inlet.

1.3.3 General Geomorphology

Seymour Valley is a relatively narrow valley about 5 km wide. The valley rises to the east to an elevation of 1455 m (Mt. Seymour) and to an elevation of 1466 m to the west (Coliseum Mnt., Lynn Ridge, and The Needles). The valley formed since the late Cretaceous, by fluvial incision (antecedence) as the Coast Plutonic Complex began to rise above sea-level. Evidence of this are the two elevated erosional surfaces on the south slopes of Seymour and Grouse mountains. These two surfaces probably once formed a single surface stretching across what is now Seymour and Lynn Valleys (Armstrong, 1990).

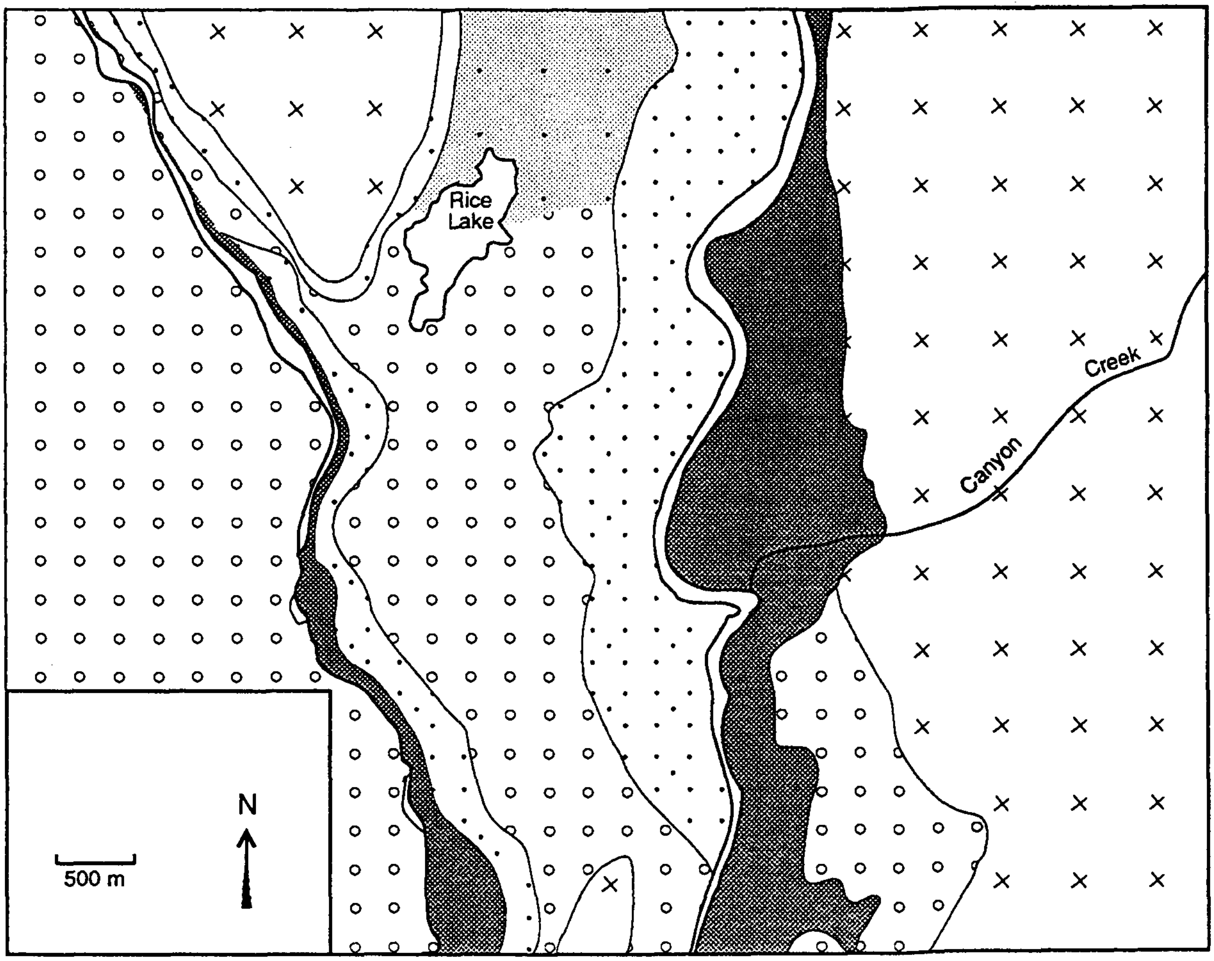
Well rounded peaks and the characteristic U shape of the valley provide evidence for repeated ice sheet glaciations. Additional evidence is supplied by an extensively exposed valley fill revealing sediments representing at least one major glacial cycle. The top of the valley fill forms a terrace (hereafter referred to as the Main Terrace) at about 200 m asl between Seymour Falls Dam and Rice Lake. Above Rice Lake, glacial sediments are usually covered by a veneer of outwash deposits (alluvial fans and aprons) emanating from the valley sides. The Main Terrace is best preserved on the west side of the Seymour River. South of Rice Lake the valley fill slopes downward over 7 km to about 15 m asl through a series of post-glacial wave-cut terraces. In addition to the wave-cut terraces, prominent landforms at the mouth of the valley include raised deltas.

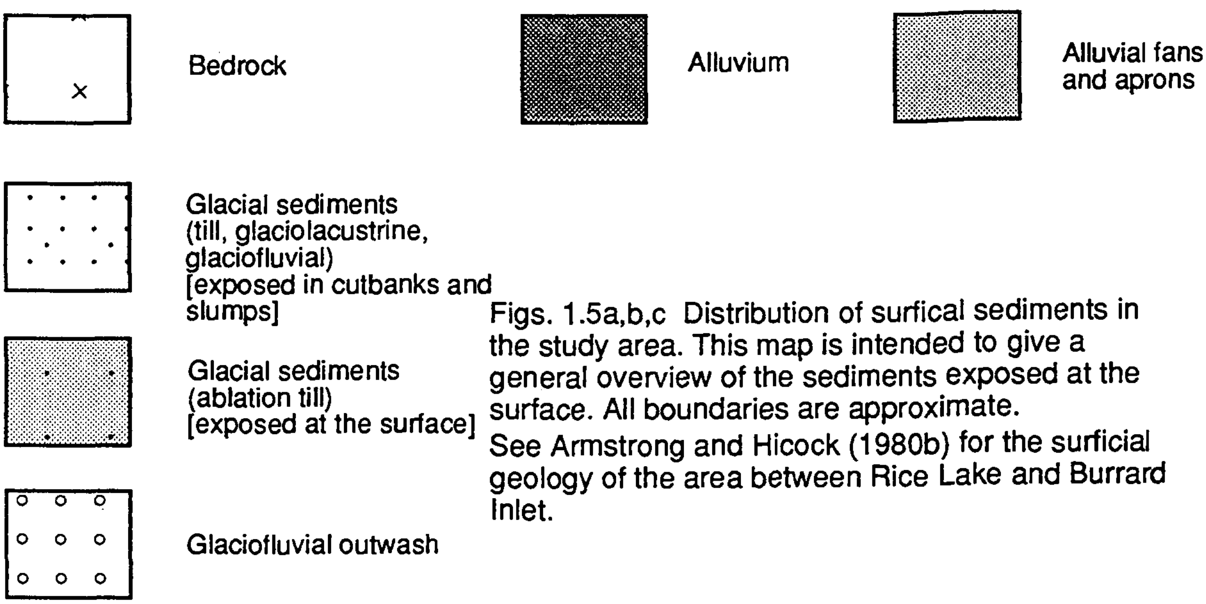
Seymour River flows near the surface of the valley fill (200 m asl) at the Seymour falls Dam, and is incised to about 100 m asl at Rice Lake, leaving behind a complex system of terraces dissected by numerous tributaries graded to the Seymour River. The base level of the river, below the dam, presently is controlled by a bedrock canyon between 2 and 4 km from the mouth.

The general distribution of surficial sediments in the study area is shown in figures 1.4 a, b, and c.

Figure 1.4 Stereopair (1:29 434) showing the valley fill near Rice Lake. FT = Fisherman's Trail; T = terrace where Unit 14 sediments are observed to overlay Unit 1 sediments (see Chapter 4).

Figure 1.5a





Figs. 1.5a,b,c Distribution of surfical sediments in the study area. This map is intended to give a general overview of the sediments exposed at the surface. All boundaries are approximate. See Armstrong and Hicock (1980b) for the surficial geology of the area between Rice Lake and Burrard Inlet.

Figure 1.5b

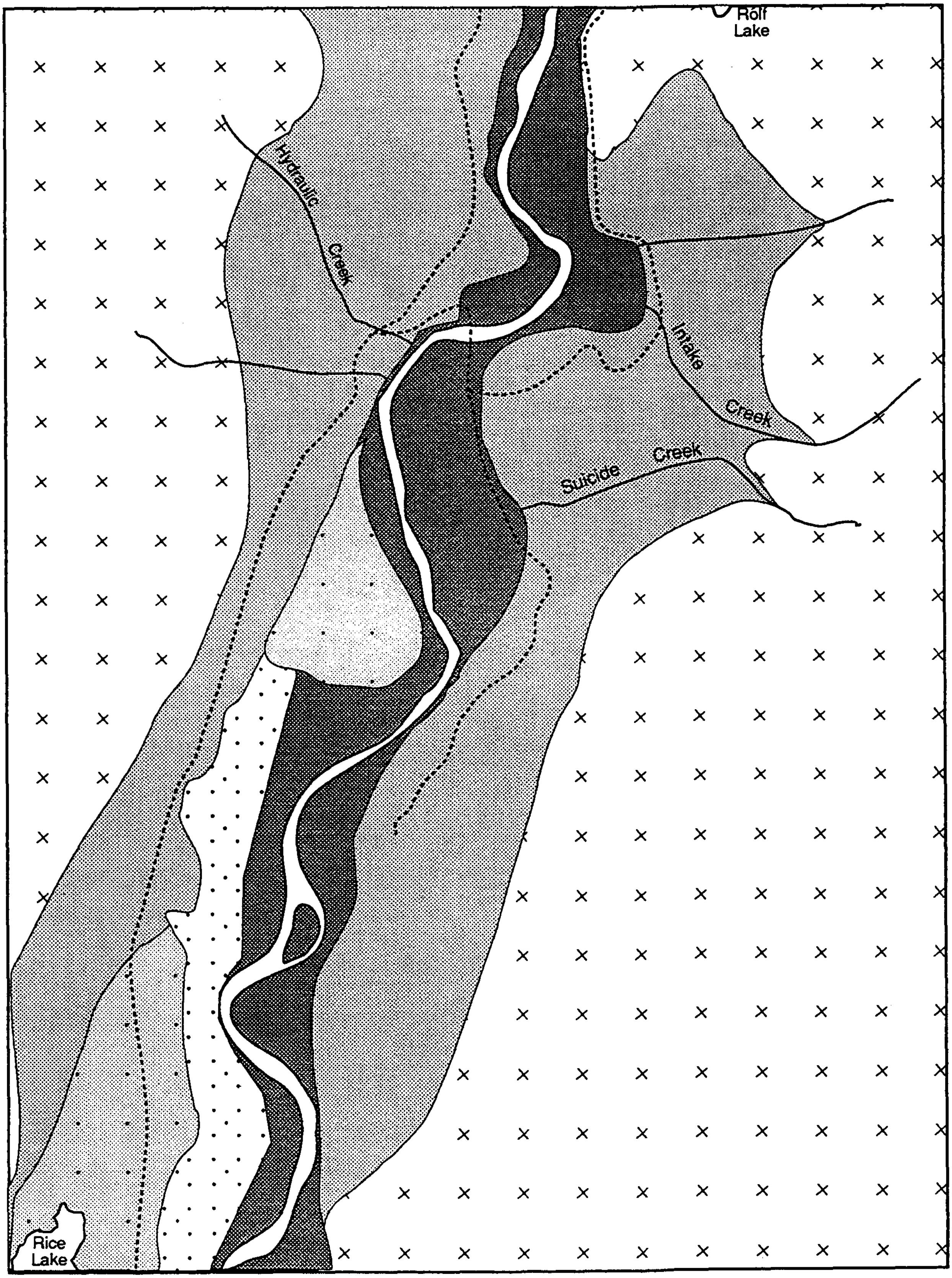
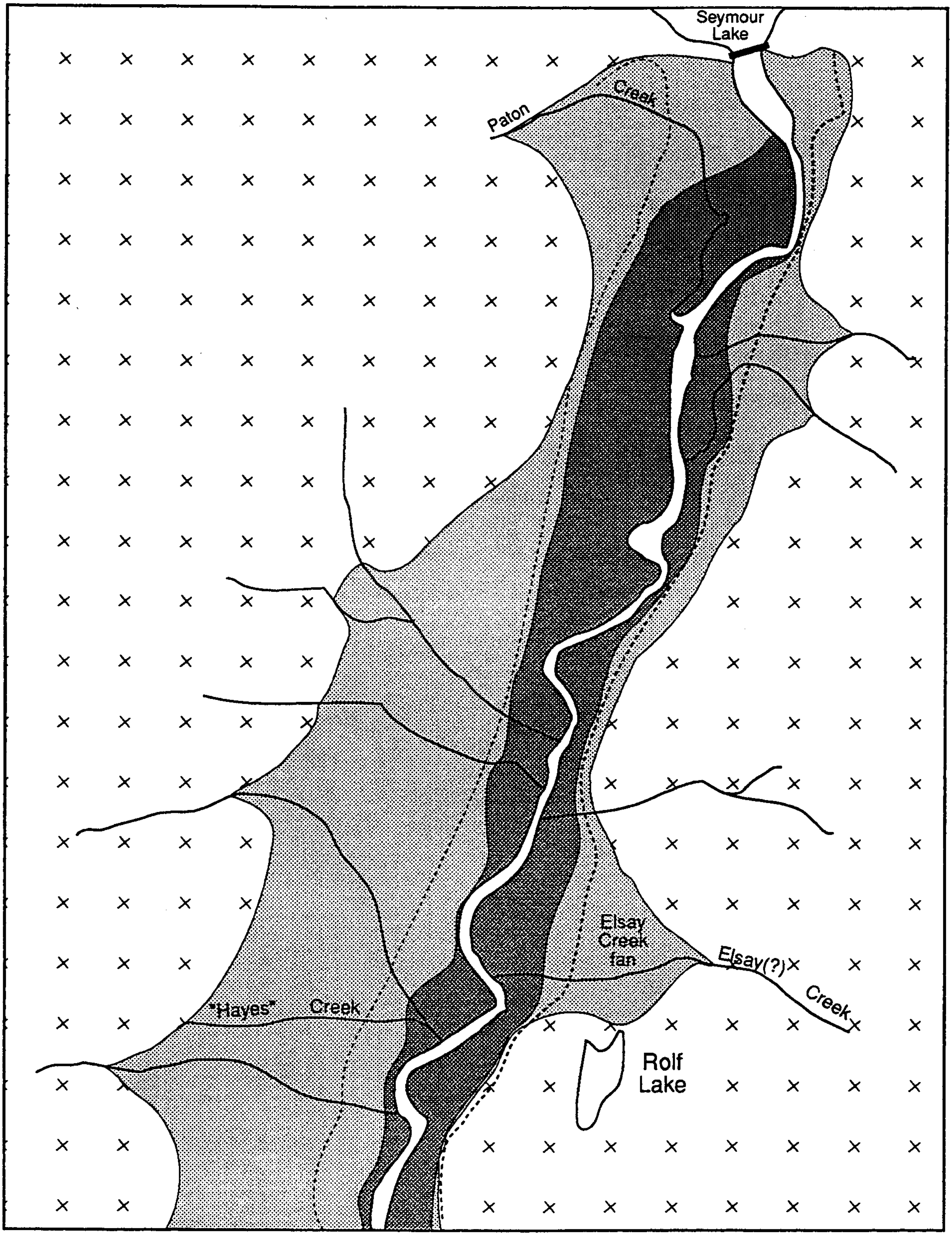

Rolf
Lake
Hydraulic
Creek
Intake
Creek
Suicide
Creek
Rice
Lake

Figure 1.5c


Seymour
Lake
Paton
Creek
Elsay
Creek
fan
Elsay(?)
Creek
"Hayes"
Creek
Rolf
Lake

1.3.4 Bedrock Geology

The bedrock in the study area is part of the Coast Plutonic Complex consisting of mainly plutonic rocks including quartz diorite, diorite, migmatite, granodiorite, and minor granite (Fig. 1.6). The rocks of the Coast Plutonic Complex were formed in the Cretaceous and erosion since the Tertiary (Eocene) has exposed them. The research area is bracketed by two roof pendants, the Lynn Creek Pendant to west, and the Mount Seymour Pendant to the east. The Mount Seymour Pendant is separated from the study area by plutonic rocks, while Lynn Creek Pendant comes into direct contact with surficial deposits in the general area of Hydraulic Creek. The Mount Seymour Pendant is a composite pendant made up of the Gambier Group (upper Jurassic/lower Cretaceous) and underlying Twin Island Group (pre-Jurassic) rocks. The Lynn Creek Pendant is probably composed of the Gambier Group rocks (Roddick, 1979).

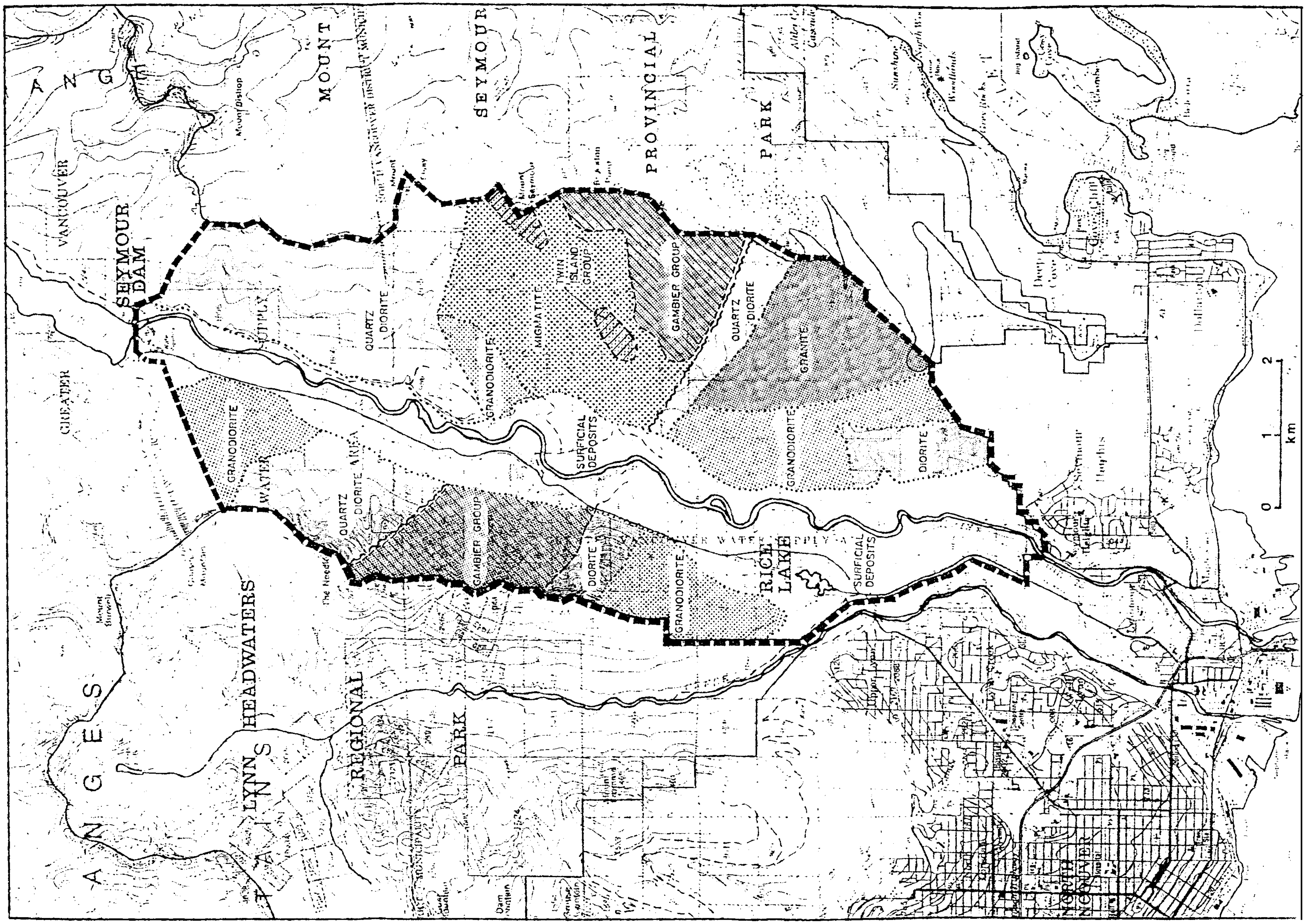


Figure 1.6 Bedrock geology map of the lower Seymour Valley (GVWD and GVRD Parks Department Map 7, REF. WB-923, SH.1; after Roddick, 1979).

CHAPTER 2

PREVIOUS QUATERNARY RESEARCH

2.1 The Fraser Lowland: A Brief History of Quaternary Research

Although the surficial geology and geomorphology of the Fraser Lowland was first noted by explorers in the mid-nineteenth century, detailed descriptions did not occur until early in the twentieth century. Burwash (1918) described the Pleistocene drift deposits in the Fraser Delta area and in the Coast Mountains north of Burrard Inlet. Burwash divided the drift deposits into an upper Vashon Till[1] and a lower Admiralty Till [Semiahmoo Drift][2] separated by the Admiralty Sediments [Quadra Sands], which he described as interglacial deposits. He also noted numerous raised deltas and marine deposits and concluded that past sea levels were at least 650 feet (200 m) above present sea level.

Johnston (1923) produced a Geological Survey of Canada (GSC) Memoir in which he reported on the geology and physical features of the Fraser River Delta map area from the international boundary north to the Coast Mountains, just north of Burrard Inlet, and from the west coast to Fort Langley. Johnston described the two till sheets of Burwash and noted that the uppermost till sheet contained fossil marine shells and concluded that it was a result of an old sea bottom that had been 'ploughed up' by ice. He also described the sea-cliffs at Point Grey (Burwash's Admiralty Sediments) and concluded that because of the occurrence of a lower unit containing peat beds and fossil plant material, they were deposited during an interglacial. He named this lower unit the Point Grey Formation [Quadra Sands], and reserved the name Admiralty Sediments to the overlying and underlying glacial outwash deposits. Johnston also described the numerous raised beaches and terraces of Burwash, specifically along the mouths of tributary valleys on the north shore of Burrard Inlet.

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1. Vashon till and Admiralty till were originally defined by Bailey (1898) working in the Puget Lowland (northwestern Washington state).

2. Bracketed terms refer to present day equivalents.

Johnston also briefly discussed Pleistocene oscillations in sea-level and concluded that, because of spatially different marine limits (marine limit decreasing in direction of ice retreat), uplift was probably isostatic and associated with deglaciation.

In 1949 J.E. Armstrong began to map the surficial and bedrock geology of the lower Fraser valley area and adjoining mountains. Armstrong and Brown (1954) produced a paper which discussed the nature of late Wisconsinan post-glacial sediments, specifically marine drift. The authors argued that the glacially *ploughed up* fossiliferous sediments of Johnston actually represented sediments that had been deposited by ice wasting into invading sea water during deglaciation, or by the reworking of tills by wave action. Armstrong (1956) produced a surficial geology map and report of the Vancouver area. His study indicated that the area was subject to at least three major glaciations, the Seymour [Westlynn], Semiamu [Semiahmoo], and Vashon. Armstrong also noted the existence of one probable interglacial period, the Quadra [Highbury Nonglacial Interval?], between the Seymour and Semiamu glaciations. The time interval between the Vashon and Semiamu glaciations was represented by merely an erosional interval. Armstrong also quoted two radiocarbon dates, one from post-Vashon Capilano Group sediments (11 500 ± 500 yrs), and another from Quadra Group sediments (>30 000 yrs).

Through the next two decades the increased use of radiocarbon dating allowed for the correlation of time stratigraphic units with lithostratigraphic units. In the early 1970's the process of defining and cataloging lithostratigraphic units as stratotypes (Hedberg, 1976) was initiated, and many of the ambiguities associated with the misuse of unit names were resolved; for example Armstrong and Clague (1977) supplied a long-needed strict definition for the term *Quadra Sand.* The result of this on-going work is the now-accepted Quaternary stratigraphy presented in Figure 2.1. Armstrong's 1956 surficial geology map was eventually updated by Armstrong (1980a,b) and Armstrong and Hicock (1980a,b). A Brief summary of the stratigraphic record of the Fraser Lowland, and adjoining mountains is presented below.

2.2 The Stratigraphic Record of the Fraser Lowland

The stratigraphy of the Fraser Lowland has been studied in detail, and at least 14 lithostratigraphic units (Fig. 2.1) have been defined. Of these 14 units, 9 represent three distinct glacial cycles, while the remainder represent local advances or surges of ice margins, and post-Fraser sediments. The general distribution of surficial deposits in the Fraser Lowland is shown in Figure 2.2.

2.2.1 Late Sangamonian(?) to Mid Wisconsinan

The oldest named glaciations (evidence of stratigraphically older glacial sediments, in the Faser Lowland, have been found in drill cores) in the Fraser Lowland are the Westlynn (Armstrong, 1956, 1975) and the Semiahmoo (Armstrong, 1975; Hicock and Armstrong, 1983). The Westlynn glaciation is the stratigraphically oldest and most poorly documented of the two and is represented by Westlynn Drift. Westlynn drift consists of till, glaciomarine, glaciofluvial, and glaciolacustrine sediments and has been found in various drillholes in the Fraser Lowland. Westlynn Drift is also thought to be visible at the Westlynn parastratotype[3] for the Highbury Sediments (see below) (Hicock and Armstrong, 1983; Armstrong *et al.*, 1985). The Semiamhoo glaciation was the penultimate glaciation, and is represented by Semiamhoo Drift. Semiahmoo Drift consists mainly of till, glaciofluvial, ice-contact, glaciomarine, and glaciolacustrine sediments (Hicock and Armstrong, 1983). Semiahmoo Drift has been studied in relatively more detail and has a holostratotype and parastratotype associated with it. Both the Westlynn and Semiahmoo drifts are beyond the radiocarbon limit, so that all associated dates are infinite. Semiahmoo Drift may, however, be associated with a single

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3. "A stratotype is the type representative of a named stratigraphic unit, constituting the standard for the definition and recognition of that unit. A holostratotype is an original stratotype designed at the time of establishment of a stratigraphic unit. A parastratotype is a supplementary stratotype used in the original definition to aid in elucidating the holostratotype" Armstrong and Clague (1977).

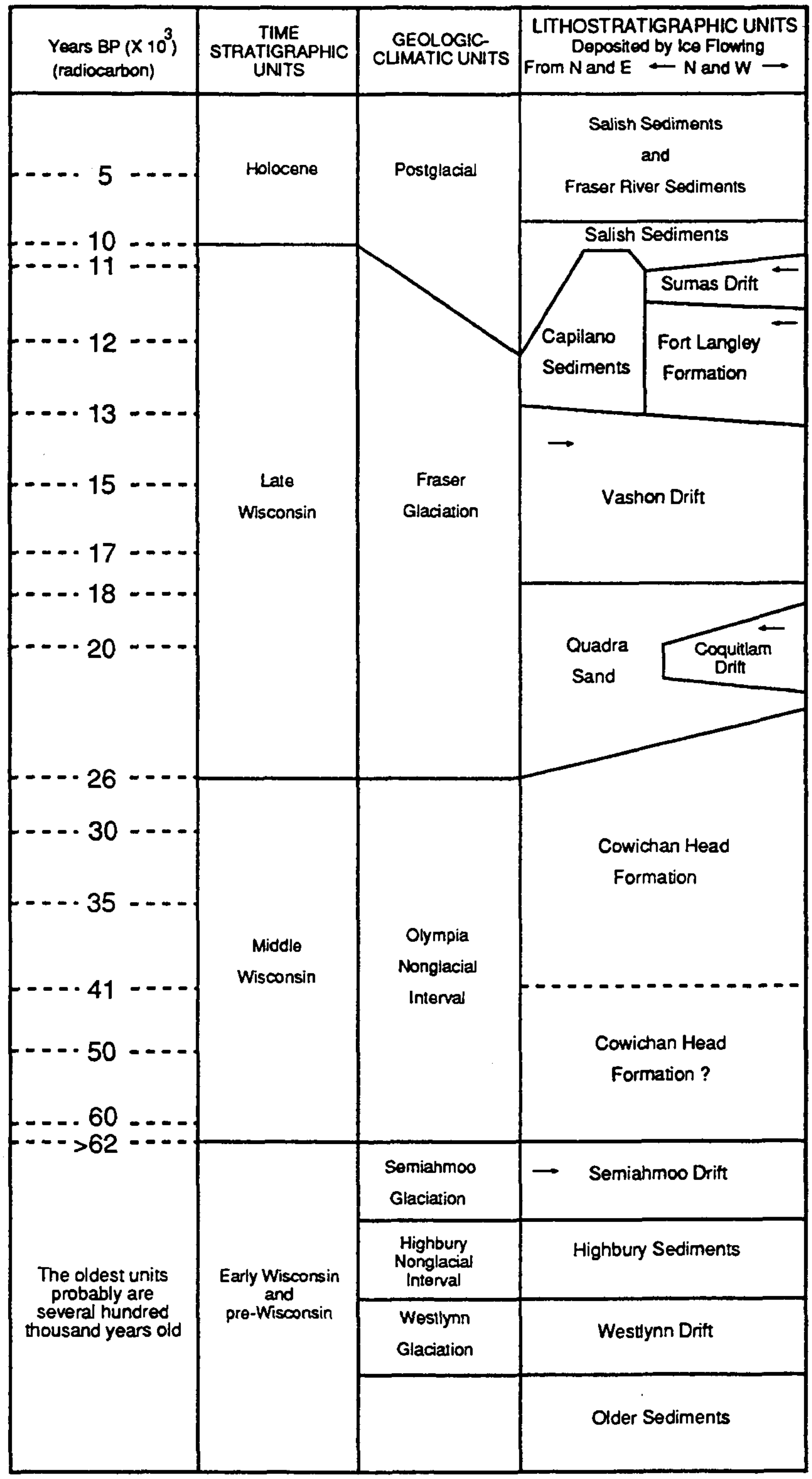


Figure 2.1 Relationship between radiocarbon years, time stratigraphic units, geologic climatic units, and lithostratigraphic units for the Fraser Lowland (after Armstrong, 1984)

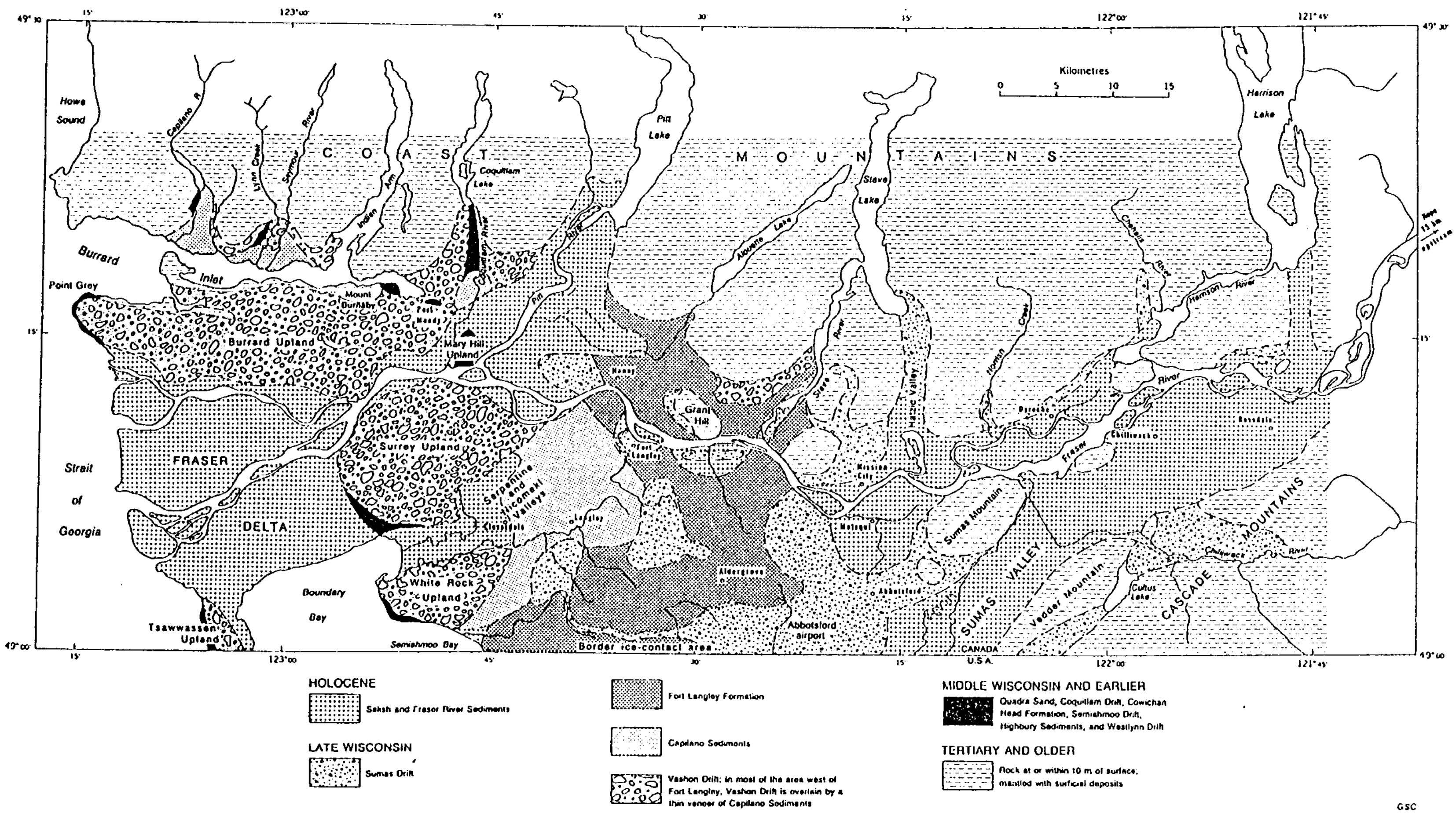


Figure 2.2 Distribution of Quaternary deposits in the Fraser Lowland (from Armstrong, 1984).

finite date of 58 800 +2900,-2100 years BP, from wood in overlying sediments, which *may* be considered a minimum age for the drift (Hicock, 1976; Armstrong and Clague, 1977; Armstrong and Hicock, 1983), while the Westlynn Drift may be >75 000 years BP old (Armstrong, 1975).

The Westlynn and Semiahmoo glaciations were separated by the Highbury Nonglacial Interval. Highbury Sediments consist of fluvial, marine, esturine, and organic sediments (Hicock, 1980; Hicock and Armstrong, 1983; Armstrong, 1984). Wood extracted from Highbury Sediments at the parastratotype gave infinite radiocarbon dates of >54 000 and >52 000 years BP

The Semiahmoo Glaciation was followed by the Olympia Nonglacial Interval which is represented by the Cowichan Head Formation. The Cowichan Head Formation can be separated into two members (an upper terrestrial member and a lower marine member), but generally includes fluvial, esturine, marine silt, sand and gravel. Radiocarbon dates from the Cowichan Head Formation range from 25 800 ± 310 to 47 000 ± 1100 years BP, but a single date (mentioned above) of 58 000 +2900,-2100 extends the upper age limit to about 60 000 years BP (Armstrong and Clague, 1977). This upper age limit is supported by $^{230}Th/^{234}U$ ages reaching 67.0 +11,-10 ka from speleothems on Vancouver Island (Gascoyne *et al.*, 1981).

2.2.2 Late Wisconsinan

Late Wisconsinan lithostratigraphic units, due to relatively abundant exposures, all have well defined stratotypes; associated radiocarbon dates are all within the limit of radiocarbon dating techniques.

The Fraser Glaciation is recognized as the last glaciation in which glaciers occupied the mountains and lowlands of British Columbia (Armstrong *et al.*, 1965), and therefore is responsible for most of the landforms and stratigraphy found in British Columbia today. The Fraser Glaciation may be divided into three stades: the Coquitlam, Vashon, and Sumas. The Coquitlam and Sumas stades were local advances or surges, and the Vashon Stade was the main glacial advance of the southwestern part of the Cordilleran ice sheet.

The advance stage of the Fraser Glaciation began about 29 000 years BP when cooler climatic conditions caused glaciers to advance from mountain valleys into the fjords. As the valley glaciers advanced, glacial outwash in the form of braid planes or sandurs were deposited in front of the ice margins. These outwash sediments have been studied in great detail and are referred to as the Quadra Sands. The Quadra Sands consist of cross-stratified, well-sorted sand, minor gravel, and silt. Radiocarbon dates have shown that Quadra Sands were deposited diachronously, being more than 29 000 years old at the north end of Georgia Strait, yet younger than 15 000 years at the south end of the Puget Sound (Armstrong and Clague, 1977; Clague, 1977).

The Coquitlam Stade represents the initial advance of ice during the onset of the Fraser Glaciation. The Coquitlam Stade is represented by the Coquitlam Drift which has only been positively identified at three exposures in the Fraser Lowland. A holostratotype and two parastratotypes have been defined in the Coquitlam Valley-Port Moody area (Hicock and Armstrong, 1985). Coquitlam Drift consists of till, glaciofluvial, ice-contact, and glaciomarine deposits. Radiocarbon dates from the type location show that the Coquitlam Stade lasted from about 21 700 ± 130 to about 18 700 ± 170 years BP and therefore occurred within about 3000 years of the main Fraser Glaciation. The interval between the end of the Coquitlam Stade and start of the Vashon Stade has been informally named the Port Moody interstade by Hicock and Armstrong (1985) and has radiocarbon dates ranging from 18 700 ± 170 to 17 800 ± 150 years BP associated with it.

The Vashon Stade followed the Port Moody interstade and represents the main advance of the southwestern part of the Cordilleran ice sheet during the Fraser Glaciation. During the Vashon Stade valley glaciers coalesced in the lowlands as a large piedmont glacier and ice accumulated to depths of over 1800 m. During this time Vashon Drift was laid down. Vashon Drift was deposited diachronously and consists of till, glaciofluvial, and glaciolacustrine sediments. The Vashon Drift is bracketed by radiocarbon dates of 18 300 ± 170 and 13 500 ± 220 years BP in the Fraser Lowland. The Vashon ice sheet reached its maximum by about 14 500 years ago (Hicock and Armstrong, 1985).

The retreat phase of the Fraser Glaciation (Fig. 2.3) is represented by Capilano Sediments. Capilano Sediments are diachronous and were deposited away from the retreating ice margin. Radiocarbon dates have shown that Capilano Sediments were laid down between 12 800 ± 175 and 10 430 ± 150 years BP Capilano Sediments consist of marine and glaciofluvial sediments deposited when relative sea levels were at least 15 m above the present sea-level. They are represented by seafloor muds with dropstones, fossil shells, raised deltas of sand and gravel, raised intertidal sand, and beach gravels (Armstrong, 1981, 1984). Capilano Sediment usually form a thin veneer overlying Vashon Drift.

During the retreat phase of the Vashon ice, there were several minor readvances and retreats of the ice margin into the invading sea. This period is referred to as the Fort Langley Time Interval and is represented by the Fort Langley Formation. The Fort Langley Formation consists of Interbedded marine and glaciomarine sediments and glacial drift, and is bracketed by radiocarbon dates of 12 900 ± 170 and 11 680 ± 180 years BP (Armstrong, 1981). The Sumas Stade followed the Fort Langley Time Interval and probably represents the final surge of the retreating Vashon ice margin. The Sumas Stade is represented by Sumas Drift which has only been found in the eastern part of the Fraser Lowland. The drift consists of lodgment and flow tills, advance and recessional glaciofluvial deposits, and glaciolacustrine deposits. The Sumas Drift is bracketed by radiocarbon dates of 11 700 ± 150 and 11 300 ± 100 years BP (Armstrong, 1981)

2.2.3 Post-Glacial

The post-glacial is represented by Salish and Fraser River sediments

(Armstrong, 1984). Salish Sediments include all post-glacial terrestrial and marine sediments that were deposited when the sea level was within 15 m of the present sea level. They include lowland mountain stream sediments, lacustrine, eolian, colluvial, slide, beach, and bog deposits. Fraser River Sediments represent sediments deposited by the Fraser River from the time of the initiation of the Fraser Delta, some 9000 years ago, until present. The sediments include distributary, floodplain, and deltaic deposits. Salish and Fraser River sediments have associated radiocarbon dates ranging from 12 350 ± 190 to modern (Armstrong, 1981, 1984).

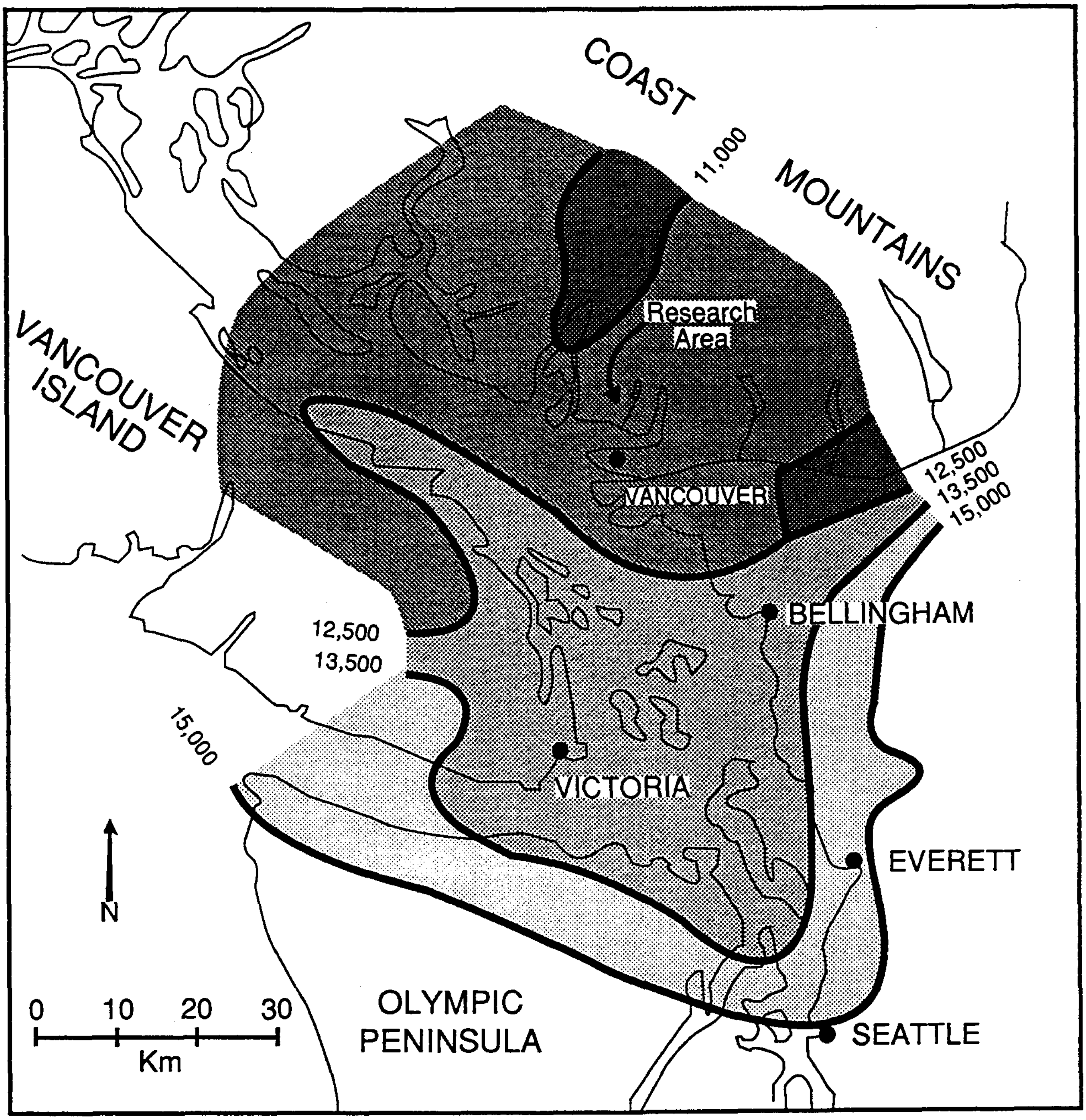


Figure 2.3 Retreat of the Fraser ice sheet between 15 000 and 11 000 years BP (after Armstrong, 1990)

2.3 Sea Levels and Crustal Movements

Glacial cycles invariably are accompanied by isostatic and eustatic variations in sea-level. The isostatic and eustatic processes may be considered interdependent. The relative post-glacial sea-level fluctuations in southwest British Columbia are complex and vary between the outer, middle, and inner coasts (Clague *et al.,* 1982). At the inner coast they consist of terrestrial submergences of up to 200 m at the time of retreat of the Vashon ice sheet at about 13 000 years BP. The submergence was followed by quick emergence, and by about 12 000 years BP the relative sea level was about 50 m above present sea-level. A short (~500 year) pre-Sumas submergence may have possibly occurred, followed by another quick emergence (Mathews *et al.,* 1970; Clague, 1975; Clague *et al.*, 1982; Armstrong, 1981). By about 8000 years BP sea-levels were about 12 m lower than present, and by about 3000 years BP the relative sea level was much like it is today (Williams and Roberts, 1989).

The initial post-Vashon submergence can be explained by positive eustatic sea level changes being greater than the rate of isostatic rebound. The pre-Sumas submergence, based on few radiocarbon dates, is problematic, but has been thought to be due to isostatic depression resulting from Sumas ice building up in the Coast Mountains (Mathews *et al.*, 1970). The following emergence and relative drop in sea level to about 12 m below present is thought to be due to glacial forbulge migration (Clark *et al.*, 1978; Clague *et al.*, 1982; Clague, 1983). Two sea level curves for the Fraser Lowland are presented in Figure 2.4.

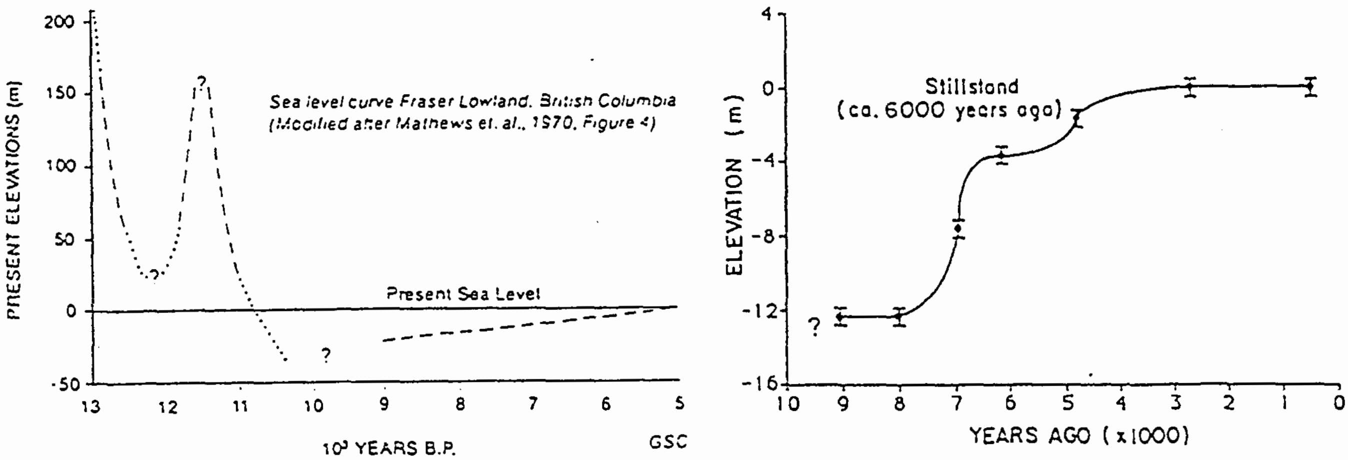


Figure 2.4 Sea level curves for the Fraser Lowland. The curve on the left is from Armstrong (1981), and the one on the right is from Williams and Roberts (1989). The curves are based on radiocarbon dates and stratigraphic relationships.

2.4 Previous Quaternary Research in and near Seymour Valley

The first published report on the Quaternary geology and geomorphology of the study area did not appear until 1918. Burwash (1918) described the lower Seymour Valley as one of the eight best "drift-sections" in the Vancouver area. Burwash's study was regional, and he therefore did not perform any detailed studies of the exposures in the valley. He does, however, present a stratigraphic section from a roadcut ~2 km west of the Seymour Valley and divides the sediments exposed there into Admiralty Drift, Admiralty Sediments, and Vashon Drift. Burwash also describes and discusses the raised terraces at the mouth of Seymour and Lynn canyons and attributes them to higher sea-levels following deglaciation. He also paid special attention to the lower bedrock canyons of the Seymour, Lynn and Capilano valleys and concluded, by noting their youthful appearance and relation to the surrounding topography, that they were Holocene in age. Johnston (1923), also mentions the raised deltas at the mouth of the Seymour Valley and more or less confirms what Burwash saw. Johnston also describes the bedrock canyons at the mouth of the Seymour, Lynn, and Capilano valleys and once again comes to the same conclusion as Burwash.

Armstrong (1956), produced a surficial geology map, at a scale of 1:63 360, of the Vancouver area which included the Seymour Valley study area north to about 49°22'. Included in this map is a location, in the Seymour Valley, of fossil shells. The map shows the general location of glacial, glaciomarine, and interglacial deposits. Armstrong also states in his accompanying paper that "Seymour [Westlynn] group sediments are exposed in the valleys of Capilano, Seymour, and Lynn creeks...". He also states that "Quadra [Cowichan Head?] interglacial deposits" are found in these valleys, and that "peat and wood were observed in these sediments". Later maps by Armstrong (Armstrong and Hicock, 1980b; Armstrong, 1984) show that no additional work had been done in the Seymour Valley.

At least four fossil shell locations in the study area were documented by Wagner (1959) and are probably the same locations appearing on a later map by

Armstrong (1981; p.19). Wagner's study was to interpret the ecological conditions of the non-glacial intervals.

At least four radiocarbon dates have been produced from an exposure of the Cowichan Head Formation in the neighbouring Lynn Canyon area of Lynn Valley. The dates range from 33 000 ± 620 to 47 000 ± 1100 years BP (Fulton, 1971; Lowdon and Blake, 1981; Armstrong *et al.*, 1985; Armstrong, 1990). Thermoluminescence dating of fine-grained (4-11 μm) sediments extracted from peat, at a position corresponding to a radiocarbon age of 34 900 ± 810 (GSC-2873) years BP, yeilded an apparent TL age of 25 ± 4 ka [~21 ka BP] (Divigalpitiya, 1982; Huntley *et al.*, 1983).

A parastratotype for the Highbury Sediments was defined by Hicock and Armstrong (1983) at a road cut along the Upper Levels Highway at Westlynn (east bank of the Upper Levels highway, 1.5 km northwest of the north end of the Second Narrows Bridge). Westlynn Drift (Armstrong, 1975) and the Cowichan Head Formation (Armstrong and Clague, 1977) are also believed to appear at this location. Wood from Highbury Sediments at this parastratotype was radiocarbon dated at >54 000 and >52 000 years BP, while wood from the Cowichan Head Formation was radiocarbon dated at 32 200 ± 3300 years BP (Hicock and Armstrong, 1983).

A brief study on the use of remote sensing techniques in detecting the differences between subsurface glacial and outwash deposits was completed by Joyce (1976). Three sites were studied in the Seymour watershed. His concern was with detection, not interpretation of the deposits studied.

A geologic field trip guide for the Lynn Valley-Seymour area was produced by Maynard (1977). A few geologic sections (exposures) were measured and mapped, mostly in the adjacent Lynn Valley. Maynard (1978) also produced an M.Sc. thesis concerned with the geomorphic constraints to urban residential development in the Seymour area. His research spanned the area between Lynn Creek and Deep Cove, north to about 49°20'. Although a number of geologic sections along the lower reaches of Seymour River and Lynn Creek were logged and stratigraphically interpreted, his main concern was with relating surficial deposits to possible urban use, rather than to the Quaternary history of his study area, or the Fraser Lowland.

Numerous bore-holes have been drilled for the Geological Survey of Canada, many of which were in the lower (south of the Hydro power line) Seymour Valley and surrounding area. The data from the boreholes are kept in the Vancouver Subsurface Data Bank (Belanger and Harrison, 1976), a GSC Open File. The borehole data give limited information on texture and distance to bedrock, and generally is poor. The borehole logs do, however, on occasion, note the presence of till and shells. The borehole data for the lower Seymour Valley have been compiled by Maynard (1978).

CHAPTER 3

METHODOLOGY

3.1 General Methodology

In order to construct a comprehensive lithostratigraphic history of the Seymour Valley the following procedure was followed:

1. Before the study could proceed, a sufficient number of exposures had to be located. This was done by exploring virtually all the tributaries of the Seymour River (within the study area) and noting the location of any exposures (sections) believed to be relevant.

Because of a sufficient number of natural exposures, the less-reliable borehole data from the GSC Subsurface Data Bank (Belanger and Harrison, 1976) were not used; one exception was when depth to bedrock was estimated at the east bank of the Seymour River during the construction of a valley cross-sectional diagram (see Figure 4.3a).

2. Relevant sections were then logged in terms of the following sediment properties:

- Texture and structure
- Type of contact and thickness of unit
- The presence of organics
- The presence of littoral deposits and fossil shells

3. Individual measured sections were then divided into lithostratigraphic units based on stratigraphic relation, appearance (depositional environment).

4. Using extensive radiocarbon dating, measured sections were correlated within the study area, thus building up the late Quaternary lithostratigraphic history for the valley.

3.2 Measured Sections

Elevations were measured using a Thommen type 335.01.02 altimeter in conjunction with a series of Greater Vancouver Water District (GVWD) benchmarks located throughout the study area. The benchmarks are discussed in detail in Appendix D. Where no nearby benchmarks were available, secondary benchmarks based on the closest GVWD benchmark were established. The altimeter was generally used to establish the elevation above sea-level of the top of the sections, a 30 m measuring tape was then used to measure the section. Where sections were too vertically large or irregular to efficiently make use the tape measure, the altimeter was used to find the elevations of the relevant contacts. All elevations recorded using the altimeter were repeated several times over the course of the field season. From these repeated measurement an uncertainty of ± 1.5 m may be associated with each elevation measurement.

3.2.1 Texture and Structure

Because this research is concerned with the stratigraphy and chronology of the surficial deposits in the study area, and not the sedimentology *per se*, a detailed quantitative study of texture was not undertaken. Rather, sediments were described as either fine, medium, or coarse sand, silt and/or clay etc. using the particle size classification of Wentworth (1922) (Table 3.1); textural analysis was performed qualitatively in the field using an American/Canadian Stratigraphic field card (see Miall, 1990; p.27).

Table 3.1 Particle Size Classification

> 256 mm	boulder gravel
256 to 64 mm	cobble gravel
64 to 2 mm	pebble gravel
2000 to 500 μm	coarse sand
500 to 250 μm	medium sand
250 to 62 μm	fine sand
62 to 2 μm	silt
< 2μm	clay

Structure was noted wherever possible. The presence or lack of structure such as bedding, faults, loading structures, ripple marks, etc. was essential in determining the process by which the unit in question was formed.

3.2.2 Fabric

Although the study of fabric can be essential in determining the direction of ice flow (see, for example, Roberts and Mark, 1970), it was thought that quantitative fabric analysis in the Seymour Valley would not be an efficient use of time since the flow direction of ice in the study area would have been constrained by the valley walls.

The use of fabric analysis to distinguish till from glaciomarine sediments was not thought be an effective use of time in this study. This decision is supported by the fact that fabric studies performed by Hicock (1976) in the Coquitlam Valley to distinguish till from glaciomarine sediments were inconclusive. The presence, or lack of, glaciomarine sediments therefore, was determined using the characteristics presented in Armstrong (1981, p.18).

Fabric analysis therefore, was restricted to a qualitative description, including the presence or lack of imbrication.

3.2.3 Contact and Thickness

Contacts between units were classified as gradational or sharp. Sharp contacts represent intervals of erosion or non-deposition (unconformities), or an abrupt change in the depositional environment (energy). While intervals of non-deposition are virtually impossible to deduce, intervals of erosion may be distinguished by, for example, abruptness of contact in association with "rip-up" or incorporation of sediment from the underlying unit. Gradational (conformable) contacts represent periods of continuous deposition, and are found where two units grade into each other.

3.2.4 The Presence of Organics.

The Presence of organic material is important in determining both the radiocarbon age of the unit in question, and the climatic environment (i.e. glacial or non-glacial) in which the unit was deposited.

3.2.5 The Presence of Littoral Deposits and Fossil Shells

The Presence of littoral deposits and fossil shells were used to define areas of former marine incursion. Since littoral deposits are difficult to distinguish from fluvial deposits, their presence was confirmed only in association with a related landform, for example a marine terrace.

3.3 Geochronology

The geologic and geomorphic history of the valley was developed using radiocarbon dating of organic material and more limited thermoluminescence (TL) dating of sediments. All dates appearing in Table 5.1 are new, and therefore are an addition to those already existing in the literature.

3.3.1 Radiocarbon dating

An inherent problem associated with radiocarbon dating of geologic deposits is that the age one obtains is that of the time of death of the organic material being dated, which is not necessarily the time of deposition of the geologic unit in question. There is always a chance that what is being sampled has been reworked from an older unit. Whenever possible, samples concentrated at one stratigraphic position, or in association with organic rich sediments (eg. a buried or reworked soil) were selected. In addition, the size and shape of the sample was an important factor in the selection process; the larger the sample, the smaller the chance of it being reworked, at least over the course of a glaciation. Sampling rounded or abraded wood was also avoided. Rounded or abraded wood suggests transport over long time periods and/or distances.

Radiocarbon analysis was done at Beta Analytic Incorporated and the Geological Survey of Canada (GSC) Radiocarbon Dating Laboratory. Beta Analytic was chosen for their reliability and quick turn around time. This allowed for the opportunity to re-sample some of the stratigraphic units for confirmation.

Radiocarbon samples from what was thought to be the oldest exposed unit in the study area (informally dated at >32 000 years BP at the Simon Fraser University Radiocarbon Laboratory, Department of Archaeology) were submitted to the GSC laboratory for high pressure counting. The high pressure technique extends the radiocarbon dating limit to about 54 000 years (Lowdon, 1985).

3.3.2 Thermoluminescence dating

Based on the success of Divigalpitiya (1982) in dating sediments extracted from peats in the neighbouring Lynn Valley, two samples of sediment-rich peat were collected for TL dating from what was thought to be the oldest exposed unit in the study area (see above). This was done for two reasons. (1) In the event that the GSC high pressure radiocarbon dates gave infinite results, the TL dates would be able to, at least, determine which non-glacial interval the unit represents. (2) In the event that the GSC high pressure radiocarbon dates turned out to be finite, the TL dates would be valuable for comparison, and favourable results would justify using the technique for dating sediments from units beyond the radiocarbon limit, should any be found during the course of this research.

TL dating of sediments is, at present, still in its infancy and therefore any TL dates quoted in research require a detailed discussion of experimental procedure and results. Such a discussion appears in Appendix A.

3.4 Mapping

Maps of the surfical sediments and cross-sectional diagrams showing the sub-surface stratigraphy were constructed using a series of aerial photographs and a series of topographic maps (tables 3.2 and 3.3).

Table 3.2 Aerial photographs used in this research.

Flight Line		Year Flown	Scale
BC5059	216-218		
BC5059	238-240		
BC5060	16-18		
BC5060	66-68	1963	1:12 674
BC5060	93-95		
BC5060	143-145		
BC5236	166-173	1967	1:29 435
BC87066	77-78		
BC87066	105-106		
BC87066	139-141	1987	1:17 892
BC87066	203-204		
BC87066	223-224		
BC87066	257-258		

Table 3.3 Topographic maps used in this research.

Map	Scale
NTS series 92G6/E (North Vancouver)	1:50 000
NTS series 92G7/W (Port Coquitlam)	1:50 000
GVRD map WG-625 (Seymour Demonstration Forest)	1:5000

CHAPTER 4

THE LITHOSTRATIGRAPHY OF LOWER SEYMOUR VALLEY

4.1 Introduction

Over 30 sections were measured in the study area (coded **SVMS** = Seymour **V**alley **M**easured **S**ection). The locations of the measured sections along the longitudinal profile of Seymour River are presented in Figure 4.2. Measured sections believed to represent the general lithostratigraphy of the study area, a subset of those in Figure 4.2, are presented schematically in Figure 4.3. The general valley-stratigraphy also is represented in association with composite valley cross-sections at different localities in the study area (Fig. 4.4). The location of *all* the measured sections can be found in Figure 4.1 and in Appendix B. Descriptions and interpretation of measured sections not appearing in Figure 4.3 can be found in Appendix C.

All of the measured sections appearing in Figure 4.3 have been coded using a lithofacies coding scheme based on that of Miall (1977, 1978) and Eyles *et al.* (1983). The lithofacies code is presented below in Table 4.1. A list of radiocarbon dates can be found in Table 5.1.

Table 4.1 Lithofacies Code used in Figure 4.3

	<u>Primary Classification</u>
D	Diamict
G	Gravel
S	Sand
F	Fines
	<u>Secondary Classification</u>
Dcm	Clast supported massive diamict
Dmm	Matrix supported massive diamict
Dmm(r)	Dmm with evidence of resedimentation
Dms	Matrix supported stratified diamict
Dmg	Matrix supported graded diamict
Gcm	Clast supported massive or crudely stratified gravel
Gmm	Matrix supported massive gravel
Gcs	Clast supported stratified gravel
Gcp	Clast supported gravel with planar cross-stratification
Sm/Fm	Massive sand/fines
Sh/Sp	Horizontally stratified sand/Planar cross-stratified sand
S-d/F-d	Sand/fines with dropstones
Fl	Laminated fines
OR	Organics

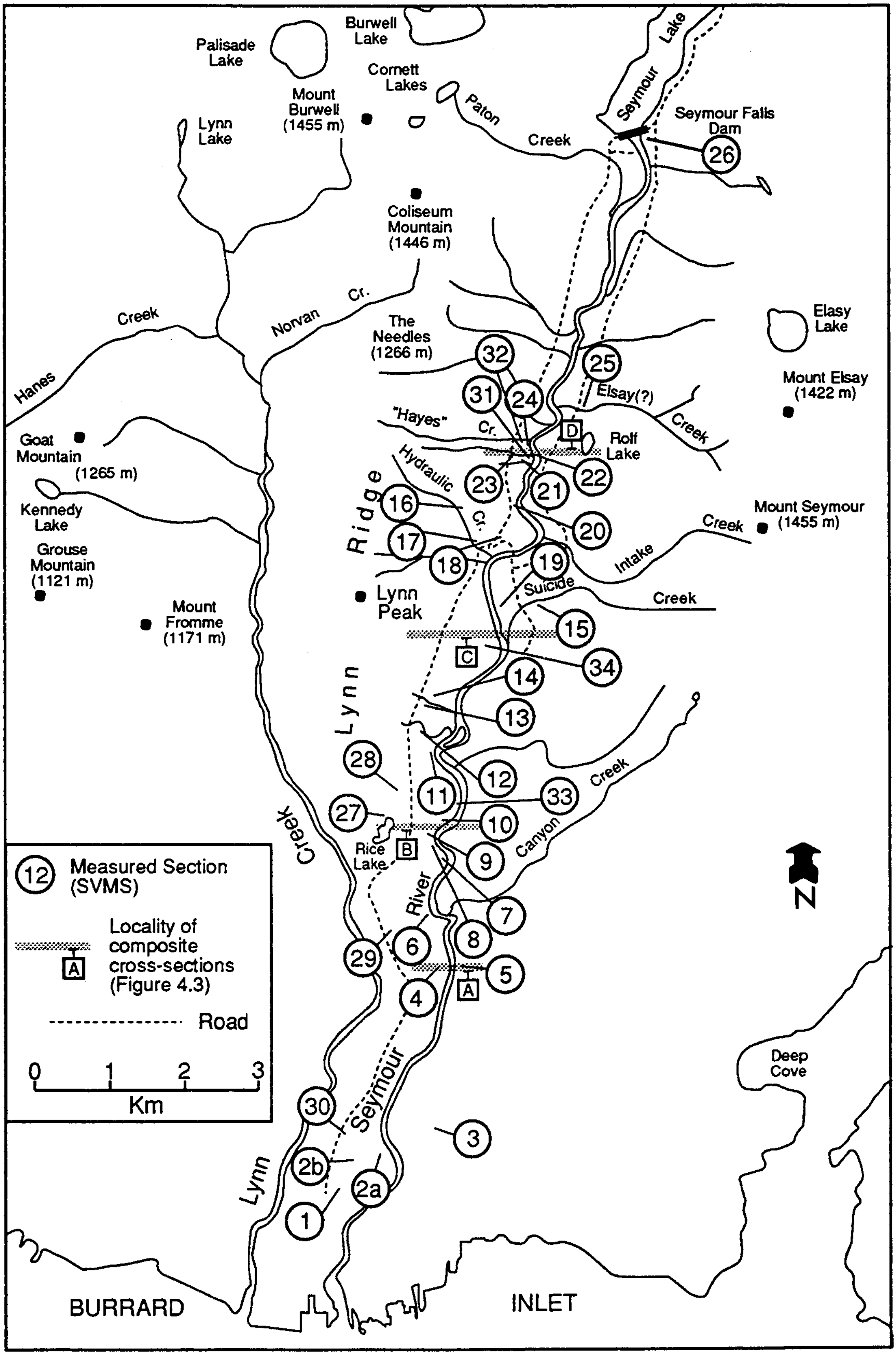
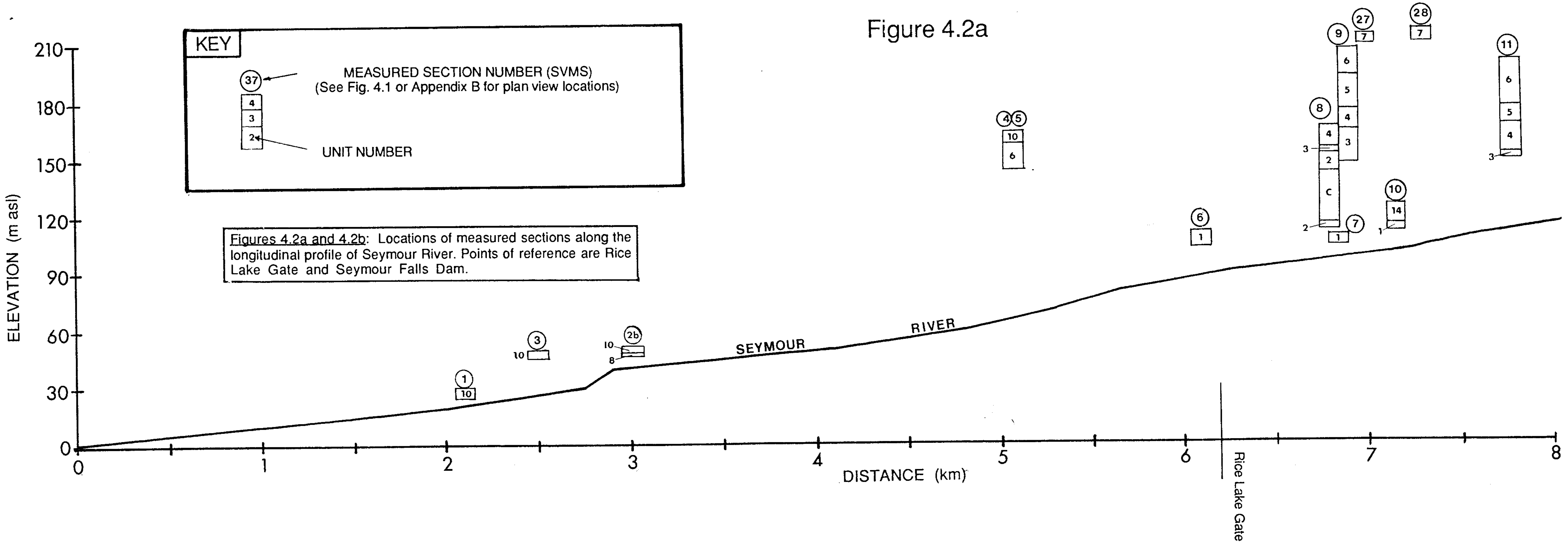


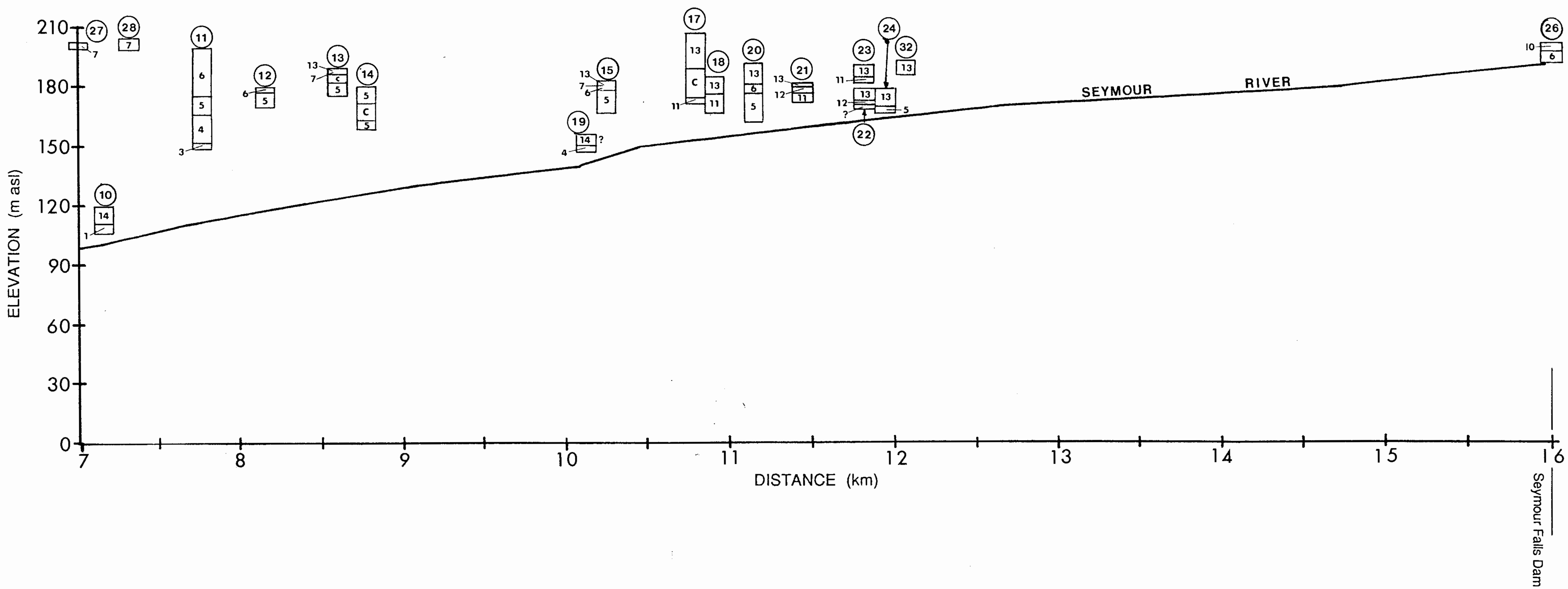
Figure 4.1 Locations of measured sections and composite cross-sections. See Appendix B for large-scale location maps.

Figure 4.2a



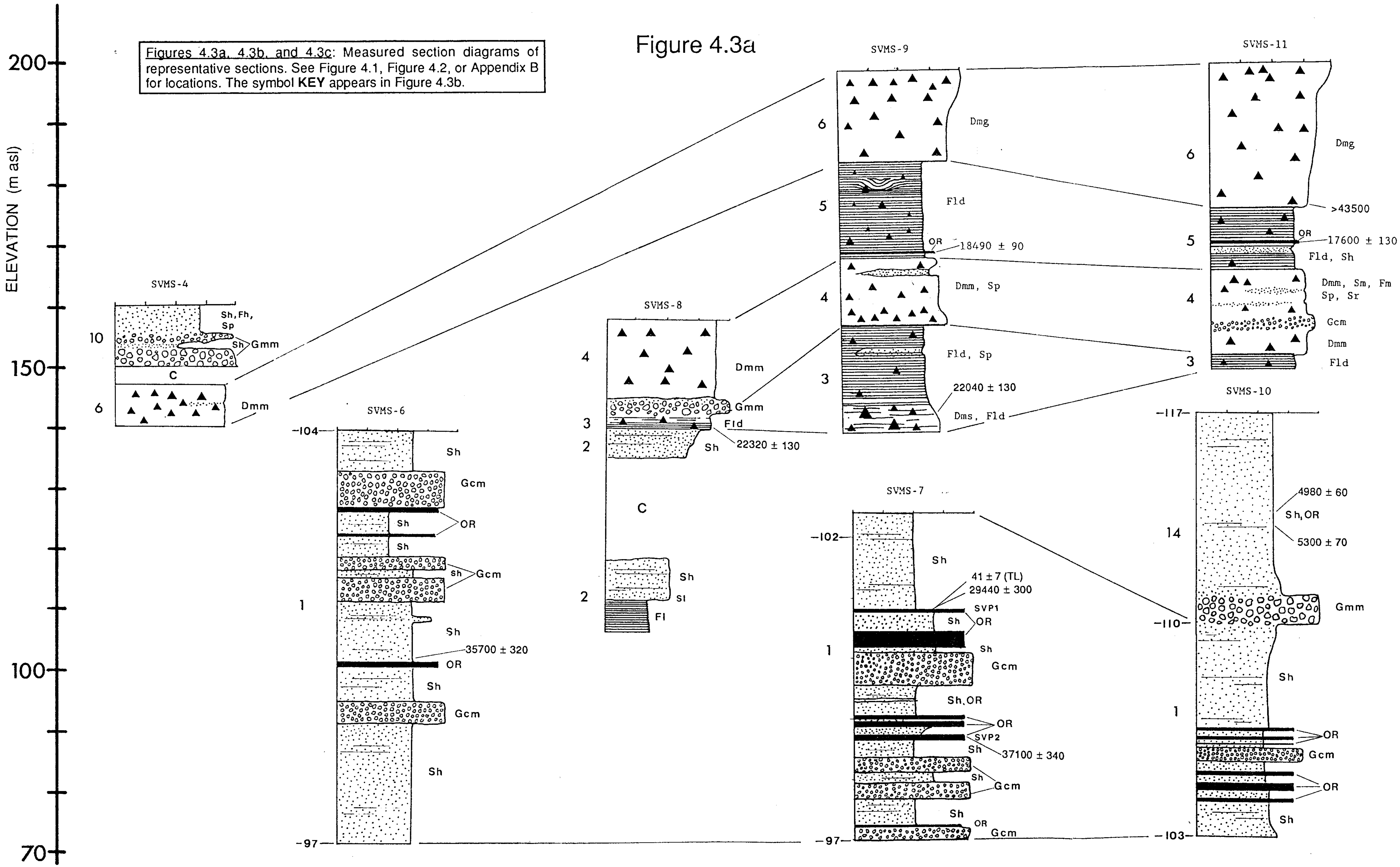
Figures 4.2a and 4.2b: Locations of measured sections along the longitudinal profile of Seymour River. Points of reference are Rice Lake Gate and Seymour Falls Dam.

Figure 4.2b


ELEVATION (m asl)
DISTANCE (km)
SEYMOUR RIVER
Seymour Falls Dam
0
30
60
90
120
150
180
210
7
8
9
10
11
12
13
14
15
16

Figures 4.3a, 4.3b, and 4.3c: Measured section diagrams of representative sections. See Figure 4.1, Figure 4.2, or Appendix B for locations. The symbol **KEY** appears in Figure 4.3b.

Figure 4.3a



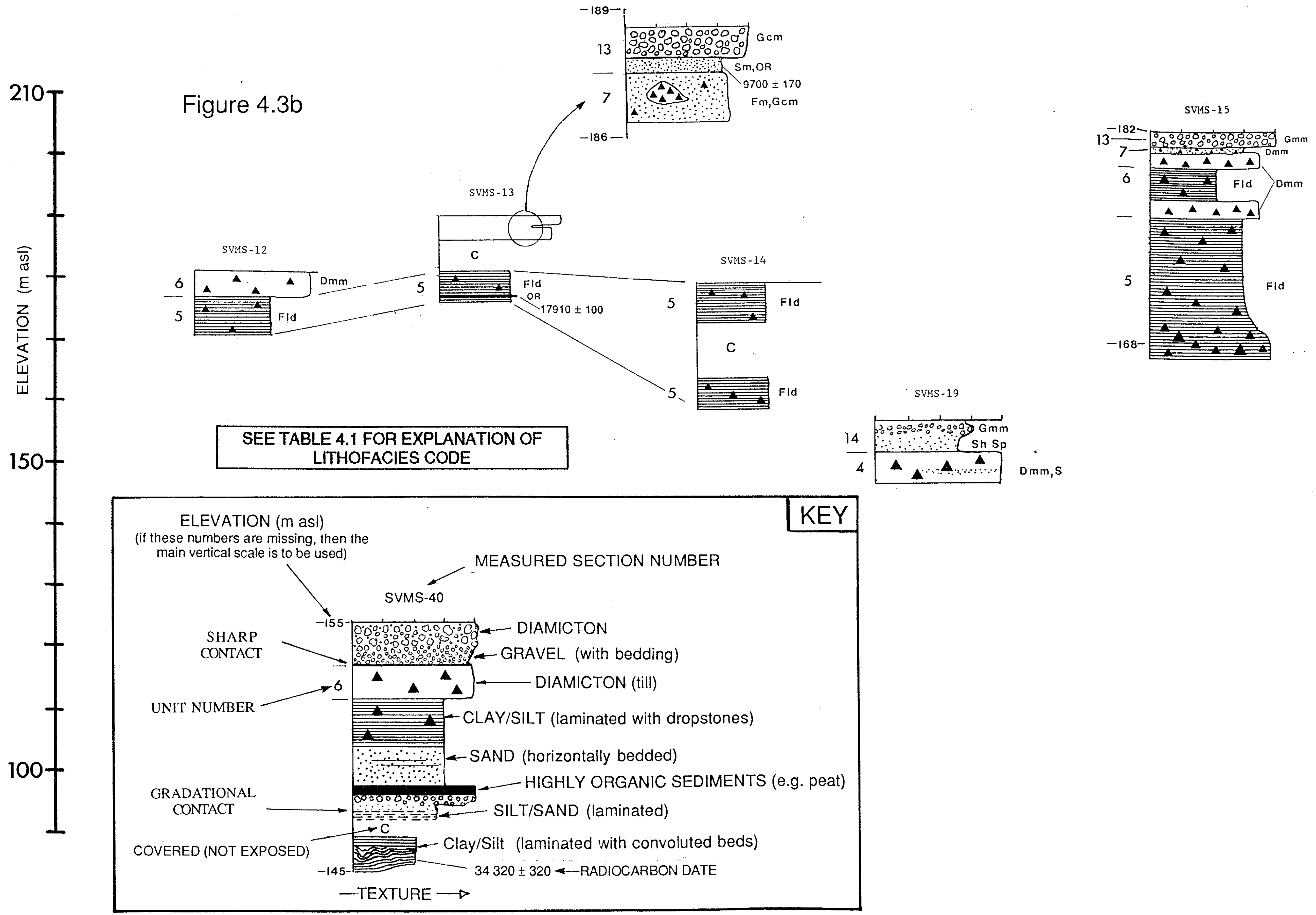
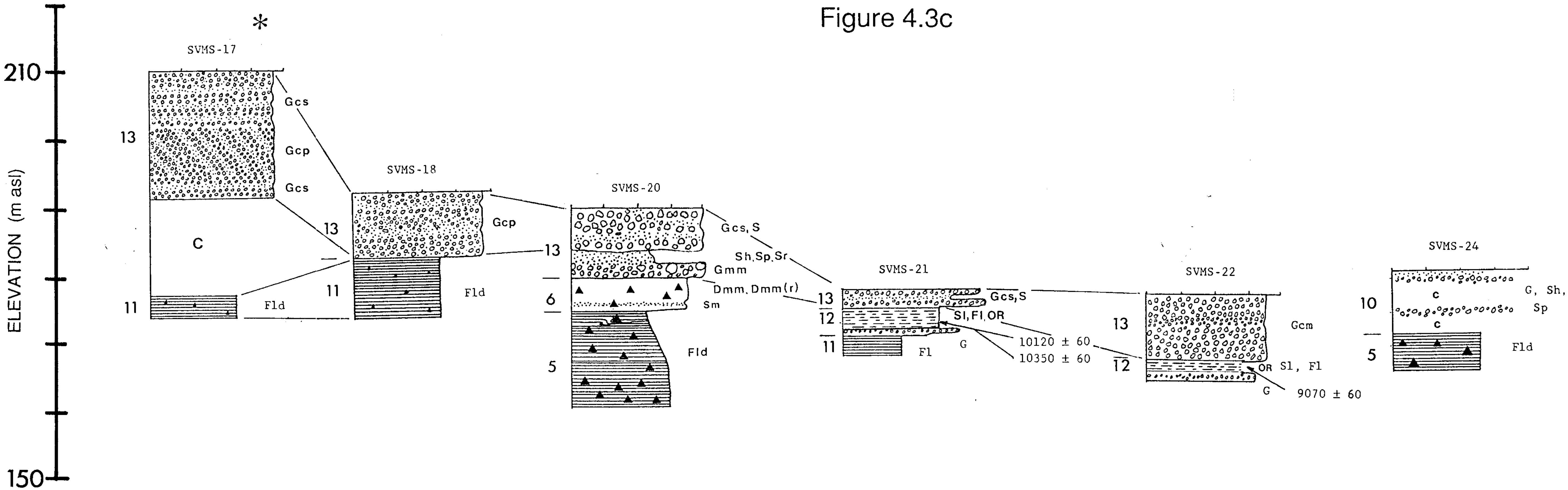


Figure 4.3b
ELEVATION (m asl)
210
150
100
SEE TABLE 4.1 FOR EXPLANATION OF LITHOFACIES CODE
SVMS-12
6 Dmm
5 Fld
SVMS-13
C
5 Fld
OR
17910 ± 100
-189-
13 Gcm
Sm,OR
7
9700 ± 170
Fm,Gcm
-186-
SVMS-14
5 Fld
C
5 Fld
SVMS-19
14 Gmm
Sh Sp
4 Dmm,S
SVMS-15
-182-
13 Gmm
7 Dmm
6 Fld Dmm
5 Fld
-168-
KEY
ELEVATION (m asl)
(if these numbers are missing, then the main vertical scale is to be used)
MEASURED SECTION NUMBER
SVMS-40
-155-
SHARP CONTACT
DIAMICTON
GRAVEL (with bedding)
UNIT NUMBER
6
DIAMICTON (till)
CLAY/SILT (laminated with dropstones)
SAND (horizontally bedded)
HIGHLY ORGANIC SEDIMENTS (e.g. peat)
GRADATIONAL CONTACT
SILT/SAND (laminated)
C
COVERED (NOT EXPOSED)
Clay/Silt (laminated with convoluted beds)
-145-
34 320 ± 320 ← RADIOCARBON DATE
TEXTURE

Figure 4.3c



* This is a composite section. Unit-11 is referred to as SVMS-17b in Appendix B.

4.2 Lithostratigraphic Units of the Seymour Valley - Descriptions and Interpretations

Unit 1 is composed of three facies: (1) weakly stratified, compact, subrounded pebble gravel, (2) horizontally bedded sands and silts with occasional disseminated organics, and (3) highly compressed woody peat beds up to 20 cm thick.

The unit shows a repeating general upward fining from pebble gravel, through coarse sand to silt with organic stringers, and then to peat. In places, beds of disseminated organics are separated only by upward coarsening sands and silt. At SVMS-7 (Figs. 4.5a and b), seven distinct peat beds separated by fluvial sands and gravel occur in ~5 m of exposure.

A continuous bed of buried wood (~100 m asl) was found within disseminated organics, and directly below a woody peat bed at SVMS-6. A radiocarbon date on a 5 cm diameter log (*Picea* sp.) from this bed gave an age of 35 700 ± 320 (GSC-5069 HP) years BP. A radiocarbon date from a piece of wood (*Abies* sp.) from SVMS-7 (~99 m asl) gave an age of 37 100 ± 340 (GSC-5121 HP) years BP, while a radiocarbon date of 29 440 ± 300 (Beta-46053) years BP was obtained directly from peat at ~101 m asl. The radiocarbon dates show, therefore, that ~2 m of deposition occurred over a time span of about 7.7 ka. Thermoluminescence (TL) dating analysis of sediments extracted from within peat were attempted at two stratigraphic positions, SVP1 and SVP2, the location of radiocarbon dates Beta-46053 and GSC-5121HP (see above), respectively. SVP1 gave a supportive TL age of 41 ± 7 ka, while the results from SVP2 were inconclusive. A detailed discussion of the TL analysis can be found in Appendix A.

Unit 1 likely represents floodplain-swamp and (overbank?) fluvial deposits (gravels and sands) laid down in an aggradational environment. The nearly massive nature of the gravel beds suggests rapid deposition. This is supported by sharp contacts between the gravels and underlying sands; in other words, there was a substantial and abrupt change in fluvial energy prior to and following the deposition of the gravels. Each organic bed, therefore, appears to represent a recovery of floodplain vegetation following a major aggradational (flood?) event. The horizontally bedded sands would therefore represent relatively low-magnitude flood events.

The time spanned by the radiocabon dates from this unit suggest a very slow rate of aggradation where each gravel bed represents an event of greater magnitude than the previous.

Unit 2, exposed only at SVMS-8, is mostly covered with debris and/or vegetation. Exposures are limited to the upper 5 m, and to about 6 m near its base (see Fig. 4.3a). The lower 6 m consists of finely laminated clayey silt conformably(?) overlain by horizontally bedded medium sands. The upper 5 m consists of horizontally bedded, generally upward coarsening, fine to coarse sand with some gravel beds. No organic material could be found in these deposits.

Although the contact with Unit 1 cannot be observed, it is thought, due to proximity, that this unit directly overlies Unit 1 at SVMS-6, SVMS-7 and SVMS-10.

Unit 2 can only be interpreted from limited exposure, but appears to be composed of fluvial sands and gravels (upper 5 m) and lacustrine clayey silt and sand (lower 6 m).

The lacustrine sediments near the base of the unit suggest that a lake once existed here. A lack of dropstones suggests the damming was caused by sediments rather than ice. The upward coarsening of the sediments at the top of the unit suggests increasing fluvial competence.

Radiocarbon dates from directly under and overlying sediments indicate that this unit was deposited between approximately 29 and 22 ka BP.

Unit 3 is generally composed of laminated blue-gray clayey silt with a relatively high concentration of dropstones (subrounded to rounded) reaching 50 cm in diameter. The unit also contains isolated beds of coarse to medium sand. The sediments are extremely compact and wood is found near the base of the unit.

Structure is initially weak, but becomes increasingly well defined (laminated) with elevation. The unit is best observed at SVMS-9.

At SVMS-8, a 50 x 20 cm piece of wood gave a radiocarbon date of 22 320 ± 130 (Beta-40686) years BP. At SVMS-9, a slice of wood from the trunk (8 cm dia.) of what appeared to be a complete tree, gave a radiocarbon date of 22 040 ± 130 (Beta-38909) years BP.

The sediments are interpreted as glaciolacustrine. The high concentration of dropstones along with poor structure at the base of the unit suggests, perhaps, a shallow ice-proximal lake that eventually deepened as a result of better damming.

Unit 4, at SVMS-9, is generally composed of a massive matrix-supported diamicton. The clasts are generally subrounded and nearly all are plutonic. The clasts range in size from about 5 to 10 cm in diameter, and are more concentrated near the base of the unit. Occasional beds of horizontally and crossbedded sands become more concentrated near the top of the unit.

At SVMS-11, however, the sediments of this unit are more complex; only the lower 2-3 m of this unit resemble the Unit 4 sediments at SVMS-9. The sediments generally consist of a massive clayey silt matrix supporting pebble sized clasts. Included are beds of massive silt containing no clasts, beds of compact diamicton, and beds of horizontally and crossbedded medium to coarse sand. Till beds with flow structure are common, as are tills that have been injected into surrounding sediments. A thick (~3 m) bed of cobble lag deposits is found near the base of the unit. The contacts between the fluvial beds and surrounding glacial sediments are sharp.

These sediments are interpreted as a glacigenic diamict. The contrast between the Unit 4 sediments at SVMS-9 (lodgement till?) and SVMS-11 (mostly flow till) (see Figs. 4.8a and b) suggests that deposition was into water at SVMS-11, while onto land at SVMS-9. The increasing number of fluvial sand beds with elevation, at both exposures, suggests, perhaps, an increase in meltwater.

The shape of the clasts (subrounded) suggests that they were not transported over a long distance. Rather, it appears that the clasts were reworked from fluvial deposits from within Seymour Valley. This is supported by their lithology (virtually all plutonic), i.e. a nonlocal ice source might be expected to deposit drift of a more varied lithology.

Unit 5 consists of laminated silty clay with relatively few dropstones. The laminations become extremely convoluted at about 190 m asl. The dropstones in this unit are of a more varied lithology, compared with the clasts in units 2 and 3, which have a small proportion of volcanic clasts. The volcanic clasts, in general, are more angular (angular to subrounded) than the plutonic clasts.

Included in this unit is a single 10 to 20 cm thick highly organic bed containing small pieces of wood, charcoal and occasional leaf imprints (Fig. 4.6). The organic bed, itself, is only weakly structured, sometimes showing a higher concentration of organic material at the surface. No evidence of soil development (soil horizons) was observed. The organic bed can be traced along the valley for ~ 3 km at an almost constant elevation of about 175 m asl. Directly overlying this bed at SVMS-9 and SVMS-11, are numerous buried trees, the largest being about 50 cm in diameter. All of the buried trees observed were within ~1 m of the organic bed, most within 50 cm. A 10 cm diameter log from just above the organic bed, at SVMS-8, gave a radiocarbon date of 18 490 ± 90 (Beta-38908) years BP, while a 50 cm diameter log from SVMS-11 yielded a radiocarbon date of 17 600 ± 130 (Beta-38907) years BP. A wood fragment (~20 cm long, 1 cm dia.) in contact with the organic bed, at SVMS-13, produced a radiocarbon date of 17 910 ± 100 (Beta-40689) years BP.

Unit 5 represents a glaciolacustrine environment. The presence of angular volcanic dropstones indicate that the ice supplying them originated further north, beyond the Seymour River headwaters. The relative scarcity of dropstones suggests a distal ice source during the deposition of these sediments.

The presence of the highly organic bed directly below numerous buried trees, near the base of this unit, suggests a major climatic recovery subsequent to the initial advance and apparent retreat of the ice. The radiocarbon dates indicate that a substantial forest had been established by about 18 ka BP.

The organic bed probably is probably derived from a soil that had developed on higher ground (floodplain) subsequent to the retreat of the ice. As the water-level rose in response to the readvancing ice, the soil would have been reworked and deposited in the lake.

Unit 6 is a compact matrix supported diamicton displaying fissility, and occasional glaciotectonic structures. The matrix ranges from clayey silt to fine sand and silt. Included in the diamicton are beds of medium to coarse sand. Clasts in this unit are generally subrounded; no clasts showing obvious stria were found.

At SVMS-11, two small rounded fragments of wood (total mass ~20 g) found in contact with each other, in a sand bed, a few centimeters above the contact with Unit 5, yielded a radiocarbon date of >43 500 (Beta-38910) years BP.

Unit 6 is interpreted as a glacigenic diamicton (till). The lack of striated clasts suggests these sediments were reworked from glaciofluvial and fluvial outwash material deposited during the 18 ka BP interstade. The unit is bracketed by radiocarbon dates of 17 600 ± 130 (at SVMS-11) and 11 420 ± 110 (alluvial fan, SVMS-25) years BP. The date of >43 500 years BP obtained from two wood fragments at SVMS-11 is thought to be from reworked material. This is supported by the size and shape of the samples, and by the fact that no other organic material was observed at this stratigraphic position throughout the study area.

Unit 7 is composed of a complex assortment of sediments apparently representing various modes of deposition. The appearance of the unit may vary greatly over distances of only a few meters. Clasts of compact diamicton (till?)

supported by stratified sands are common, as are clasts of sands and silt (often having retained their internal structure) supported by more compact massive pebble gravels. Beds may be extremely convoluted, and sometimes are positioned vertically. Plutonic and volcanic clasts (up to ~ 1 m diameter) supported by a variety of matrices are also common, as are beds of laminated silt and clay showing glaciotectonic features. These sediments are exposed immediately north of Rice Lake in roadcuts. Here sediments were apparently deposited subaqueously in a plastic state (see Fig. 4.7a). Additional exposures of these sediments are found in roadcuts along Seymour Mainline.

Unit 7 clearly represents sediments associated with recession and wasting of ice. The appearance of this unit varies greatly from place to place. It may however, generally be interpreted as ablation till (flow till and melt-out till). For detailed discussions about the genesis of these types of deposits see, for example, Boulton (1972); Halderson and Shaw (1982); Shaw (1982); Krainer and Poscher (1990); Brodzikowski and Van Loon (1991). Where these sediments are exposed north of Rice Lake the topography is hummocky suggesting meltout in a supraglacial lake, rather than in a marine environment where wave action would have eventually "smoothed" the landscape.

There are no radiocarbon dates directly associated with this unit. At SVMS-10, however, a radiocarbon date from charcoal fragments extracted from sediments directly overlying this unit shows that it was deposited more than 9700 years BP.

Unit 8 is composed of massive stoney clay, sometimes interbedded with sand or pebble gravel. The clay is not compact and can easily be carved with a trowel when wet. The stones contained within the clay have diameters of less than 1 cm. These deposits have only been found in the lower portions of the study area (limited exposures at SVMS-2a and SVMS-2b).

Unit 8 is interpreted as a glaciomarine clay. This is supported by its lack of structure and low density. The presence of relatively few (small) dropstones suggests deposition in association with a distal ice source. No organic material has been found within this deposit and therefore no radiocarbon dates are available.

Unit 9 consists of horizontally and cross bedded sands and gravels. These deposits are found in exposures south of Rice Lake Gate. At SVMS-29 and SVMS-30 the sediments consist of well rounded and sorted pebble gravel interbedded with sand, exposing the upper surface of marine terraces. Contact with underlying units was not observed.

The sediments at these exposures are interpreted as supralittoral gravel lag and sand. No organic material for radiocarbon dating could be found in these sediments.

Unit 10 consists of crossbedded sand and gravels. At the mouth of the valley (SVMS-1 and SVMS-3) these sediments form raised deltas with beds dipping in a general north-south or south-west direction at an angle of about 10 to 15°.

These deposits are interpreted as glaciolfluvial outwash sediments. Near the mouth of the valley these sediments were deposited as marine deltas at a time of higher sea level. No organic material for radiocarbon dating could be found in these sediments.

Unit 11 is composed of laminated clay and silty clay. The sediments contain few (only at SVMS-17) or no dropstones or visible organics. The deposits are unconformably overlain by deposits of units 13 and/or 14.

These sediments are interpreted as lacustrine. The absence, in most cases, of dropstones suggests that the sediments were deposited well away from the ice margin, while the absence of organic material indicates that the sediments were deposited soon after deglaciation.

Unit 12 is composed of organic rich, horizontally bedded sand and silt. At SVMS-21, at the contact with Unit 11, is a bed of gravel lag (Fig. 6.2a).

Two pieces of wood from the base of this unit, at SVMS-23, gave radiocarbon dates of 10 120 ± 60 (Beta-38911) and 10 350 ± 60 (Beta-38912) years BP. At SVMS-22, a log (10 cm dia.) gave a radiocarbon date of 9070 ± 60 (Beta-38913) years BP.

These sediments are interpreted a lacustrine. The presence of an underlying gravel lag at SVMS-21 suggests that these sediments were deposited, in this case, in an abandoned or dammed channel.

Unit 13 consists of matrix and clast supported diamicton (Fig. 6.2a). In some sections the sediments show bedding, while in other sections the sediments are massive. Imbrication is often observed, suggesting paleoflow roughly perpendicular to the valley axis. The sediments are extremely loose and can be pulled apart easily. The clasts generally are angular to subangular. At most of the exposures where this unit was observed, the diamicton is interbedded with weakly structured organic loamy sand containing pebbles and usually beds of charcoal fragments. At SVMS-17 and SVMS-18, however, the clasts are crossbedded, well sorted, and rounded to well rounded.

The deposits form aprons along the valley sides and alluvial fans (Fig. 4.10b) emanating from tributary valleys. Where the deposits form fans, the sediments are exposed at the banks of tributary streams which have incised into them. The deposits are (or were, before logging) generally covered with mature forest.

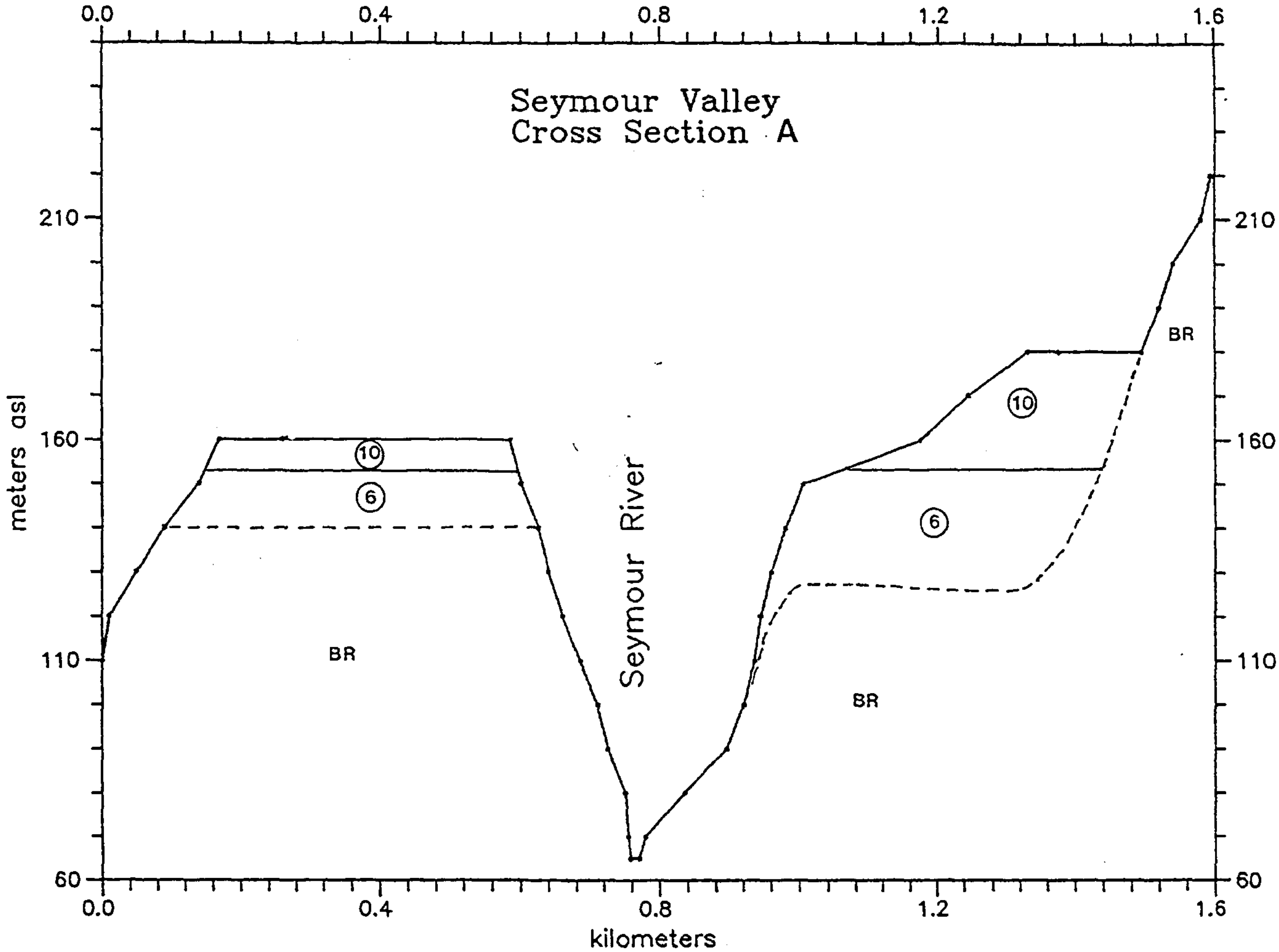
At SVMS-25 charcoal fragments from a sand bed contained within diamicton fan deposits (Fig. 6.2a) yielded a radiocarbon date of 11 420 ± 110 (Beta-40687) years BP, while at SVMS-13 charcoal fragments from similar sediments below the diamicton, gave a radiocarbon date of 9700 ± 170 (Beta-40690) years BP.

The sediments of Unit 13 are interpreted as paraglacial; that is, they are the result of the reworking of former glacial sediments subsequent to the retreat of the valley ice. The general shape of the clasts and the general lack large organic material (buried logs and sticks) indicate rapid deposition, probably in the form of debris flows or rapidly prograding alluvial fans. The organic sand beds are interpreted as mud flows separating debris flow events.

At SVMS-17 and SVMS-18, however, the roundness of the clasts suggests that these sediments were originally deposited in a fluvial environment, perhaps along the margin of the valley glacier. The presence of distinct crossbedding suggests that the sediments were redeposited relatively slowly in a fluvial environment. Therefore, they likely represent a fluvially reworked kame terrace. The gradational (conformable) contact between the Unit 13 gravels and the underlying Unit 11 lacustrine sediments, at SVMS-19, suggests that the gravels were deposited in water, possibly in a deltaic environment.

Unit 14 represents sediments deposited on an erosional terrace (Fig. 1.4) during post-glacial incision into the valley fill. The unit (exposed at SVMS-10) consists of ~1 m of boulder lag overlain by ~6 m of horizontally bedded silts and sands containing thin (<10 cm thick) beds of peat with wood. Two radiocarbon dates from wood extracted from within peat beds (~50 cm apart) 3 m above an underlying boulder lag bed yielded ages of 5300 ± 70 (Beta-40686) and 4980 ± 60 (Beta-46052) years BP. An additional piece of wood (bark) obtained from a freshly exposed bank of an incised tributary, ~2 m below the surface of the terrace in direct contact with a (the?) boulder lag bed (SVMS-33) gave an age of 140 ± 50 (Beta-43866) years BP.

The deposits of Unit 14 are interpreted as overbank deposits laid down in an aggradational environment. The 140 ± 50 years BP date is interpreted as being from modern material deposited as channel fill (see a description of this section in Appendix C), while the 5300 ± 70 and 4980 ± 60 dates are thought to represent a minimum age of the unit (there are no tributary streams, capable of transporting foreign material, incising the terrace at this location). The boulder lag, therefore, is thought to represent the position of the Seymour River at more than 5 ka BP.



Figures 4.4a, b, c, and d. Composite cross-sectional diagrams showing the stratigraphy of the Seymour Valley. The circled numbers represent the unit numbers. **BR** = bedrock; the heavy dashed line in Figure 4.3b shows the approximate position of the "18 Ka BP organic bed". The locality of each cross-section can be found in Figure 4.1. Solid lines represent observed contacts and the dashed lines show the observed extent of the unit in question.

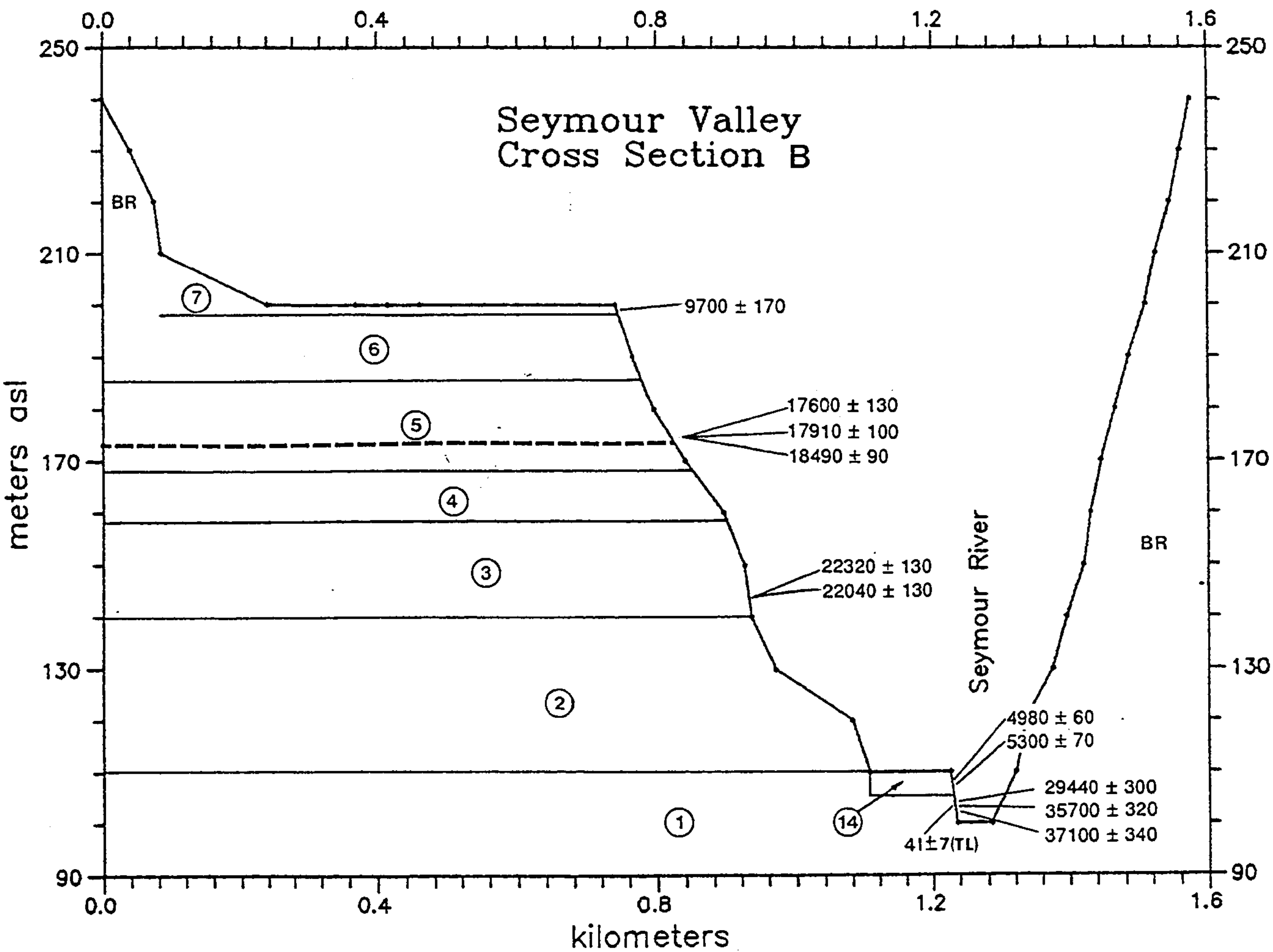
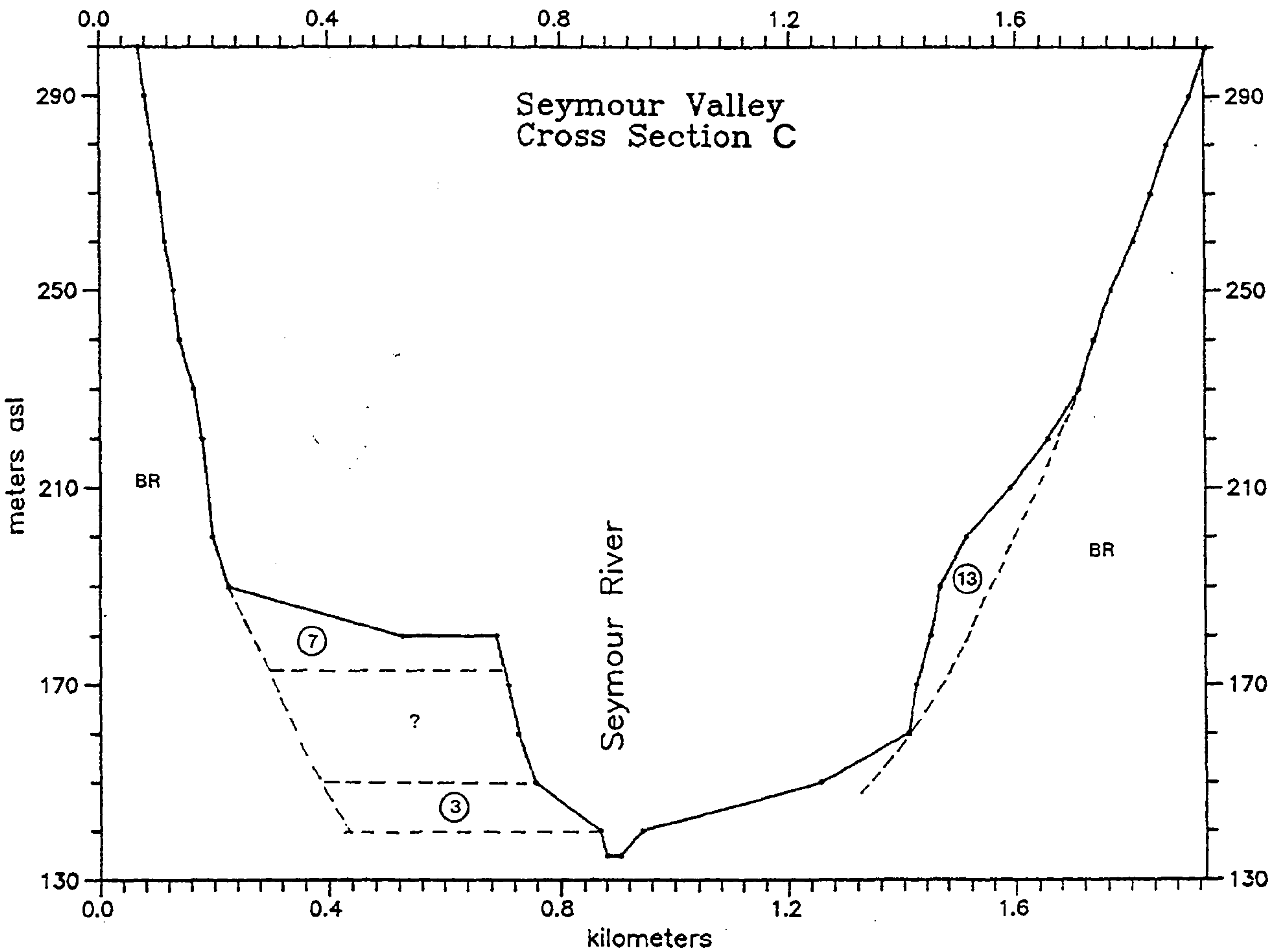
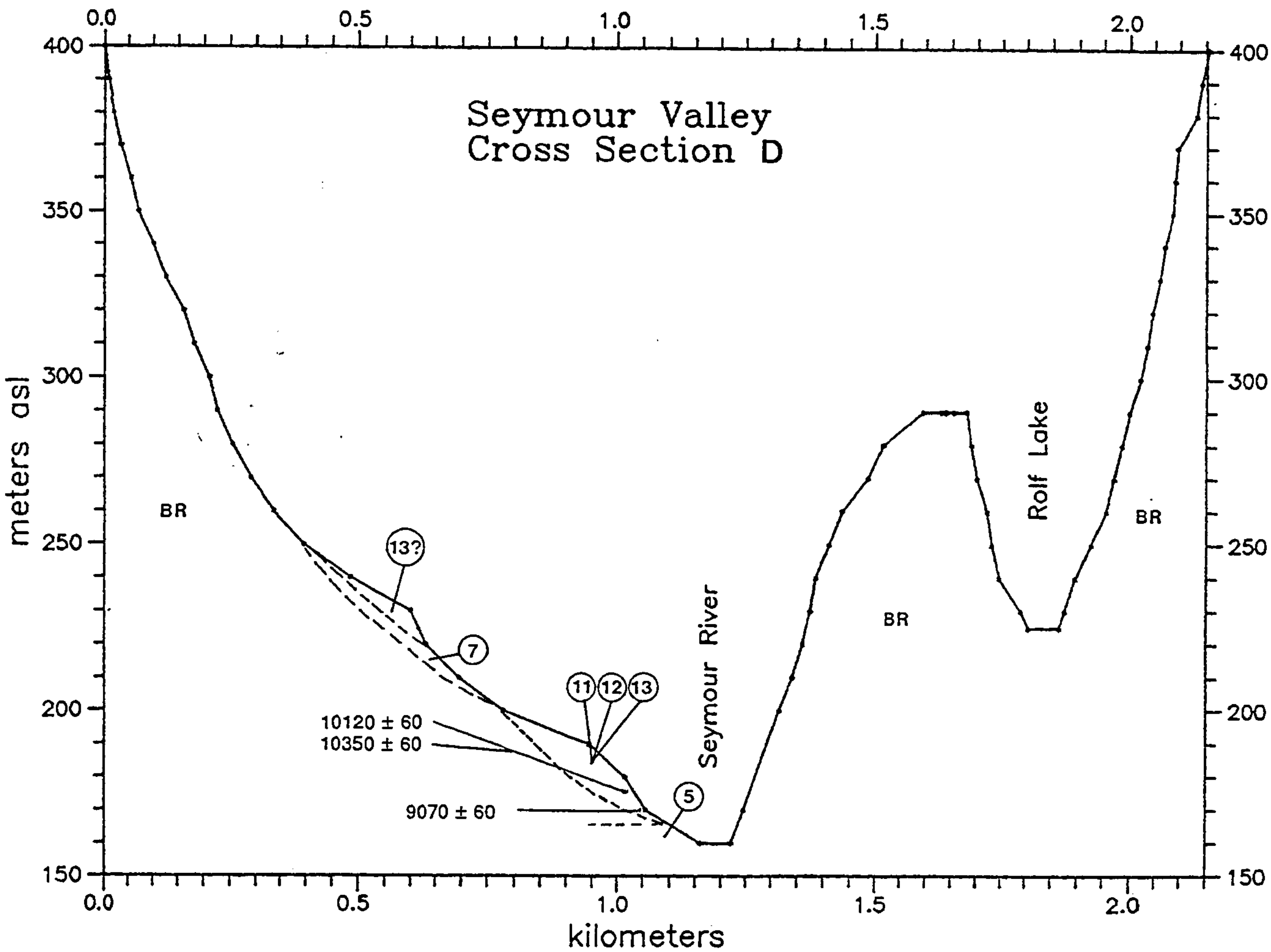

Seymour Valley
Cross Section B
meters asl
kilometers
BR
BR
Seymour River
9700 ± 170
17600 ± 130
17910 ± 100
18490 ± 90
22320 ± 130
22040 ± 130
4980 ± 60
5300 ± 70
29440 ± 300
35700 ± 320
37100 ± 340
41±7(TL)
250
210
170
130
90
0.0
0.4
0.8
1.2
1.6

Figure 4.4b



Seymour Valley
Cross Section C
0.0
0.4
0.8
1.2
1.6
290
250
210
170
130
meters asl
BR
7
?
3
Seymour River
13
BR
kilometers

Figure 4.4c



Seymour Valley
Cross Section D
meters asl
kilometers
0.0
0.5
1.0
1.5
2.0
400
350
300
250
200
150
BR
BR
BR
Rolf Lake
Seymour River
13?
7
11
12
13
5
10120 ± 60
10350 ± 60
9070 ± 60

Figure 4.4d

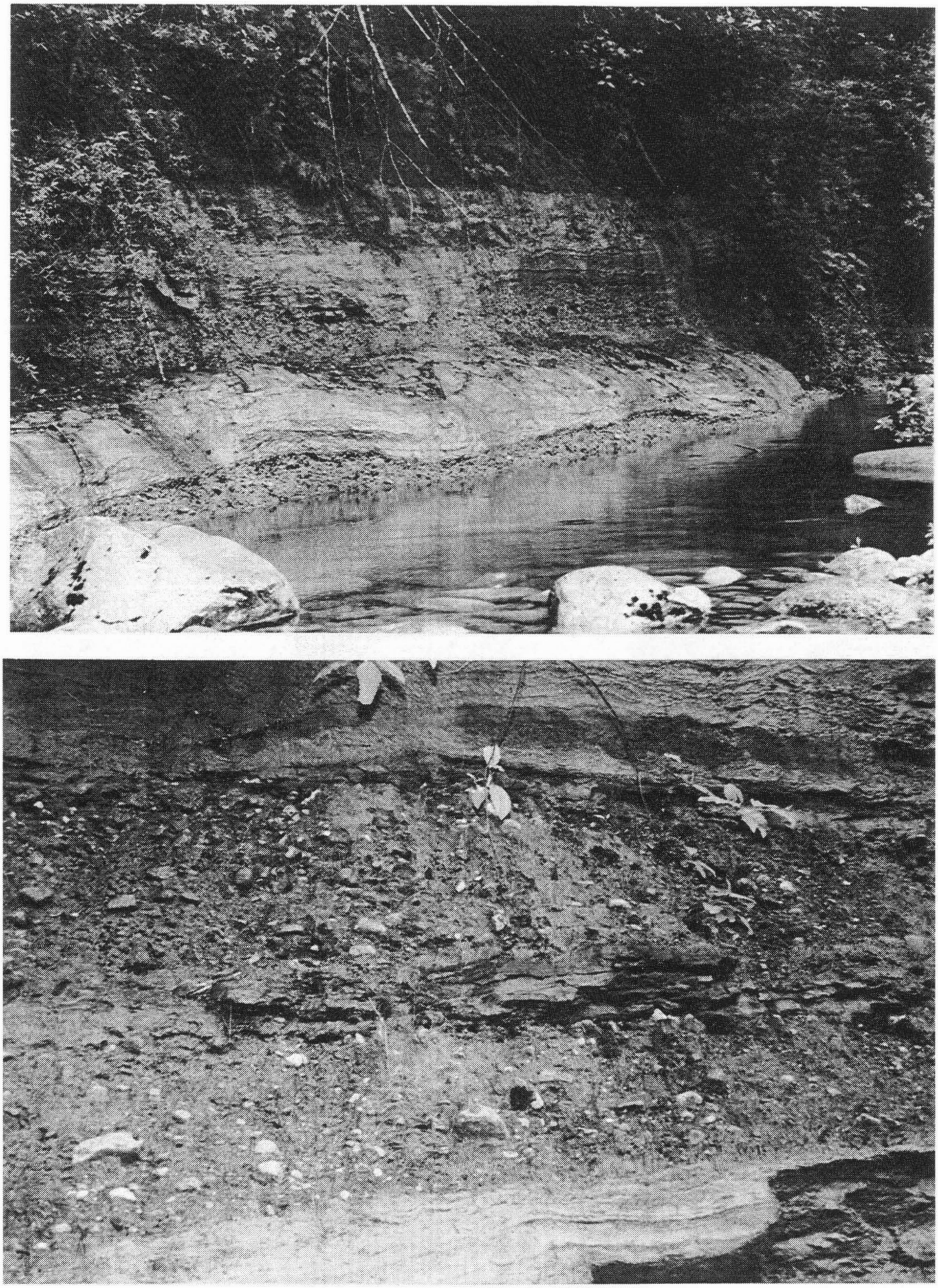


Figure 4.5: Unit 1 Sediments *(a) Above*. Photograph of the Unit 1 sediments at SVMS-7. Note the aggradational sequence of gravel and sand/silt. *(b) below*. Close-up of the central gravel beds in (a) separated by a bed of woody peat radiocarbon dated to 37 100 ± 340 years BP. The peat bed is about 20 cm thick.

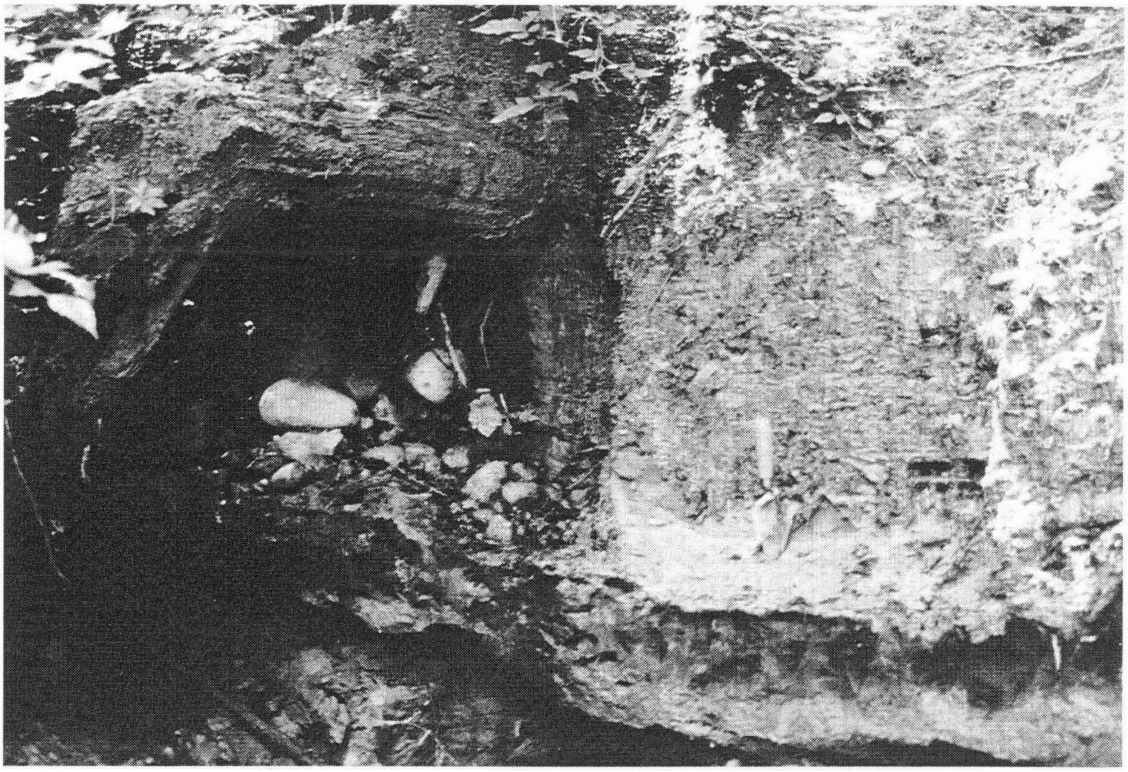
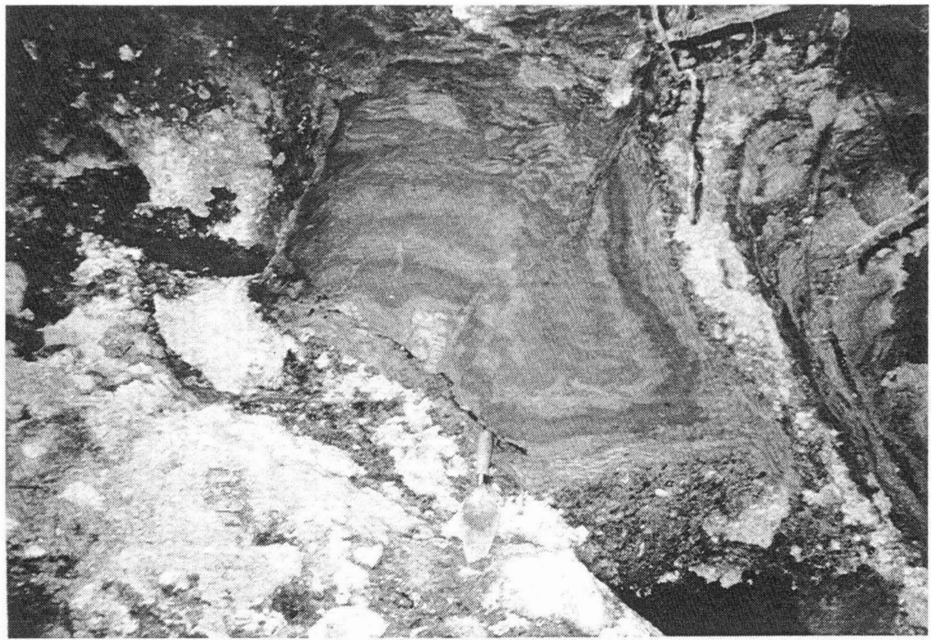


Figure 4.6: Unit 5 sediments. Shows the "18 ka BP organic bed" at SVMS-11 (dark layer below the trowel). The contact between the organic bed and the surrounding glaciolacustrine sediments is sharp suggesting the organics were reworked from close by. The organic bed is therefore thought to be stratigraphically correct. The large log protruding from the glaciolacustrine sediments had retained its bark, which implies it had not been transported very far, or reworked by ice. The log yielded a radiocarbon date of 17 600 ± 130 years BP. The trowel is ~27 cm long.



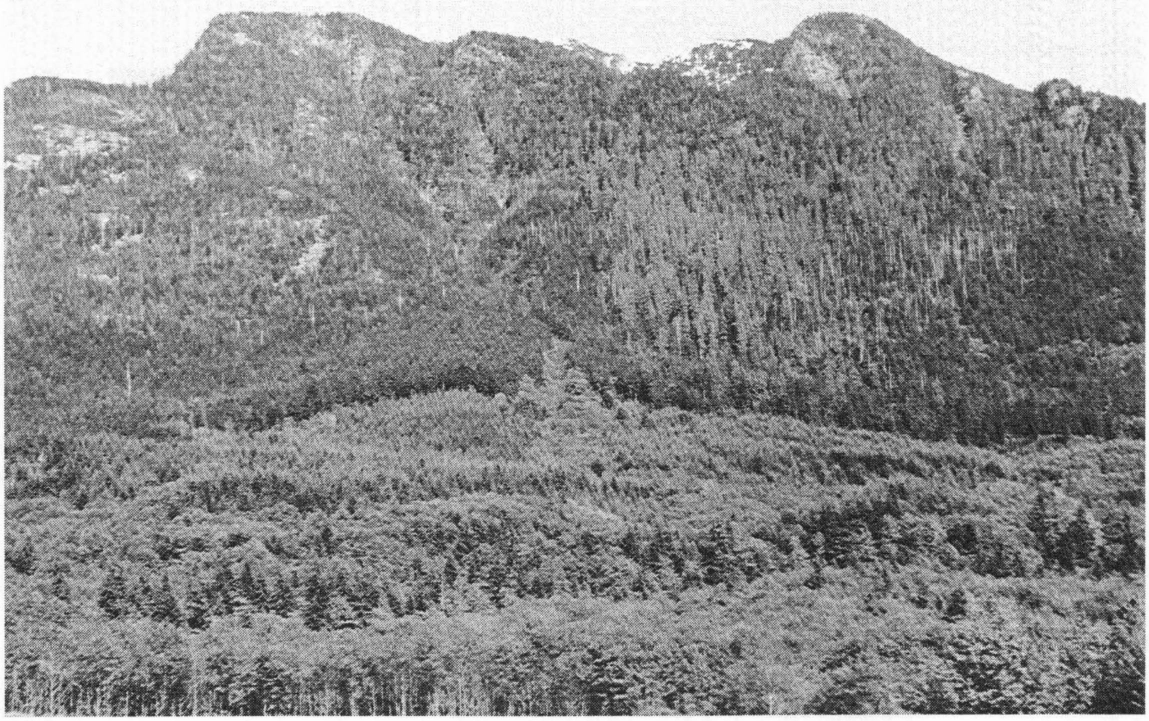


Figure 4.7 *(a) Above*. Shows sediment-flow structure contained within a coarse diamicton (Unit 7; SVMS-28). The fine sediments, which still maintain their bedding, were probably deposited in a semi-fluid (plastic) state in a meltwater channel contained within the surrounding diamicton. The trowel is ~27 cm long. *(b) Below*. Alluvial fan emanating from Intake Creek.

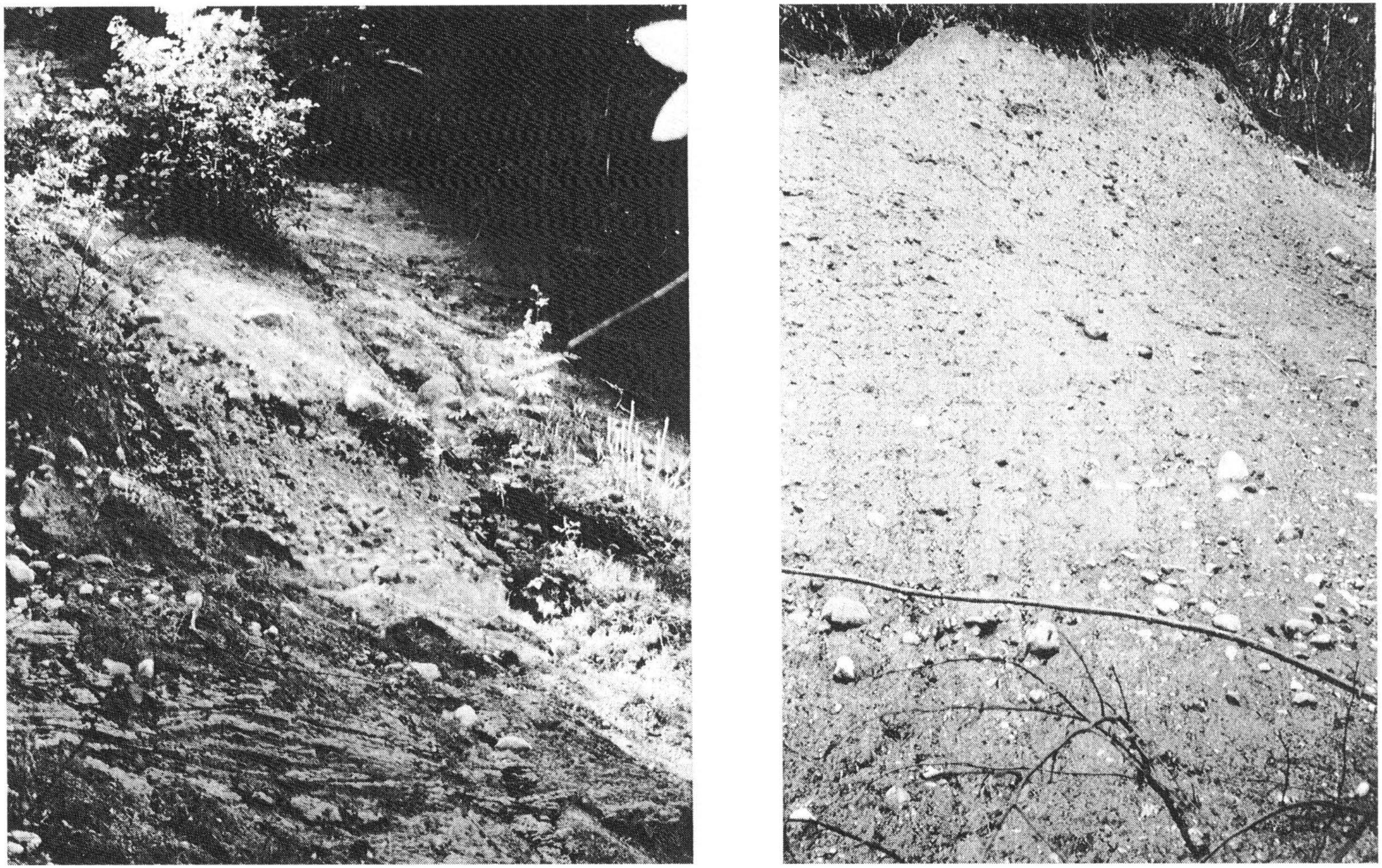


Figure 4.8: Unit 4 sediments. *(a) Left.* exposure at SVMS-11. *(b) Right.* Exposure at SVMS-9. The sediments at SVMS-11 are composed of flow and lodgement tills, glaciolacustrine and fluvial sediments, and possibly glaciomarine sediments. In contrast, the sediments at SVMS-9 consist of a massive lodgement till. This suggests that while ice was wasting into water at SVMS-11, it was grounded at SVMS-9.

CHAPTER 5

GEOCHRONOLOGY OF LOWER SEYMOUR VALLEY

5.1 Introduction

This chapter presents the apparent geochronology or sedimentary history of lower Seymour Valley based on interpretations of the measured sections discussed in Chapter 4. The sedimentology of the units used as evidence for the proposed geochronology is sometimes reviewed to aid discussion. Detailed descriptions and interpretations of all the stratigraphic units can be found in Chapter 4. The general sequence of events from ~37 ka until ~12 ka BP is depicted in Figure 5.1. A summary of the radiocarbon dates obtained during the course of this research appears in Table 5.1 at the end of this chapter.

5.2 >37 000 to 29 000 years BP

The oldest sediments exposed in Seymour Valley are those of Unit 1. The unit is aggradational in nature and generally consists of compressed peat beds separated by fluvial silt, sand and gravel. No evidence of a glacial origin can be seen in any of the associated sediments. No underlying sediments representing a previous glaciation are exposed. Radiocarbon dating has shown that these (exposed) sediments were deposited over a time period of more than 8 ka, deposition commencing more than 37 ka BP.

The nature of the deposits show that the area of the Seymour Valley immediately north of the bedrock canyon once was occupied by a low energy environment (swamp?) that periodically experienced high energy fluvial incursion resulting in aggradation. The rate of aggradation increased dramatically sometime after 29 ka BP in response to the onset of glaciation.

5.3 ~29 000 to 22 000 years BP

As ice began to advance, increased sediment supply caused Seymour River to aggrade. Between about 29 and 22 ka BP lacustrine and fluvial sediments (Unit 2) were deposited in the Seymour Valley. The deposits are about 30 m thick and are exposed at SVMS-8. The presence of fine lacustrine sediments at the base of Unit 2 suggests that the valley was being dammed, possibly by outwash sands accumulating near the mouth of Seymour Valley, perhaps in the constricted bedrock canyon. Outwash sands are suggested as the damming agent, rather than ice, because of the absence of dropstones in the lower lacustrine sediments. The lake eventually filled with lacustrine and finally upward coarsening fluvial sands and gravels from the advancing Seymour Valley glacier.

Since ice moving into the Fraser Lowland from the northeast and northwest would have been fed from higher source areas, it is conceivable that ice from those areas could have reached the mouth of the Seymour Valley before the Seymour Valley glacier did (ice from the northeast probably reached the mouth of Seymour Valley first; the northeastern source areas are closer and the flow paths would have been more direct). If this was indeed the case then it is likely that ice from those areas flowed into (or across the mouth of) Seymour Valley. It would therefore be expected that some of the upper fluvial sediments of Unit 2 would have been deposited by meltwaters flowing into (or across the mouth of) Seymour Valley. Paleoflow direction could not be determined, however, because of inadequate exposure.

5.4 ~22 000 to 18 000 years BP

By about 22 ka BP a lake formed again. This is indicated by the occurrence of glaciolacustrine sediments (Unit 3). The presence of many large dropstones (reaching ~50 cm in diameter) and the "disturbed" nature of the deposits near the base of the unit indicate a proximal ice source. The fact that Unit 3 drift is nearly massive at the base and becomes increasingly structured (laminated) with elevation suggests that the lake eventually became deeper, possibly the result of Fraser Valley ice building up at the mouth of Seymour Valley. Alternatively, the increase in structure might have been a result of a brief retreat of the Seymour Valley glacier.

A draining of the lake occurred next. Evidence of this is the presence of a cobble lag bed (only at SVMS-11) up to ~3 m thick. This implies that ice blocking Seymour Valley must have retreated far enough to permit more efficient drainage of meltwaters out of Seymour Valley. This lake drainage was followed by the retreat of the Seymour Valley glacier.

During the retreat of the Seymour Valley glacier, another lake formed. The nature of the sediments (Unit 4) indicate that while ice was wasting into water at SVMS-11, it was grounded at SVMS-8. This suggests that during the retreat of the Seymour Valley glacier, ice in the Fraser Lowland occupied the Seymour Valley to at least where Rice Lake now exists. Alternatively, the Seymour Valley may have been invaded by the sea from the southwest, while ice in the Fraser Lowland remained in the valley mouth.

Eventually the ice blocking the mouth of Seymour Valley retreated, and the lake drained (or relative sea-level dropped). No fluvial sediments indicating the occurrence of a meltwater stream following the drainage of the lake have been found, although such a stream must have existed.

5.5 ~18 000 to 17 000 years BP

By about 18 ka BP the climate had recovered dramatically, a soil developed and a substantial forest appeared on the floodplains of Seymour River. After an undetermined amount of time, possibly more than 1000 years (based on radiocarbon dates from the study area), ice began to advance again. Ice in the Fraser Lowland once again dammed the Seymour Valley forming a lake, and glaciolacustrine sediments were once again deposited (Unit 5). As the level of the lake began to rise, soil that had developed on higher ground was incorporated into the lake waters and deposited on the lake bottom. Evidence of this is the presence of a single ~20 cm thick (disseminated) organic rich bed contained within the glaciolacustrine sediments of Unit 5. The sediments directly above the organic bed are rich in wood. Buried trees reaching 50 cm in diameter can be found at SVMS-9 and SVMS-11. The extent of the 18 ka BP revegetation of the valley is not known, but based on the extent of the Unit 5 organic bed, the valley was forested at least as far as 3 km above what is now Rice Lake.

It seems likely that some of the sediment of Unit 5 probably was derived from ice in the Fraser Lowland. This is suggested because of the presence of a small, but what seems to be a relatively greater (than units 3 and 4) proportion of volcanic dropstones. Unit 5 also contains relatively few dropstones in general, indicating the Seymour Valley glacier was still distant when ice in the Fraser Lowland dammed the valley. This might be expected since the ice mass in the Fraser Lowland would have been much larger, and therefore retreated more slowly during the 18 ka BP climatic recovery.

5.6 ~17 000 to 12 000 years BP

After an undetermined amount of time ice invaded the post-18 ka lake and a till was deposited (Unit 6). The unit is bracketed by radiocarbon dates of 17 600 and 11 400 years BP.

Although the majority of the clasts in Unit 6 are plutonic, a small percentage are volcanic. The volcanic clasts generally are more angular than the plutonic clasts. This is in contrast with the till that was deposited during the initial advance (Unit 4) which contains clasts which are virtually all plutonic. This suggests that the till was deposited from ice originating from beyond the Seymour Valley. Although the source area of the clasts was not quantitatively determined, they would have had to originated further north, perhaps from the region of the Mount Garibaldi Volcanic Complex. The ice, therefore would have had to have flowed over the divide in the Seymour Valley headwaters, or along Howe Sound spreading east in the Fraser

Lowland. Alternatively, the till could have been deposited from ice originating from the northeast flowing west along what is now Burrard Inlet. The source of the volcanic clasts might have then been from the Harrison Valley area to the northeast.

5.7 ~12 000 years BP to Present

As the Seymour Valley glacier retreated, Seymour Valley was briefly invaded by the sea. Although the extent of this invasion is not known, fossil shells have been reported to have been found up to an elevation of ~127 m asl (Wagner, 1959). During the course of this research, however, none of the fossil shell localities (exposures) reported by Wagner were found; the exposures that Wagner studied were likely overgrown long ago. Obvious landforms indicating post-glacial recessional sea-levels are the raised deltaic sediments at SVMS-1 and SVMS-3, and the numerous marine terraces along Lillooet Road. A possible marine terrace at ~187 m asl (located ~100 south of Rice Lake Gate) marks a possible upper marine limit in the Seymour Valley. No sediments or landforms that could be positively identified as having a marine origin were found above Rice Lake Gate. No materials for radiocarbon dating associated with possible marine sediments were found, so that the timing of the marine incursion and(or) retreat is not known for this valley.

As the Seymour Valley glacier continued to retreat, sediments associated with the melting and wasting of ice were deposited (Unit 7). Hummocky meltout and flow till can be observed just north of Rice Lake (Fig. 4.7a) and on the east side of Seymour Mainline between SVMS-13 and Hydraulic Creek. Melt-out and flow tills can be observed in the road cut along the west side of Seymour Mainline. No direct dating control could be obtained on these deposits. At SVMS-13, however, a radiocarbon date from charcoal fragments from directly overlying valley apron deposits indicates that ablation till was being deposited more that 9700 ± 170 years BP at that location.

5.7.1 Post-glacial Adjustments

As ice retreated up the valley sediments on the valley sides were being fluvially reworked and deposited as alluvial fans (Fig. 4.7b) and aprons (Unit 13). Charcoal fragments from a sand bed contained within the Elsay Creek fan (Fig. B.2e) gave a radiocarbon date of 11 420 ± 110 years BP; this is the oldest post-glacial date obtained from Seymour Valley during the course of this research. The date was obtained ~2 m from the fan surface near the fan toe which suggests the fan became stable very soon after deglaciation. At other locations near SVMS-31 and SVMS-21, debris flow deposits are separated by mud flow beds rich with charcoal fragments. No buried trees were found in these deposits indicating that the fans and aprons developed quickly. The youngest radiocarbon date obtained from apron deposits is 9700 ± 170 years BP from charcoal fragments found in a sand bed (mud flow deposit) ~2 m from the surface of the deposit at SVMS-13.

As valley-side material was deposited in the valley bottom, numerous dammings occurred. A good example of this is the reworked deposits of a kame(?) terrace at Hydraulic Creek (SVMS-16, -17, and -18). The underlying lacustrine sediments (Unit 11), possibly a product of damming by sediments derived from the kame terrace, contain dropstones indicating deglaciation was still in progress. Other lacustrine sediments at SVMS-21, -22, -23, and -31 are clean (i.e. no dropstones or organic material) indicating that these damming events were still occurring immediately after deglaciation. The dams eventually eroded and the lakes drained. Tributaries (and distributaries?) of the Seymour River eventually incised into the exposed lacustrine sediments. Channels that were abandoned or dammed by subsequent debris flows or fan/apron progradation were quickly filled with sediments (Unit 12). The Unit 12 lacustrine sediments are highly organic (containing abundant wood and charcoal) indicating that the valley was substantially vegetated by this time. Three radiocarbon dates from wood found within these sediments gave ages of 9070 ± 60, 10 120 ± 60, and 10 350 ± 60 years BP, the 9 ka date being stratigraphically lower, while the 10 ka dates are supportive (see Fig. 4.3c). The Unit 12 sediments were finally capped with material reworked from glacial sediments on the valley sides. As this sediment supply became exhausted, fans and aprons became vegetated and relatively stable.

From the evidence presented above it is likely that most of the valley-side glacial material was redeposited in the valley bottom within 3000 years of deglaciation.

As the sediment supply from the valley sides and from the retreating ice began to dwindle, the Seymour River began to incise into the glacial valley fill deposits while at the same time tributaries, graded to Seymour River, began to incise alluvial fans and aprons. The result of this is a complex systems of terraces representing former positions of the Seymour River within the valley fill. At some point the lower river became "trapped" in its present course by the bedrock canyon; an event which prevented excessive lateral movement upstream thereby preserving the pre-Fraser and overlying sediments to this day.

Although the exact timing of incision was not determined in this study, two radiocarbon dates from an aggradational terrace directly above channel lag deposits (SVMS-10) indicate that incision into the valley fill was ~85% complete before 5 ka BP (the cause of aggradation during this time period is discussed in Chapter 6). The interval of time between ~5 ka BP and present therefore represents incision into the remaining ~10 m of valley fill and incision into bedrock. It is not known when Seymour River became graded to the lower bedrock canyon, but it was likely soon after 5 ka BP.

The rate of incision into the lower bedrock canyon is not known. Supported by its "youthful appearance", it has been suggested that the canyon was cut during the Holocene (Burwash, 1918; Johnston, 1923). Since the canyon likely was filled with glacial outwash sediment prior to each glacial advance it would have been protected from the scouring action of ice throughout each glacial advance and retreat, much like the pre-Fraser sediments (Unit 1) in the valley were during the initial advance of ice. It is more probable, therefore, that the canyon is the product of fluvial erosion occurring over a larger time span.

5.7.2 On-going Processes

Although the present physiography of Seymour Valley largely reflects glacial processes which occurred thousands of years ago, the sediments and landforms in the valley are still being reworked and reshaped, albeit at a much reduced rate. The warm winters and high rainfall of southwest British Columbia combined with steep relief result in a very dynamic geomorphic environment.

The valley fill in the study area currently is being reworked mainly by the tributaries. Although all of the tributaries are graded to the Seymour River, flash floods caused by rain-on-snow events during the winter months, and occasional summer storms, have been observed to cause substantial local erosion. A number of examples of this activity was observed during the course of this research:

During the winter of 1990/1991 the creek at SVMS-21 incised ~1 m into lacustrine sediments following a rain-on-snow event. Intake Creek washed out a road and greatly eroded Intake Creek fan. During the fall of 1990, a rainstorm caused the erosion of a large portion of apron deposits at Hydraulic Creek. During the fall of 1991 a portion of Fisherman's Trail, north of SVMS-11, was washed out during a flood of Seymour River. It is actually surprising that so much of the valley fill remains to this day - providing rates of erosion have been relatively constant in the Holocene.

Table 5.1 Summary of Radiocarbon and TL dates From Seymour Valley.

Age[a]	Lab No.[b]	Material	Elevation(m asl)	Location
140 ± 50	Beta-43863	bark	109	SVMS-27
4980 ± 60	Beta-46052	stick	113	SVMS-7
5300 ± 70	Beta-40686	stick	113	SVMS-7
9070 ± 60	Beta-38913	log	167	SVMS-22
9700 ± 170	Beta-40690	Charcoal frags.	166	SVMS-13
10120 ± 60	Beta-38911	log	175	SVMS-21
10350 ± 60	Beta-38912	log	175	SVMS-21
11420 ± 110	Beta-40687	Charcoal frags.	179	SVMS-25
17600 ± 130	Beta-38907	log	171	SVMS-11
17910 ± 100	Beta-40689	stick	172	SVMS-13
18490 ± 90	Beta-38908	log	176	SVMS-8
22040 ± 130	Beta-38909	log	142	SVMS-8
22320 ± 130	Beta-40686	log	141	SVMS-9
29440 ± 300	Beta-46053	Peat	101	SVMS-7
35700 ± 320[c]	GSC-5069HP	log (*Picea* sp)[e].	100	SVMS-6
37100 ± 340[d]	GSC-5121HP	log (*Abies* sp)[f].	99	SVMS-7
>43500	Beta-38910	wood frags. (2 pc.)	178	SVMS-11
41 ± 7[g]	SVP1	sediments in peat	101	SVMS-7

[a] Age in ^{14}C years BP (except SVP1 which is an apparent TL age - see Appendix A).

[b] GSC: Geological Survey of Canada Radiocarbon Laboratory, 601 Booth Street, Ottawa, Ontario, Canada K1A 0E5. The GSC reports errors as $\pm 2\sigma$.

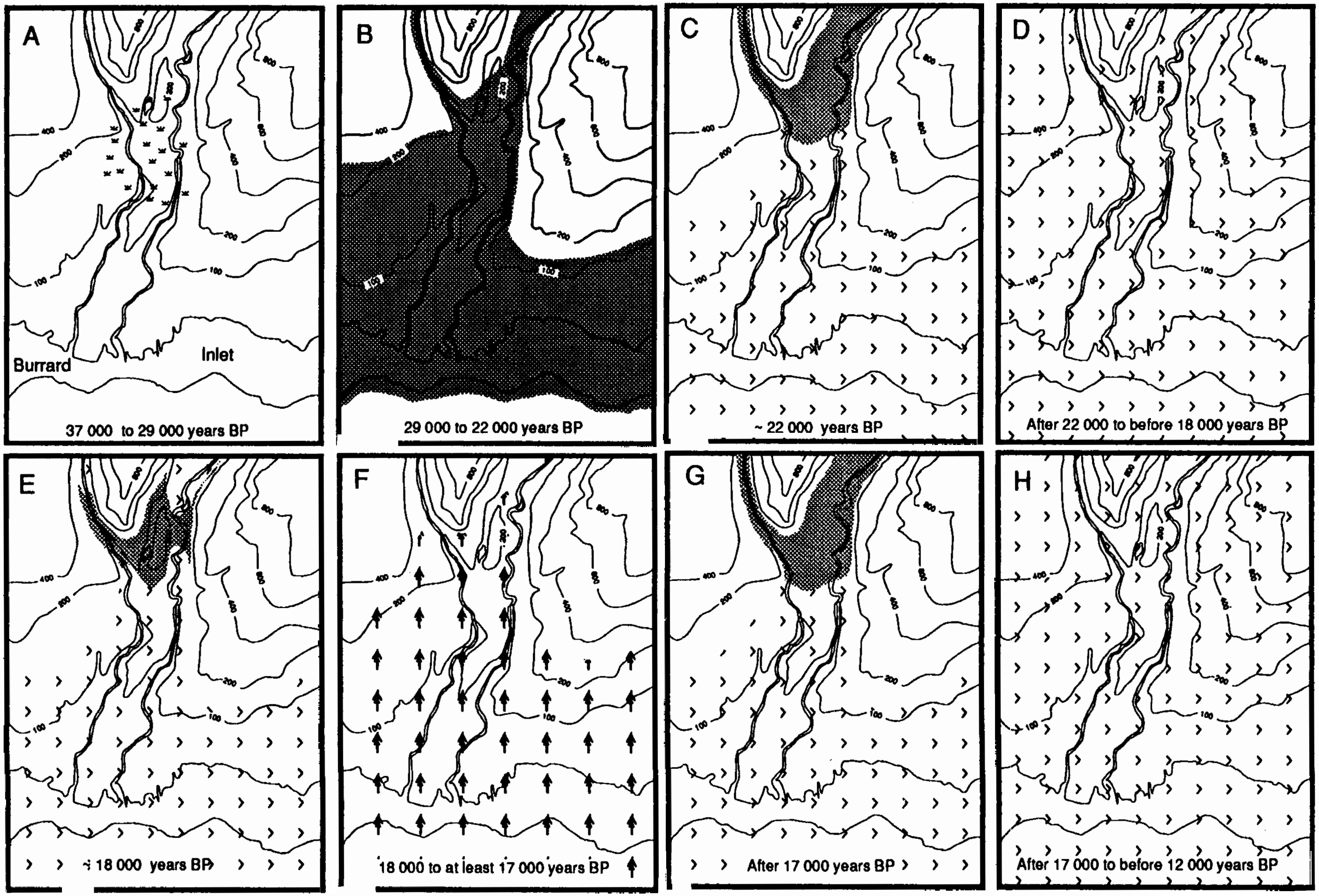
Beta: Beta Analytic Inc., University Branch, 4985 S.W. 74 Court, Miami, Florida, U.S.A. 33155. Beta reports errors as $\pm 1\sigma$

[c] δ^{13}C: -24.7 %
[d] δ^{13}C: -23.3 %

[g] Thermoluminescence date. Analysis performed at the Thermoluminescence and Optical Dating Laboratory, Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6.

[e] Identified by R.J. Mott (GSC wood report No. 90-41)
[f] Identified by R.J. Mott (GSC wood report No. 90-74)

- All samples were collected by O.B. Lian



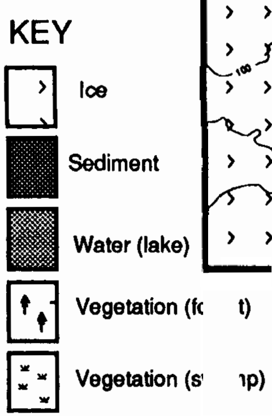


Figure 5.1 Generalized sequence of events between 37 ka BP and ~12 ka BP for the lower Seymour Valley. See the text for the explanation.

CHAPTER 6

DISCUSSION AND CONCLUSIONS

6.1 Introduction

This chapter discusses how the findings of this study relate to existing knowledge from the Fraser Lowland and elsewhere. Based on the evidence presented in Chapter 4, the stratigraphic units in the Seymour Valley are correlated with the time-stratigraphic, geoclimatic, and lithostratigraphic units defined for the Fraser Lowland (reviewed in Chapter 2).

6.2 Middle Wisconsinan

6.2.1 The Olympia Nonglacial Interval

6.2.1.1 The Cowichan Head Formation

Based on radiocarbon dating and lithostratigraphy, the Unit 1 sediments may be considered equivalent to the upper member (see Chapter 2) of the Cowichan Head Formation; the lower member is not exposed, and may not exist, in the Seymour Valley. Unit 1 was therefore deposited during the Olympia Nonglacial Interval (hereafter referred to as the Olympia).

Locally, these sediments may be correlated with an exposure of the Cowichan Head Formation in the neighbouring Lynn Canyon in Lynn Valley. In Lynn Canyon these sediments generally consists of about 1 m of compressed peat containing a 2 cm thick bed of sand. Also exposed is about 25 cm of underlying till that has been correlated with Semiahmo Drift (Armstrong *et al*, 1985; Armstrong, 1990). Four radiocarbon dates ranging from 47 800 ± 1100 (GSC-3290) to 33 100 ± 620 (GSC-2797) years BP have been obtained from this unit (Armstrong *et al*, 1985; Armstrong, 1990).

It appears therefore that in Lynn Canyon this unit represent a more or less continuous accumulation of peat over a time span of about 15 ka interrupted by only one small fluvial incursion. This is in contrast to the situation in Seymour Valley where ~2 m of the 5 m exposure of peat and sediment accumulated over a time span of ~8 ka. The different nature of these two exposures may be attributable to the pre-Fraser position of the two respective streams. The exposure in Lynn Canyon obviously was not effected by fluctuations in discharge and sediment load of the pre-Fraser Lynn Creek.

An extensive palynolgical study of the Lynn Canyon exposure has been completed and is presented in Armstrong *et al.* (1985). Due to the proximity of this exposure with Seymour valley, the results are likely applicable to Unit 1 in the Seymour Valley. The results and interpretations are quoted below:

> The peat and silt beds of the Cowichan Head Formation [in Lynn Canyon] contain a singular record of middle Wisconsin vegetation and climate. The lowermost 5-10 cm of the Cowichan Head sequence contain pollen and spore assemblages dominated by club-moss (Lycopodium cf. annotinum), grasses (Poaceae), and diverse herbs. These assemblages which are more than 48,000 radiocarbon years old, represent grass-herb meadows similar to those of subalpine or alpine sites today.
>
> Lodgepole pine (Pinus contorta) woodland of forest succeeded the meadows, presumably in response to a warming climate. This woodland, in turn, was replaced by a forest dominated by spruce (species unknown, but probably picea sitchensis) and mountain hemlock (Tsuga mertensiana), which most likely grew in a moist climate that was cooler than present.
>
> Later, western hemlock (Tsuga heterophylla) became a forest co-dominated with lodgepole pine and mountain hemlock. The abundance of mountain hemlock suggests that this was the warmest part of the Olympia nonglacial interval. However, the climate was probably not as warm as the present because mountain hemlock, which now occurs in the southern Coast Mountains only above 1000 m a.s.l., coexisted with western hemlock at this low-elevation (65 m) site. The high pollen values may indicate local stands of lodgepole pine on the peat-forming wetland.
>
> High percentages of spruce and mountain hemlock pollen in the upper part of the peat signal the return of cooler conditions before 33,000 years BP. The uppermost silty peat and overlying silt are dominated by pollen of grasses and diverse herbs and by spores of club-moss and ferns. Grass-herb meadows covered the terrain in the vicinity of Lynn Canyon, and the climate was relatively cold, perhaps a herald of the Fraser Glaciation to come.
>
> These middle Wisconsin vegetation changes were accompanied by changes in the character of the Lynn Canyon depositional site. The initial wet grassy meadow was succeeded by a Sphagnum bog, which in turn was replaced by a sedge fen. A stream coursed through the fen, depositing the 2-cm-thick sand bed on top of the lower peat. The fen was then replaced by herb-rich wet grassy meadow. Still later, the site became a floodplain or shallow lake in which silt accumulated on top of the upper peat (p. 15-10).

These results of this palynolgical study appears to agree with the general "appearance" of the Seymour Valley exposure: in Seymour Valley there is a relative abundance of fossil logs at the stratigraphic positions corresponding to 36 and 37 ka BP, which is about the same time where large pine and spruce signals occur in the Lynn Canyon pollen diagram (Fig. 6.1). At the 29 ka BP position the Seymour Valley peats appear relatively barren of wood, a time represented by mainly herbs and shrubs in the Lynn Canyon pollen diagram.

It appears, therefore, that the majority of Unit 1 was deposited during generally warm climatic conditions. Aggradation in the Seymour Valley during the Olympia, therefore, cannot be attributed to increased rates of erosion and sedimentation brought upon by a major climatic deterioration (the onset of glaciation) although relatively minor climatic fluctuations may be responsible (see below).

There are three primary reasons why a river valley may experience aggradation:

(1) An increase in base level elevation
(2) An increase in sediment supply
(3) A decrease in fluvial energy

(1) An increase in base level elevation can be caused by a rise in relative sea-level. Although it is not known if sea-levels were rising (fluctuating?) during the entire time of formation of this unit, the character of the overlying sediments (Unit 2) suggest that sea-level should have been dropping by about 29 ka BP due to the onset of glaciation.

(2) A stream may aggrade if sediments are being deposited downstream at a rate greater than they are being transported out of the valley. There are at present no obvious sources or source areas of sediment upstream, or downstream of the Unit 1 deposits that could have been responsible for this, although there could have been in the pre-Fraser Seymour Valley.

(3) A decrease in fluvial energy may cause sediments to accumulate rather than be transported through the system. If the lower Seymour River was multichannel during this time, channel shifting and abandonment could have resulted in local aggradation (in-filling). The nearly massive gravels of Unit 1 could therefore be a result of periodic flooding. The problem still remains, however, that over 5 m of aggradation have to be accounted for.

Aggradation may have been caused by a combination of these factors. Knowledge of the climate during the Olympia may suggest a mechanism for the formation of the Unit 1 peat sequence. If the Olympia did indeed begin more than 60 ka BP, then the 48 ka BP cold period represented in the Lynn Canyon pollen diagram could be interpreted as relatively short fluctuation in a generally warm climatic interval. The two spikes of fern and mountain hemlock which coincide between 48 ka BP and 33 ka BP, may then, suggest brief returns to cooler climates. In fact, Gascoyne *et al.* (1981) have found from $\delta^{18}O$ studies of speleothems from cave deposits on Vancouver Island, that temperatures during the Olympia were considerably warmer 65 ka BP than 48 ka BP, declining steadily until the onset of the Fraser Glaciation ~29 ka BP. Gascoyne *et al.* did not detect, however, any fluctuation in temperature during this decline, a result they attributed to the buffering effect of the nearby ocean.

Evidence of fluctuating climatic conditions during the Olympia have been found elsewhere. Heusser (1977), working on the Olympic Peninsula (northwestern Washington), has argued that during the Olympia temperatures were sometimes as cold as those experienced during the Fraser Glaciation maximum, yet at other times as warm as those of the present. Climatic fluctuation during the Olympia is also supported by information from the Cowichan Head Formation (southern Vancouver Island) (Armstrong and Clague, 1977). Hansen and Easterbrook (1974) apparently found evidence that the Puget Lowland was occupied by glaciers during part of the Olympia. Others have argued, however, that the lithostratigraphic evidence for this is likely invalid since no evidence of a glaciation during this time period has been found in British Columbia (Fulton *et al.*, 1976; Clague, 1980).

Even in today's relatively warm climate there exists perpetual patches of snow in the mountains surrounding Seymour Valley. It is conceivable that during the Olympia, the amount of summer snow in the surrounding mountains expanded and contracted by orders of magnitude, changes that periodically effected the erosional efficiency of the tributary streams in Seymour Valley.

It therefore seems plausible that periods of aggradation in the Seymour Valley during the Olympia could have been in response to changes in temperature, rainfall, snow, and possibly ice in the surrounding mountains. The above notion is, of course, an hypothesis which has yet to be tested. However, because of the time span covered by the unit and its vertical size, periodic climatic fluctuations during the Olympia appears, at this time, to be a likely cause of aggradation.

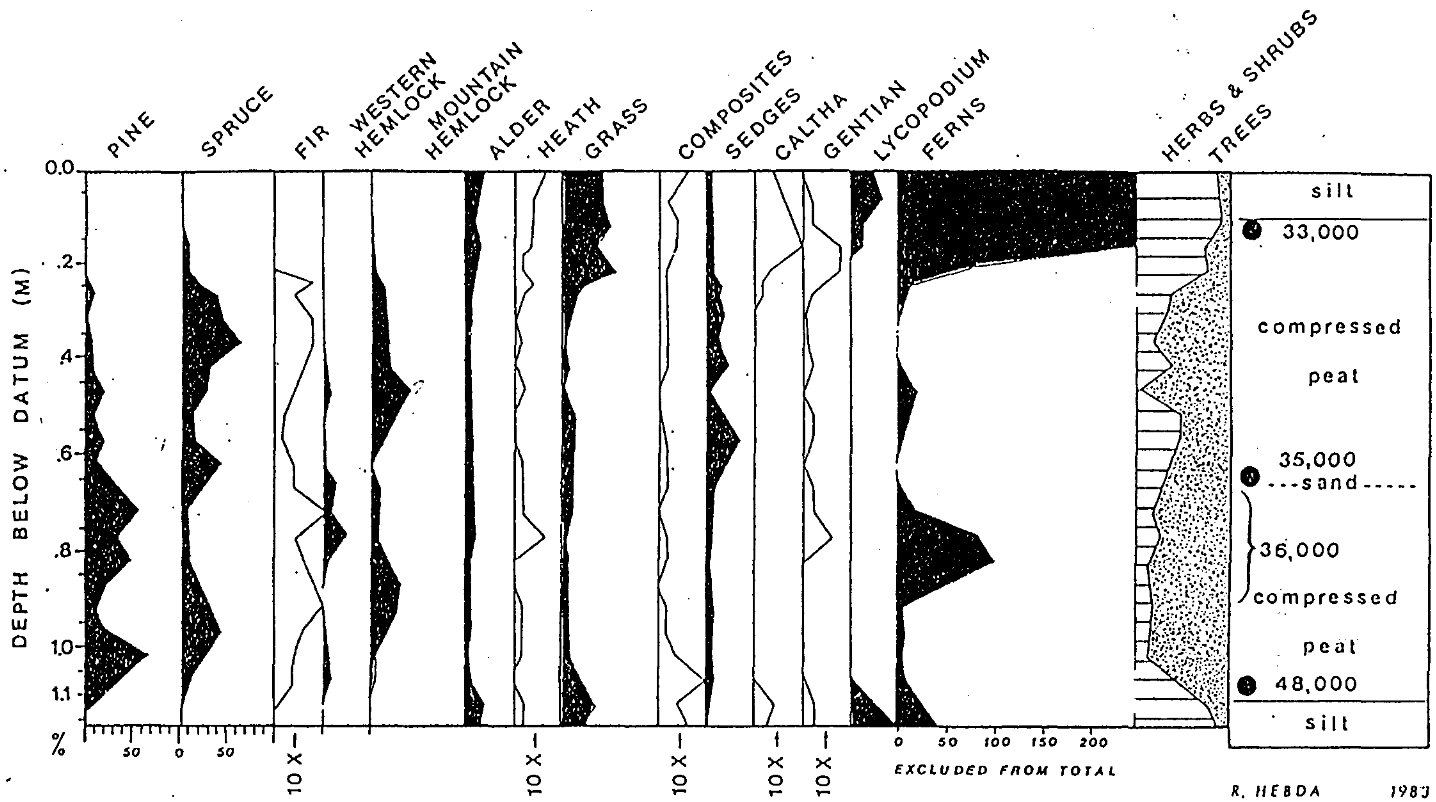


Figure 6.1 Relative pollen diagram from an exposure of the Cowichan Head Formation in Lynn Canyon (Armstrong, *et al.*, 1985).

6.3 Late Wisconsinan

6.3.1 The Fraser Glaciation

6.3.1.1 Quadra Sands

Bracketed by radiocarbon dates of 29 440 ± 300 (Beta-46053) and 22 320 ± 130 (Beta-40686) years BP, the Unit 2 sediments are correlated with the Quadra Sands and were therefore deposited during the onset of the Fraser Glaciation. The unit falls within the time of deposition of Quadra Sand in the Fraser Lowland suggested by Clague (1977).

6.3.1.2 Coquitlam Drift

Bracketed by five radiocarbon dates between 22 320 ± 130 (Beta-40686) and 18 490 ± 90 (Beta-38908) years BP (Table 6.1), the Unit 3 and Unit 4 sediments are correlated with Coquitlam Drift (Hicock, 1976; Armstrong, 1977; Clague *et al*, 1980; Hicock and Armstrong, 1981).

The sediments comprising Coquitlam Drift at Coquitlam Valley holostratotype are similar to the Unit 4 sediments in Seymour Valley, especially at SVMS-11. Descriptions and interpretations of the Coquitlam Drift type sections can be found in Hicock and Armstrong (1981) and are quoted below:

> Here [at the Coquitlam Valley holostratotype] the drift attains a thickness of at least 20 m and includes at least three lodgement tills separated by glaciofluvial, ice-contact, and glaciomarine deposits. The ice deposits contain at least two massive and stony flow tills (each up to 70 cm thick) interbedded with sand and gravel..... The lodgement tills contain abundant subrounded stones, up to 1 m across, entirely derived from the Coast Mountains to the north. Lodgement till clasts are supported in a matrix typically composed of approximately 55% sand, 35% silt, and 10% clay. Glaciofluvial sediments are interbedded with other units of the formation and include fine to medium sand, gravelly sand, sandy gravel, and pebble to boulder gravel. They are generally horizontally bedded but also crudely cross-bedded in places and contain subrounded stones up to 1 m across, also derived from the Coast Mountains. A massive, blocky, clayey silt unit occurs near the top of the holostratotype and contains abundant marine dinoflagellate cysts identical to *Operculodinium* cysts described by Harland (1973). the unit also contains scattered pebbles and cobbles and is interpreted in this paper as having a glaciomarine origin.
>
> In the Coquitlam Valley contacts between units within the formation are usually undulatory and unconformable. The lower contact of the formation with pre-Coquitlam Quadra sand may not be exposed in the holostratotype but is

inferred from radiocarbon dates from the adjacent Cewe pit. therefore, the holostratotype ... combines information from both the S & S and Cewe pits, as the record of the pre-Coquitlam Quadra sand is taken from Cewe, although no Coquitlam Drift has been recognized there. In the S & S pit holostratotype, Coquitlam Drift overlies pre-Coquitlam Quadra and (or) Cowichan Head rusty sand and gravel, with apparent unconformity, which overlie up to 2 m of Cowichan Head nonglacial silt and fine sand over at least 10 m of coarse sandy gravel. The upper contact is sharp, level, and apparently conformable with thinly bedded post-Coquitlam Quadra sand, but very undulatory and unconformable with Vashon drift. In places where Vashon ice-contact or glaciofluvial sediments overlie those of Coquitlam Drift, the contact is not easily discernible.

Coquitlam Drift rests on a buried landscape (by this we mean an undulating erosional paleosurface developed on older sediments), which slopes steeply into the Coquitlam Valley, as does the Vashon drift (Armstrong and Hicock, 1976).

...At [the] Mary Hill [parastratotype], Coquitlam Drift has a composite thickness of at least 17 m and includes a lodgement till, *Nuculana*-bearing glaciomarine stony clayey silt (with scattered stones; shells identified by the authors), and glaciofluvial sand and gravel. The lodgement till stones are mainly Coast Mountain derived and its matrix contains approximately 50% sand, 35% silt, and 15% clay. The till also contains westward- and southward-rising shear planes, as well as a significant component (30%) of stones derived from mainly metasedimentary rocks to the east. A similar provenance is found in the outwash. The lower contact of the Drift is sharply unconformable on pre-Coquitlam Quadra sand and wood rich Cowichan Head rusty sand and gravel. The upper contact is also sharp and unconformable with post-Coquitlam Quadra sand and Vashon drift.

At the Port Moody disposal pit the Drift contains lodgement till (matrix composed of approximately 50% sand, 45% silt, and 5% clay) and flow(?) tills intermixed with glaciofluvial material in a layer, up to 3 m thick, resting on a southward-sloping buried landscape. Stones from these sediments are dominantly Coast Mountains derived, with minor input (10%) from eastern sources. Here the Drift unconformably truncates up to 60 m of horizontally bedded medium pre-Coquitlam Quadra sand and unconformably underlies post-Coquitlam Quadra horizontally bedded organic silt and sand. (p. 1444)

Evidence gathered by Hicock and Armstrong (1981) suggests that by ~21.5 ka BP glacial ice blocked lower Coquitlam Valley creating a "reservoir" where pre-Coquitlam Quadra Sand was deposited. This appears to be what happened in Seymour Valley, although the Unit 2 sediments suggest that Seymour Valley was initially dammed by outwash sediments from ice advancing into the Fraser Lowland (the lower Unit 2 lacustrine sediments have no dropstones suggesting that ice had not reached the Seymour Valley at that time). The ice margin therefore may have been somewhere between Seymour Valley and Coquitlam Valley during the initial post-Olympia damming of Seymour Valley. There is, however, no evidence of this from radiocarbon dating (Table 6.1). This lack of evidence may be due to the paucity of dates, from each valley, representing the onset of the Coquitlam Stade.

Both Coquitlam Valley and Seymour Valley show that the Coquitlam Stade was a relatively unstable time when ice margins advanced and retreated into water. In the Coquitlam Valley, marine indicators suggest that the sea invaded the valley during the time between deposition of the till beds. Since no microfossil studies were performed on the Seymour Valley sediments it is not know whether the Unit 4 sediments were deposited in a freshwater lake or into the invading sea. The character of the sediments at SVMS-8 suggest, however, that the valley below SVMS-11 was blocked by ice during this time which in turn suggests that the sediments at SVMS-11 were deposited in fresh water. It is therefore conceivable that the sea never invaded the Seymour Valley during the retreat of the Coquitlam ice. Alternatively, the sea may have briefly entered Seymour Valley from the southwest, north of SVMS-8, while ice and sediment remained intact at SVMS-11.

In Coquitlam Valley, both pre- and post-Coquitlam Quadra Sand is present. In Seymour Valley, however, only the pre-Coquitlam Quadra Sand is represented. Seymour Valley post-Coquitlam Quadra Sand may have been deposited as lacustrine sediments (Unit 5), the coarser sand-sized material (not exposed) settling out somewhere up-valley at the lake margin.

Table 6.1 Summary of radiocarbon dates from Coquitlam-Port Moody area and Seymour Valley pertinent to the Coquitlam Stade/Port Moody interstade chronology.

Date (^{14}C yrs BP)	Lab. No.	Locality	Location	Elevation (m)
17800 ± 150[a]	GSC-2297	Coq. Valley	49°20.3'N 122°46.7'W	214
18000 ± 150[a]	GSC-2371	Coq. Valley	49°17.3'N 122°46.7'W	210
18300 ± 170[b]	GSC-2322	Port Moody	49°17.3'N 122°52.7'W	61
18600 ± 190[b]	GSC-2194	Mary Hill	49°14.0'N 122°14.0'W	61
18700 ± 170[b]	GSC-2344	Mary Hill	49°14.0'N 122°14.0'W	61
21500 ± 240[c]	GSC-2536	Coq. Valley	49°18.8'N 122°46.8'W	125
21600 ± 200[d]	GSC-2203	Coq. Valley	49°19.8'N 122°46.6'W	190
21700 ± 130[d]	GSC-2416	Coq. Valley	49°19.8'N 122°46.6'W	130
21700 ± 240[d]	GSC-2335	Coq. Valley	49°19.8'N 122°46.6'W	205
17600 ± 130[a]	Beta-38907	Sey. Valley	49°21.3'N 123°00.2'W	175
17910 ± 100[a]	Beta-40689	Sey. Valley	49°22.4'N 123°00.0'W	172
18490 ± 90[a]	Beta-38906	Sey. Valley	49°21.9'N 122°59.8'W	176
22040 ± 130[c]	Beta-38909	Sey. Valley	49°21.3'N 123°00.2'W	142
22320 ± 130[c]	Beta-40686	Sey. Valley	49°21.3'N 123°00.2'W	141

[a] Dates glaciolacustrine sediments which underlie Vashon till. Indirectly dates the Port Moody interstade.
[b] Dates organic layer underlying glaciofluvial sand, which in turn underlies Vashon till.
[c] Dates Coquitlam till.
[d] Dates glaciofluvial sand which underlies Vashon till.

As of 1980, Coquitlam Drift had only been positively identified in the Coquitlam-Port Moody area at three sites (sediments described in quotation above) covering an area of 50 km^2 (Clague *et al*, 1980; Clague, 1981).

In Chilliwack Valley, radiocarbon dates of 21 400 ± 240 (SFU-66) and 21 600 ± 240 (SFU-65) years BP from mammoth tusks found in glacial outwash gravels have been correlated in age with Coquitlam Drift (Hicock *et al.*, 1982b; Saunders, 1985). No exposures of Coquitlam till have been found in the Chillwack Valley, however.

On southeastern Vancouver Island there exists drift and outwash deposits which possibly correlate to an early advance and retreat of Fraser ice (Halstead, 1968). There is a lack of evidence, however, to suggest that this event was distinctly separate from the Vashon Stade (Clague, 1981).

Blaise *et al.* (1990) have found evidence that the Queen Charlotte Islands were occupied by an "extensive network of glaciers" during the time of the Coquitlam Stade, but there is no evidence to show that those glaciers receded before the Fraser maximum was found.

A summary of the Quaternary stratigraphy in the Canadian Cordillera by Ryder and Clague (1989) reports no further sedimentary evidence of the Coquitlam Stade. Seymour Valley, therefore, likely is the only site where Coquitlam Drift has been positively identified outside the Coquitlam-Port Moody area. It is likely, then, that the Coquitlam Stade only occurred in the southern Coast Mountains.

It has been suggested by Hicock (1976), Alley and Chatwin (1979), Clague *et al.* (1980) that Coquitlam Drift may be correlated with Evans Creek Drift (Crandell, 1963; Armstrong *et al.*, 1965) in northwestern Washington. In the Cascade Mountains, Evans Creek Drift was deposited by glaciers advancing (advance ≈20 km at Mount Ranier) and then retreating during the onset of the Fraser Glaciation. The timing of this advance is supported by palynological evidence from Davis Lake (~10 km northwest of the Evans Creek glacial margin) which indicates that a cooler climate existed between 26 and 16 ka BP followed by a climatic warming between 16 and 15 ka BP, in turn followed by cooler conditions of the Fraser maximum (Barnosky, 1981). Evans Creek Drift in the Hoh Valley originating from a glacial advance in the Olympic Mountains underlies three basal bogs which have produced limiting radiocarbon dates ranging from 18 800 ± 800 (RL-228) to 14 480 ± 600 (Y-2454) (Heusser, 1964; Crandell, 1965; Easterbrook, 1986). No evidence of Evans Creek Drift has been found in the Puget Lowlands (Easterbrook, 1969).

6.3.1.3 The Port Moody interstade

The Port Moody interstade is represented in the Seymour Valley by a single organic-rich bed ~20 cm thick underlying buried wood. Although these sediments and wood are clearly reworked, the organic-rich bed is always found within a few meters of the underlying Coquitlam Drift and is therefore believed to be stratigraphically correct. Correlative sediments occur in the Coquitlam valley, Port Moody and at Mary Hill (Hicock *et al.*, 1982a). Comparison of radiocarbon dates (Table 6.1) from Coquitlam-Port Moody with radiocarbon dates from the Seymour Valley show no observable difference in the timing of this event.

Palynological studies at Port Moody and Mary Hill indicate that during the Port Moody Interstade, the mean annual temperature in the Fraser Lowland was 8°C lower than today and tree lines were depressed by 1200 to 1500 m. Although these were sufficient conditions for glaciation, it is thought that a lack of precipitation prevented this. The lack of precipitation is thought to have been caused by a rain shadow effect from the Vancouver Island mountains, as the open ocean would have retreated some 200 km west of the Fraser Lowland during this time (Hicock *et al.*, 1982a). Four radiocarbon dates (ranging from 17.2 to 19.1 ka BP) collected from sediments in southcentral and southeastern British Columbia (Clague, et al., 1980) indicate, however, that at least part of these regions were ice-free at or around the time of the Port Moody interstade and that climatic changes responsible for the recession of Coquitlam ice was likely more regional. None of the organics dated from southcentral and southeastern British Columbia, however, were found in association with Drift.

Based on degree of soil development, the Port Moody interstade, at Port Moody, is thought to have lasted 3000-4000 years. This is supported by limiting radiocarbon dates (Table 6.1) of 21 500 ± 240 (GSC-2536) years BP (Coquitlam maximum) and 17 800 ± 150 (GSC-2297) years BP (youngest pre-Vashon date from the Coquitlam-Port Moody area) (Hicock and Armstrong, 1981). In the Seymour Valley limiting radiocarbon dates range from 22 ka BP (arrival of Coquitlam ice) to 17.6 ka BP (youngest pre-Vashon date from the Seymour Valley). The continuous presence of drift between these two stratigraphic positions in the Seymour Valley (i.e.. the lack of datable post-Coquitlam Quadra Sand) makes it impossible to constrain the duration of the Port Moody interstade there. There is no evidence from the Seymour Valley, however, to contradict the findings of Hicock and Armstrong (1981).

6.3.1.4 Vashon Drift

Bracketed by radiocarbon dates of 17 600 ± 130 and 11 420 ± 110 years BP, the Unit 5 and Unit 6 sediments are correlated with Vashon Drift. The Vashon Stade is thought to have been initiated by increased precipitation possibly due to shifts in zonal weather pattens (Hicock *et al.*, 1982a). Both the Seymour and Coquitlam valleys were occupied by Vashon ice by about 17.5 ka BP. Chilliwack Valley, however, remained ice-free for at least another 1000 years (Calgue *et al.*, 1988) indicating that the Vashon advance occurred slowly at first, and rapidly after about 16 ka BP, reaching its maximum by about 15 ka BP. The timing of the Vashon Stade in Seymour Valley falls within the accepted time period for the Vashon Stade in the Fraser Lowland.

6.4 Late Wisconsinan to Holocene

6.4.1 Capilano Sediments

Sometime before 11 420 ± 110 years BP (Beta-40687) Fraser ice began to recede from Seymour valley followed by invasion of the sea. As discussed in Chapter 5, the maximum extent of marine incursion following deglaciation is not exactly known. However, the highest documented elevation that fossil shells have been found is ~127 m asl (Wagner, 1959). A possible marine terrace at ~187 m asl is the highest possible marine landform or marine sediment exposure found during this research. Joyce (1976) described sediments exposed in a roadcut (north access road to Rice Lake) at about 210 m asl (elevation measured by this author) as being glaciomarine. Examination of these sediments during the course of this research, however, have classified them as ablation till. The proposed extent of post-Fraser marine invasion in the Seymour Valley (somewhere between 127 and 187 m asl) is supported by data from Coquitlam Valley where marine terraces and raised deltas are found up to an elevation of 140 m asl (Armstrong and Hicock, 1976b). One radiocarbon date on shell from Coquitlam Valley indicates that at 12 ka BP sea-levels were at least 69 m asl (Armstrong and Hicock, 1976; Clague, 1980; Lowdon *et al.*, 1977).

If the 11.5 ka (pre-Sumas) submergence proposed by Mathews *et al.* (1970) and by Armstrong (1981) did indeed occur, then Seymour Valley below Rice Lake Gate was being reshaped by marine processes while the valley above Rice Lake Gate was becoming vegetated. Seymour Valley therefore was not directly effected by ice from the Sumas Stade.

Sediments from Units 8 through 10, therefore, are associated with glaciomarine and recessional glaciofluvial processes and correlated with Capilano Sediments.

6.5 Post-glacial Adjustments

As ice left Seymour Valley, drift deposited on the valley sides was fluvially reworked and deposited as paraglacial alluvial fans and aprons. The term *paraglacial*, first introduced by Ryder (1971a, 1971b) and formally defined by Church and Ryder (1972), is used here to describe nonglacial processes, sediments, and landforms that are a direct result of ice having once occupied the area in question (see Jackson *et al.* (1982) for a discussion on the use of this term).

Radiocarbon dates from post-glacial (Table 6.2.) sediments in Seymour Valley indicate that the majority of paraglacial sedimentation had ended shortly after 10 ka BP. Radiocarbon dates from an aggradational terrace (SVMS-10) shows that incision of Seymour River into the valley fill was ~85% complete before 5 ka BP. This rapid incision suggests that paraglacial sedimentation of Seymour Valley was negligible. This is supported by the fact that paraglacial fans and aprons in the valley have remained virtually intact to this day. At present, many if not most of the tributary streams in the study area have cut through the paraglacial fan and apron deposits and are currently reworking underlying glacial drift. The majority of the paraglacial sediments originally derived from the valley sides therefore are in storage.

Table 6.2 Radiocarbon dates pertinent to paraglacial sedimentation in the Seymour Valley. These dates are a subset of those appearing in Table 5.1.

Date (^{14}C yrs BP)	Lab. No	Location	Significance
11420 ± 110	Beta-40687	SVMS-25	Elsay Creek fan construction is nearly complete. Oldest post-glacial date from the valley.
10350 ± 60[a] 10120 ± 60[a] 9700 ± 170	Beta-38912 Beta-38911 Beta-40690	SVMS-22 SVMS-22 SVMS-13	The last Valley-side material is being deposited in the valley bottom after this time.
5300 ± 70[b] 4980 ± 60[b]	Beta-40686 Beta-46052	SVMS-10 SVMS-10	Incision of Seymour River into the valley fill is ~85% complete before this time.

[a,b] Dates are supportive.

Detailed studies of paraglacial sedimentation in valleys have been undertaken in the interior of British Columbia (Ryder 1971a, 1971b; Church and Ryder, 1972) and in the Bow Valley, Alberta (Jackson *et al.*, 1982). In the Thompson valley (interior British Columbia) ~175 m of valley fill derived under paraglacial conditions accumulated within 1000 years, till comprises only a small proportion of the fill (Church and Ryder, 1972). Similar conditions exist in the Bow valley, where 50-70% of the valley fill is comprised of sediments derived from alluvial fans deposited upstream (Jackson *et al.*, 1982). Jackson *et al.* argue that because of a lack of wood in the fan ("debris flow") deposits they likely formed in the "early millennia" after deglaciation.

In Seymour Valley, like the Thompson and the Bow, the majority of paraglacial fan construction (and aprons in this case) occurred within a few thousand years of deglaciation. In Seymour Valley, however, most of the valley fill is comprised of glacial drift and very little material derived from paraglacial fans and aprons has been deposited downstream. It probably never played a major role in post-glacial aggradation of the Seymour Valley. Toes of fans at Intake (Fig. 4.10), Suicide, and Elsay creeks clearly have been reworked by Seymour River but most of this sediment appears to have quickly moved out of the valley.

In apparent contrast to the Thompson and Bow valleys, the timing of fan and apron formation in Seymour Valley appears to be more complex for much of the apron material overlies organic-rich sediments, and mudflow deposits within fans always contain abundant charcoal. Although the lack of wood (sticks and logs) in fan and apron deposits in Seymour Valley does indicates rapid deposition, it does not in all cases indicate immediate construction following deglaciation - there was clearly a time, albeit short, where vegetation flourished in the valley bottom while a large quantity of glacial sediment remained intact high on the valley sides. The remaining valley-side glacial material may have finally been deposited in response to minor climatic deterioration.

The palynological record in British Columbia shows cool and moist conditions following deglaciation followed by an interval of relatively low precipitation and high temperatures, sometimes referred to as the "early Holocene xerothermic interval" (Mathewes and Heusser, 1981), between about 10 and 7.5 ka BP. This in turn was followed by a return to cool and moist conditions after 7 ka BP (Mathewes, 1985); in fact, glaciers in the Garibaldi area advanced between 6 and 5 ka BP (Ryder and Thomson, 1985). The post-glacial history of the Seymour Valley therefore may be summarized as follows:

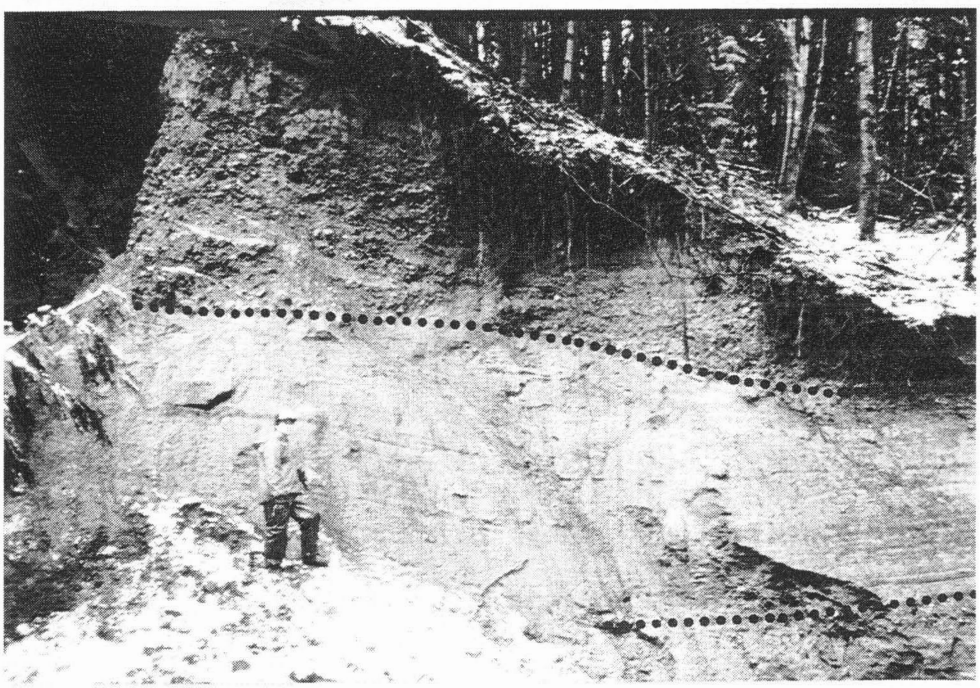


Figure 6.2 *(a) Above*. Elsay Creek fan deposits (SVMS-25). The mudflow deposit in the center of the photograph contains charcoal fragments that were radiocarbon dated to 11 420 ± 110 years BP. The fan surface is near the top of the photograph. This date is significant because it indicates that construction of this fan was complete soon after deglaciation. *(b) Below*. SVMS-21 showing organic-rich Unit 12 lacustrine sediments (between the dotted lines) capped with alluvial apron deposits (Unit 13). Two logs from the base of the Unit 12 sediments yielded radiocarbon dates of 10 120 ± 60 and 10 350 ± 60 years BP. The presence of the Unit 12 sediments here suggest that there was a hiatus before the deposition of the last valley-side glacial sediments in the valley bottom.

1. *Deglaciation to ~11 ka BP*: Climate cool and moist. Early paraglacial sedimentation in progress. Elsay Creek fan construction nearly complete by ~11.4 ka BP.

2. *~11 ka BP to ~7 ka BP(?)*: Climate warm and dry. A drier climate in conjunction with the increasing presence of stabilizing vegetation results in reduced rates of erosion and sedimentation. As paraglacial sedimentation slows Seymour River (and tributaries) begin to incise the valley fill.

3. *After ~7 Ka BP(?)*: Climate cool and moist. Increasing rates of rainfall result in increased rates of erosion and sedimentation. Paraglacial sedimentation chokes tributaries, channels get infilled with organic-rich sediments and are finally capped with debris flow material. Sediment supply from the valley sides quickly diminishes. Fan and apron surfaces become vegetated and stable as streams once again incise.

Given this history, then the pre-5 ka BP aggradation of the lower Seymour Valley (Unit 14 sediments), might have been a response to (3), above.

6.6 Conclusions

The late Quaternary history and stratigraphy of lower Seymour Valley has now been elaborated. The surficial sediments and landforms in the valley show an almost continuous record of sedimentation over a time span more than 37 000 radiocarbon years. Of the 13 lithostratigraphic units defined for the Fraser Lowland (Fig. 2.1), 6 occur in Seymour Valley (Table 6.3). The sedimentary history of Seymour Valley, over this time period, therefore may be summarized as follows:

(1) *Before 37 ka BP to at least 29 ka*: Seymour Valley between Rice Lake and the bedrock canyon, and probably beyond, was occupied by a swamp(?) which was periodically infilled with fluvial sediments, possibly in response to climatic change.

(2) *After 29 ka BP to 22 ka BP*: The rate of sedimentation in Seymour Valley increased dramatically; vegetation was overridden by outwash sands as ice in the headwaters began to advance. By 22 ka BP ice reached the mouth of the valley.

(3) *22 ka BP to ~17 ka BP*: An unstable ice margin in the Fraser Lowland resulted in multiple impoundments of Seymour River. Till, glaciofluvial, fluvial, and possibly glaciomarine sediments were deposited. Sometime before 18 ka BP the ice has retreated far enough, and for long enough, to allow vegetation to become established. This hiatus lasted at least 1000 years (based on radiocarbon dates from Seymour Valley) and possibly up to 4000 years (based on Coquitlam Valley data from Hicock *et al.*, 1982a). By about 17 ka BP ice once again arrived at the mouth of Seymour Valley and till is deposited.

(4) *17 ka BP to 12 ka BP*: Ice probably remained in the valley until about 12 ka BP. Before 11.4 ka BP ice had retreated and vegetation once again became established.

(5) *12 ka BP to present*: Glacial sediments were reworked by Seymour River and its tributaries, and by marine processes as the sea invaded the isostatically depressed valley. Alluvial fans and aprons composed of reworked glacial sediments formed and became stable after 10 ka BP, their rate of formation somewhat conditioned by climatic fluctuations during the immediate postglacial. Before 5 ka BP incision of the Seymour River into the valley fill was ~85% complete, interrupted by only minor period(s) of aggradation. Seymour River became graded to bedrock. The glacial valley

fill, and to a smaller extent, the paraglacial fans and aprons, presently are being eroded by Seymour River and its tributaries.

Table 6.3 Correlation of the lithostratigraphy of the Fraser Lowland with that of the Seymour Valley

Lithostratigraphic units defined in the Fraser Lowland	Lithostratigraphic units defined in the Seymour Valley
Cowichan Head Formation	Unit 1
Quadra Sands	Unit 2
Coquitlam Drift	Unit 3, Unit 4
Vashon Drift	Unit 5, Unit 6, Unit 7
Capilano Sediments	Unit 8, Unit 9, Unit 10, Unit 11
Salish Sediments	Unit 12, Unit 13, Unit 14

6.6 Recommendations for Future Research

(1) The cause of aggradation in Seymour Valley during the Olympia Nonglacial Interval is not known. A detailed palynolgical study of the Unit 1 sediments could possibly confirm if aggradation was the result of climatic fluctuation. Although a palynolgical study was done on correlative sediments in Lynn Canyon, the exposure there is much smaller (~15 ka of deposition represented by only 1 m of peat). A Pollen spectrum from the Seymour Valley exposure would be expected to have greater resolution.

(2) A detailed sedimentological, palynolgical, and microfossil study of the Unit 4 and Unit 5 sediments at SVMS-8, SVMS-11, SVMS-13 etc., would refine the geochronological history of the Valley. Did the sea invade Seymour Valley during the Coquitlam retreat? If so what was the extent of the invasion? What was the climate in the valley like during the Port Moody interstade and how does it compare to the paleoclimatic data already existing for the Coquitlam Valley during that time?

(3) A study of Seymour Valley above Seymour Falls Dam might show the extent of the Coquitlam retreat. There is as yet no evidence to indicate the extent of this retreat.

(4) Post glacial sedimentation in Seymour Valley appears to have been complex. There appears to be an interval when the rate of post-glacial sedimentation decreased during a time of generally high rates of sedimentation. The timing of this interval is not exactly known but could be defined with additional radiocarbon dating. It is possible that this "interval" was climatically induced. A palynolgical study of the sediments deposited during this time (Unit 12) could test this hypothesis.

(5) A more regional study of valleys opening into Burrard Inlet (Lynn, Capilano, etc. valleys) and Howe Sound may shed light on the extent of the Coquitlam Stade.

APPENDIX A

THERMOLUMINESCENCE DATING OF UNIT 1 PEATS

A.1 Introduction

This appendix presents the experimental procedure, data, results, and conclusions of the thermoluminescence (TL) experiments performed on Seymour Valley Unit 1 peats (SVP1 and SVP2). This appendix is required because the science of TL dating of sediments is still in its infancy and therefore if TL dates are to be quoted, the data must also be presented. The general principles of the TL dating of Quaternary events can be found in Berger (1988) or Aitken (1985). The rationale behind this study is discussed in Chapter 3.

A.2 The Experiment

The Partial Bleach (R-Γ) method (Wintle and Huntley, 1982) was used to determine the time of deposition of fine-grained (4-11 μm) sediments found within two of the woody peat beds contained within the sediments of Unit 1. Peat beds were chosen because they represent former low energy environments (relatively slow rates of sediment deposition) important to the zeroing of the TL clock. It was hoped that, by sampling peat clean of fluvial sand beds, aeolian sediments would be acquired. Peat also has been found to act as a closed system thereby reducing the probability of inputs or outputs of uranium and/or thorium over time (Van der Wijk *et al.*, 1986) .

A.3 Field Procedures

Two woody peat beds (SVP1 and SVP2) were selected for TL dating. The location and stratigraphic position of these beds can be found in Chapter 4. SVP1 consisted of an ~20 cm thick bed of woody peat, while SVP2 consisted of a ~20 cm thick peat bed containing an ~2 cm thick bed of sand. The peat below this sand bed was sampled.

In order to determine the gamma-ray contribution to the dose rate, on-site gamma-ray spectroscopy was performed using an Exploranium model GR-256 portable gamma-ray spectrometer. In each case, the spectrometer probe was inserted ~50 cm into the section. In the case of SVP1, the probe was inserted into a sand bed directly above the peat bed, and in the case of SVP2, the probe was inserted in a sand bed directly below the peat bed. In each case the surface of the probe was in contact with the peat bed to be sampled. The probe was inserted into the adjacent sand beds because the peat beds were impossible to auger using the equipment available at the time.

Subsequent to the gamma-ray analysis, a section (block) of each peat bed was removed for laboratory analysis.

A.4 Laboratory Procedure - Sample preparation

The following is the procedure that was used to extract the desired sediments from the peat. It is essentially the same procedure used by Divigalpitiya (1982). One can refer to this reference for a more detailed explanation. All of the following steps were performed under appropriate lighting conditions.

1. The outer surfaces of the peat blocks sampled from the field were removed. This material had been exposed to light and therefore could not be used for dating purposes.

2. The peat blocks were examined for any small sand beds. If a sand bed was found, the block was split about this bed. This was done to avoid sampling any sediments which had been deposited by fluvial processes. It was therefore hoped that aeolian sediments were being sampled. Two such beds (~3 mm thick) were found in SVP2; none were found in SVP1.

3. A few grams of peat was shaved off with a knife and left in distilled water for about two days. This was done so that the peat could expand and loosen up.

4. The sample was then wet-sieved through a 37 μm nylon screen. This was done to minimize the size of the organic fragments used in step 5.

5. The <37 μm fraction was put in 10% H_2O_2; fresh H_2O_2 was added each day. After three days the organics had oxidized and the remaining sample (minerals) was rinsed with distilled water.

6. The sample was put in 10% HCl for two hours and then rinsed with distilled water. This was done to remove any carbonates present.

7. The sample was put in 100 ml of citrate bicarbonate dithionate (CBD) for 12 hours. This was done to remove any TL-blocking iron oxide coatings on the sediment grains. The CBD solution was made by adding 71 g of citrate, 8.5 g of bicarbonate, and 2 g of dithionate to 1 liter of distilled water.

8. Stokes settling in a 20 cm column of 1 g/liter Calgon solution for 4 hours (suspension discarded) and then for 30 minutes (suspension saved) to separate 4-11 μm size grains. The Calgon is needed to defloculate any clay present.

9. The 4-11 μm grains were rinsed with distilled water, methanol, and acetone. Equal quantities (1 ml) of a suspension of the sediment in acetone was then pipetted into vials containing 1 cm diameter aluminum disks. The vials were then set aside to allow the acetone to evaporate. The final result was a number of aluminum disks covered with a uniform layer of sediment.

A.5 Laboratory Procedure - Determination of the Equivalent Dose

The equivalent dose (D_{eq}) was determined using the Partial Bleach (R-Γ) method. The procedure was as follows:

1. To construct the R-Γ curves, portions of each sample were given gamma doses of 0, 30, 60, 90, and 120 Gy γ using a ^{60}Co source (Atomic Energy of Canada Ltd. model 200 *Gammacell*; dose rate = 0.75 Gy/min).

2. To determine the α effectiveness (b-value), portions of each sample were irradiated for 80, 160, 240, and 320 min. using an Oxford style α-irradiator (^{241}Am source; strength ~0.38 $\mu^{-2}min^{-1}$).

3. The "bleachability" of the samples was tested by exposing one of them (SVP1) for different durations under artificial light (simulated sunlight). A Philips halogen automobile headlamp (lens removed) behind a Corning O-52 glass filter was used to deliver 5.8 mW of light to the sample. The Corning O-52 filter cuts out excessive UV light (<340 nm) produced by the halogen lamp and therefore helps approximate the natural bleaching that would have occurred during aeolian transportation.

After studying the results (Fig. A.1) it was decided that 10 hours of exposure would be used to produce the bleached portion of the samples.

4. To eliminate the effects of anomalous fading, the samples were heated at 110 °C for four days as per the recommendation of Dr. Glenn Berger, (personal communication, 1991).

5. Half of the sample disks were bleached for 10 hours (see step 3 above) and then set aside for approximately two weeks.

6. The TL of all the sample disks were measured using the apparatus described by Divigalpitiya (1982). The optical filters used in front of the photomultiplier tube, in this case, consisted of a Schott KG-1 (heat absorbing filter), a Schott BG-38, and a Corning 7-59.

7. R-Γ plots or growth curves (Fig. A.2) and finally plateau plots (D_{eq} vs temperature) (Fig. A.4) were constructed from the acquired data. The D_{eq} for each sample was estimated from the "plateau" data and appears in Table A.4.

A.6 Dose Rate Determination

The equations used to determine the TL age are essentially those discussed in Divigalpitiya (1982). An additional factor, ξ, appears here to convert the concentrations of U, Th, and K_2O concentrations of the bulk sample (organics plus minerals) to that of only the minerals. The equations are presented below with the constants and measured values appearing in tables A.1 and A.2 respectively.

The TL age, *t*, was determined by the age equation:

$$t = D_{eq}/(\dot{D}_\alpha + \dot{D}_\beta + \dot{D}_\gamma + \dot{D}_c) = D_{eq}/\dot{D}_{TOT}$$

where D_{eq} is the equivalent dose (Gy) and $\dot{D}_\alpha$, $\dot{D}_\beta$, $\dot{D}_\gamma$, and $\dot{D}_c$ are the dose rates (Gy/ka) from alpha, beta, gamma, and cosmic radiation, respectively.

(a) alpha dose rate:

$$\dot{D}_\alpha = 4\eta b\,(C_U + C_{Th})/0.835$$

where,

$$C_U = \chi_U \bullet [U] \quad \text{and} \quad C_{Th} = \chi_{Th} \bullet [Th]$$

(b) beta dose rate:

$$\dot{D}_\beta = \dot{D}_{\beta_K} + \dot{D}_{\beta_{Th}} + \dot{D}_{\beta_U}$$

where,

$$\dot{D}_{\beta_K} = d_{\beta_K} \bullet \%K_2O \bullet \xi/[1 + (H_{\beta w})(\Delta^w) + (H_{\beta o})(\Delta^o)]$$

$$\dot{D}_{\beta_{Th}} = d_{\beta_{Th}} \bullet [Th] \bullet \xi/[1 + (H_{\beta_w})(\Delta^w) + (H_{\beta_o})(\Delta^o)]$$

$$\dot{D}_{\beta_U} = d_{\beta_U} \bullet [U] \bullet \xi/[1 + (H_{\beta_w})(\Delta^w) + (H_{\beta_o})(\Delta^o)]$$

(c) gamma dose rate: measured in the field using a portable gamma-ray spectrometer.

Table A.1 Constants Used in the Determination of the Dose rate

CONSTANT	VALUE	UNITS	REFERENCE
d_{β_K}	0.676	$(Gy/ka)\bullet(\%K_20)^{-1}$	Berger, 1988
$d_{\beta_{Th}}$	0.0286	Gy/ka•ppm	Nambi and Aitken, 1986
d_{β_U}	0.147	Gy/ka•ppm	Nambi and Aitken, 1986
H_{β_o}	1.20	none	Divigalpitiya, 1982
$H_{\beta w}$	1.25	none	Berger, 1988
χ_U	0.0372	$counts/ks\bullet cm^2\bullet ppm$	Nambi and Aitken, 1986
χ_{Th}	0.1281	$counts/ks\bullet cm^2\bullet ppm$	Nambi and Aitken, 1986
η	0.90	none	Aitken, 1985

Table A.2 Measured/Calculated Values used in the Determination of the Dose Rate

SAMPLE	ξ	Δ^o	Δ^w	b^3	$[U]^1$	$[Th]^1$	$\%K_2O$ [2]
SVP1	1.51	0.51	2.6	1.20 ± 0.08	1.42 ± 0.07	3.3 ± 0.3	0.72
SVP2	3.14	2.14	2.1	1.10 ± 0.08	0.82 ± 0.07	2.3 ± 0.2	0.26

1. Concentrations of Uranium and Thorium (ppm) were determined by DNA and NAA analyses, respectively. The analyses were performed by the Australian Nuclear Science & Technology Organization (Ansto) at Lucas Heights Laboratories, New Illawara Road, Lucas Heights , New South Wales, Australia.

2. Percentage K_2O was determined by Chemex Labs Ltd., 212 Brooksbank Ave., North Vancouver, British Columbia.

3. b-value in $Gy\bullet\mu m^2$. See Berger (1988) for an explanation of this quantity.

Δ^O = Organic content of peat = (mass organics)/(mass minerals).

Δ^W = Water content of peat = (mass water)/(mass mineral). Δ^W was measured immediately following collection from the field.

ξ = (mass of dry peat)/(mass of minerals in peat).

A.7 Results

Table A.3 Dose rates (Gy/ka)

SAMPLE	$\dot{D}_\alpha$	$\dot{D}_\beta$	$\dot{D}_\gamma$[1]	$\dot{D}_c$[2]	$\dot{D}_{TOT}$
SVP1	0.480 ± 0.004	0.249 ± 0.004	0.427 ± 0.017	0.04 ± 0.02	1.21 ± 0.03
SVP2	0.306 ± 0.025	0.183 ± 0.001	0.425 ± 0.017	0.04 ± 0.02	0.945 ± 0.035

1. It should be noted that since the gamma-spectrometer probe was not inserted, in each case, directly into the peat beds sampled, the values of $\dot{D}_\gamma$ are in error. To correct for this discrepancy, $\dot{D}_\gamma$ was recalculated for SVP2 using a "layered model" which takes into account the attenuating effects of the surrounding layers of sediment (see Aitken (1985) Appendix H for a discussion of this model). The calculations showed that the value of $\dot{D}_\gamma$ measured from the underlying sand bed (Table A.3) was about 20% too high. This does not, however, effect the the apparent TL age reported in Table A.4, for the uncertainty in D_{eq}, in this case, dominates the uncertainty in the final TL age.

2. $\dot{D}_c$ estimated from data found in Prescott and Hutton (1988).

Table A.4 TL Ages

SAMPLE	D_{eq} (Gy)	$\dot{D}_{TOT}$ (Gy/ka)	TL AGE (ka)
SVP1	50 ± 8[1]	1.21 ± 0.03	41 ± 7
SVP2	inconclusive[2]	0.945 ± 0.035	inconclusive

1. Estimated from the 280 to 320 °C region.

2. See discussion below.

A.8 Discussion

TL analysis of the two woody peat beds SVP1 and SVP2 yielded an apparent TL age of 41 ± 7 ka for SVP1 (Table A.4) and an inconclusive result for SVP2. A slight plateau, it's presence probably masked somewhat by the effects of the 110 °C preheat, gives confidence to the age determined from SVP1. The TL age from SVP1 may be compared with a radiocarbon date of 29 440 ± 300 years BP (Beta-46053) obtained directly from the peat where SVP1 was sampled. In order to compare this radiocarbon date with the TL date, the radiocarbon date must first be converted to calendar years. Using the calibration curve of Bard *et al.* (1990) it can be estimated that ~3.5 ka should be added to Beta-46053 bringing it up to about 33 ka. This is almost within the uncertainty estimated for SVP1.

SVP2, however, fails the plateau test and therefore a TL age for this sample could not be determined. The anomalous results from SVP2 are discussed below.

Berger (1990) hypothesized that the lack of a plateaux for four of his samples could be due to the possible effects of a large fraction of quartz. Berger argued that "the light-sensitive TL of quartz in [his] waterlaid sediments might not be zeroed at the time of deposition, and at higher useful glow-curve temperatures...the thermally stable TL signal from feldspars (peak <300°C at 5°C/s) is masked by that of quartz (peak >320°C)." This could certainly be the case here. Comparison of the "natural" glow curves of SVP1 and SVP2 (Figs A.3 and A.4) shows that there is greater relative TL in the high temperature region of SVP2 than of SVP1, in fact one can see the presence of a peak at ~350°C in the SVP2 Natural and N + 10 hrs sun glow-curves. On the other hand, if the high temperature TL that was being measured was dominated by the TL from an inadequately zeroed quartz peak, then the resulting Deq would be higher than expected, which is the opposite of what occurred.

The assumption that the sediments sampled in SVP2 were transported by aeolian processes could possibly be incorrect. The presence of two small sand beds within the SVP2 peat suggests that this peat bed formed near a stream. Although the sediment extracted for dating purposes was from a "clean" portion of the peat, there is still a chance that a significant fraction of the sediment sampled could have been transported by fluvial processes. If this was indeed the case, then the choice of bleaching filter was incorrect. A filter which cuts off more UV light, for example a Corning 3-67, should have been used. The data suggests, however, that the choice of filter for the bleach was not incorrect, for a TL age older than expected would have resulted, which again is just opposite of what occurred.

The low estimated TL age of SVP2, could be the result of a change (increase) in the dose rate over time. An input of uranium through ground water sometime after deposition could be responsible for this. The presence of at least five highly organic peat beds above SVP2 should have, however, acted as filters to prevent this (Van der Wijk, 1986). It is conceivable though, that "unfiltered" groundwater, originating from the Seymour River before it incised to its present position, could have entered SVP2 by moving laterally through directly overlying or underlying sand beds. Whether or not there is disequilibrium in any of the TL-producing radioactive decay chains is not known at this time.

An interesting effect was observed in the high temperature region of the SVP2 Natural and N + 10 hrs sun glow-curves (Fig. A.4). At temperatures greater than 440°C the TL from the bleached sample is greater than that of the Natural sample. This seems to suggests that high temperature traps are not only being emptied but are being filled during the "bleaching" process, the filling being greater than the emptying at temperatures greater than 440°C. If this (phototransfer) is actually what is being observed, then not only would one not get a plateau, but one would obtain a D_{eq} which is too low - which appears to be what happened.

All of the above are of course just speculations. The fact still remains that due to the absence of a plateau, a TL age cannot be determined from SVP2 data.

A.9 Recommendations for future study

(1) Use the appropriate optical filters in front of the photomultiplier tube, a Corning 5-58 for example, to select TL from the more "bleachable" feldspars.

(2) Use an optical filter during the laboratory bleach which passes only the longer wavelenghths. This would reduce the effects of phototransfer.

(2) Improve the field dossimetry. This could be accomplished by inserting the gamma spectrometer probe directly into the peat beds to be dated. This would require a better auger.

A.10 Conclusions

Apparent TL age of 41 ± 7 ka (SVP1) was obtained from sediments extracted from a woody peat bed of Unit-1. The TL age of 41 ± 7 ka is supportive of the ^{14}C age of 33 ka (calibrated to calendar years) obtained from peat at about the same elevation. TL analysis of SVP2 gave inconclusive results.

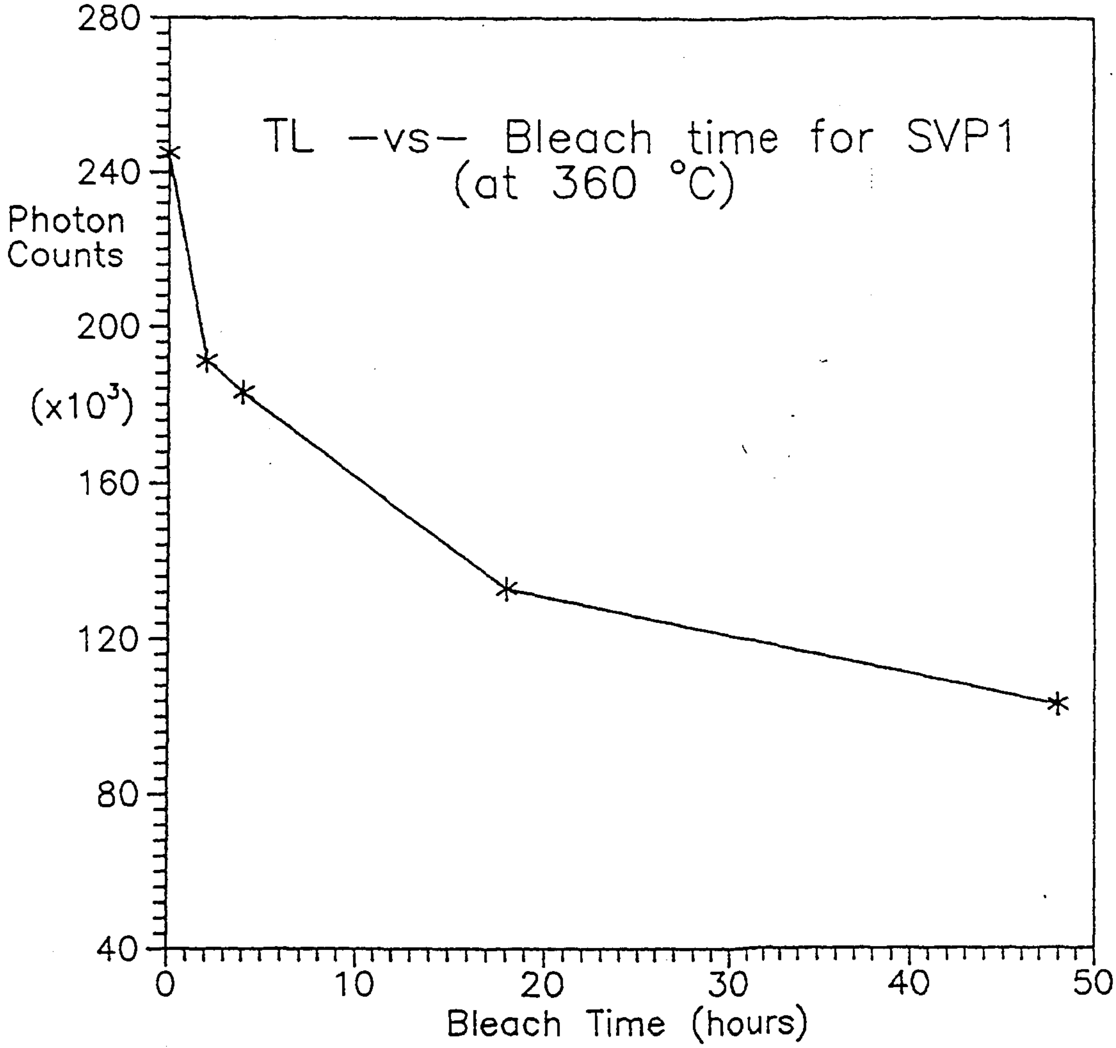


Figure A.1 Reduction of TL at 360°C as a function of bleach time for SVP1

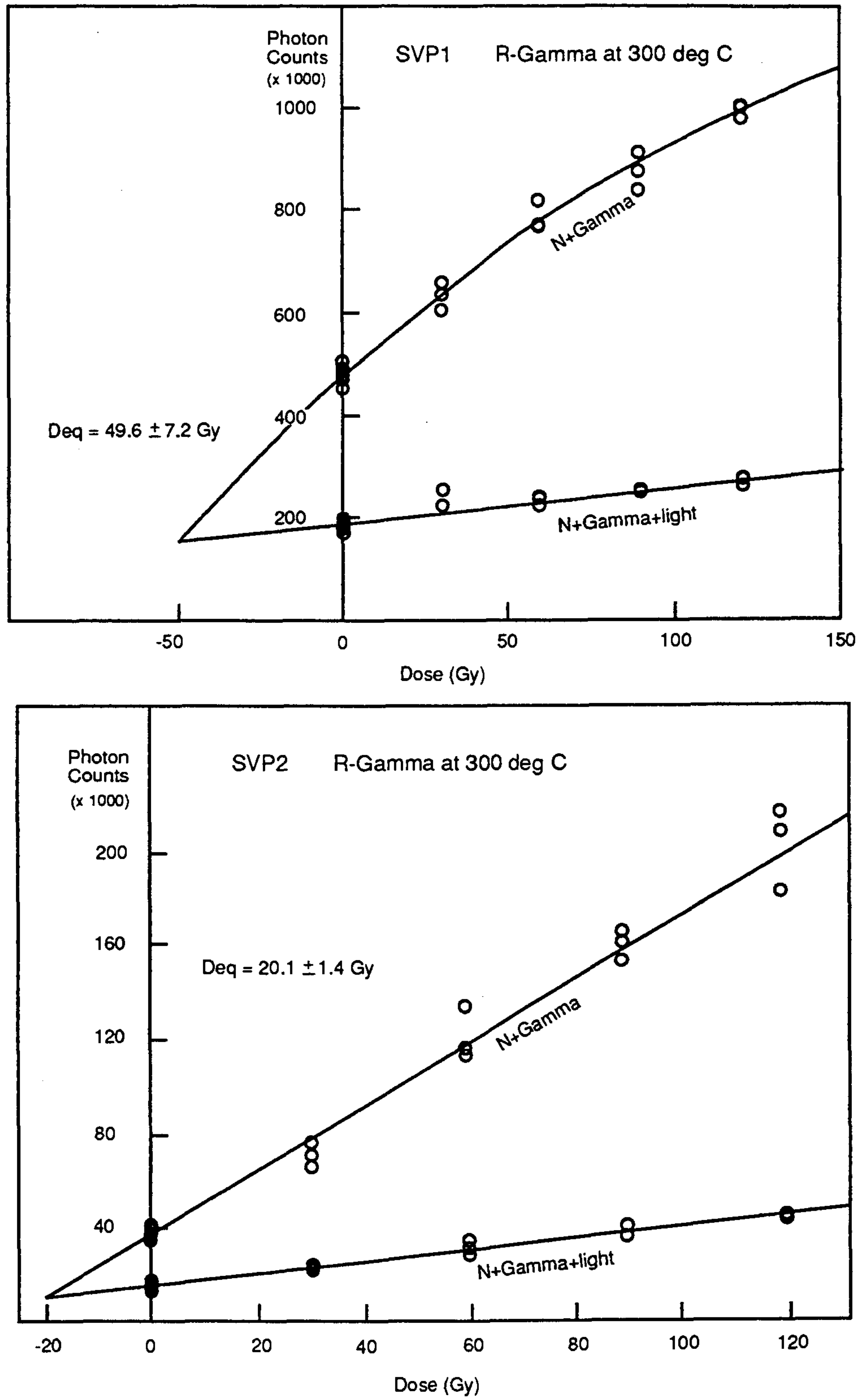


Figure A.2 Growth curves for SVP1 and SVP2 at 300 degrees C.

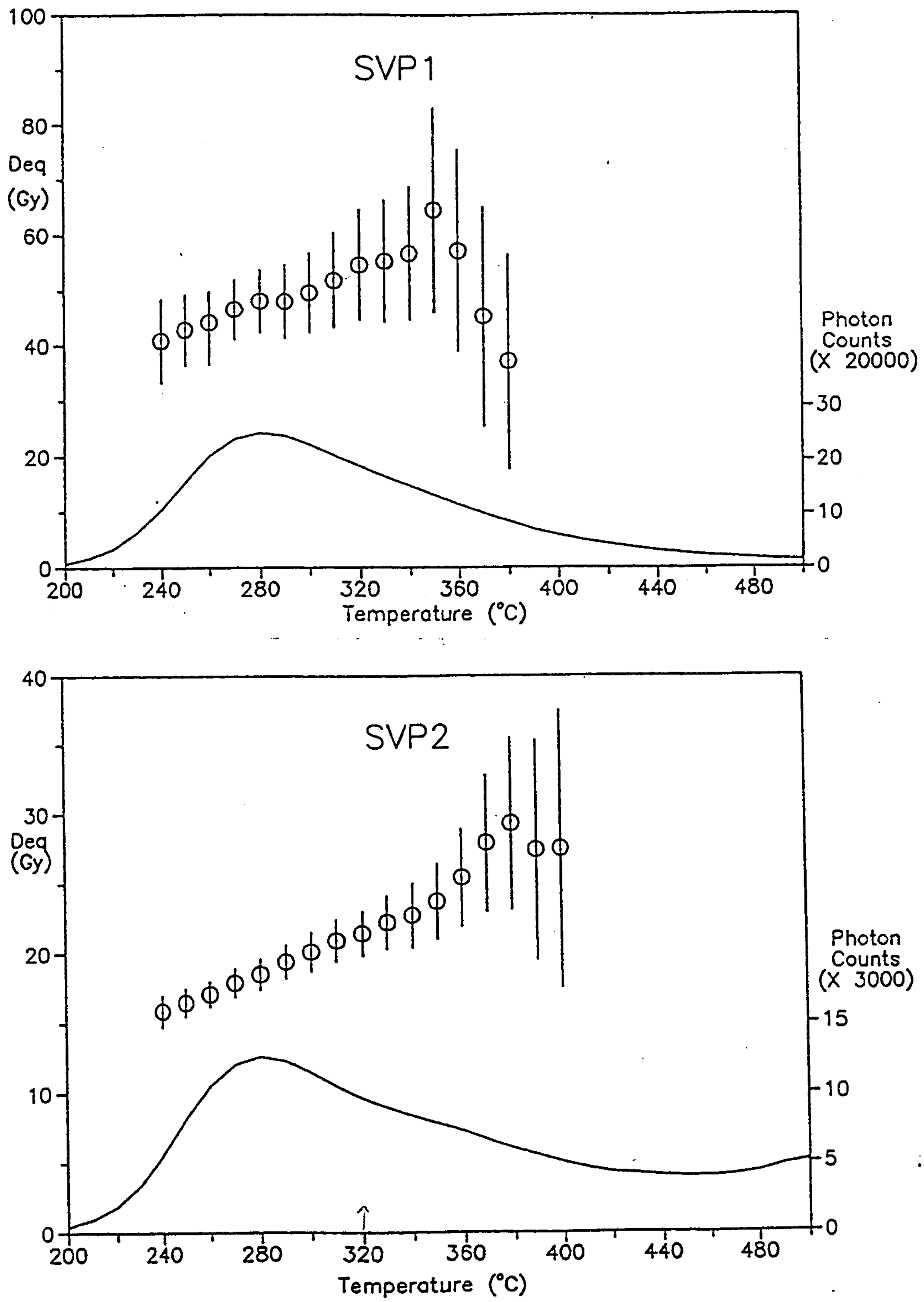


Figure A.3. Plateau plots (D_{eq} -vs- temperature) for SVP1 and SVP2. "Natural" glow curves are shown for comparison.

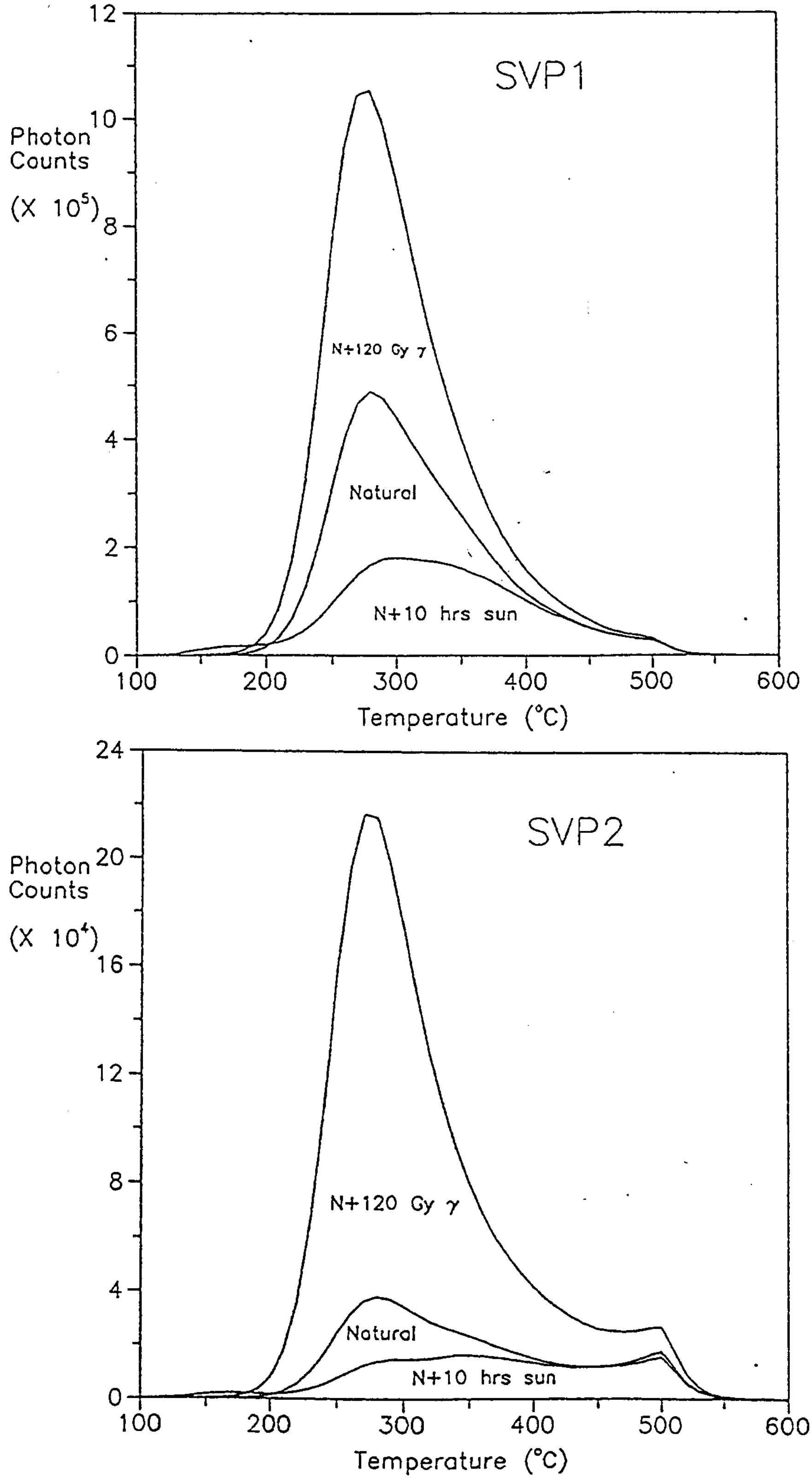


Figure A.4 Glow curves (TL -vs- temperature) for SVP1 and SVP2. The *Natural* (N) and *Natural plus 10 hours sun* (N + 10 hrs sun) curves are the average of six measurements, while the other curves are averages of three measurements. See the text for a discussion of these curves.

APPENDIX B

LOCATION OF MEASURED SECTIONS

This appendix gives the locations of the measured sections (SVMS) used in this research. The maps are modified forms of GVRD maps WG-625. Not shown in Figure B.2 are the locations of SVMS-1, -2a, -2b, -3, -29, and -30 (the GVRD maps do not cover this area); the location of these sections are described in Table B.1. The general location of all the measured sections appear in Figure 4.1, and again here in Figure B.1.

Table B.1 Location of measured sections not appearing in Figure B.2.

SVMS-1	Upper parking lot behind the Coach House Motel.
SVMS-2a	Corner of Seymour Boulevard and Mount Seymour Parkway.
SVMS-2b	Capilano College south campus parking lot. The exposure was part of an excavation during the construction of the Sportsplex building, summer 1990.
SVMS-3	East side of Riverside Drive, 400 m north of the intersection of Riverside Drive and Seymour Boulevard.
SVMS-29	Drainage ditch on the east side of Lillooet Road, 900 m south of Rice Lake Gate or 2.8 km north of Monashee Drive.
SVMS-30	East side of Lillooet Road, 400 m north of Purcell Way

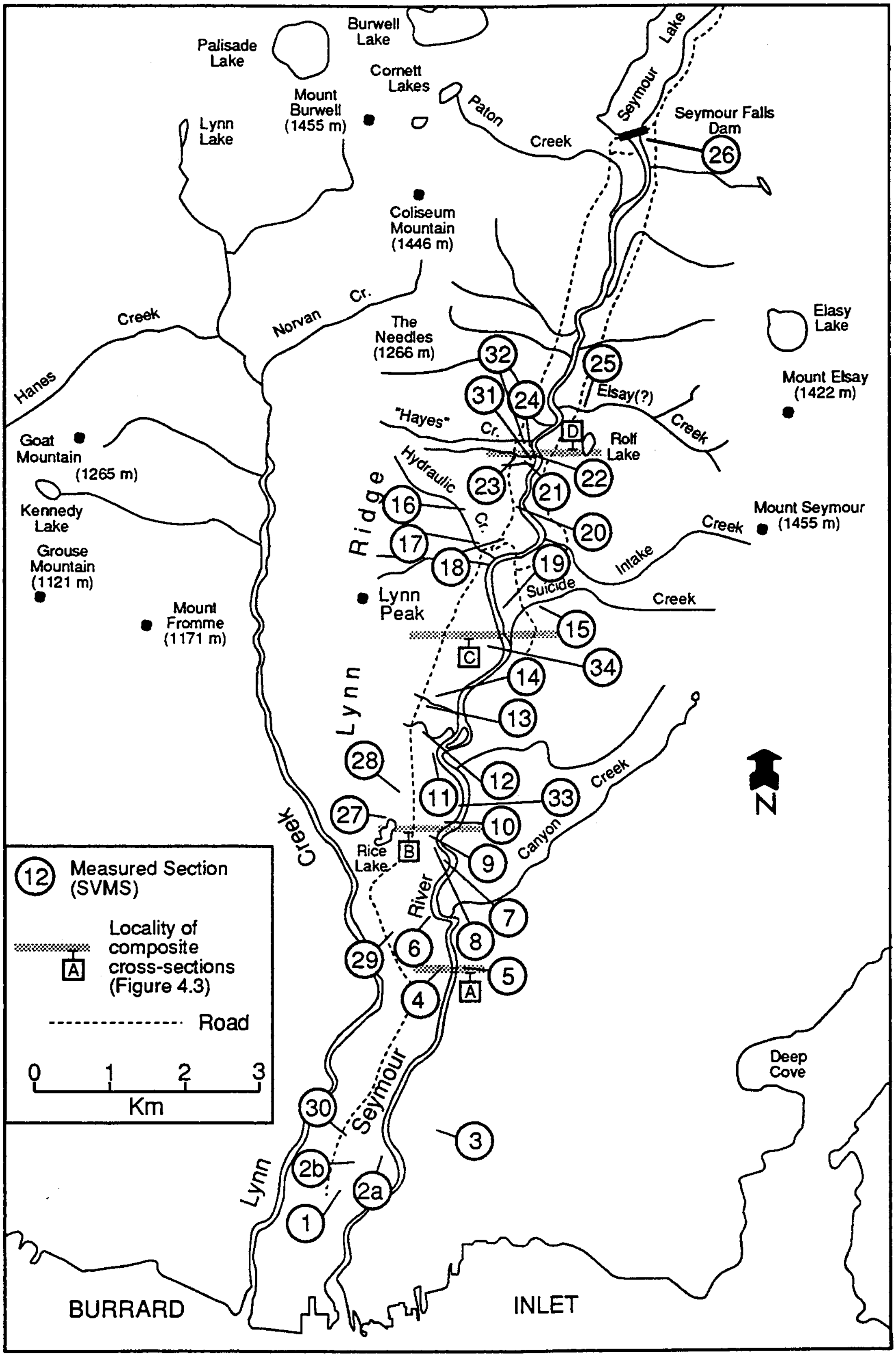
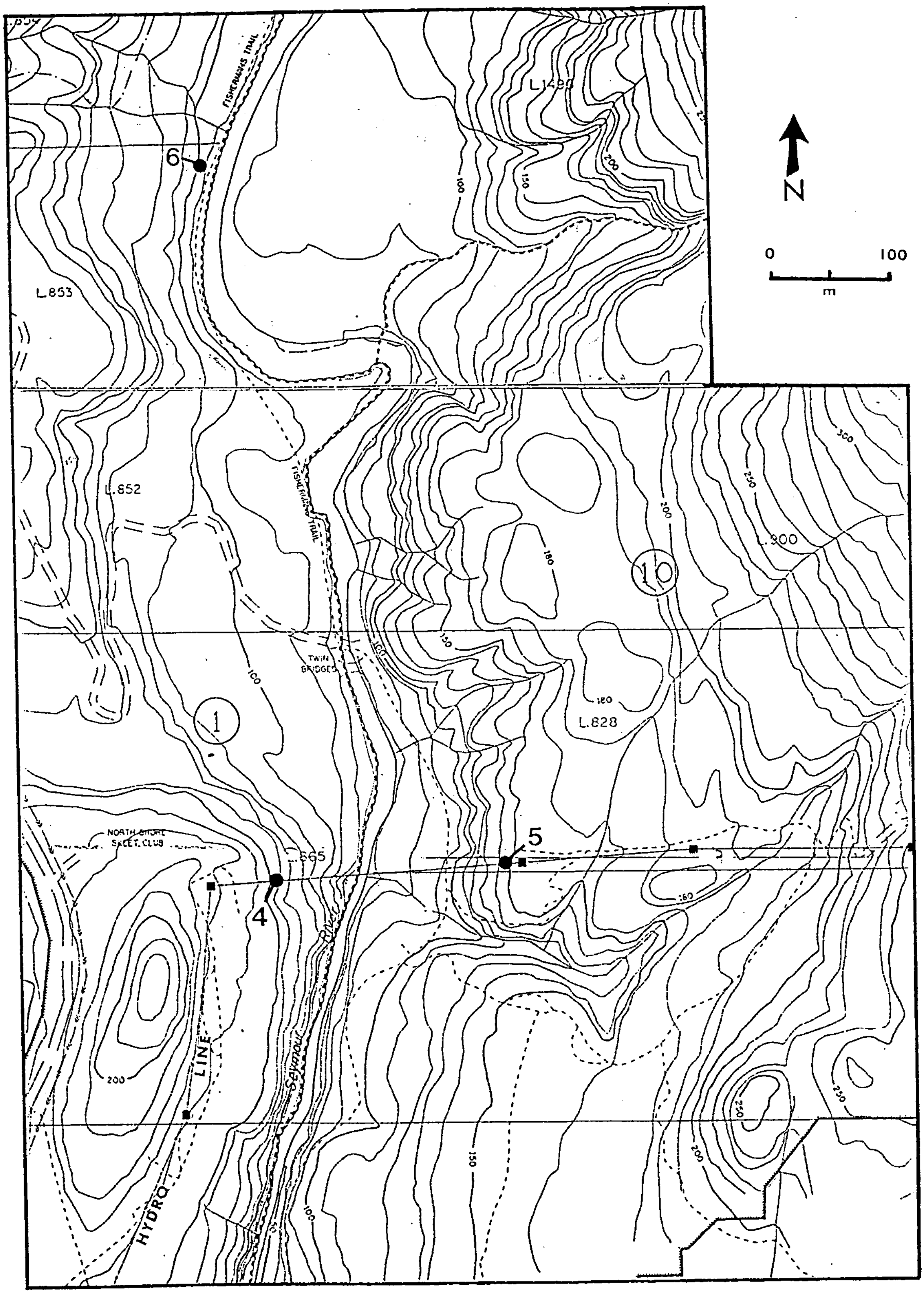


Figure B.1 General locations of measured sections.

Figure B.2a



Figures B.2a to B.2f Location maps of measured sections (SVMS). Scale 1:10 000.

Figure B.2b

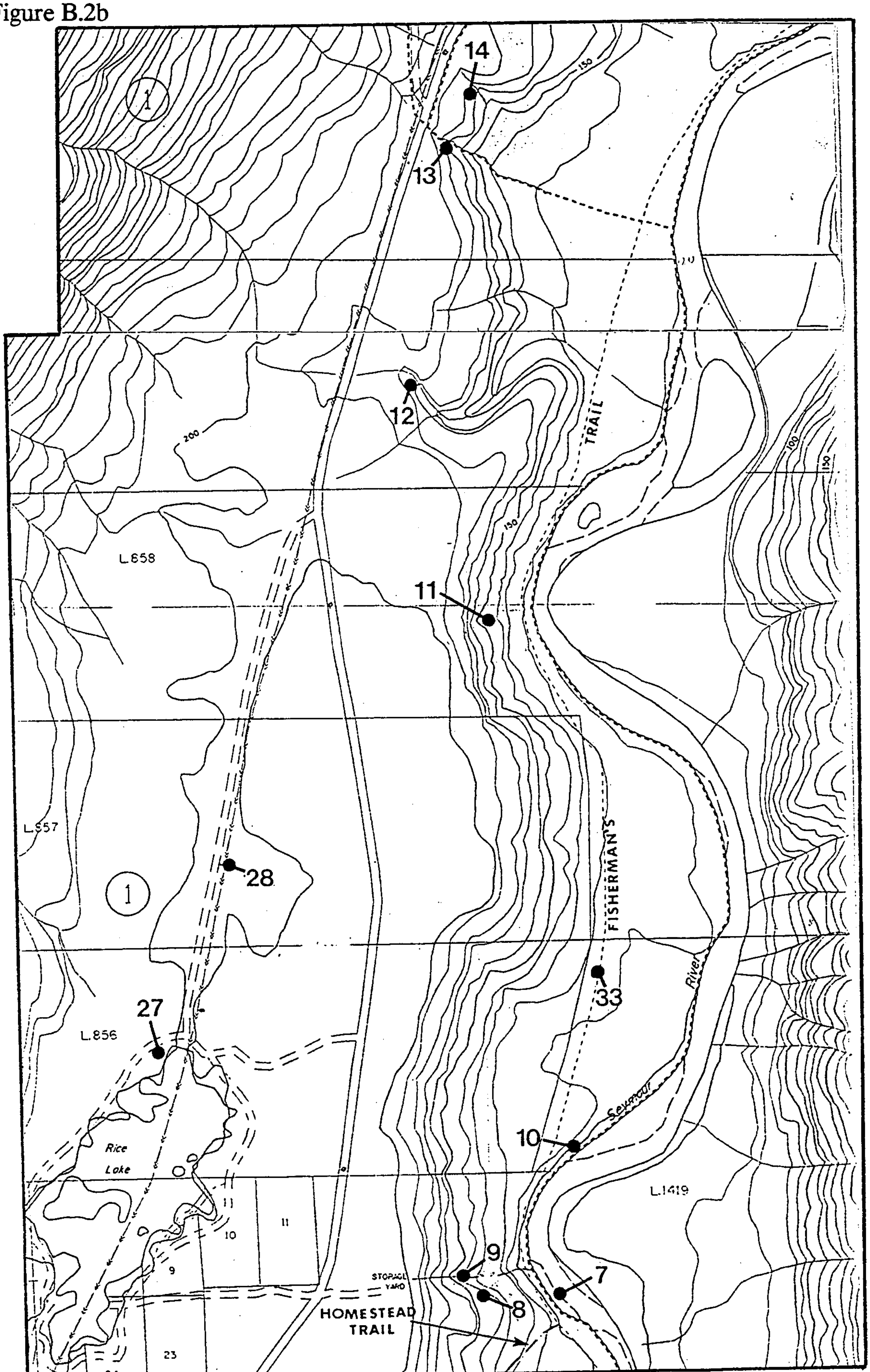

14
1
13
150
200
12
TRAIL
100
150
L.658
150
11
L.857
FISHERMAN'S
1
28
33
River
27
L.856
Seymour
10
Rice
Lake
L.1419
11
11
10
9
9
STORAGE
YARD
7
8
HOMESTEAD
TRAIL
23
24

Figure B.2c

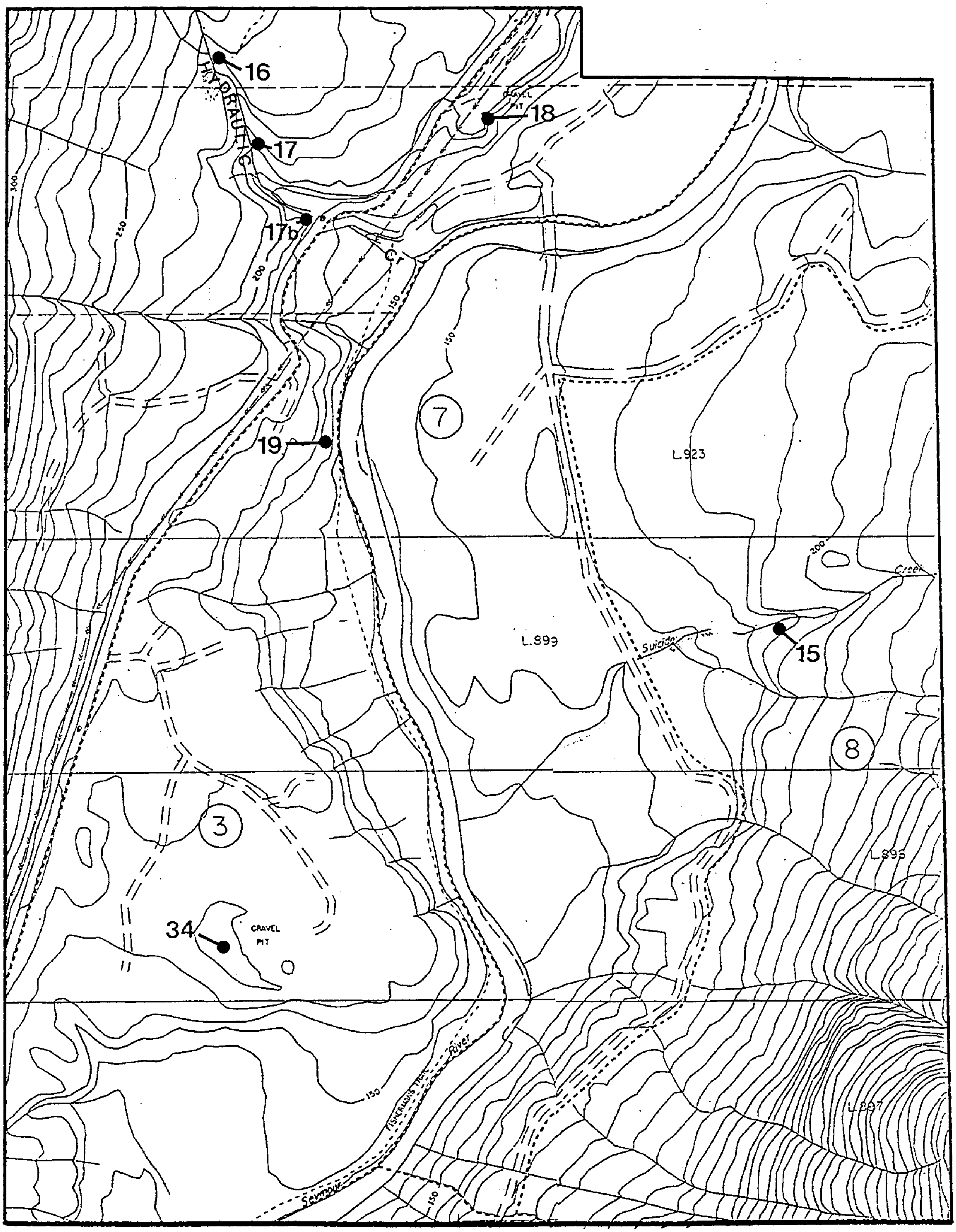
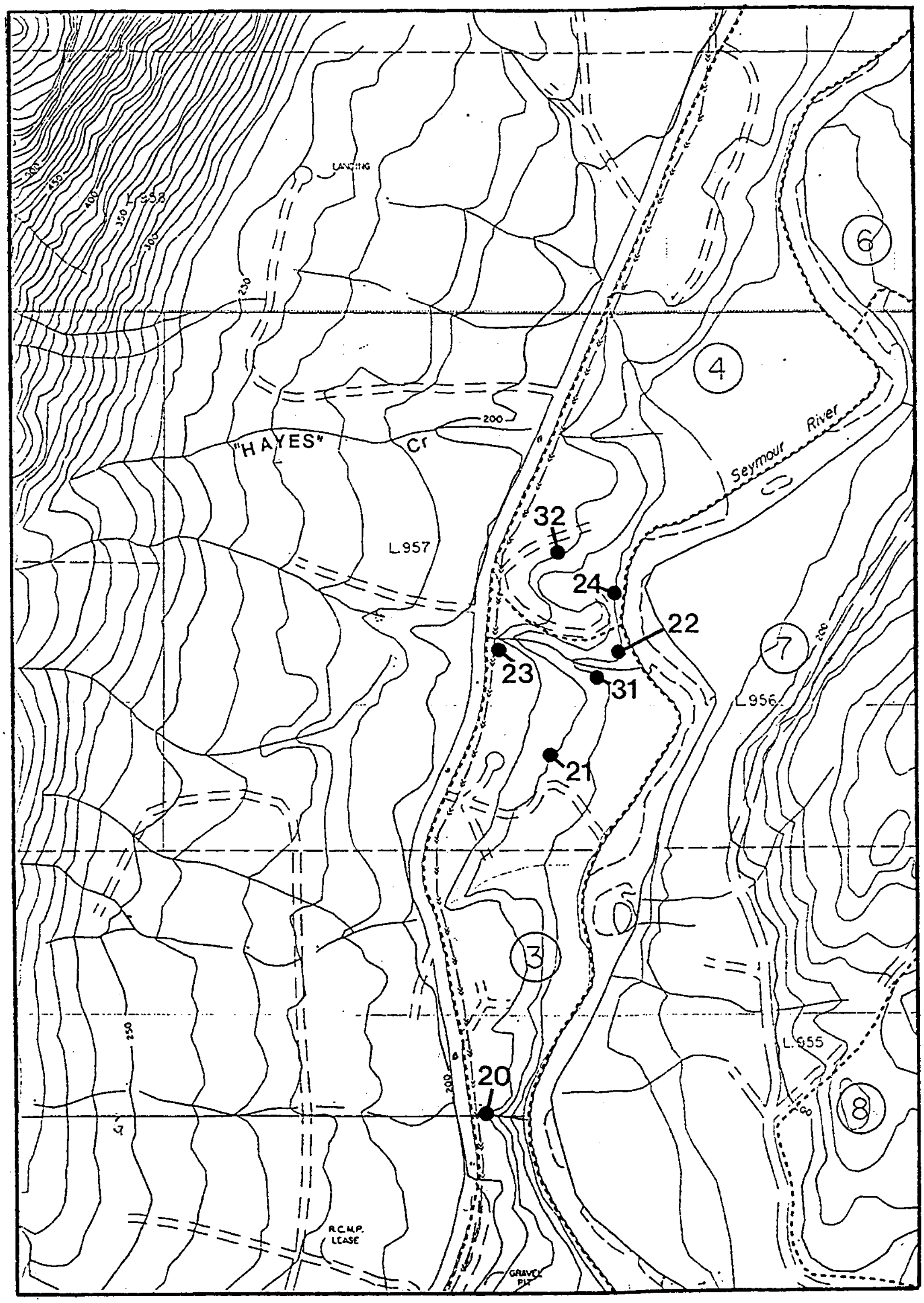

16
HYDRAULIC
17
17b
GRAVEL PIT
18
300
250
200
150
7
19
L.923
L.899
200
Creek
Suicide
15
8
3
L.896
34
GRAVEL PIT
River
130
L.897
Seymour
150

Figure B.2d



LANDING
L.958
"HAYES" Cr
200
L.957
Seymour River
4
6
7
L.956
3
L.955
8
32
24
22
23
31
21
20
R.C.M.P. LEASE
GRAVEL PIT

Figure B.2e

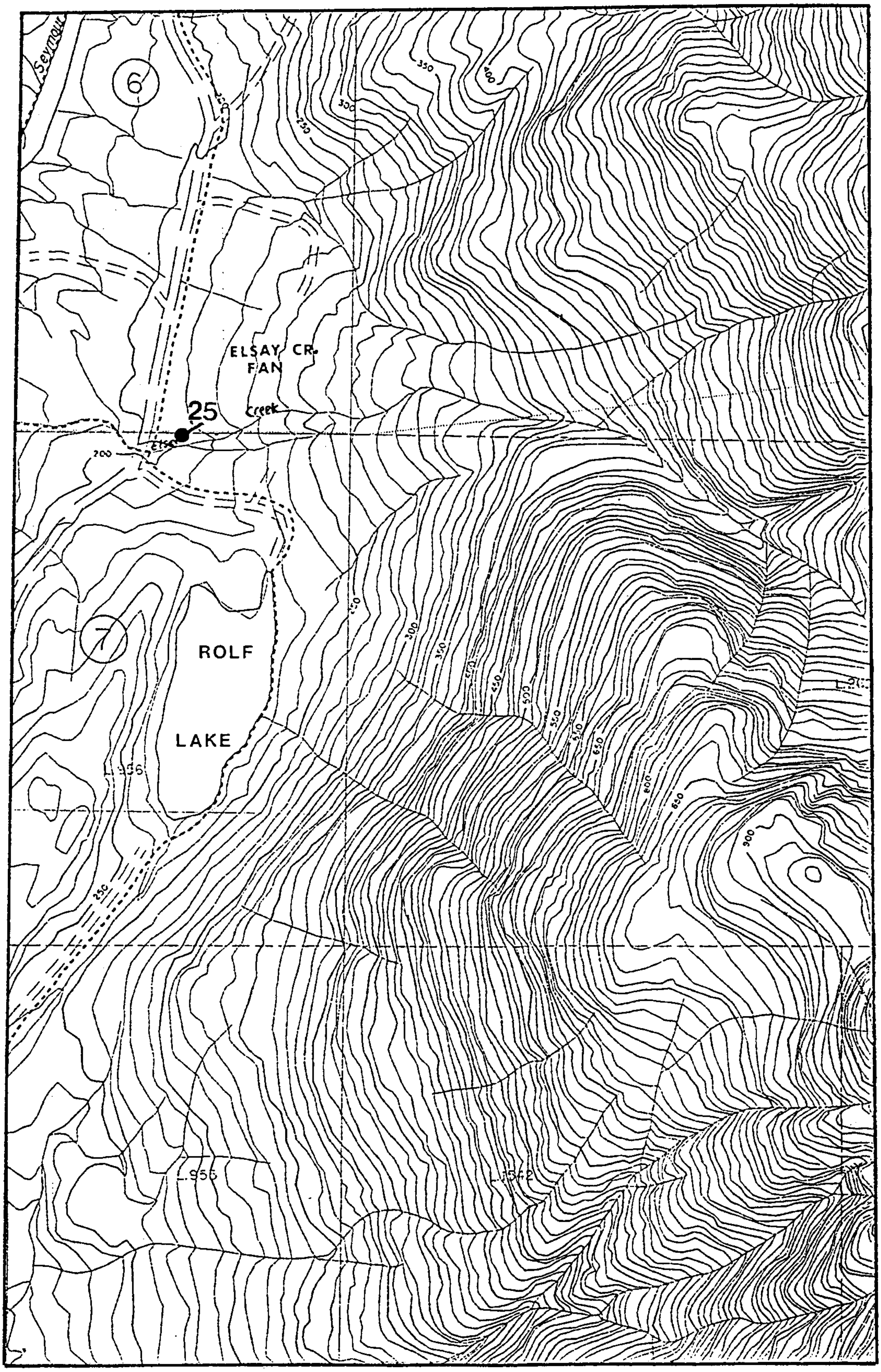
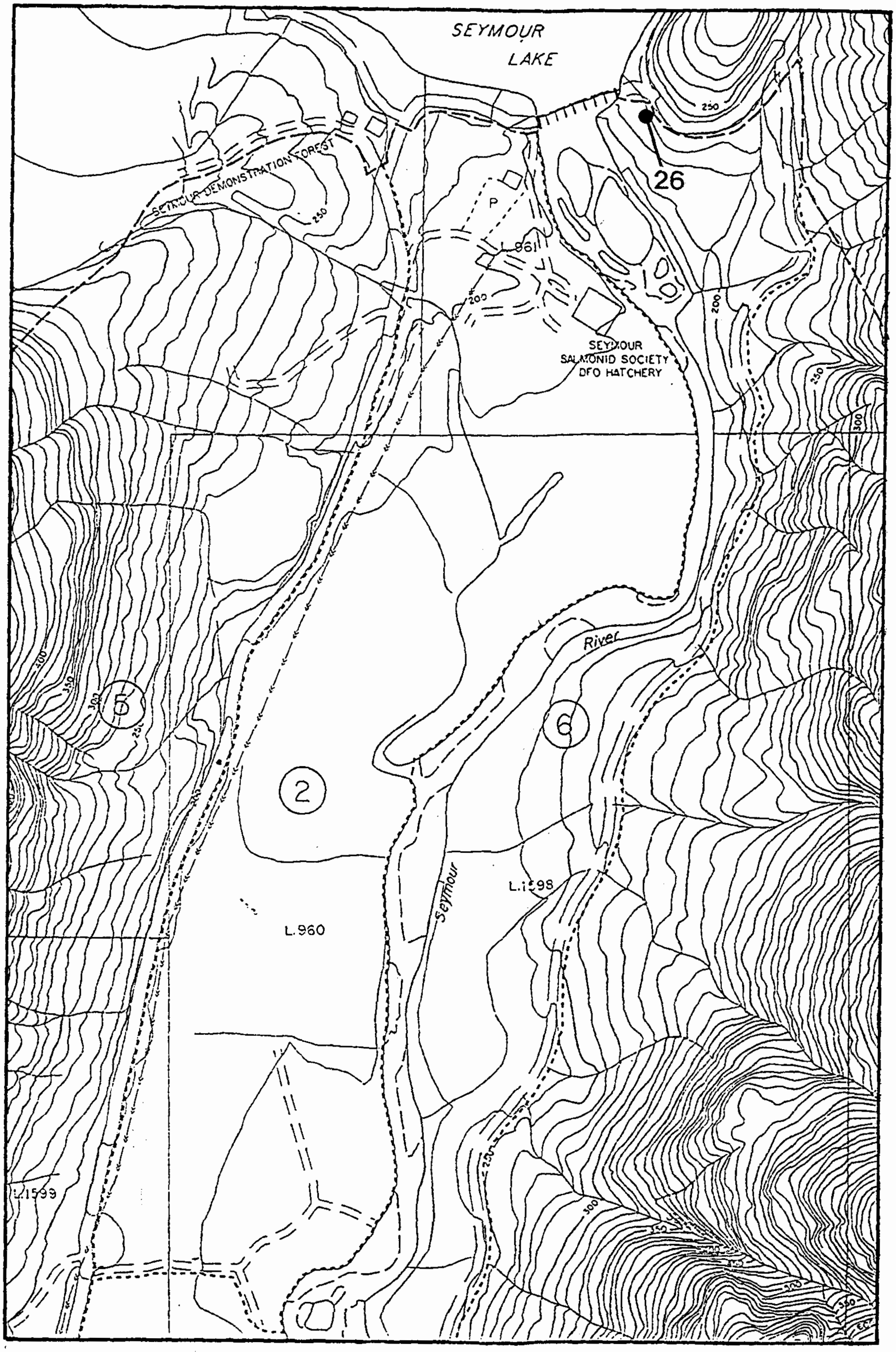


Figure B.2f


SEYMOUR
LAKE
SEYMOUR DEMONSTRATION FOREST
26
P
L.961
SEYMOUR
SALMONID SOCIETY
DFO HATCHERY
River
Seymour
5
6
2
L.960
L.1599

APPENDIX C

DESCRIPTIONS AND INTERPRETATIONS OF MEASURED SECTIONS NOT APPEARING IN FIGURE 4.3

SVMS-1

29 to 18 m asl: Interbedded silt and sands (fine to medium). Beds become somewhat "confused" in lower half of exposure. Occasional clay clast (rip-up) in lower half of exposure. Beds are dipping to the southwest at approximately 15°.[glaciofluvial outwash-deltaic]

SVMS-2a

19 to 16 ma sl: Bioturbated (massive?) blue-grey clay with occasional sand stringer. Occasional dropstones are also observed [glaciomarine drift].

SVMS-2b

50 to 48 m asl: Fill

48 to 46 m asl: Pebble beds (imbrication noted in the south direction), horizontally bedded and crossbedded medium and coarse sands [glaciofluvial outwash].

46 to 45 m asl: Horizontally interbedded fine and medium sands [glaciofluvial outwash].

45 to 42 m asl: Non-compact massive blue clay with occasional sand stringer. Occasional dropstones, 1 cm dia. average [glaciomarine drift].

SVMS-3

49 to 45 m asl: Crossbedded sands, gravels, and cobbles. beds dipping roughly northwest [glaciofluvial outwash-deltaic?].

SVMS-30

80 to ~82 m asl: Horizontally bedded and crossbedded sands, gravels, pebbles, and cobbles. High degree of sorting noted in some of the pebble beds. Surface of exposure is a terrace [littoral deposits?].

SVMS-5

This section gives virtually the same information as SVMS-4. See Figure 4.3a.

SVMS-29

170 to 167 m asl: Subrounded to rounded clasts up to 20 cm dia. (~ 5 cm ave. dia.) in a compact sand matrix [glaciofluvial outwash].

167 to 165 m asl: Subrounded to rounded pebbles interbedded with medium sand. High degree of sorting in the pebble beds [glaciofluvial outwash].

165 to 164 m asl: Horizontally interbedded medium and coarse sands. Included is the occasional pebble bed [glaciofluvial outwash].

SVMS-27

203 to 201 m asl: Matrix-supported diamicton. Fairly compact. Subrounded to angular clasts- granitic with occasional volcanic clast. Diamicton is interbedded with bedded sand, gravel, and cobbles [ablation till, glaciofluvial outwash].

SVMS-28

202 to 198 m asl: Bedded sands and gravels containing lenses of compact diamicton and isolate "clasts" of structured sand (see Fig. 4.10a) [ablation till, glaciofluvial outwash].

SVMS-33

111 to 110.2 m asl: Forest floor.

110.2 to 109.3 m asl: Massive medium sands with pebbles and clayey-silt clasts and charcoal fragments [fill].

109.3 to 109.1 m asl: Paleosol containing roots, pebbles, and wood. A piece of bark from this unit was radiocarbon dated to 140 ± 50 (Beta-43863) years BP. See Chapter 4 for interpretation.

109.1 to 109.3 m asl: Rounded cobbles; clast-supported [channel lag].

SVMS-34

184 to 182 m asl (upper 2 m of ~14 m excavation; the remainder was covered): Matrix-supported diamicton; fairly compact [ablation till].

SVMS-16

234 to 229 m asl: Massive matrix-supported non-compact diamicton interbedded with stratified sands and gravel [ablation till].

229 to 222 m asl: Horizontally bedded and crossbedded coarse sand with some pebble beds [glaciofluvial outwash].

SVMS-31

178 to 176 m asl: Massive non-compact matrix-supported diamicton interbedded with mudflow deposits containing charcoal fragments [debris flow sediments].

176 to 175 m asl: Laminated silty clay; no organics or dropstones [lacustrine]. The contact with the overlying debris flow sediments is sharp.

SVMS-32

191 to 185 m asl: Matrix-supported subrounded to angular clasts (gravel sized) containing three beds (few cm thick) of organic-rich (charcoal fragments) sand (no clasts found). The organic-rich beds are horizontally (weakly) bedded [debris flow/mud flow sediments].

SVMS-25

178 to 180 m asl: Clast-supported diamicton containing an organic-rich sand and gravel bed ~30 cm thick [alluvial fan deposits]. Charcoal fragments from the sand bed yielded a radiocarbon age of 11 1420 ± 110 (Beta-40487) years BP. See Figure 4.6a.

SVMS-26

200 to 195 m asl: Horizontally bedded cobbles and boulders (angular to rounded) interbedded with sand [glaciofluvial outwash].

195 to 192 m asl: Matrix-supported compact diamicton. Clasts are subrounded to rounded and up to 5 cm in diameter [lodgement till].

APPENDIX D

LOCATION OF BENCHMARKS USED IN THIS RESEARCH

Table D.1 shows the location and elevation of the benchmarks used throughout the course of this research. The benchmarks in Table D.1 are a subset of 19 GVRD "Class B" benchmarks located throughout the study area. The remainder could not be located. The reported elevations of all benchmarks in Table D.1 have been confirmed by cross-checking. All of these benchmarks are represented by brass plates, except B-50 which is represented by a steel rod.

In Table D.1, the columns "Location" and "Elevation in feet" contain information obtained from the Greater Vancouver Regional District (GVRD) Department of Engineering Standards and Instructions (Part B, Item 301, section 3, pp. 4-5, Oct. 1973). The reported elevations in feet (ft.) are converted to meters above sea-level (m asl) by subtracting 91.37 ft. and multiplying by 0.3048 m/ft. The column "Additional Information" contains additional information on the location of some of the benchmarks compiled during this research. Distances relative to Rice Lake Gate were measured along Seymour Mainline (main paved road to Seymour Falls Dam) where distances are posted every km.

Table D.1 Location and Elevation of Benchmarks Used During This Research.

B.M. No.	Location	Additional Information	Elevation in feet	Elevation in m asl
B-33	Lillooet Road. Southeast corner of rock cairn at northeast corner of Kieth Road and Lillooet Road.	Monument located at the southwest corner of the south parking lot, Coach House Motel. (brass plate not found)	138.41	14.05
B-36	Lillooet Road. Top of front wall of Meter House (built in 1948) just south of watershed gate. pipeline station 358+03.	Located 200 m south of Rice Lake Gate.	714.10	189.81
B-37	Set on northwest corner of on top of chamber wall of overflow chamber, at east end of spillway structure at north end of Rice Lake.		744.86	199.18
B-38	Set on top of northeast corner of culvert head wall on west side of pipe. Pipeline station 279+55	2.35 km north of Rice Lake Gate.	695.38	184.10
B-42	Set in Culvert headwall at pipeline station 166+46.	5.9 km north of Rice Lake Gate.	723.12	192.56
B-43	Set in concrete block over main pipeline station 125+61.	7.1 km north of Rice lake Gate, or 100 m south of "Hayes Creek". East side of road.	708.37	188.06
B-44	Set in north end of 42" twin culvert endwall east side of road at pipeline station 90+01	8.2 Km north of Rice Lake Gate.	704.39	186.85
B-49	Set on center line concrete conduit encasement, 1' southwest of southwest edge of air valve chamber which is 75' northeast of Seymour Chlorination House.		730.38	194.77
B-50	Monument "Suzy" about 120' north of Seymour Chlorination House on top of rock outcrop.	The monument is ~1' high. The name "Suzy" is now barely visible.	765.78	205.56

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