THE LATE QUATERNARY GEOMORPHIC HISTORY OF THE SUMAS VALLEY

by

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The Late Quaternary Geomorphic History

of the Sumas Valley

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ABSTRACT

The Sumas Valley is located in the eastern portion of the Fraser Lowland of British Columbia. A long, flat-floored valley sandwiched between two elongate mountains and bordered at each end by rivers, the Sumas Valley's evolution has commanded much interest but only limited directed study.

The objectives of this study were: 1) to reconstruct the geomorphic evolution of the Sumas Valley in Late Quaternary time by examination of the subsurface sedimentary architecture of the region, and 2) to address the question of whether the Fraser River (or a distributary) could have flowed through the valley and discharged into Bellingham Bay.

To achieve these objectives, subsurface sample collection was necessary. Core obtained in the field was examined for texture, sedimentary structure, lithology, and organic matter content. Personally collected data was supplemented with water well drill logs and B.C. Department of Highways test hole data.

Correlation of the data permitted the identification of nine lithostratigraphic units, which were then used to construct the subsurface sedimentary architecture of the Sumas Valley. The subsurface sedimentary architecture of Sumas Valley suggests that the most significant aspect of the Sumas Valley's evolution in post glacial time was the progradation of two fans into a basin left by the downwasting of glacial ice. The fans are identified, in both the north end and the south end of the Sumas Valley, by lobes of gravel which display the lateral and vertical grading patterns characteristic of a prograding fan or delta. The presence of Mazama tephra in some of the cores, as well as the age of radiocarbon dated wood, places the deposition of these fan sediments clearly within the Holocene.

Lithological identification of sediments suggests that the source of the northern fan is the Chilliwack River, whereas the southern fan is believed to have originated

from the progradation of the Nooksack River, or a greatly enlarged Sumas River, into the valley.

The hypothesis of the Fraser River flowing through the Sumas Valley during the Holocene is rejected due to the obstacle presented by the Nooksack gravel lobe in the southern portion of the valley and because of the absence of Fraser River sediments in the valley.

DEDICATION

This thesis is dedicated to Victor and Crystal.

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Dr. M. C. Roberts deserves special recognition for providing guidance, inspiration, and funding. His helpful comments in writing this thesis were greatly appreciated.

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TABLE OF CONTENTS

APPROVAL........ii

ABSTRACT........iii

DEDICATION........v

ACKNOWLEDGMENTS........vi

LIST OF TABLES........x

LIST OF FIGURES........xi

CHAPTER ONE: INTRODUCTION

1.0 Introduction........1

1.1 Objectives........1

1.2 Study Area........4

1.2.0 Bedrock Geology........4

1.2.1 Surficial Geomorphology........10

1.2.2 Evidence of Glaciation........13

1.3 Sumas Valley--Previous Research........14

CHAPTER TWO: METHODOLOGY

2.0 Surficial Geomorphology........22

2.1 Subsurface Methods........24

2.2 Laboratory Analysis........27

CHAPTER THREE: LITHOSTRATIGRAPHY OF THE SUMAS VALLEY FILL

3.0 Lithostratigraphy of the Sumas Valley Fill........29

3.0.1 Unit 1--Blue Clayey Silt........47

3.0.2 Unit 2--Interbedded Sand and Silt........47

3.0.3 Unit 3--Gravel--Southern Valley........49

3.0.4 Unit 4--Gravel--Northern Valley........51

3.0.5 Unit 5--Sand--Southern Cores....52

3.0.6 Unit 6--Sand--Northern Cores....52

3.0.7 Unit 7--Silt--Fluvial Proximal....53

3.0.8 Unit 8--Clayey Silt....53

3.0.9 Unit 9--Silt and Fine Sand....53

CHAPTER FOUR: SEDIMENTARY ARCHITECTURE OF THE SUMAS VALLEY

4.0 Introduction....55

4.1 Longitudinal Sections....55

4.1.0 Central Valley--Transect A....55

4.1.1 Valley Flank--Transect I....58

4.1.2 Longitudinal Sections--Summary....60

4.2 Cross Valley Sections....61

4.2.0 Northern Valley--Transects B & K....62

4.2.1 Central Valley--Transects C, D. & E....63

4.2.2 Western Valley--Transects F & N....65

4.2.3 Southern Valley--Transects L & M....66

4.2.4 Cross Valley Sections--Summary....67

4.3 Discussion....69

4.3.0 Unit 1....69

4.3.1 Units 2, 3, & 5....70

4.3.2 Unit 3(a)....73

4.3.3 Units 4 & 6....73

4.3.4 Unit 7....75

4.3.5 Unit 8....75

4.3.6 Unit 9....75

CHAPTER FIVE: GEOMORPHOLOGY AND PROVENANCE OF SEDIMENTS

5.0 Topography....77

5.0.0 Fan Deposits....77

5.0.1 Glacial Deposits....78

5.1 Mineralogy and Lithology of Sediments....80

5.1.0 Provenance of Sediments--Sumas Valley....80

5.1.1 Custer-Ferndale Drill Holes....87

5.2 Tephra....93

5.3 Organic Matter and Radiocarbon Dates....95

5.3.0 Wood and Peat....95

5.3.1 Forams....98

5.4 Sea Level Fluctuation....98

CHAPTER SIX: EVOLUTION OF THE SUMAS VALLEY

6.0 Late Wisconsinan Glaciation....102

6.0.0 Fort Langley Time Interval 11,000-13,000 yr B.P....102

6.0.1 Sumas Stade 11,000-11,400 yr B.P....103

6.1 Early Holocene 10,000 yr B.P. 107

6.1.0 Nooksack Fan Progradation....107

6.1.1 Chilliwack Fan Progradation....108

6.2 Mid-Holocene....109

6.3 Late Holocene....111

CHAPTER SEVEN: SUMMARY AND CONCLUDING REMARKS

7.0 Summary....112

7.1 Suggestions for Future Research....114

7.2 Conclusion....114

APPENDIX A: PRECISE LOCATION OF DRILL HOLES....115

APPENDIX B: CORE DESCRIPTIONS....132

REFERENCES....149

LIST OF TABLES

Table 2.0 Maps and Aerial Photographs....23

Table 3.0 Sumas Valley--Lithostratigraphic Units....30

Table 5.0 Lithology and Mineralogy--Sand and Gravel....82

Table 5.1 Radiocarbon Dates....96

FIGURES

Figure Page

1.0 The Location of the Sumas Valley within the Fraser Lowland....................................2

1.1 The Sumas Valley and its relation to adjoining physiographic regions....................3

1.2 Geology of the Upper Fraser Valley--Key...5

1.3 Geology of the Upper Fraser Valley..6

1.4 Mt. Baker, Washington..8

1.5 The topography of the floor of the Sumas Valley.. 9

1.6 Sumas Valley, looking southwest..10

1.7 Sumas Lake..11

1.8 Chilliwack River entering Fraser Valley..12

1.9 Sumas Valley looking south from Sumas Mountain...15

1.10 Quaternary Stratigraphy, Fraser Lowland..18

1.11 Distribution of Quaternary Deposits in the Fraser Lowland.....................................19

2.0 Concore C-68 Drill Rig..24

2.1 Vibracore...25

3.0 Cross sections plotted from drill cores and well logs...31

3.1 Key to cross sectional transects..32

3.2 Transect A...33

3.3 Transect B...34

3.4 Transect C...35

3.5 Transect D...36

3.6 Transect E..37

3.7 Transect F..38

3.8 Transect G...39

3.9 Transect H...40

3.10 Transect I...41

3.11 Transect J..42

3..12 Transect K..43

3.13 Transect L..44

3.14 Transect M..45

3.15 Transect N..46

3.16 SV26 Sand-silt couplets, Unit 2..48

3.17 Location of gravels in the Sumas Valley..50

5.0 Distribution of sediments based on lithology..83

5.1 Provenance of sediments..85

5.2 Transect W..88

5.3 Location of dateable materials..90

5.4 Transect P-Q: Location of dateable materials..91

5.5 Transect R-S: Location of dateable materials..92

5.6 Tephra beneath Unit 3..93

5.7 Sea level fluctuations--Fraser Lowland..99

6.0 Sequence of Glacial Retreat and Sedimentation Pattern.and Suggested Dates

(a) ca 11,300 yr B.P. 104

(b) ca 11,200 yr B.P. 104

(c) ca 11,100 yr B.P. 106

(d) ca 11,000 yr B.P. 106

(e) 1900 110

(f) Present 110

CHAPTER ONE
INTRODUCTION

1.0 Introduction

The Fraser Lowland region of southwestern British Columbia contains a complex array of geologic and geomorphic features. Glacial, fluvial, marine and tectonic processes have combined to create a fascinating, and frequently puzzling, landscape. Despite the careful analysis of surficial landscape features by several researchers, many questions still exist as to the precise sequence of events involved in the evolution of the lowland. One such area within the Fraser Lowland is the Sumas Valley (Fig. 1.0 & 1.1).

The Sumas Valley is located in the eastern portion of the Fraser Lowland. A long, flat-floored valley sandwiched between two elongate mountains and bordered at each end by rivers, the Sumas Valley's evolution has commanded much interest but only limited direct study. The Sumas Valley's anomalous position within the Fraser Lowland and proximity to the Fraser River floodplain has led to speculation as to whether the Fraser River had flowed through the Sumas Valley at one time. Because examination of surface features permits only limited interpretation of the evolution of the valley, the challenge of reconstructing the geomorphic history of the Sumas Valley lies with the interpretation of its subsurface sedimentology and stratigraphy.

1.1 Objectives

My objectives in pursuing this study were as follows:

1) Reconstruction of the geomorphic evolution of the Sumas Valley in Late Quaternary, primarily post-glacial, time by assembling all available geomorphic evidence, and by examining the subsurface sedimentary architecture of the region.

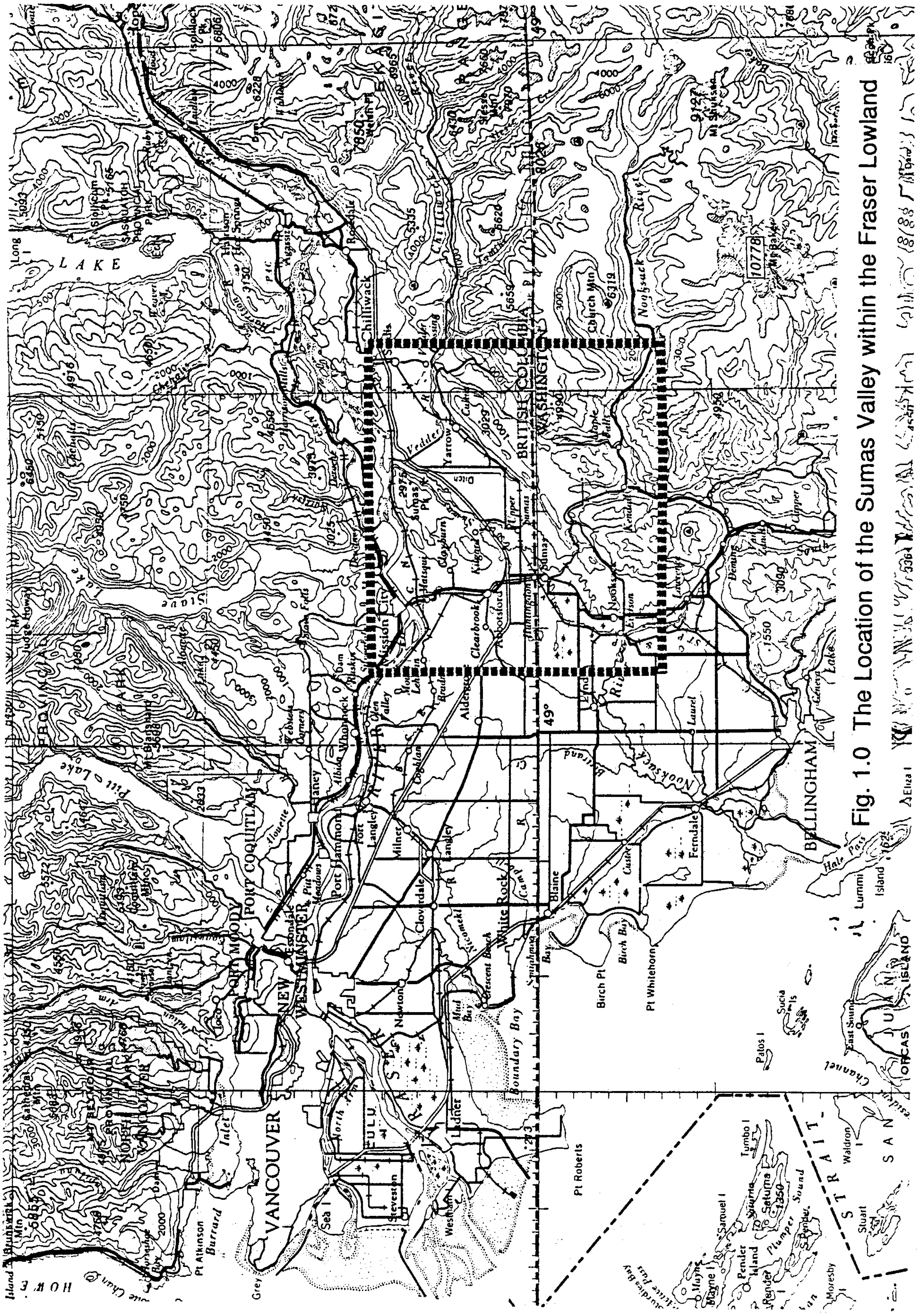


Fig. 1.0 The Location of the Sumas Valley within the Fraser Lowland

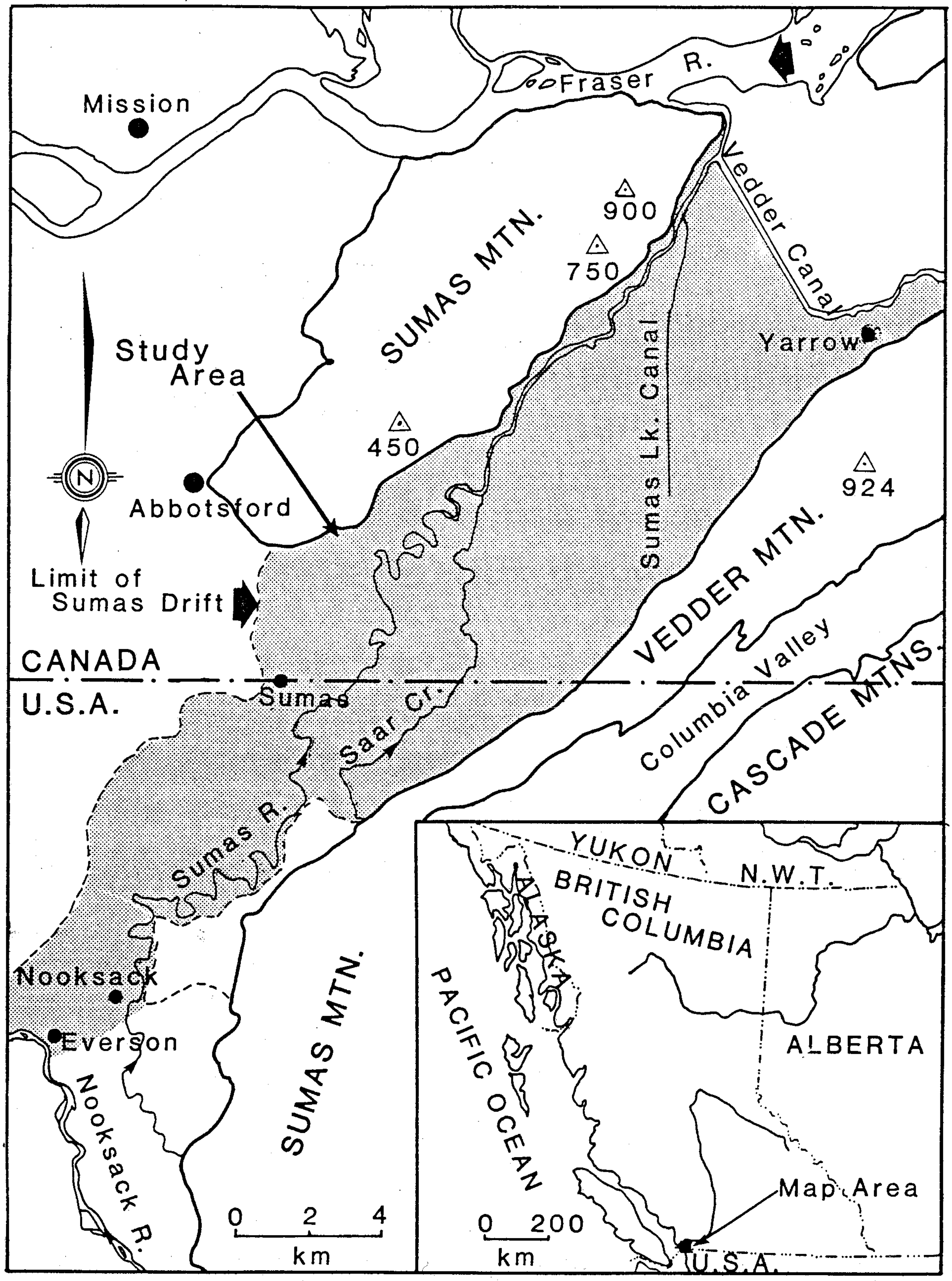


Fig. 1.1 The Sumas Valley and its relation to adjoining physiographic regions

2) To address the question of whether the Fraser River (or a distributary) could have flowed through the valley and discharged into Bellingham Bay.

It was hoped that these findings and interpretations would supplement that research currently being conducted into the evolution of the Fraser Lowland and delta.

1.2 Study Area

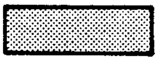
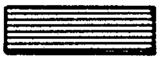
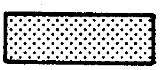
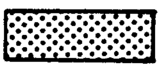
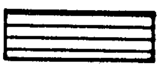
The Sumas Valley extends southwest from Yarrow, B.C. (near Chilliwack) to Abbotsford, B.C. and then south across the Canadian--U.S. border to the town of Everson, Washington on the Nooksack River (Fig. 1.1). The valley's length is 25 km and its width averages 6 km, tapering to 2.5 km near its southern-most extremity. The Sumas Valley (also referred to as Sumas Prairie on National Topographic Survey maps) is bordered to the north by the Vedder Canal, which crosses the valley near the eastern tip of Sumas Mountain., B.C. before entering the Fraser River. At its southern boundary, the valley is bordered by the Nooksack River which flows north from Mt. Baker, Washington 35 km to the southeast. The Nooksack River sharply changes direction at the south tip of Sumas Valley, turning west at Everson, and eventually flows into Bellingham Bay.

1.2.0 Bedrock Geology

Sumas Valley, as part of the Fraser Valley, lies between the Coast Plutonic Complex to the north and the largely volcanic Cascade Fold Belt to the south (Fulton & Halstead, 1972; Clarkson, 1977). Locally, however, the valley is confined by three bedrock outliers which differ geologically from those found elsewhere in the region: Sumas Mountain, B.C., Vedder Mountain, B.C. , and Sumas Mountain, Wa.(Fig. 1.2 & 1.3).

Fig. 1.2 Geology of the Upper Fraser Valley

KEY

Age	Symbol	Name	Description
Pleistocene		Mount Baker FM	andesite, basalt
Tertiary			granodiorite
Eocene		Huntingdon FM	sandstone, shale
Cretaceous/ Tertiary		Chuckanut FM	arkose, conglomerate
Jurassic/ Cretaceous		Nooksack Group	greywacke, slate, phyllite
mid Jurassic		Harrison Lake FM	acidic flows
Triassic/ Jurassic		Cultus FM	pelite, sandstone, conglomerate
Carboniferous/ Permian		Chilliwack Group	greywacke, pelite, andesite, basalt
Paleozoic		Darrington FM	phyllite, greenschist slate
Silurian		Vedder Mountain FM	metaquartz diorite, amphibolite
age unknown		Coast Mountain Complex	quartz diorite, diorite
age unknown			ultramafic rocks
age unknown			migmatite

(from Roddick et al., 1979)

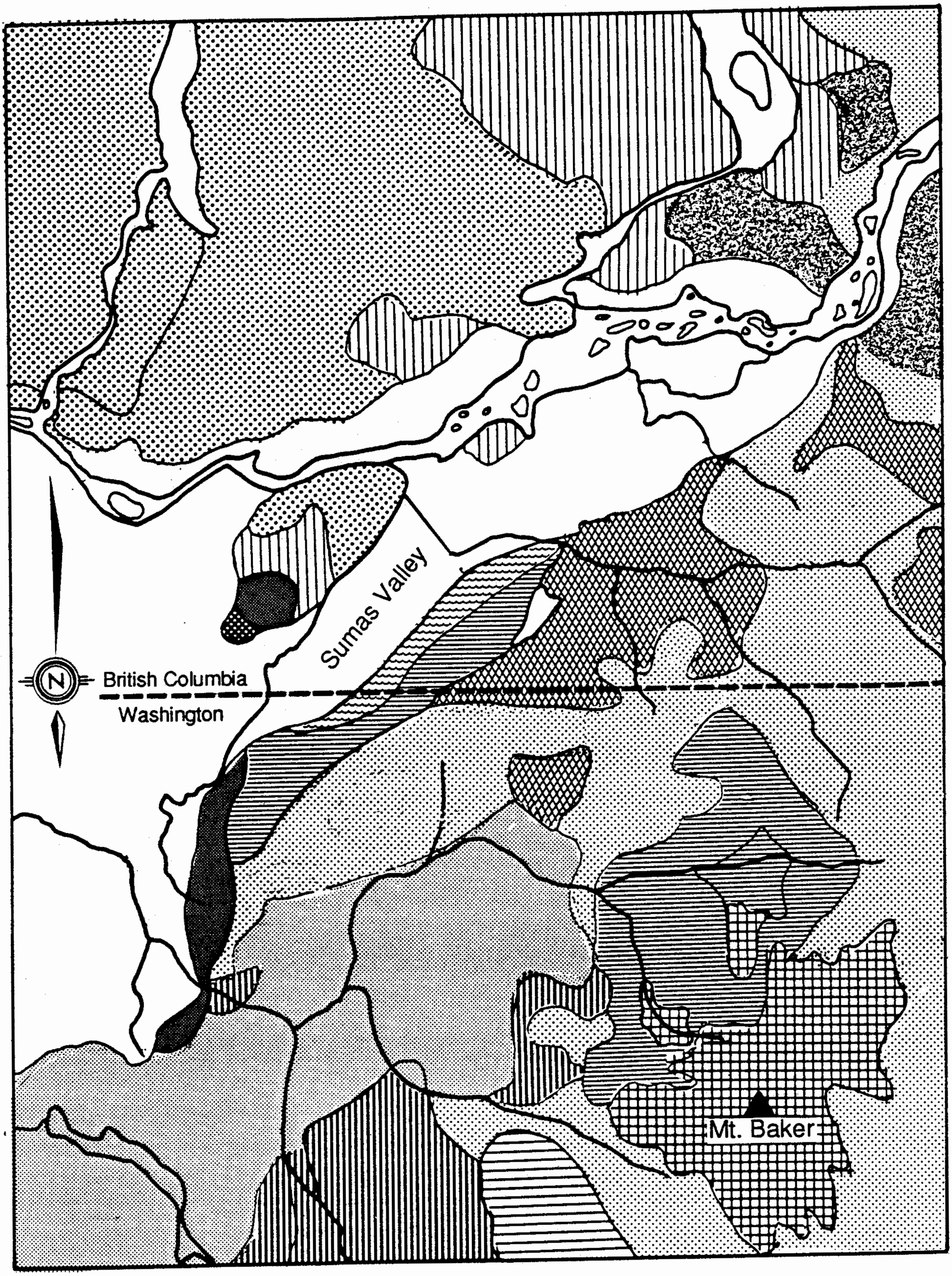


Fig. 1.3 Geology of the Upper Fraser Valley (from Roddick et al., 1979)

Sumas Mountain, B.C. is a complex of igneous, sedimentary, and metamorphic rock types. As with the Coast Mountains to the north, Sumas Mountain is composed of Coast Plutonic Complex rocks, including outcrops of both quartz diorite and amphibolitic migmatite, all of unknown age. However, sections of Eocene sandstones and shales of the Huntington Formation, and mid-Jurassic dark greenish grey acidic flows of the Harrison Lake Formation are found adjacent to the dioritic pluton (Roddick, 1965, Roddick et al , 1979).

Vedder Mountain, B.C. and Sumas Mountain, Wa. are part of the Cascade Fold Belt, and display lithologic complexity (Hopkins, 1966; McKee, 1972). The western portion of Vedder Mountain, which is most proximal to the Sumas Valley, consists of Silurian Vedder Mountain Formation metaquartz diorite and amphibolite, primarily schistose in character (Roddick, 1965). Dominating the east side of Vedder Mountain are Nooksack Group greywackes, slates, and phyllites which are believed to be Mesozoic, Jurassic and Cretaceous in age. These Nooksack metasediments extend south as part of Sumas Mountain, Wa. Also part of Sumas Mountain, Wa. are the Huntingdon Formation sedimentaries found on Sumas Mountain, B.C. (Roddick et al., 1979).

Other units of importance in the geology of the Sumas Valley region are the Chilliwack Group and the Cultus Formation. The Cultus Formation is found along the eastern flank of the upper Fraser Valley, and consists of pelite, sandstone, and conglomerate. Also present in the Cascade Fold Belt and exposed in the upper Fraser Valley is the Chilliwack Group--an assemblage of greywacke, pelite, andesite and basalt of Carboniferous and Permian age (Monger, 1980).

Although it is situated 100 km to the southeast, Mt. Baker must be included when examining the geology of the Sumas Valley area due to its importance as a supplier of sediment for the Nooksack River, which flows from its slopes (Fig. 1.4). Mt. Baker, a stratovolcano of Pleistocene age, is composed primarily of hematite-rich red and dark grey porphyritic andesite, and quartz veined dark basalt (McKee, 1972). Because of their distinct red and black colour and the inclusion of felsic phenocrysts, the volcanic rocks of Mt. Baker differ visually from the dark green and grey acidic flows of the Harrison Lake Formation, which are also of volcanic origin. Mt. Baker has been active in historical time, last erupting in 1870, and exhibiting fumerolic activity as recently as 1975 (Harris, 1980).

ASPECT IN VALLEY LIFE (NATIVES)

Fig. 1.4 Mt. Baker, Washington (Sumas Valley in the foreground)

Armstrong proposed that the Sumas Valley is a graben, probably formed in late Tertiary time (1984). Depth to bedrock has not yet been established throughout the valley. However, core taken from a test hole commissioned by the B.C. Dept. of Mines and Petroleum Resources at a location 10 km east of the Vedder Canal in the Fraser floodplain (Appendix A(O)) revealed lithified sediments at a depth of 400 m.Water well records within the Sumas Valley itself indicate that bedrock has not been encountered at even the deepest well (183 m).

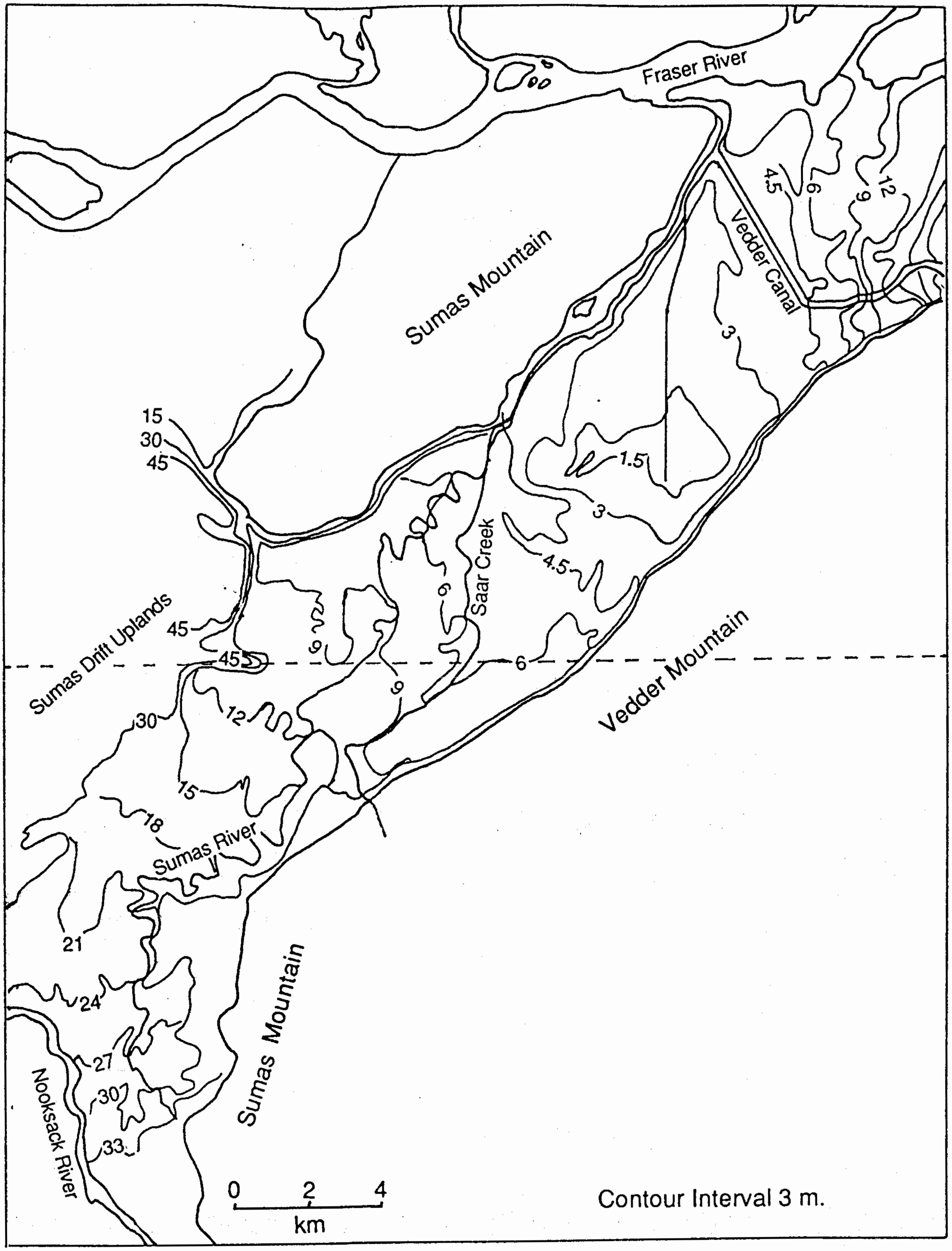


Fig. 1.5 The topography of the floor of the Sumas Valley

1-800
387-4499

1.2.1 Surficial Geomorphology

The subdued relief of the Sumas Valley floor is emphasized by the contrasting abrupt vertical rise of Sumas and Vedder Mountains on either side. Although the valley floor appears to be nearly flat, careful examination of its longitudnal profile reveals that elevation gently increases at either end of the valley, creating a shallow basin mid-valley (Fig.1.5). Elevations vary from 6 m adjacent to the Fraser River at

Fig. 1.6 Sumas Valley, looking southwest. Vedder Canal in foreground

the Vedder Canal to 0 m in the vicinity of the Sumas Lake Canal, and gradually increase to 24 m at the Nooksack River in the south.

In the early part of this century, Sumas Lake occupied the mid-valley basin (Fig.1.7). The depth and extent of Sumas Lake depended upon the erratic behaviour of the Chilliwack River, which at times flowed into the lake but alternately flowed directly across the floodplain through Sardis and Chilliwack to the Fraser River .

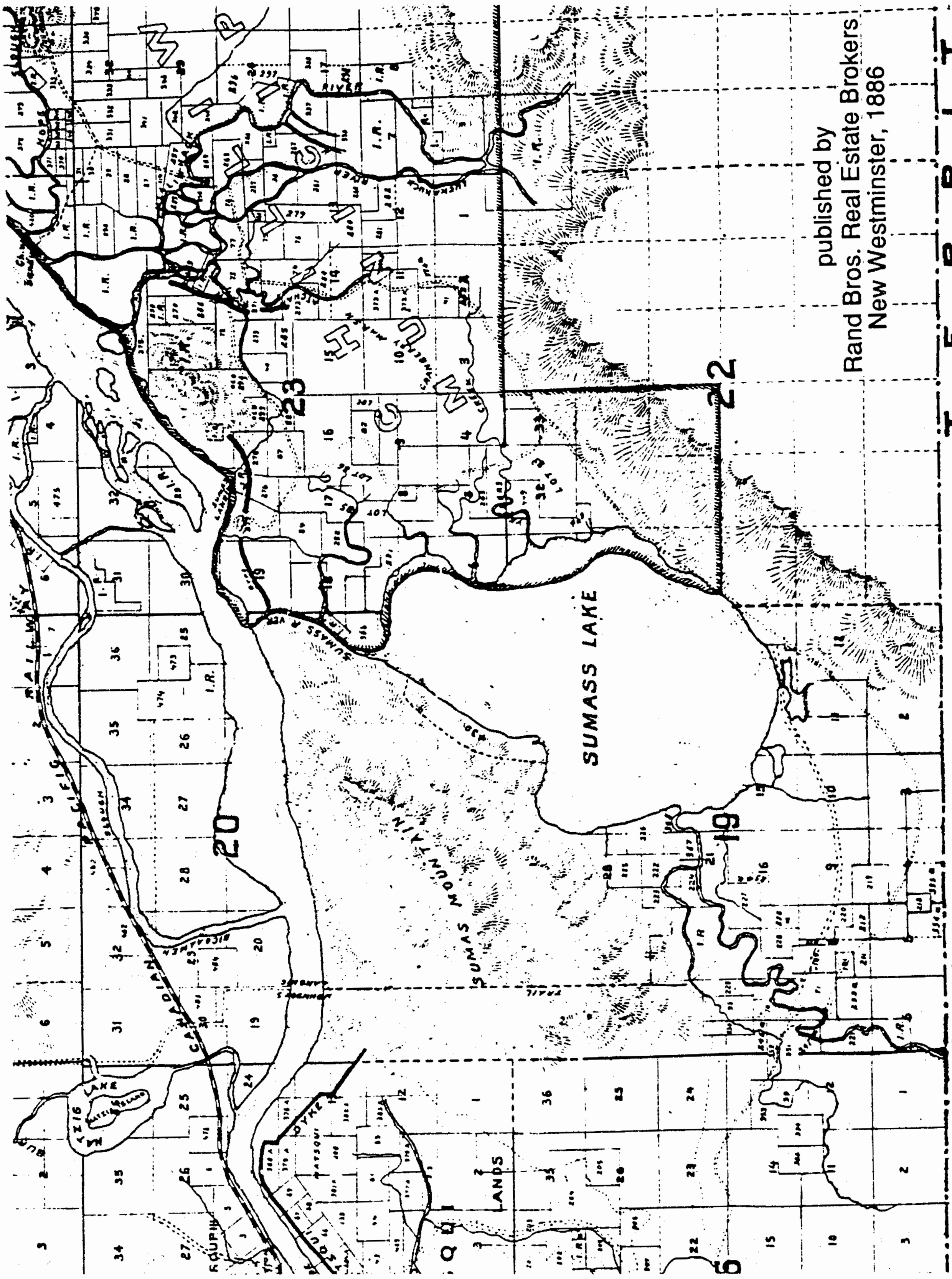


Fig. 1.7 Sumas Lake

(Sinclair, 1961). The Chilliwack River (also known as the Vedder River near Yarrow, B.C.) was channelled into the Vedder Canal in 1924 to prevent flooding of the agricultural communities of Chilliwack, Sardis, and Yarrow (Fig. 1.8). Concurrently, the shallow lake was drained into the Sumas Lake Canal to permit agricultural development of the Sumas lakebed. Evidence of the lake is present in the form of thin sandy silt (0-2 m) deposits throughout much of the central portion of the valley.

Fig. 1.8 Chilliwack River entering Fraser Valley (Vedder Canal in foreground)

A series of elongate sandy ridges cross the central portion of the valley. These ridges have elevations of up to 12 m and may have been wave and/or wind generated beach deposits (Armstrong, 1960a & b, Halstead, 1961).

Sumas Valley is drained at present by a number of small waterways, both natural and man-made. The largest natural river is the Sumas River which meanders north from Sumas Mountain, Wa. and empties into the Fraser River at the northeast tip of Sumas Mountain, B.C. (Fig. 1.1). The Sumas River is less than 2 m wide and 1 m deep throughout most of the valley, although it widens considerably as its nears Sumas Mountain, B.C., reaching a width of 100 m near the Vedder Canal. Even during periods of high precipitation, the Sumas River usually has low flows. The Sumas River has two tributaries--Johnson Creek and Saar Creek -- which also originate in Washington. Although meander scars from these waterways are visible in aerial photographs, terracing is not present and the Sumas Valley does not display obvious floodplain development.

The Sumas Valley is drained by a number of artificial ditches and canals. Vedder Canal and Sumas Lake Canal, which were mentioned earlier, are the largest of these. Arnold Slough is the largest of the many ditches. Due to the low elevation of these waterways in relation to the Fraser River, an elaborate series of pumps is employed in controlling water levels. These waterways are necessary in the lower lying areas of the Sumas Valley to reduce flooding when the water table rises.

The high precipitation of the region assures that groundwater is plentiful in the Sumas Valley. Groundwater table contour lines indicate that subsurface water flows from the Everson-Nooksack area north to the Sumas Prairie basin (Washington State, 1960), not surprising given the fact that the water table slopes to follow surface contours. Due to the low elevation of the Sumas Prairie basin (0-1.5 m) the water table in the central valley tends to rise to the surface and flood low lying areas to the north during periods of peak precipitation.

1.2.2 Evidence of Glaciation

Geomorphic evidence of glaciation in the Sumas Valley is plentiful. Vedder and Sumas Mountains exhibit a streamlined, lee and stoss appearance resulting from the southwest flow of glacial ice. The sharp vertical rise of mountain walls from the flat valley floor suggests a glacial trough infilled with sediment. Striated and grooved ask Kurt why no Sumas ... [illegible]

surfaces, characteristic of glacially scoured rock , are found on bedrock throughout the valley.

The most abundant sedimentary evidence of glaciation is the extensive distribution of Sumas Drift, which is found mostly outside the Sumas Valley. Sumas Drift, which is spread over much of the central Fraser Valley between Abbotsford and Langley,.is composed of glaciofluvial sands and gravels, diamicton, and ice contact deposits, and is associated with the advance of Sumas ice during the Sumas Stade 11,000 -11,400 yr B.P. Sumas outwash is also extensive throughout the Nooksack Lowland (Easterbrook, 1963; Goldin, 1986). The source of Sumas till and outwash was from the east and northeast, based on an examination of pebble provenance by Armstrong (1981). The conclusion that Sumas ice moved westward from the Cascade Mountains and Fraser River Valley east of the Fraser Lowland was supported by till fabric analyses (Roberts & Mark, 1970, Armstrong et al, 1971). A 40 m cliff exposing the Sumas Drift holostratotype flanks the western border of the Sumas Valley (Fig 1.9) (Armstrong, 1980, 1981, 1984; Clague & Luternauer, 1983). Other exposures of Sumas Drift are visible on Sumas Mountain, B.C. and to a lesser extent on Vedder Mountain, B.C

1.3 Sumas Valley--Previous Research

Most of the attention which has been focused on the Sumas Valley has been within the context of the evolution of the Fraser Valley. In spite of the paucity of published data dealing with the subsurface sedimentology and stratigraphy of the Sumas Valley, there has been much speculation as to the evolution of the valley.

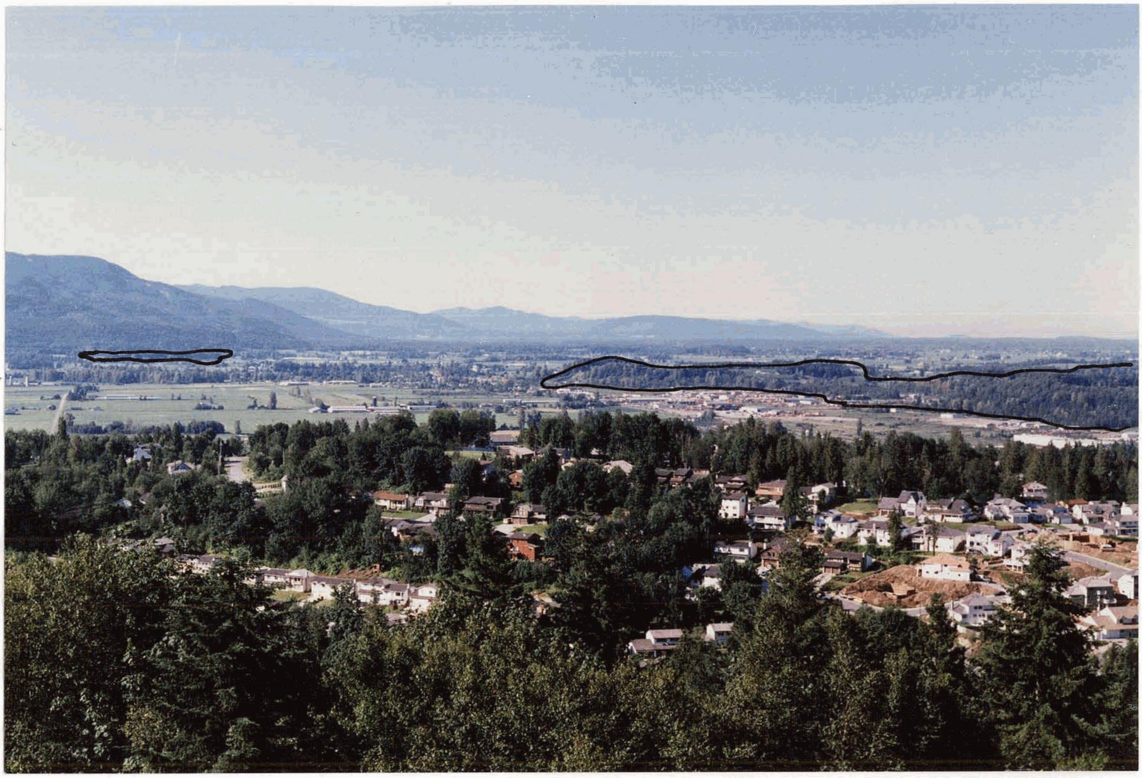


Fig. 1.9 Sumas Valley looking south from Sumas Mountain
(Sumas Drft exposures outlined in black)

Three hypotheses have been entertained in the literature:

1) Sumas Valley was at one time an arm of the sea (Armstrong, 1960a, 1981, 1984)

2) A remnant ice block occupied the valley after the major withdrawal of ice from the Fraser Lowland, subsequently filling in with lacustrine sediment (Armstrong, 1960a, 1981, 1984)

3) The Fraser River flowed south through the valley to Bellingham Bay for some time during or after deglaciation (Armstrong, 1960a).

Several variations of these central hypotheses exist and will be mentioned in the following discussion on previous research done in the valley.

The earliest published references to the Sumas Valley deal mostly with the draining and dyking of Sumas Lake, a shallow lake that occupied much of the Sumas Valley during settlement of the area (Sinclair, 1961, Smith, n.d.). The annual spring freshet on the Fraser, Chilliwack, and Sumas Rivers and the resulting enlargement of Sumas Lake, into which they flowed, posed a tremendous problem for farmers in the area. The most notable flood was the 1894 flood which caused Sumas Lake to enlarge from its regular area of 10,000 acres to 33,000 acres, extending into Washington State (Sinclair, 1961) Sinclair believed that the Fraser River probably was responsible for much of the sedimentation of the Sumas Valley lands but that the growth of a "conical delta" by the Chilliwack River eventually forced the Fraser out of the east area of the valley. Sinclair's conclusions were based on personal observation of flooding processes in the area as an engineer involved in the dyking project, and not upon directed scientific study.

The most comprehensive published work done on the Sumas Valley to date has been by Armstrong (1960a & b, 1977, 1980a & b, 1981, 1984). On the basis of field observations, some shallow sampling (1-7 m), and analysis of water well logs for his earliest work, Armstrong analysed and formally classified the surficial sediments of the Sumas and Fraser Valleys. Armstrong stated that the Fraser Valley had experienced several glacial advances and retreats within the late Quaternary period, which resulted in a complex array of sedimentary deposits. Near the end of the late Wisconsinan age, a small Sumas ice lobe advance in the eastern Fraser Valley between 11,400 and 11,000 yr B.P., when most of the Lower Mainland of B.C. was ice free, resulted in the deposition of Sumas Drift, which was the final glacial deposit present in the Lower Mainland.

Armstrong mapped the surficial deposits within the Sumas Valley, and concluded that throughout the Wisconsinan the Sumas Valley had been alternately occupied by ice during glacial stades, and an arm of the sea during interstades. He explained the presence of fine textured surficial sediment within the Sumas Valley (stated to be less than 5 m in thickness) as being lacustrine in nature. Armstrong's hypothesis was that a large ice block must have remained in the Sumas Valley after active glacial ice had retreated. As the stagnant ice downwasted, lacustrine sediments settled into the depression that remained (Armstrong, 1981). In addition, Armstrong believed that the post-glacial Sumas Lake was dammed by the Chilliwack River fan which began forming after the withdrawal of Sumas ice. The surficial lacustrine sediments within the Sumas Valley were stated to be underlain by marine sediments, which Armstrong (1980b) speculated could extend to a depth of 300 m or more.

On the basis of his observations Armstrong (1960, a & b, 1981, 1984) has formally classified the Quaternary stratigraphic units present in the Fraser Valley (Fig. 1.10 & 1.11). The deposits within the Sumas Valley are classified as Salish (recent), as are the sediments immediately to the northeast of the Sumas Valley across the Vedder Canal, although the latter are further defined as being Fraser Floodplain deposits and Chilliwack fan deposits. Armstrong believed that the marine silts which underlie the surficial deposits in the Sumas Valley were Fort Langley or possibly Semiahmoo marine silts. Armstrong also described the holostratotype of Sumas Drift which is exposed in the 40 m cliff bordering the west side of the Sumas Valley, and noted its superposition above Fort Langley glaciomarine silts (1981).

In his earlier work (1960a), Armstrong entertained the possibility that the Fraser River could have flowed through the Sumas Valley enroute to Bellingham Bay in the

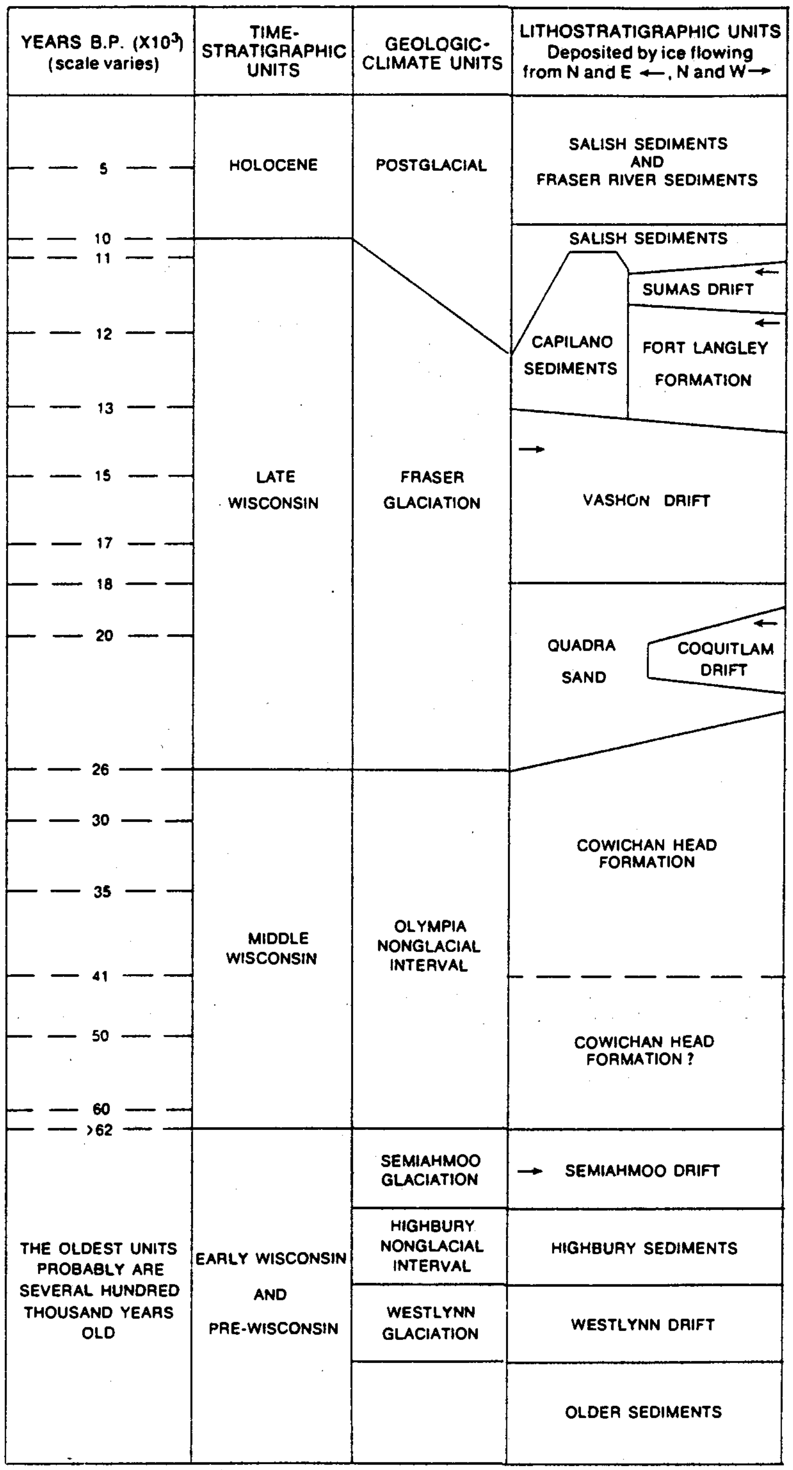


Fig. 1.10 Quaternary Stratigraphy, Fraser Lowland (from Armstrong, 1981)

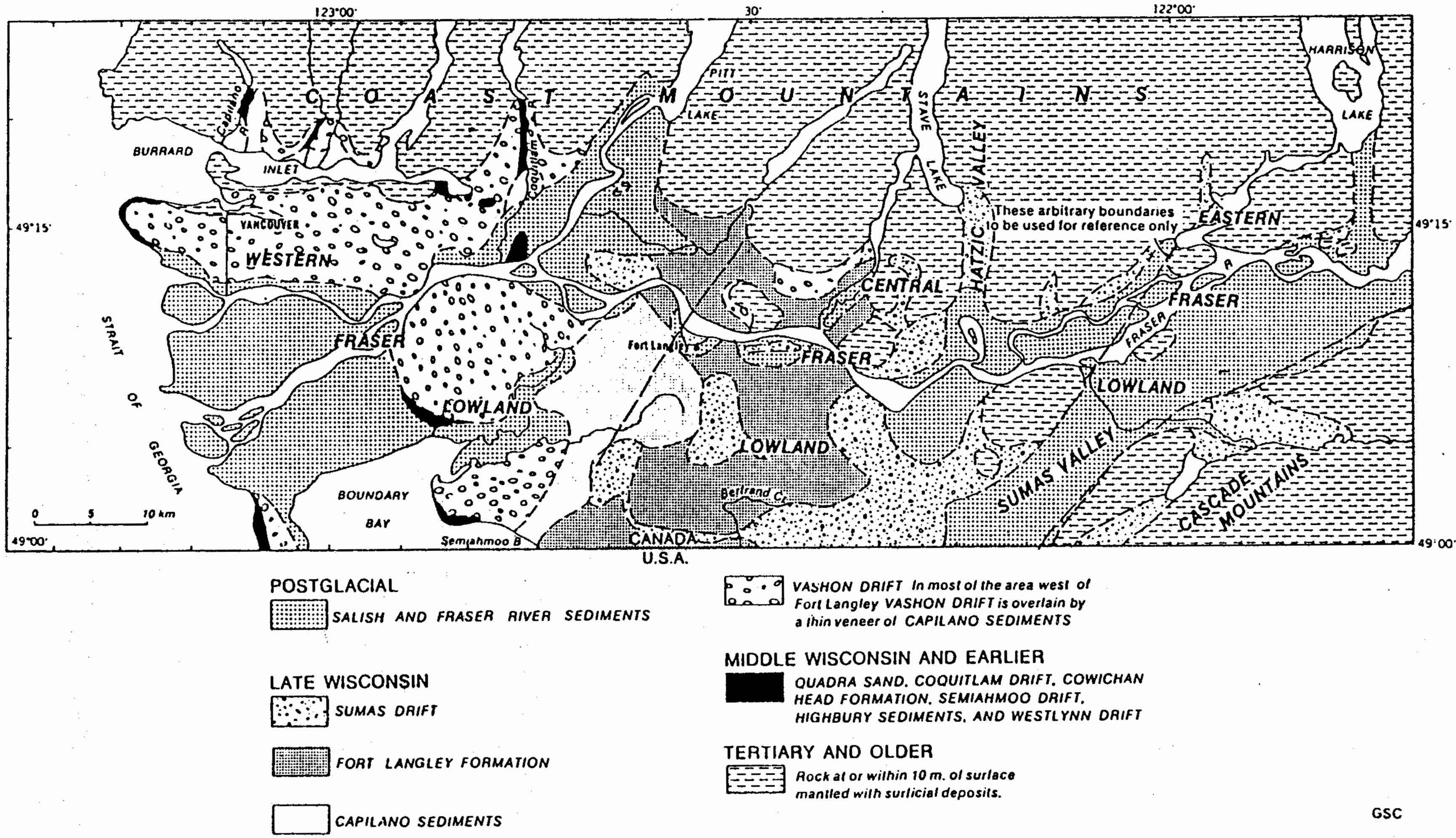


Fig. 1.11 Distribution of Quaternary Deposits in the Fraser Lowland (Armstrong, 1981)

early Wisconsinan (Armstrong, 1960). This idea appears to have been abandoned in later works, although Armstrong does mention that if sea level was 10 m higher than at present , the valley would once again be inundated by sea water. Armstrong stated that the Fraser River did not enter the Sumas Valley because when sea level was 10 m higher than at present (11,000-13,000 yr B.P.) the eastern Fraser Lowland was occupied with ice (1981). When the ice left the eastern lowland and the meltwaters created the Fraser River, sea level had lowered and the Sumas Valley contained a stagnant ice block which prevented the Fraser River from entering the valley.

Armstrong's 1980 map, Surficial Geology--Mission, British Columbia, represents the culmination of all available data and shows the distribution and character of surficial deposits in the central Fraser Valley. His map also includes 2 cross sections, one of which extends into the Sumas Valley. However, the portion of the cross section extending into the Sumas Valley is speculative because it is limited by a lack of subsurface data.

Armstrong based much of his subsurface geological interpretation of the Sumas Valley on water well logs collected by Halstead (1961). Halstead carefully documented 3 deep holes within the Sumas Valley (maximum depth 186 m) as well as numerous holes in adjacent areas to determine water resource capabilities. The silts and sands which Halstead found in the upper 12 to 25 m of valley sediments were classified as lacustrine. Underlying these surficial deposits were deep blue clays which Halstead (and Armstrong) believed to be glaciomarine in origin, possibly of Capilano (termed "Cloverdale"in early works) age[1].

Little attention appears to have been directed specifically to the portion of the Sumas Valley which lies between the Canadian-U.S. border and the Nooksack River in Washington State. Emphasizing pebble and sand provenance, Easterbrook

[1]Armstrong later changed the classification of the underlying sediments from "Capilano" to "Fort Langley" (Easterbrook et al, 1975).

(1963,1975) classified sedimentary units throughout the Northern Puget Lowland, including the Sumas Valley. However, Easterbrook does not specifically mention the Sumas Valley except (referring to Armstrong, 1960) that a small lobe of Sumas ice extended southward across the border near Sumas, Wa., and that this ice lobe deposited till and gravel in the Sumas Valley north of the town of Nooksack, Wa. Easterbrook's 1963 surficial geology map indicated the presence of these till and gravel deposits along the valley perimeter, but the valley floor deposits themselves were classified as being "older alluvium", possibly of Sumas outwash origin.

Blunden (1975) acknowledged the importance of Sumas Lake sedimentation in the formation of the valley, and attributed the filling of Sumas Lake to flooding by the Fraser River. Blunden's map indicated Fraser River sands and gravels north of the Sumas Valley, and Fraser River lacustrine sediments within the valley itself.

The only mention of the Nooksack River entering the Sumas Valley comes from Mathews (1972). On the basis of topographic analysis (personal communication, 1985) Mathews stated that the Nooksack River must have flowed northeast into the valley to the Fraser River for a portion of post-glacial time. Mathews also mentioned the presence of spagnum peat in the western portion of the Sumas Valley as having accumulated in recesses in the walls of the Nooksack River's former floodplain.

Previous work in the valley has not addressed the fact that the valley floor lies well below the most recent drift deposits, and that drift deposits are exposed in sharp escarpments particularly in the western valley rather than in the hummocky terrain of decreasing relief usually associated with glacial retreat and wastage. Also, the absence of a continuous distribution of drift along the valley perimeter has not been dealt with. The purpose of this thesis is to act as an extension to that work previously conducted in the area and to address some of the problems which remain outstanding in the reconstruction of the valley's geomorphic evolution.

CHAPTER TWO
METHODOLOGY

A variety of techniques were employed to address the objectives of the study. Because of the nature of the study, subsurface analytical techniques were emphasized. These were supplemented with observations at the surface. Finally, laboratory analysis of cores was conducted.

2.0 Surficial Geomorphology

A general reconnaissance of the valley was made to examine erosive and depositional evidence of glaciation and of fluvial activity. Particular attention was given to the location and nature of drift exposures along the valley sides and their relation to the valley floor with respect to elevation.

Exposures of valley fill were limited to stream banks and to two shallow (2 m) excavation pits.

The three rivers that border the Sumas Valley-- the Fraser, Chilliwack, and Nooksack Rivers-- were surveyed, and samples were taken of their present bed load for comparison with subsurface sedimentary samples.

Field observations were supplemented with topographic map and aerial photographic analysis. Large scale topographic maps were necessary for examination of low relief surface features. Aerial photographs were helpful in the identification of meander scars and other subtle surface disruptions.

TABLE 2.0

Maps and Aerial Photographs

Maps

Canada	1: 25,000	Yarrow	92G1a
(NTS)	1: 25,000	Kilgard	92G1b
	1: 25,000	Abbotsford	92G1c
United States	1: 24,000	Kendall	
(USGS)	1: 24,000	Sumas	
	1: 24,000	Lynden	
	1: 24,000	Bertrand Creek	

Aerial Photographs

Canada	B.C. 87084 No. 80-83
United States	USGS 82214 No.80

2.1 Subsurface Methods

Analysis of subsurface sedimentology and stratigraphy was necessary to interpret the post-glacial evolution of the Sumas Valley. Therefore the assembly of subsurface data, both personally collected and from other sources, was essential for the pursuit of this study. The following subsurface analytical techniques were employed:

1) Drilling. A Concore C-68 drill rig (Dept. of Geography, S.F.U.) was used to obtain samples (Fig. 2.0). Although augering was used, on occasion, to penetrate gravel, a mud rotary drilling unit with a tri-cone rotary bit was usually employed. Core samples obtained with a split-tube core barrel sampler were taken at 3-6 m intervals.

Fig. 2.0 Concore C-68 Drill Rig

As well, cuttings were carefully monitored for compositional variation. The maximum depth sampled was 45 m. Cores were generally intact with minimal disruption of internal structure. In situ organic samples retained in cores were carefully extracted and wrapped in aluminium foil for identification and radiocarbon dating purposes. All cores were wrapped in coated paper and retained for laboratory analysis and archival purposes.

The advantage of using a Concore drill rig was that it provided reliable and deep samples. However, because continuous coring was not undertaken gaps in the stratigraphic record exist.

2) Vibracore Drilling. For quicker sampling of shallow sediments, a vibracore was employed. The maximum depth of vibracore sampling achieved was 7.5 m. As

Fig. 2.1 Vibracore

with the conventional drilling technique, organic samples were extracted and retained. Although entire cores were not kept, samples were selected and bagged. The advantages of using this technique were that the preservation of the internal sedimentary structures was excellent, and that a continuous core could be retained for the entire length of the drill pipe.

The ease of setting up and using the vibracore permitted quicker and more extensive data collection. However, because this technique was limited to shallow sampling (maximum 10 m) it was used mostly to define lithological and mineralogical boundaries at and near the valley surface.

In both types of drilling (C-68 and vibracore), cores were carefully logged as they were recovered. Features which were recorded in the field were mineralogical content, grain size and shape, sedimentary structure, and the position and character of organic matter and tephras.

3) Geophysical Logging. Drill holes which did not collapse or squeeze were logged with a Mt. Sophis 1000-C geophysical borehole logger. The tool measured a continuous record of gamma, self potential, and resistance data. Geophysical logs were intended to supplement data collected from drilling, particularly in the case of information gaps between core barrel samples. However, application of this technique was limited due to the difficulty of log interpretation and the paucity of records.

4) Water-Well and Highway Logs. Personally collected data were supplemented with information received from government agencies. The B.C. Department of Highways provided borehole information (core descriptions and cone penetrometer readings) for sites along Highway #1. Descriptions of subsurface material during water well drilling were taken from the archival records of Groundwater Division of the B.C. Water Management Branch, Department of the Environment, and from the State of Washington Department of Ecology. The B.C.

Department of Mines,Energy and Petroleum Resources provided a detailed description of a deep exploratory borehole in Chilliwack (B.C. Dept. of Mines and Petroleum Resources, 1965 a & b). Engineering reports for dyking projects also provided valuable subsurface data (B.C. Ministry of Lands, Forests, and Water Resources, 1970; District of Abbotsford, 1989).

2.2 Laboratory Analysis

Laboratory analysis of cores was undertaken primarily to confirm observations made in the field. Sediments with grain sizes larger than silt were examined under both petrographic and standard microscopes to determine mineralogical composition and, in larger samples, lithology. The presence or absence of quartzite, muscovite mica, and volcanic andesite and basalt was carefully noted as these indicated provenance. Grains were also examined under the microscope to assess the degree of rounding as an indicator of depositional environment. In addition, the marine clays were scrutinized for the presence of marine forams. Sieving for particle size was not undertaken as it was felt that the field descriptions of sediment size were sufficiently accurate.

Tephras were identified in the laboratory using a number of techniques. Suspected tephras were examined with a petrographic microscope to determine whether the shards were isotropic. Also, immersion oil tests were conducted to determine the refractive index of the sample shards (Shelley, 1985). Confirmation of the presence of tephra was important for dating control.

Three wood samples extracted from cores were radiocarbon dated. Mass spectrometer (A.M.S.) dating was necessary due to the small size of the samples (< 2 gm) and was conducted by the SFU Riddl Group. These dates were supplemented with two dates obtained from material collected in a previous study (M.C.Roberts) and from one date provided by the Geological Survey of Canada with wood collected from a Highways test hole (Table 4.0, Chapter Four).

Information derived from cores was displayed graphically in vertical section form. A series of cross-sections showing various profiles of the valley fill was constructed and correlation of defined stratigraphic units was attempted. Interpretations were then made based on these profiles and the dates derived from organic and tephra samples.

CHAPTER THREE
LITHOSTRATIGRAPHY OF THE SUMAS VALLEY FILL

Because the main objective of this thesis was to describe the late Quaternary history of the Sumas Valley based on the interpretation of subsurface sediments, the lithostratigraphy of the Sumas Valley, is central to the data base. Additional non-lithostratigraphic data providing further evidence to support the interpretation of the valley's evolution is discussed in Chapter Five.

3.0 Lithostratigraphy of The Sumas Valley Fill

Subsurface deposits in the Sumas Valley include gravels, sands, silts, and clays which exhibit a variety of vertical and horizontal distribution patterns. Examination of the assembled core data made it possible to identify nine lithostratigraphic units within the Sumas Valley. Although minor variations existed within each of the units, they were homogeneous enough in terms of lithostratigraphic characteristics to be separately classified. The following table, which orders the units from shallowest to deepest, is followed by a series of unit descriptions.

TABLE 3.0

Sumas Valley--Lithostratigraphic Units

Unit 9	Silt and Fine Sand
Unit 8	Clayey Silt
Unit 7	Silt--Fluvial Proximal
Unit 6	Sand--Northern Valley
Unit 5	Sand--Southern Valley
Unit 4	Gravels--Northern Valley
Unit 3	Gravels--Southern Valley
Unit 2	Interbedded Sand and Silt
Unit 1	Blue Clayey Silt

The lithostratigraphic units discussed in this chapter are illustrated in a series of transects compiled from core data (Figs. 3.0 to 3.15). The categorization of units in each of the transects was in most cases made with confidence, but because some of the data obtained from water well drill core were questionable, some speculation on the continuity of units was necessary. Inferred unit correlations are indicated on the transect profiles with dashed lines.

Interpretations of the core cross-sections are included with each transect. Analysis of the spatial distribution of these lithostratigraphic units is essential for interpretating the environments of deposition and therefore the geomorphic evolution of the Sumas Valley. Unit distributions and interpretations are discussed in Chapter Four.

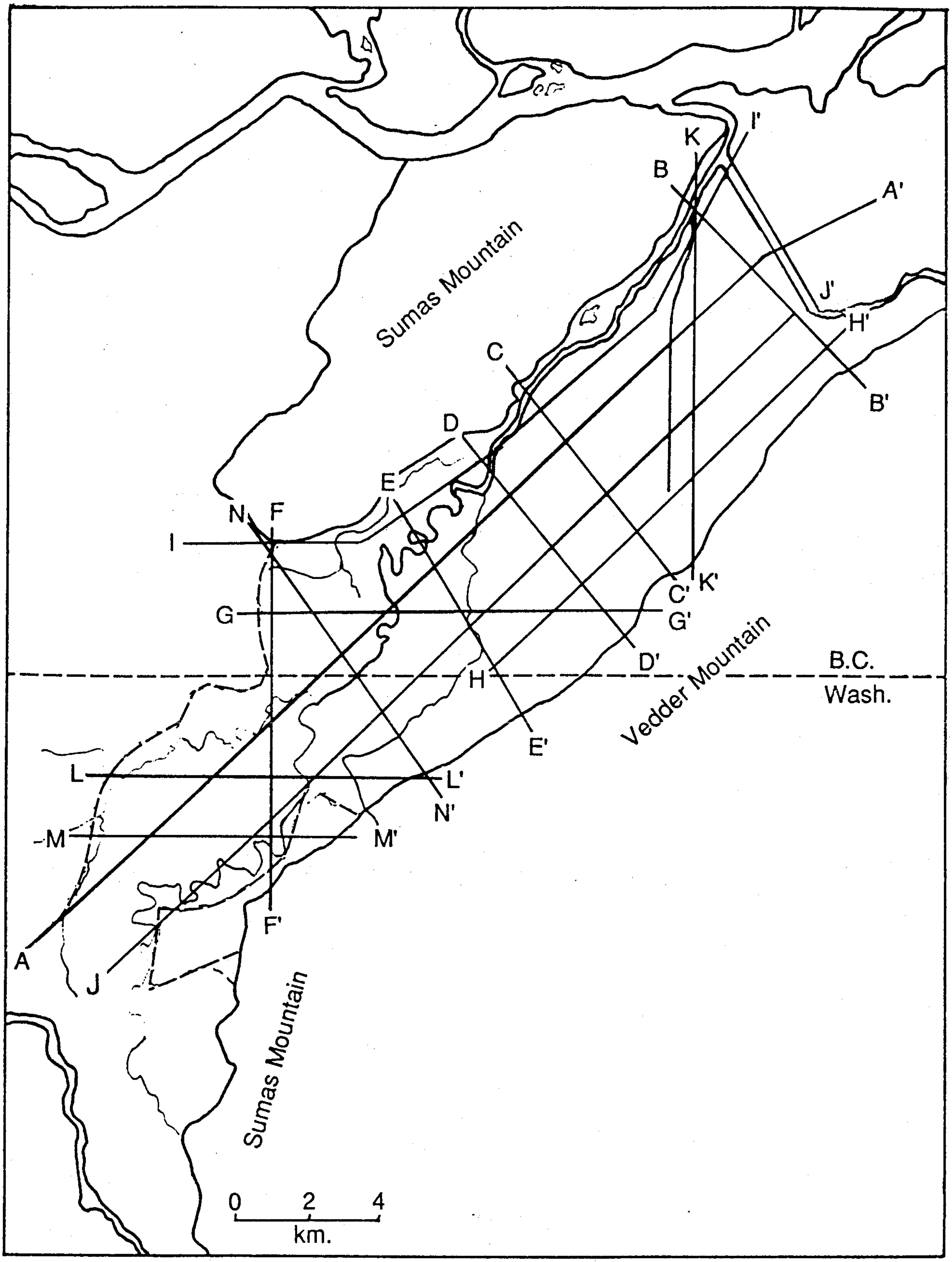


Fig. 3.0 Cross Sections plotted from drill cores and well logs

Fig. 3.1 **KEY TO CROSS SECTIONAL TRANSECTS**

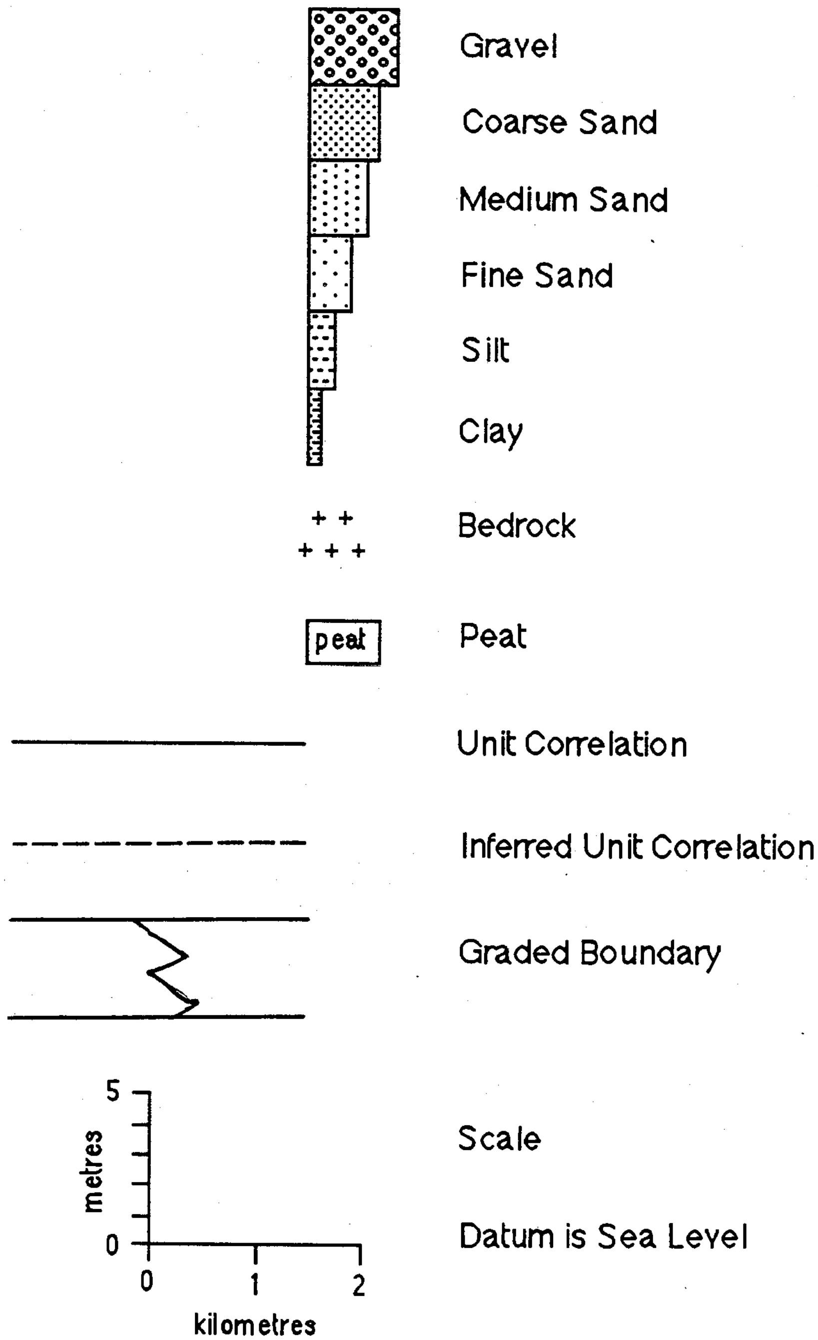
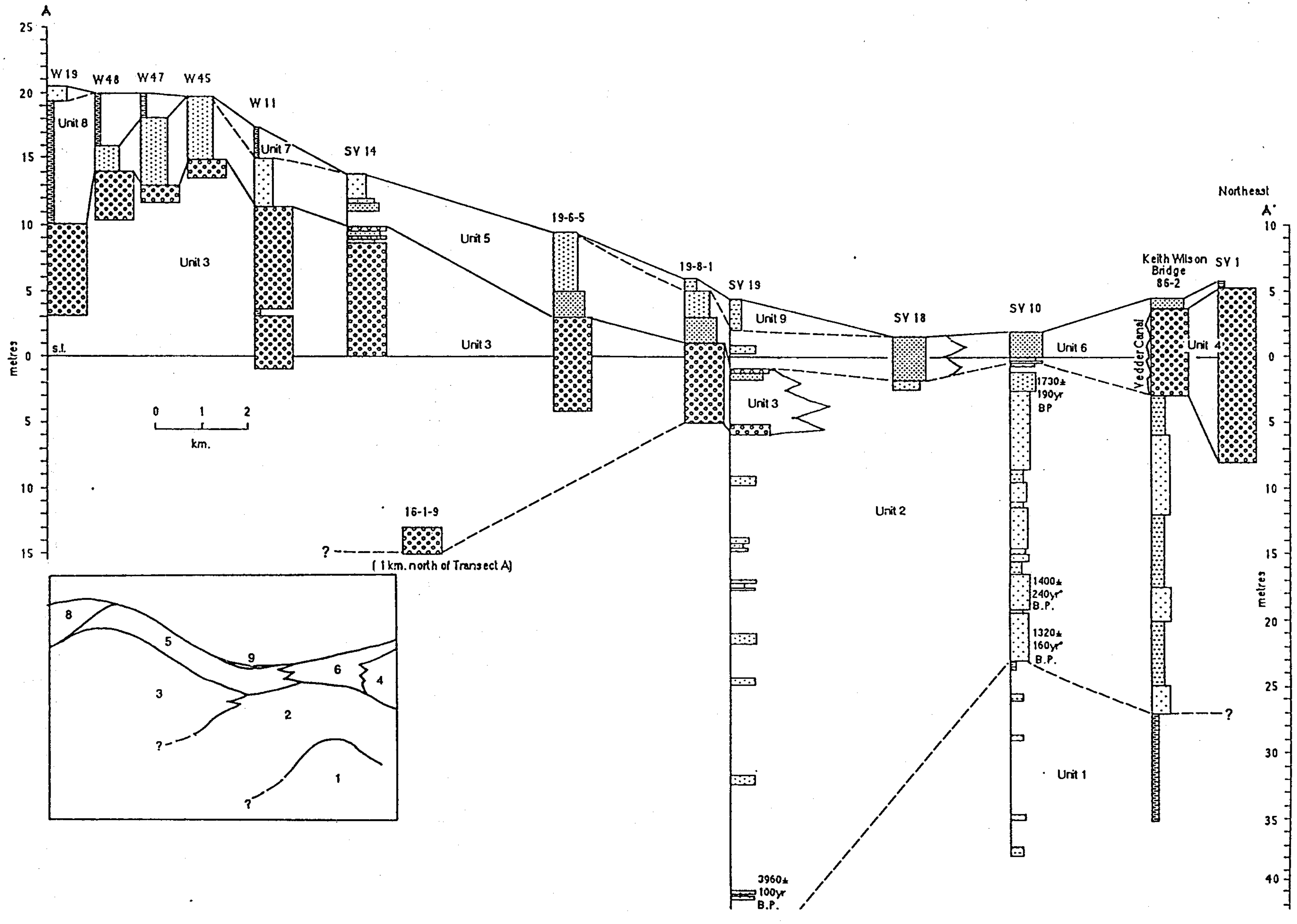


Fig. 3.2 Transect A



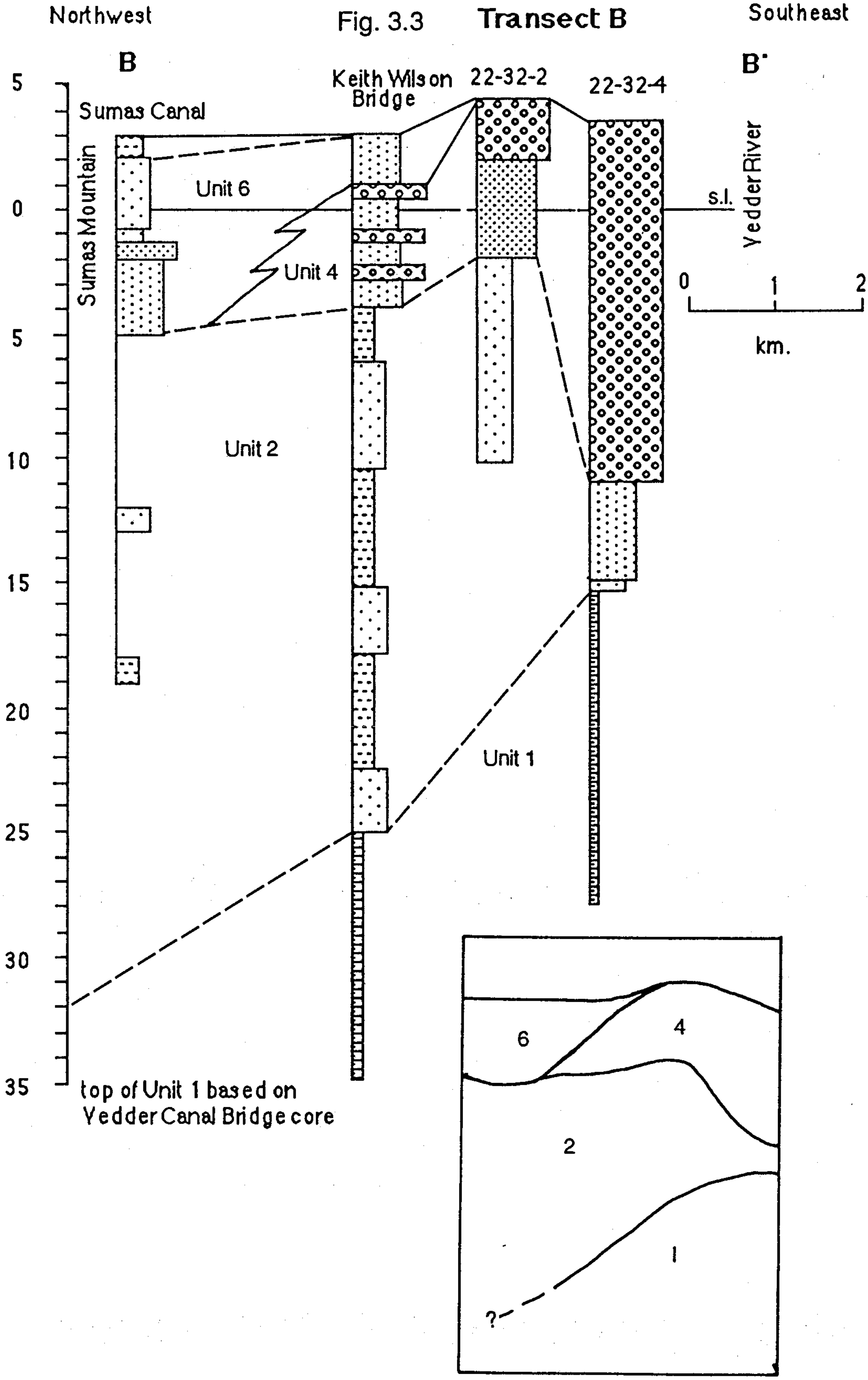

Northwest
Fig. 3.3 Transect B
Southeast
B
B'
Sumas Canal
Sumas Mountain
Keith Wilson Bridge
22-32-2
22-32-4
Vedder River
s.l.
Unit 6
Unit 4
Unit 2
Unit 1
0 1 2
km.
5
0
5
10
15
20
25
30
35
top of Unit 1 based on Yedder Canal Bridge core
6
4
2
1
?

Fig. 3.4 **Transect C**

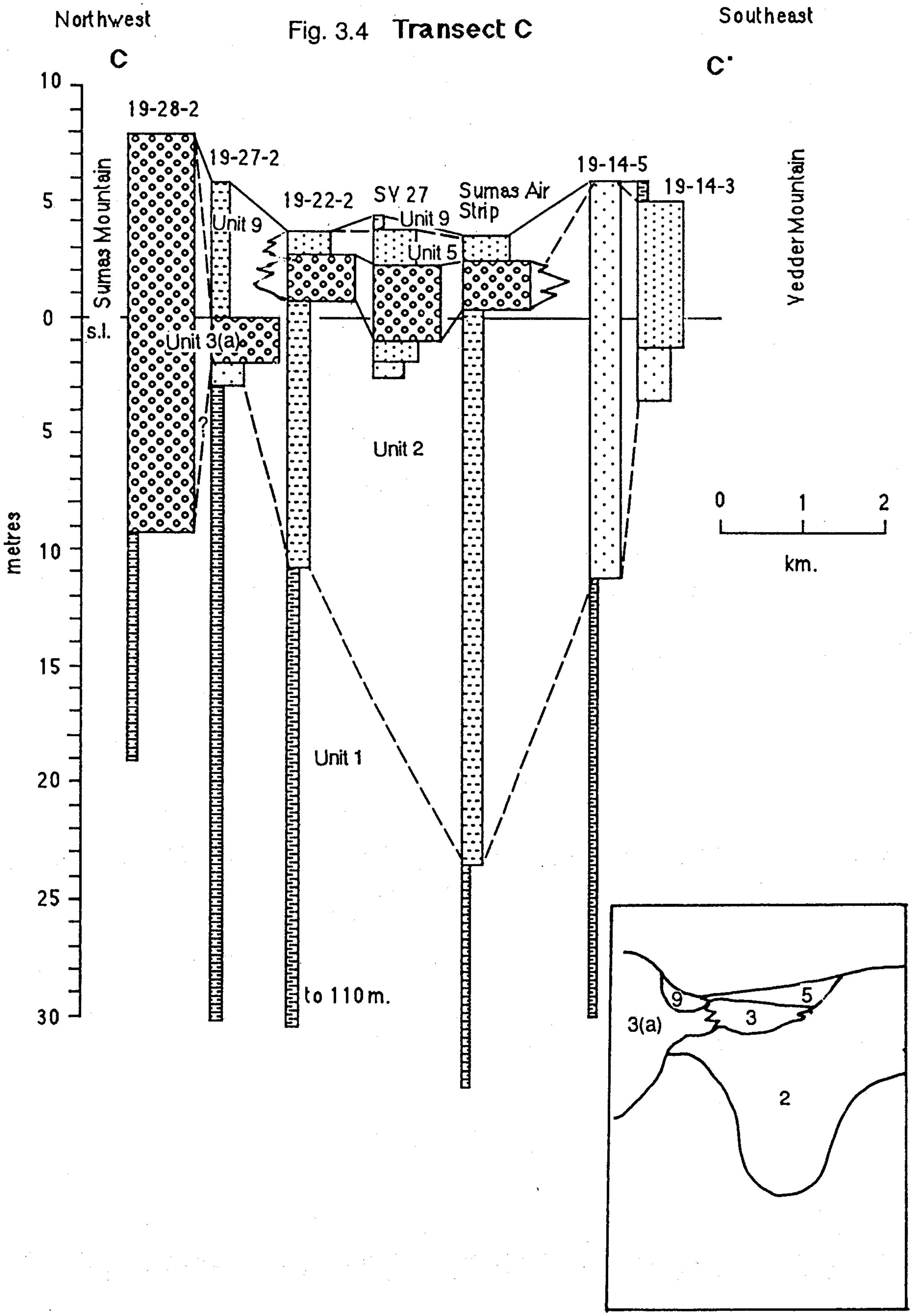


Fig. 3.5 **Transect D**

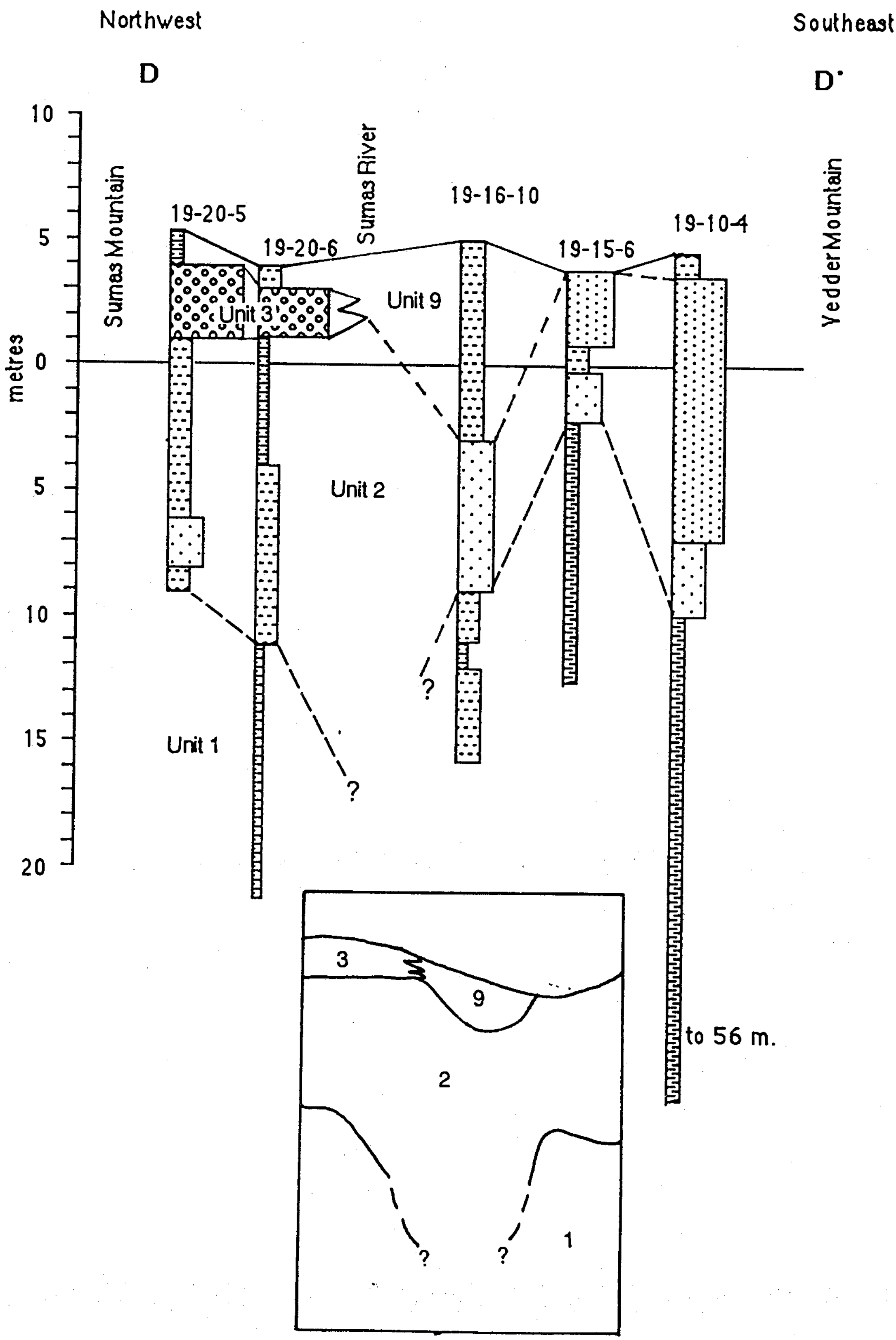


Fig. 3.6 **Transect E**

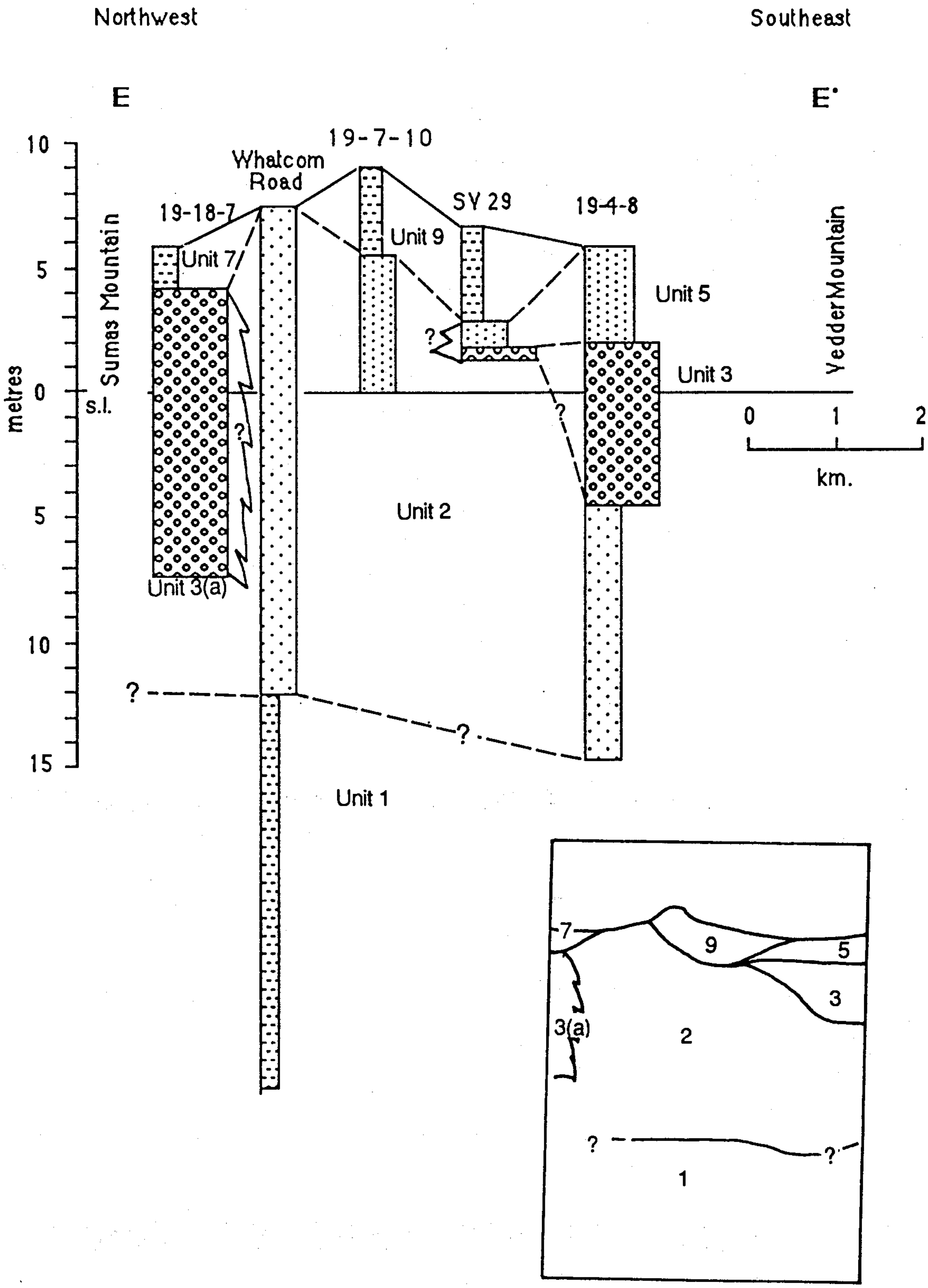


Fig. 3.7 Transect F

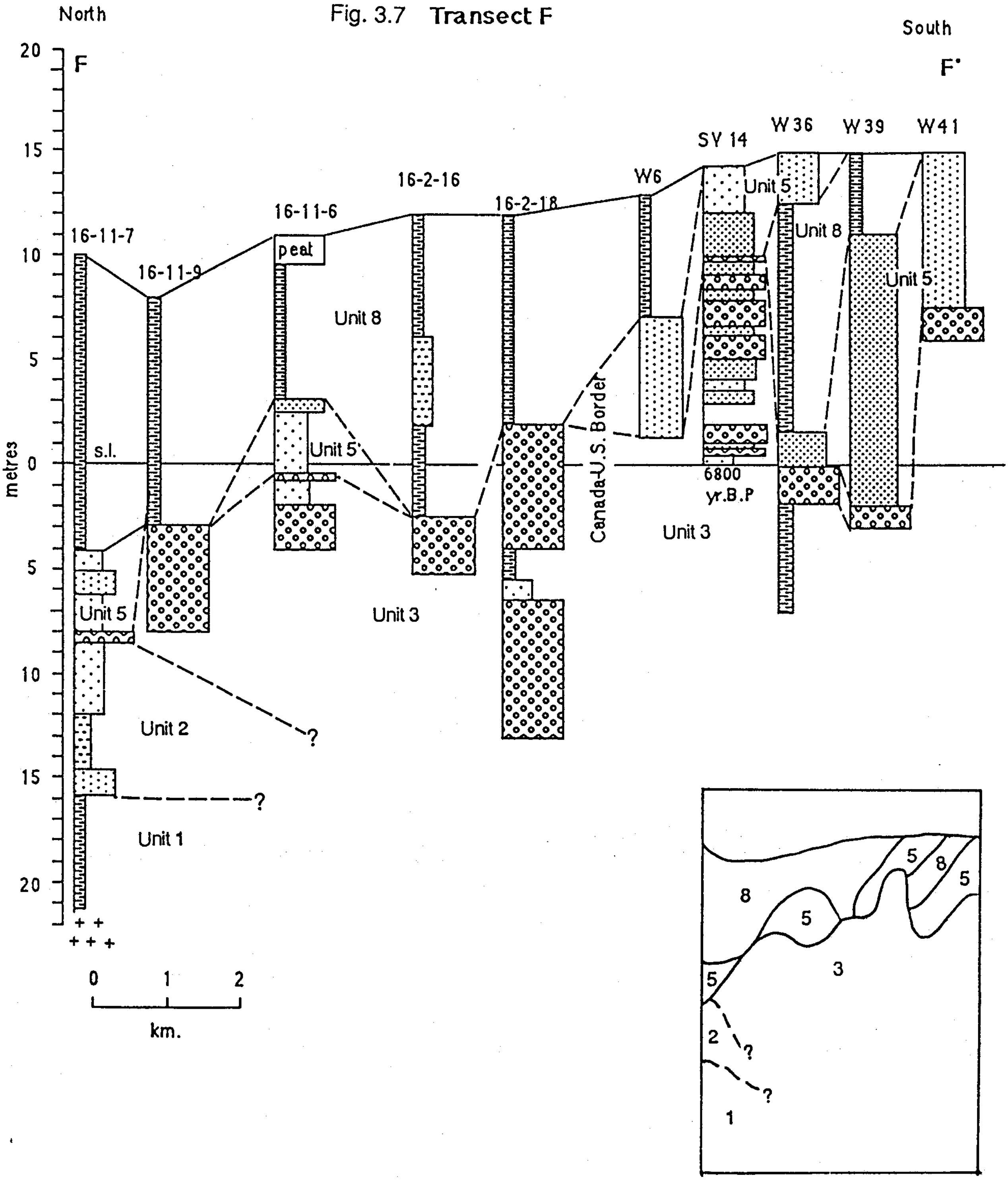


Fig. 3.8 **Transect G**

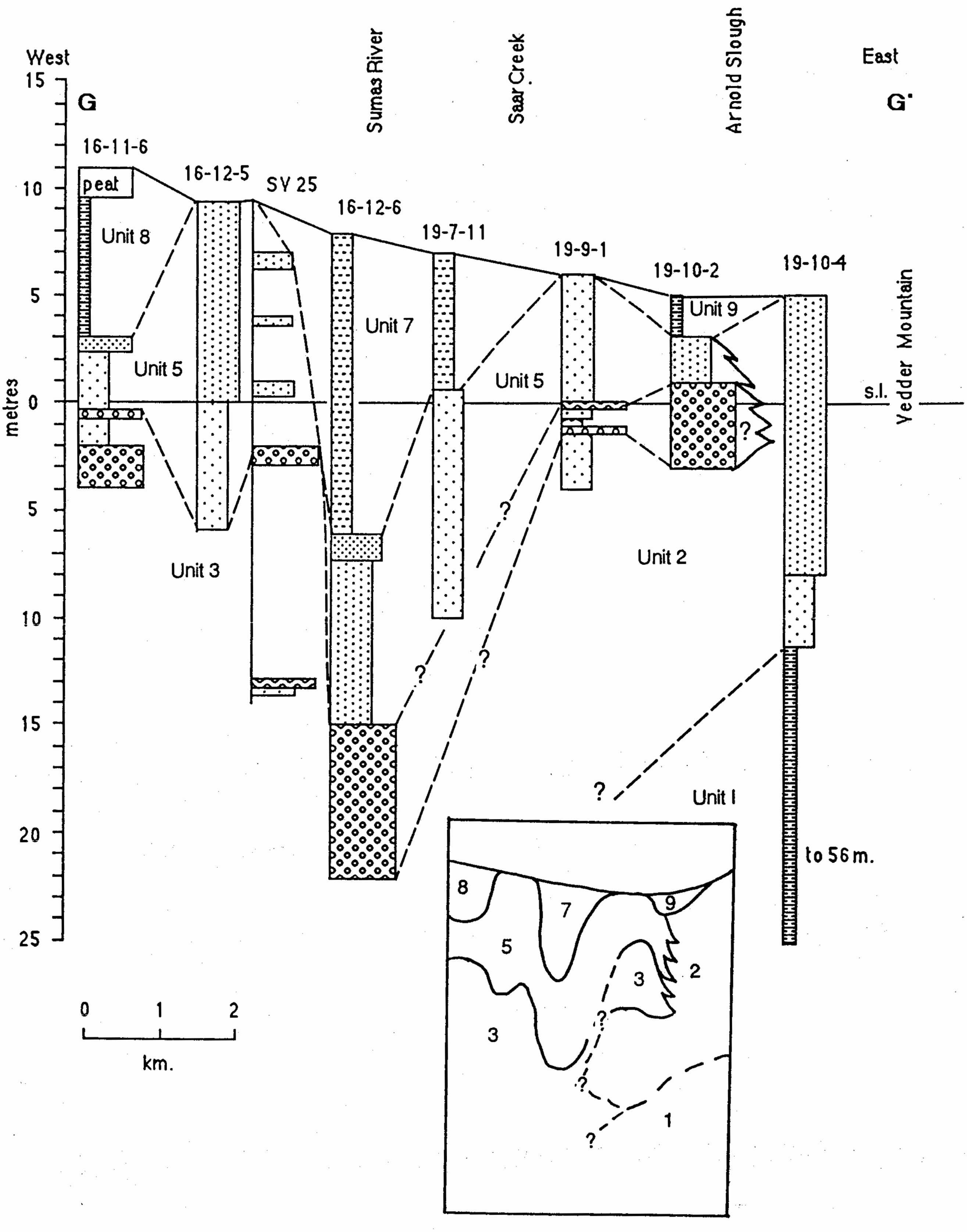


Fig. 3.9 **Transect H**

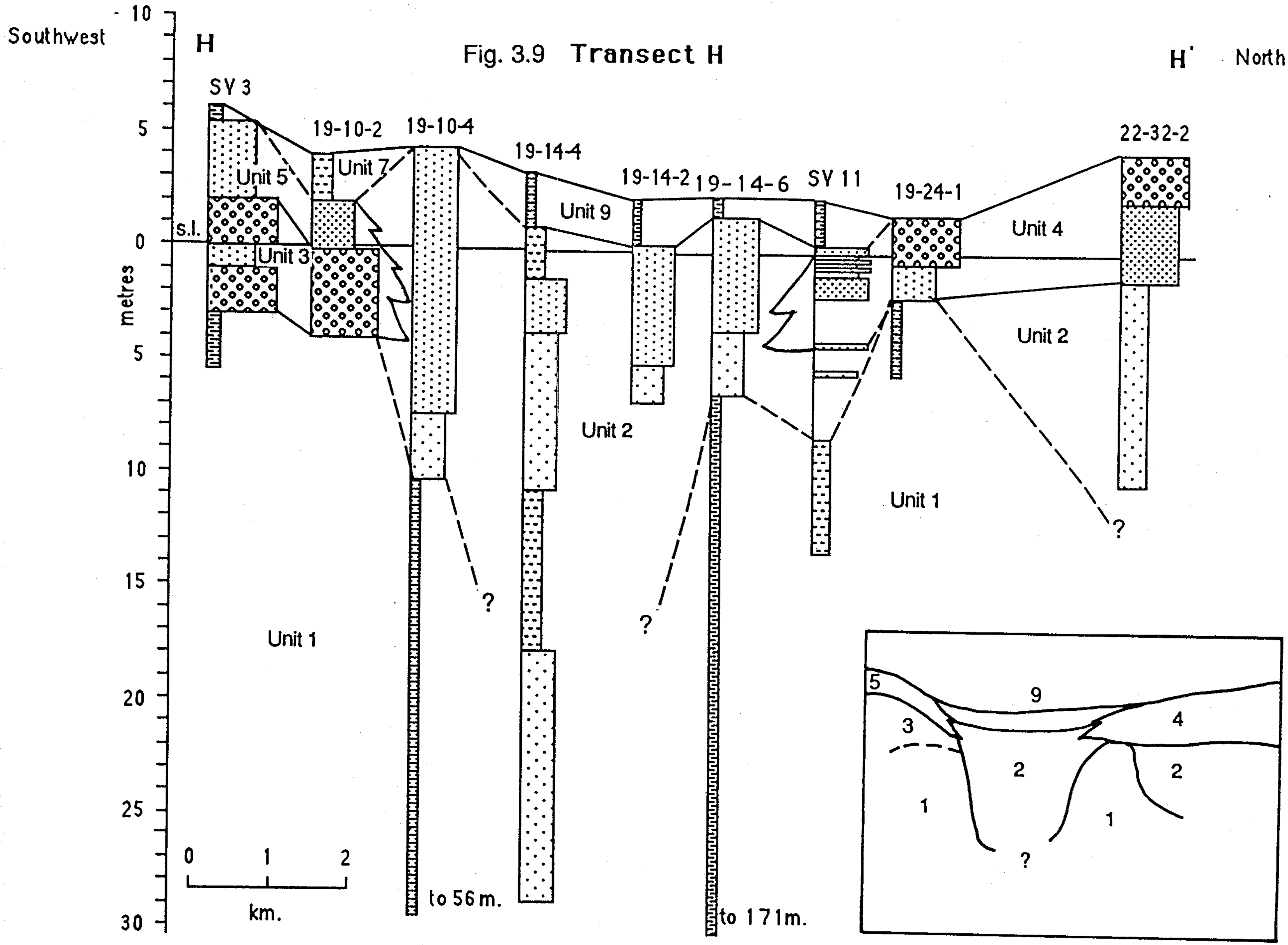


Fig. 3.10 Transect I

Transect I East

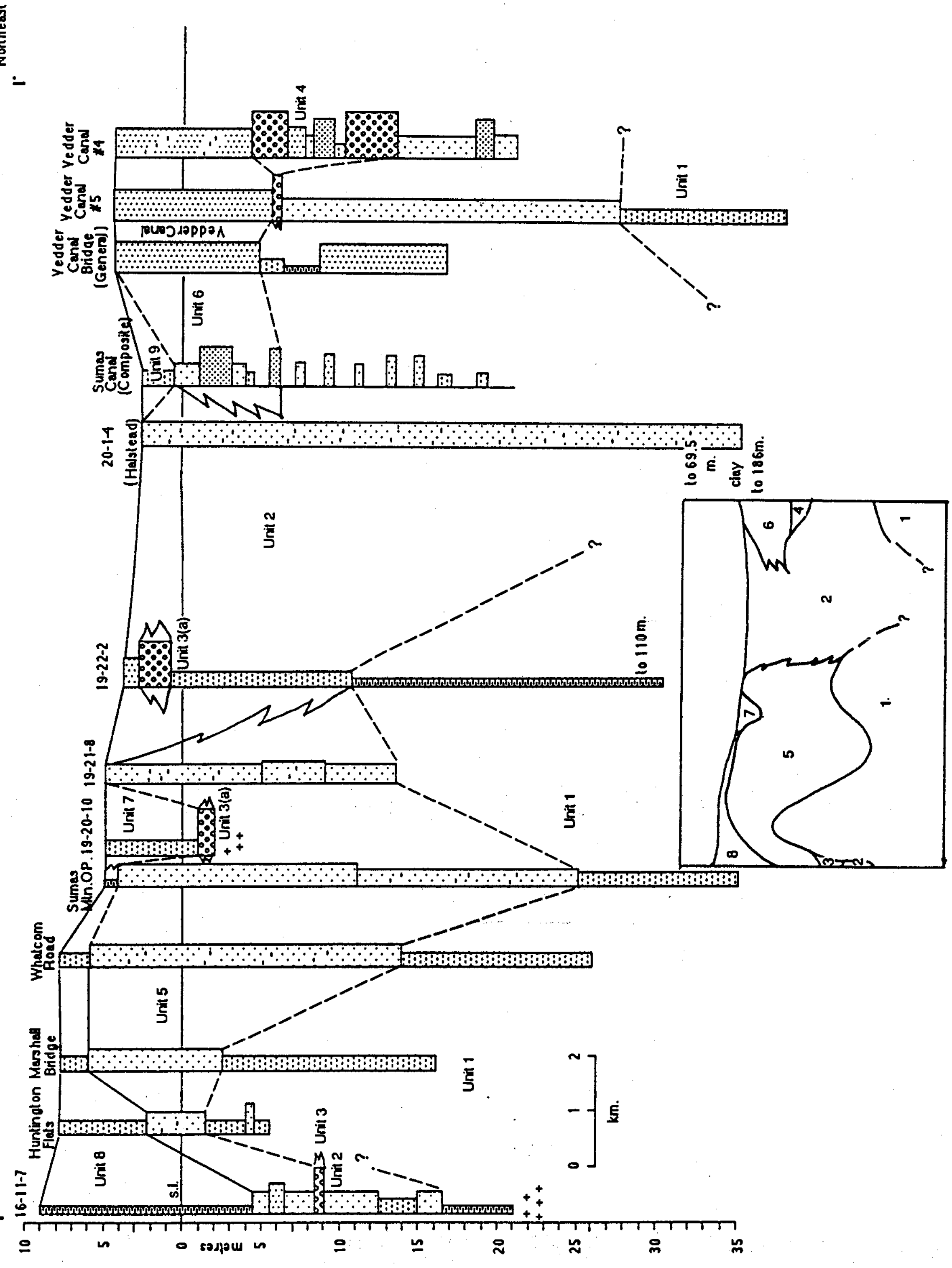


Fig. 3.11 Transect J

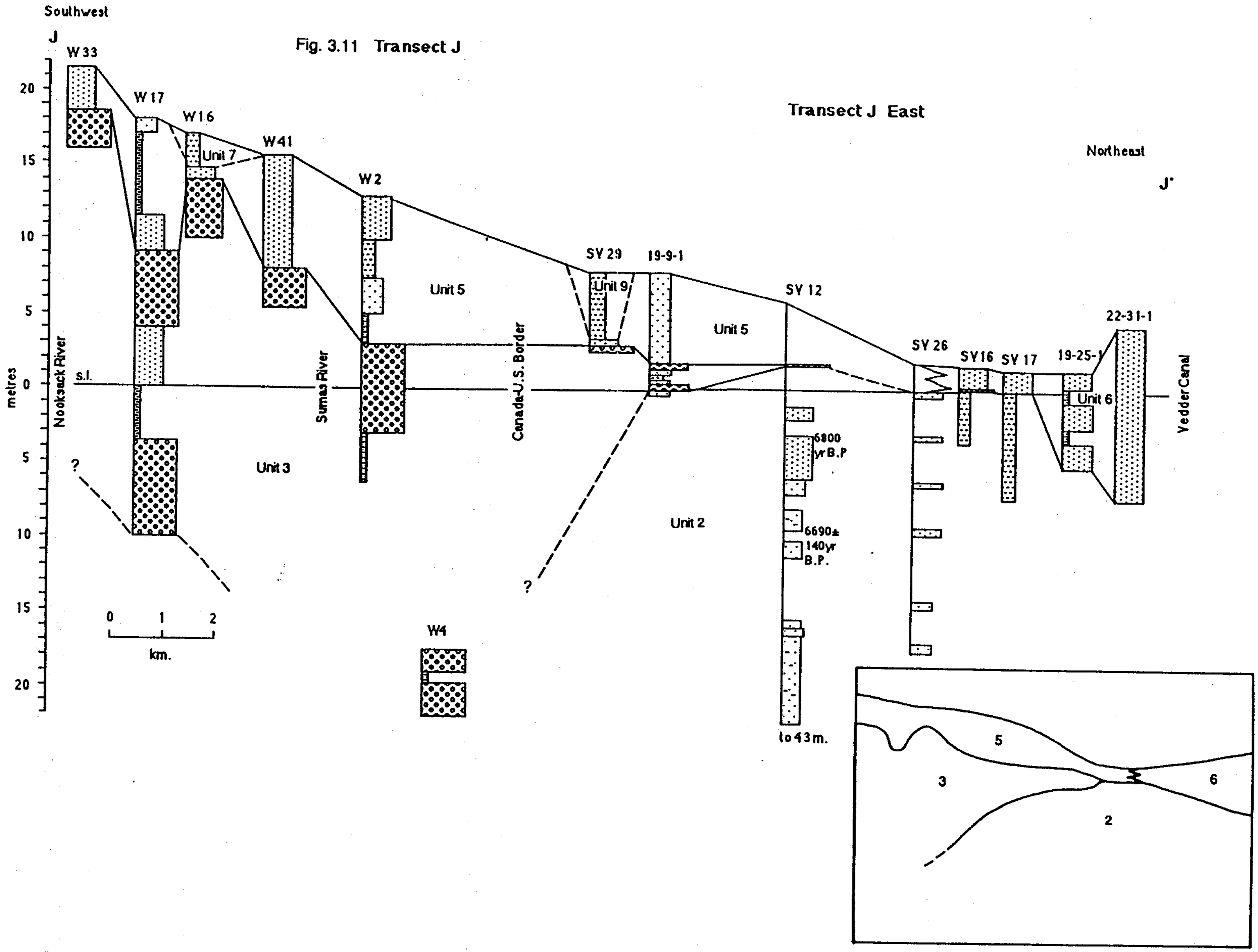


Fig. 3.12 **Transect K**

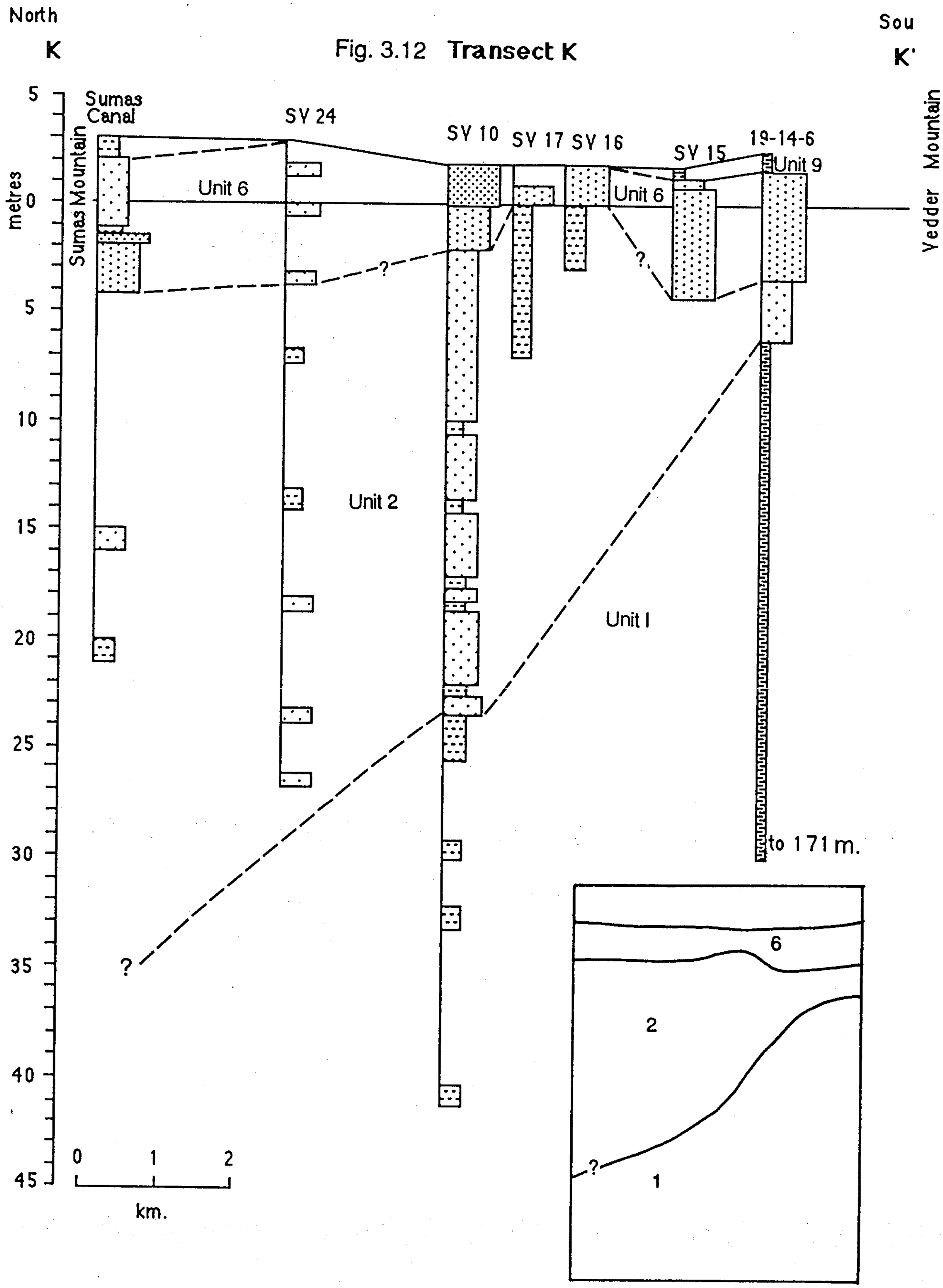


Fig. 3.13 **Transect L**

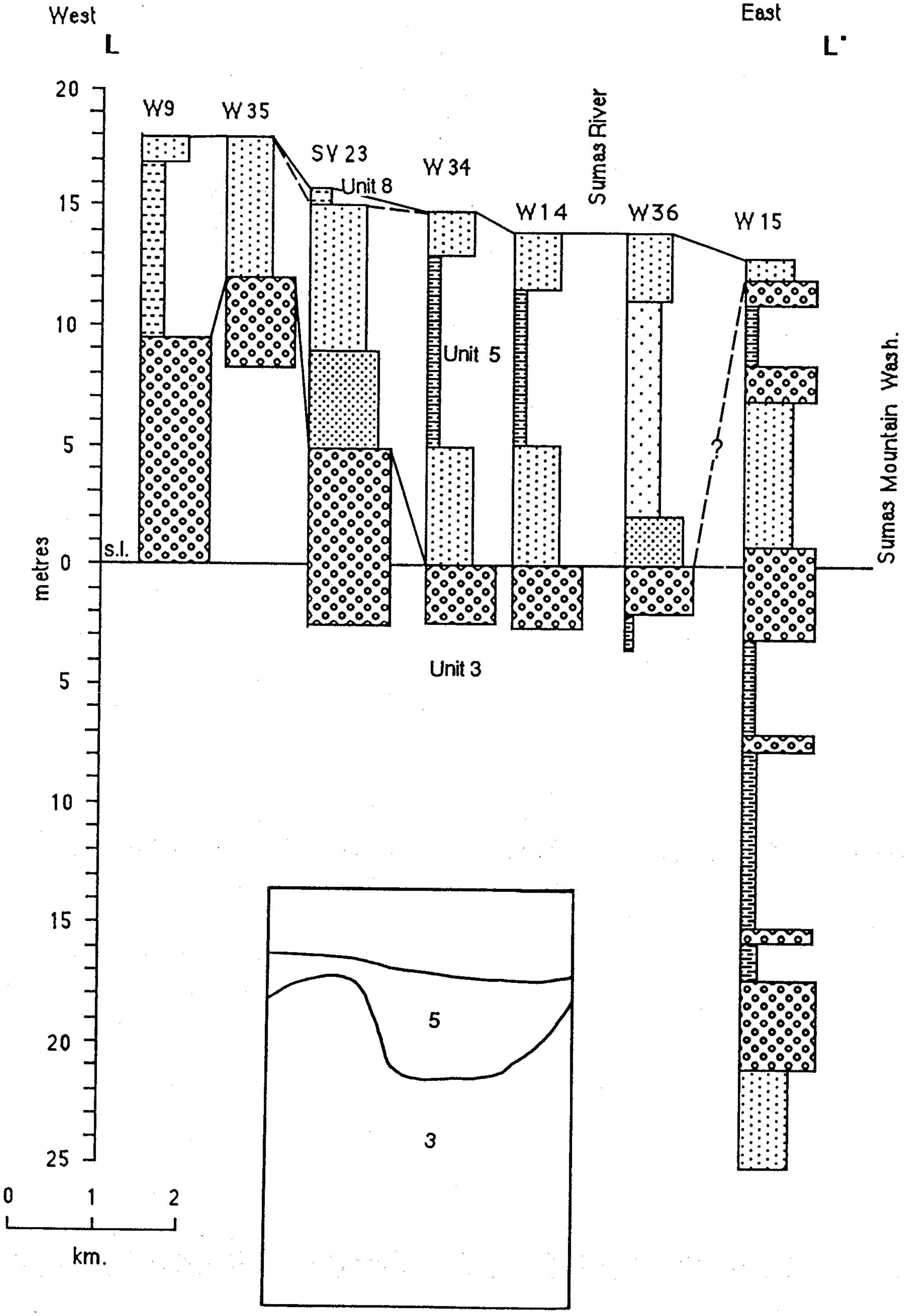


Fig. 3.14 **Transect M**

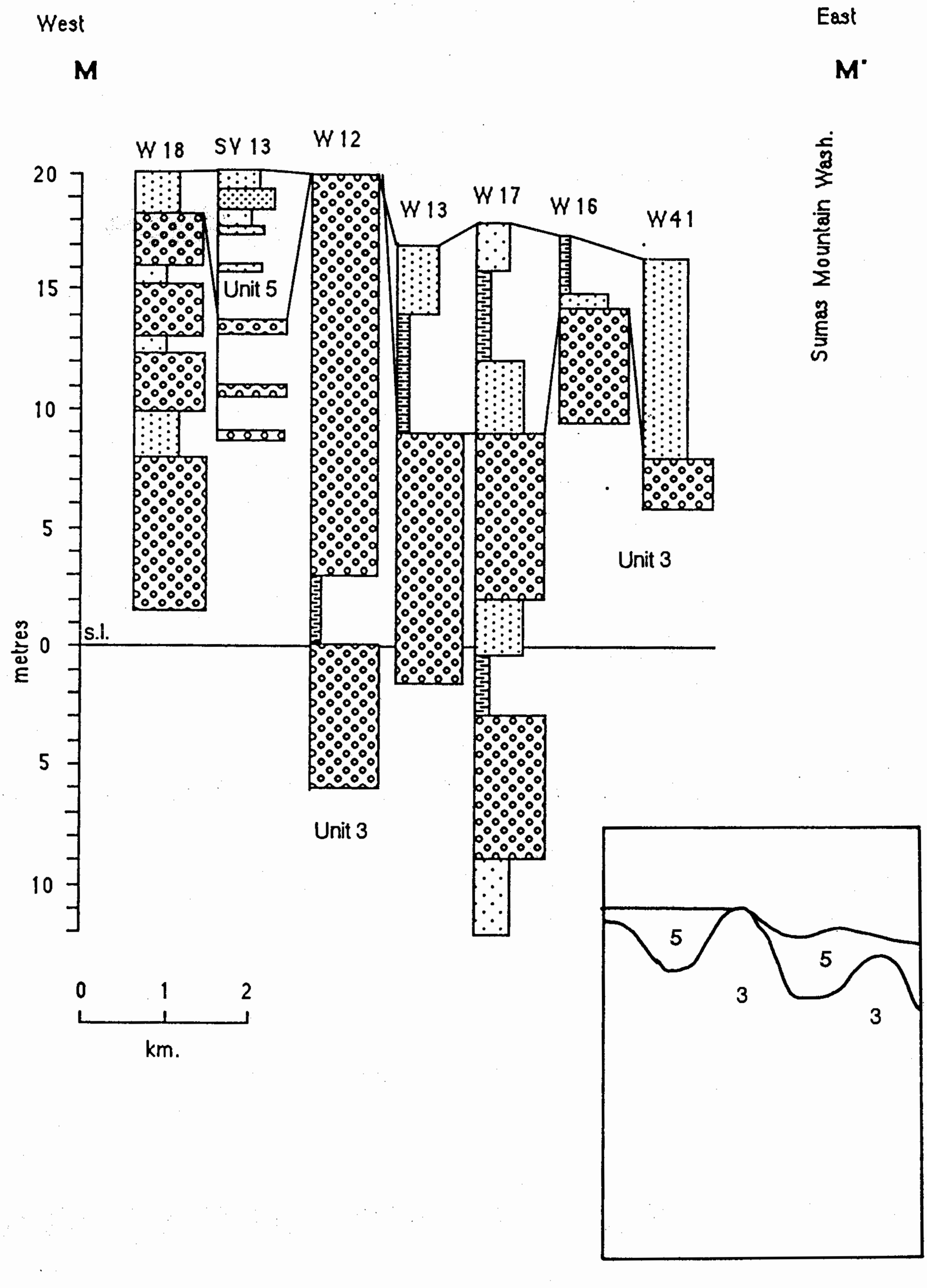
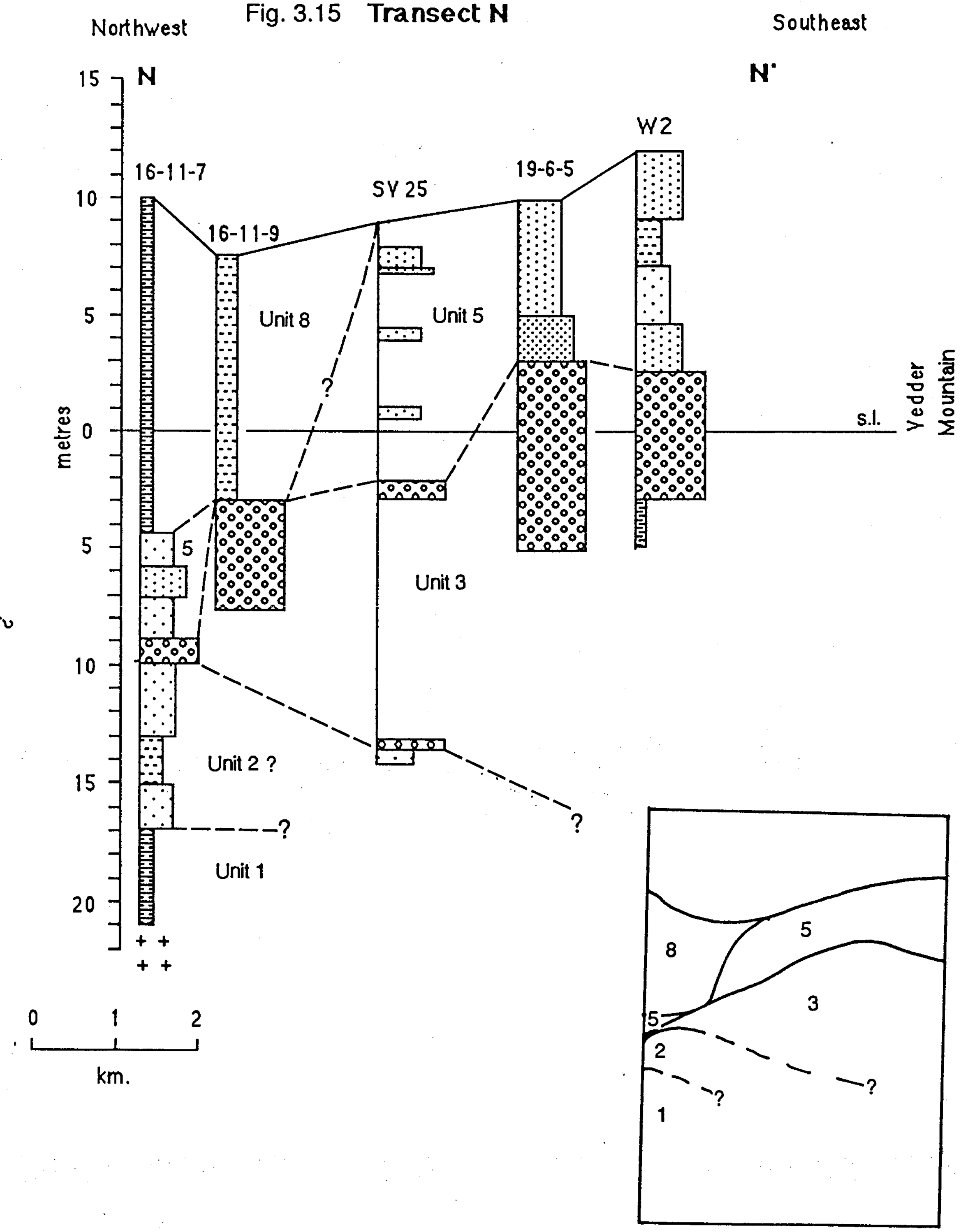


Fig. 3.15 **Transect N**



3.0.1 Unit 1-- Blue Clayey Silt

Underlying much, if not all, of the Sumas Valley is clayey silt, classified here as Unit 1. This basement clayey silt is typically blue, water saturated, and has a sticky consistency.

Unit 1 is found at the base of many of the cores, water wells, and engineering test holes throughout the Sumas Valley. The absence of Unit 1 silt at the base of holes in the southern portion of the valley is attributed to the shallowness of the water well holes there, and Unit 1 silt is assumed to exist at depth.

The clayey silt of Unit 1 is of unknown thickness but is presumed to be very deep (Armstrong, 1960). One water well close to Transect C (Fig. 3.4) and near Vedder Mountain (19-14-6, Appendix A(L))was drilled though 177 metres of this unit without hitting bedrock.

Cross sectional profiles indicate that the upper limit of the basement clayey silt appears to be shallowest along the sides of Sumas Valley particularly along Vedder Mountain and deepest in the central portion of the valley (Transects B and C, Figs. 3.3 and 3.4). Further, the depth at which Unit 1 clayey silt is found tends to increase towards the south (Transect A, Fig. 3.2).

It has been suggested that Unit 1 clayey silt is of marine origin (Armstrong, 1960), although an examination of Unit 1 silt under a microscope failed to reveal the presence of any marine forams.

3.0.2 Unit 2 -- Interbedded Sand and Silt

A thick sequence of interbedded sand and silt layers found in the central Sumas Valley is classified as Unit 2. This unit lies between the basement silt of Unit 1 and the gravels of Units 3 and 4. It is not known whether the Unit 1-Unit 2 boundary is graded or sharp. After Unit 1 silt, which is of unknown thickness, Unit 2 is the thickest unit found in the Sumas Valley. Sand and silt from Unit 2 was found at a depth of 45 m at SV19.

The sand in Unit 2 is characteristically sub-angular to sub-rounded and is usually fine textured, although occasionally some medium-fine sand is present. In Unit 2 sand is typically interbedded with silt layers. The layers of silt and sand display varying thicknesses, although in some cases, sand-silt couplets of uniform thickness (1-2 mm at SV26) are present (Fig. 3.16).

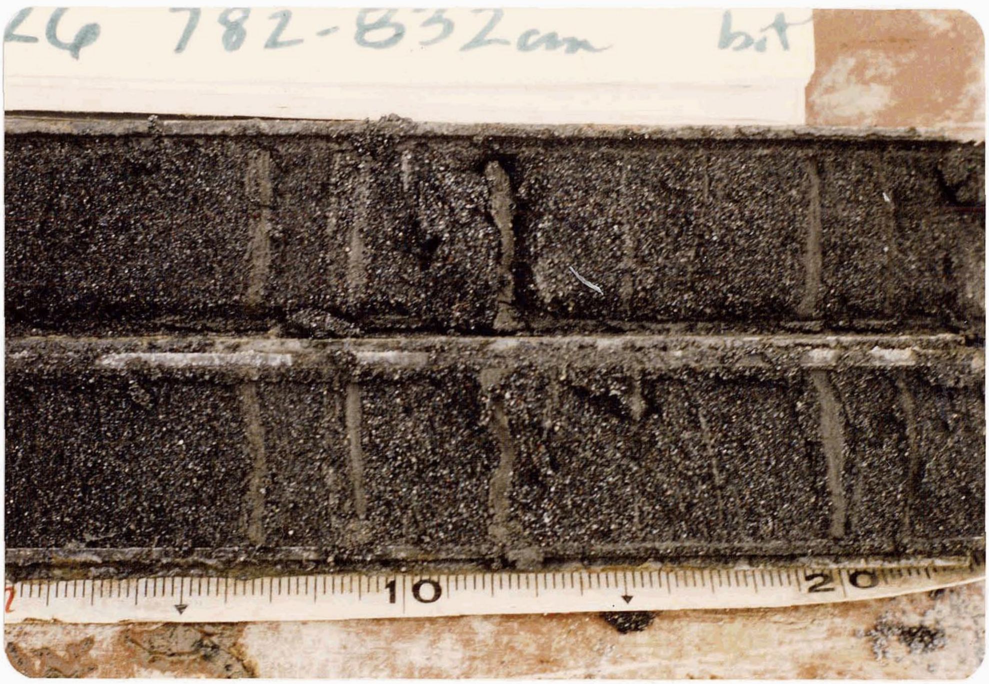


Fig. 3.16 SV26 Sand silt couplets, Unit 2.

A significant characteristic of Unit 2 is that it displays upward coarsening. At the base of the core holes, although both sand and silt are present, the latter predominates. Towards the top of the core holes, however, sand constitutes a greater proportion of the core sample. Examples of this grading pattern are best seen at SV12 and SV26 on Transect J (Fig. 3.11), and at SV10 on Transects A and K

(Figs.3.2& 3.12). In some cases, Unit 2 upwardly grades into even coarser sand (Unit 6), as can be seen at SV10 and at SV11 (Transect H, Fig. 3.9).

Unit 2 appears to be confined to the north central portion of Sumas Valley. It is not known whether Unit 2 exists in the southern Sumas Valley because water well logs in the south valley only extend as for as the Unit 3 gravels.

3.0.3 Unit 3 -- Gravel--Southern Valley

Gravel is abundant within the Sumas Valley, although it is found almost entirely beneath the surface. Due to the limited preservation of gravel in the core sample, it was impossible to determine if imbrication was present or if the gravel was clast or matrix supported. However, observations on gravel depth, distribution, size, roundness, and lithology could be made.

Because of the importance of gravel as an aquifer in the region, it was possible to determine its subsurface distribution by the analysis of water well logs. The abundance of these logs enabled detailed subsurface correlation of gravel units to be carried out.

Unit 3 is a wedge of gravel which enters the Sumas Valley from the south from the vicinity of the Nooksack River. Although Unit 3 is predominantly composed of gravel, it also includes occasional sand layers and silt/clay layers. These finer sediments are believed to represent ponding events in the depositionary record, but are included in Unit 3 because they are overlain by more gravel.

Unit 3 is most clearly seen in Transects A,J. M, and F (Figs.3.2. 3.11, 3.14, & 3.7) and is present throughout almost the entire southern half of the Sumas Valley. (Fig. 3.17). Just north of the Canada-U.S. border, Unit 3 splits into two lobes with the northern lobe extending along the north side of Sumas Valley for a further 10 km before pinching out, and the more minor southern lobe extending for 2 km into the valley. It should be noted that the location of these two lobes correlates with the

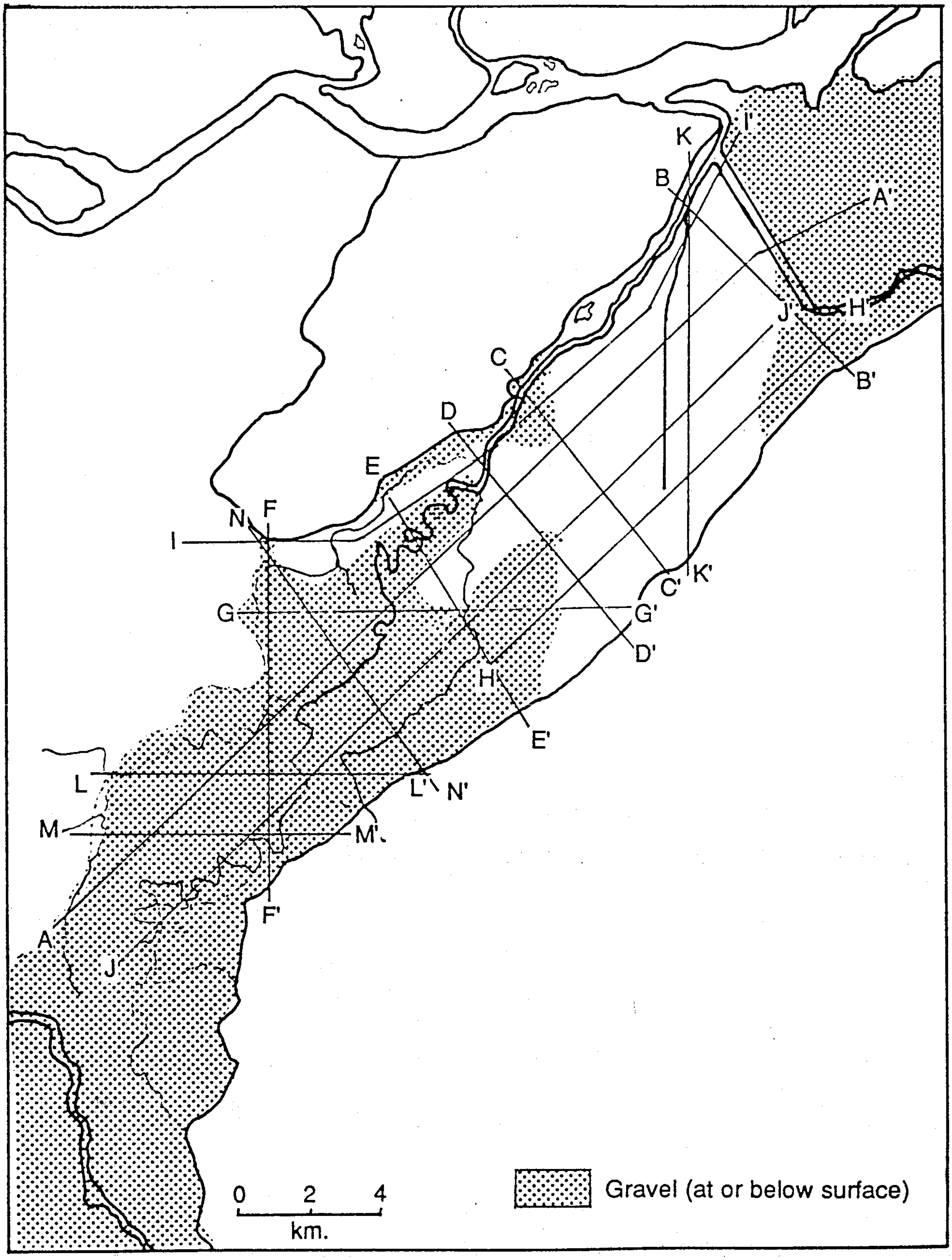


Fig. 3.17 Location of gravels in the Sumas Valley

location of the modern day Sumas River and Saar Creek, and is clearly related to their presence.

Unit 3 tapers from a thickness of more than 20 m in the southern valley near Everson to just a trace in the northernmost extremity of the valley (Transects A and J, Figs. 3.2 and 3.11). Mirroring the surface topography, Unit 3's upper surface slopes towards the north. In addition the upper surface of the wedge dips from 1-3 m below the valley surface in the south to 5 m below the surface in the north. The maximum depth of this gravel unit has not been determined, due to the difficulty of penetrating this layer and to the absence of water well hole information at the depths required.

Gravel in Unit 3 is sub-angular to sub-rounded. The degree of sorting within the gravel was not discernable due to sampling techniques. However sand appeared to be relatively plentiful in the samples which were taken. Gravel also exhibited lateral grading from cobble size (6 cm or larger) near the Nooksack River to pea gravel and finally to coarse sand at the gravel wedge's northernmost extremity. Vertically within cores gravels graded as well, initially coarsening upwards, then fining upwards.

Gravel found adjacent to Sumas Mountain (visible in Transects C, D, and I, Figs. 3.3, 3.4, and 3.10) is assigned the classification of Unit 3(a) as it is not known whether this gravel is associated with Unit 3 gravel, or is colluvium or alluvium from Sumas Mountain.

3.0.4 Unit 4 -- Gravel -- Northern Valley

Unit 4 gravel constitutes a smaller, more conical wedge than Unit 3, and enters the Sumas Valley from the northeast from the vicinity of the Chilliwack River. It extends for 2.25 km west into the valley along the Vedder Canal and 5.5 km south into the valley from its point of entry. Like Unit 3, it dips below the valley surface and is found at 2.5 m below the surface before finally disappearing at its distal boundary. This gravel tapers from a thickness of 14 m where it enters the Sumas Valley at

Yarrow to less than 2.5 m at its most distal point near Sumas Mountain. Unit 4 gravel is best seen in Transects H and B (Fig.3.9 & 3.3).

Data from boreholes northeast of the Vedder Canal at Sardis in the vicinity of Chilliwack confirms the extension of Unit 4 gravel into the Fraser River floodplain. A borehole log from the B.C. Department of Energy and Petroleum Resources places the lower limit of the gravel at 24 m below the surface (12 m below sea level). In the exploration borehole, the gravel is underlain by sand to 43 m below sea level, and then by clay to 400 m below sea level, at which depth lithified sediments are finally encountered.

Like Unit 3, the gravel in Unit 4 is sub-angular to sub-rounded, and exhibits lateral grading from cobble size to coarse sand. Unit 4 differs from Unit 3 in terms of lithology (see Chapter Five) and location -- it is separated from Unit 3 by Units 2 and 9 in the central Sumas Valley.

3.0.5 Unit 5 -- Sand -- Southern Cores

Unit 5 is classified as a sand unit found above Unit 3 gravel in the southern portion of the Sumas Valley. Sand within Unit 5 is sub-angular to sub-rounded and displays horizontally layered structure. Unit 5 grades from very coarse to fine sand and displays vertical and lateral grading patterns. This unit typically diplays upward fining within cores, and lateral fining from south to north. It is believed that Unit 5 grades into Unit 2 in the north-central Sumas Valley.

The lthological/mineralogical composition of Unit 5 sand is the same as Unit 3 gravel, and it is therefore interpreted to be a distal extension of that unit.

3.0.6 Unit 6 -- Sand -- Northern Cores

Unit 6 sand is conformably overlying Unit 4 gravel in the northeastern portion of the Sumas Valley. Like Unit 5, Unit 6 sand is sub-angular to sub-rounded, is horizontally layered, and displays vertical and lateral grading from very coarse to fine sand. However, its lithological composition resembles Unit 4 and it is interpretated to be a distal extension of that unit. Unit 6, like Unit 5, is believed to grade into Unit 2 in the mid-valley region.

Units 4 and 6, despite structural similarities with Units 3 and 5, are classified separately because of different lithology and mineralogy (see Chapter Five) and because of location. Units 4 and 6 are confined to the northeastern tip of the Sumas Valley, and are separated from Units 3 and 5 in the southern half of the valley by Units 2 and 9 .

3.0.7 Unit 7 -- Silt -- Fluvial Proximal

In the south portion of the Sumas Valley, as seen in Transect M (Fig.3.14), is silt which lies above Unit 3 gravel. This silt displays no regular horizontal or vertical distributional pattern, and because of its proximal location to rivers (Sumas and Nooksack Rivers and Saar Creek), is interpretated as being associated with fluvial activity, perhaps as overbank silt, or as an irregular extension of Unit 8 (Section 3.0.8).

3.0.8 Unit 8 -- Clayey Silt

Unit 8 is an extensive region of surface clayey silt found along the western margin of the Sumas Valley at the base of the Sumas Drift exposure. Unit 8 overlies Unit 3 gravel and is on average 10 m thick. The silt of Unit 8 is interspersed with peat deposits, some of which presently extend to the surface. Unit 8 appears to be confined to the western portion of the valley, particularly in the sharp recess in the valley wall near the town of Abbotsford, and can be best seen in Transects I and G (Figs. 3.10 and 3.8).

3.0.9 Unit 9 -- Silt and Fine Sand

A very shallow (<2 m) unit of surface silt and fine sand is found in the flat Sumas Prairie region in the north central Sumas Valley. This Unit 9 surface silt and sand is seen to be overlying the upper coarser sands of Units 2, 5, and 6. Because Unit 9 is shallow and is confined to the mid valley region, it is believed to be a lacustrine deposit associated with Sumas Lake. The raised ridges of fine sand which mark the periphery of old Sumas Lake and which are believed to be beach deposits, are also included as part of this unit .

CHAPTER FOUR

SEDIMENTARY ARCHITECTURE OF THE SUMAS VALLEY

4.0 Introduction

The construction of valley cross sections (Figs. 3.2 to 3.15) and subsequent correlation of lithostratigraphic units provided insight into the subsurface sedimentary architecture of the Sumas Valley. Sections were analyzed in particular for :

1) spatial distribution of lithostratigraphic units within the valley, and
2) horizontal and vertical variations in texture.

Sections were organized into longitudinal and cross valley profiles to enable the analysis and interpretation of stratigraphic sequences.

4.1 Longitudinal Sections

Four sections extending lengthwise through the Sumas Valley provided a longitudinal subsurface profile of the valley. The four transects were oriented in a southwest to northeast direction, and were, from north to south, Transects I, A, J, and H (Figs. 3.10, 3.2, 3.11, and 3.9), with Transect A (Fig. 3.2) being the longest (28.5 km) and encompassing the entire length of the valley.

Similar sedimentary trends were observed in all longitudinal sections. To best illustrate these trends, Transect A (Fig. 3.2), representing a central valley profile, and Transect I (Fig. 3.10), representing a valley flank profile, will be focused upon.

4.1.0 Central Valley--Transect A

The deepest unit observed in Transect A (Fig. 3.2) is Unit 1 basement silt and clay. This unit is only observable in the northeast portion of the section (SV10 and Keith Wilson Bridge). Unit 1 is not visible in the southern portion of Transect A, but is present in the south in other profiles (Transect H, Fig. 3.9) and is therefore presumed to exist at a greater depth than represented in the cores throughout Transect A.

Positioned above Unit 1 silt and clay in the northern half of the section is Unit 2. Unit 2, which is composed of interlayered fine sand and silt, is extensive throughout Transect A, and is confirmed to exist at a depth of -42 m (bmsl) in the mid-valley (SV19). Vertically within cores in Transect A, Unit 2 exhibits little variation, displaying limited upward coarsening clastic sequences at SV10. (Although cores in Transect A do not show obvious signs of upward coarsening clastic sequences in Unit 2, SV12 and SV26 in Transect J, Fig. 3.11, do.) Laterally within Unit 2, northeastern cores have a higher silt composition than southwestern cores.

The longitudinal profile of the Sumas Valley is dominated by the presence of the two gravel units: Unit 3 at the south end and Unit 4 at the north end of the valley. Units 3 and 4 are separated by Unit 2 in the mid-valley region.

Unit 3 is the more extensive of the two, encompassing almost two-thirds of the valley. The upper boundary of Unit 3 in Transect A slopes from an elevation of 14.5 m (amsl) (W45) to a depth of -1.5 m(SV19) over a distance of 13 km. Its depth is unknown at the south end of the valley, but Unit 3 is known to exist at least 15 m below sea level, based on water well records at 16-1-9 (Fig. 3.2). The gravel lobe tapers in thickness towards the north, finally pinching out between SV19 and SV18.

Data on the character of the gravel are available for SV14 and SV19. The maximum size of gravel clasts observed at SV14 was 3 cm, whereas SV19 yielded gravel clasts with a diameter of 3 mm. Based on this observation, it can be concluded that the gravel of Unit 3 grades in size from the south end of Sumas Valley towards the north.

Unit 4, although less extensive than Unit 3, is still important in the construction of the stratigraphic profile of Transect A. Unit 4 predominates on the north side of the Vedder Canal, and terminates sharply on the south side of the canal.[1] In Transect A, Unit 4 drops from an elevation of 5 m (amsl) at SV1 to 3.5 m (amsl) at Keith Wilson

[1]However, in longitudinal Transect H, Fig. 3.9, Unit 4 does extend into the Sumas Valley for 4 km.

Bridge over a distance of 1 km. Based on the lower boundary of these gravel units the terminus of the Unit 4 gravel lobe is found at a slightly higher elevation (-3 m bmsl) than that of the Unit 3 lobe (-6 m bmsl). The range of clast sizes within Unit 4 is unknown.

Unit 3 and 4 gravels are respectively overlain by Unit 5 and Unit 6, which are upwardly fining sand units. Unit 5 displays a greater range of clastic grading (coarse to fine sand at SV14 and 19-8-1) than Unit 6 (coarse sand at SV18, SV10, and Keith Wilson Bridge) in this subsurface section. Both Units 5 and 6 extend to the surface throughout much of Transect A.

Following the upper contact of Unit 3 in the south portion of the Sumas Valley, Unit 5 dips from a maximum upper boundary elevation of 20 m (amsl) at W45 to a minimum 1.5 m (amsl) at SV18 over approximately 16 km. Throughout Transect A, Unit 5 is on average 5 m in thickness.

Unit 6 varies in upper boundary elevation from 6 m (amsl) at SV1 to approximately 2 m (amsl) between SV18 and SV10 over a distance of 5 km. Its thickness increases from 1 m at SV1 and Keith Wilson Bridge to 2.5 m at SV10.

Units 5 and 6 are shown to interlayer in the mid-valley region between SV18 and SV10. Because these two units are so similar in character, it was impossible to determine if there was an exact location of transition from one unit to the other.

Unit 7, an overbank silt, is only found in one location adjacent to the Sumas River at W11.

Unit 8 is confined to the southwestern segment of Transect A. It lies above Unit 3 gravel and Unit 5 sand, and is separated from the rest of the Sumas Valley by a lobe of Unit 5 sand at W45.

Unit 9, which is a surficial silt and fine sand deposit, is confined to the central valley and has a maximum thickness of 2.5 m at SV19.

The vertical and lateral assembly of lithostratigraphic units described in Transect A are observable in Transects H and J (Figs. 3.9 and 3.11). The main differences in stratigraphy arise from minor differences in the extent of unit distribution. Transect A, for example, has a less extensive distribution of Unit 9 surface silt and fine sand than Transect H (Fig. 3.9), and a more extensive distribution of Unit 4 gravel than Transect J (Fig. 3.11). However, for the most part the correlation between lithostratigraphic sequences between these longitudinal profiles is good.

4.1.1 Valley Flank--Transect I

Transect I (Fig. 3.10) along the northern flank of the Sumas Valley diverges somewhat from the pattern of sedimentation observed within the other longitudinal sections discussed in 4.1.0. Although Transect I displays the same patterns of elevational variation, unit assembly, and subsurface grading seen elsewhere, some significant differences are worthy of note. [1]

Unit 1 clay and silty clay, which was present only in the northeastern portion of Transect A, is traceable throughout the entire length of Transect I. (Although not shown in Fig. 3.10, water well records indicate that clay fitting the description of Unit 1 is present at a depth of 69.5 m at 20-1-4.)

Unit 2 occupies the same mid-valley position in Transect I as it did in Transect A, but appears to be slightly less extensive. The core in Transect I displaying the most detailed data, Sumas Canal, illustrates a subtle upward coarsening trend in the clastic sequence of Unit 2.

A major difference between Transect I and the other mid-valley longitudinal sections is the distribution of gravel. Unit 3 gravel in this transect is not present in the western portion of the valley except as a trace at 16-11-7 at a depth of -9 m (bmsl). Lenses of gravel 1-2 m in thickness found at 19-20-10 and 19-22-2 at elevations of -1

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[1]Because the data used to contruct Transect I were derived entirely from water well and Department of Highways records, the lithology and grading characteristics within units could not be used to supplement the lithostratigraphic classifications in this longitudinal section.

m and 2.5 m (amsl) respectively appear to be untraceable to any other units in the transect and are thus classified as Unit 3(a).

Unit 4 gravel and sand, while present, is found at a greater depth (-5 m) than in Transect A (5 m). As in Transect A (Fig. 3.2), Unit 4 gravel stops abruptly west of the Vedder Canal. However, Unit 4 is overlain by a greater thickness of Unit 6 sand (approximately 9 m) than in Transect A.

Unit 5 sand is more extensive in Transect I than Transect A, displaying a lobate plan in the western portion of the section. Unit 5's upper boundary varies in elevation from 6 m (amsl) at Marshall Bridge, Whatcom Road, and 19-21-8 to -4.5 m (bmsl) at 16-11-7, and is found at a maximum depth of -26 m (bmsl) at Sumas Mountain Road Overpass. The location of the boundary between Unit 5 and Unit 2 in the mid-valley region between 19-21-8 and 19-22-2 is not known, but the boundary between the two units is believed to be gradational.

Unit 6 sand superimposed over Unit 4 gravel in the eastern portion of the Sumas Valley is located in the form of a lobe between Vedder Canal #4 and 20-1-4. Although the lower boundary of Unit 6 is roughly horizontal at an elevation of -6 m, the upper boundary of this unit slopes from an elevation of 4.5 m (amsl) to below 0 m (amsl) thus appearing to taper. Unit 6 is believed to interlayer or grade into Unit 2 in the vicinity of 20-1-4. At the Sumas Canal, Unit 6 displays an upward fining clastic sequence.

Unit 8 clay and silt is found above Unit 5 sand in the western portion of the Sumas Valley where Unit 5's upper boundary slopes from its apex at Marshall Bridge to a lower elevation at 16-11-7. Unit 8 is also seen in the western portion of the valley in Transect A, but is more extensive in Transect I, having a maximum thickness of 13.5 m as opposed to a maximum thickness of 9 m in Transect A.

Units 7 and 9, which are composed of surface silt and fine sand, are minorly represented in Transect I , with Unit 7 at 19-20-10 associated with overbank deposits or ponding from the Sumas River, and Unit 9 at the Sumas Canal associated with historical Sumas Lake.

4.1.2 Longitudinal Sections--Summary

Analysis of the longitudinal sections constructed for this study reveals a number of significant observations.

1) The Sumas Valley is underlain by extensive silt and clay deposits, classified as Unit 1. This unit is observed to be closer to the valley surface along the valley flank than it is in the central valley.

2) Unit 2 (interlayered sand and silt), which overlies the clay and silt of Unit 1, also encompasses a large portion of the Sumas Valley's subsurface sedimentary profile. Unit 2, which extends from the surface or close to the surface to a minimum confirmed depth of 42 m, is located in the north central portion of the Sumas Valley. Unit 2 displays an upward coarsening clastic sequence.

3) The Sumas Valley's subsurface lithostratigraphic structure is dominated by lobes of gravel at either end of the valley. Unit 3, in the south is the most extensive gravel lobe, whereas Unit 4, while terminating abruptly at the Vedder Canal in the sections studied, is also significant. The lobe of Unit 4 gravel is positioned marginally higher in elevation than the Unit 3 lobe. The upper boundary of both gravel units appears to dip towards the valley centre, where they are separated by Unit 2. Within the lithostratigraphic boundaries of Units 3 and 4, gravels grade both vertically and laterally.

4) Superimposed on gravel Units 3 and 4 are sand Units 5 and 6, respectively. As with the subsurface gravel units, Units 5 and 6 dip toward the centre of the Sumas Valley and grade into or interlayer with Unit 2. Units 5 and 6 display upward fining clastic sequences, and particularly in the case of Unit 5, appear to grade laterally towards the valley centre as well.

5) Small isolated gravel lenses are present along the north flank of the Sumas Valley.

6) Units 7 and 9 are the shallowest and least extensive lithostratigraphic units present in the Sumas Valley. Unit 7 is found adjacent to the Sumas River, whereas Unit 9 is found in the north central portion of the valley, particularly along the southern flank.

7) Unit 8, a surficial clay deposit, is confined to the western corner of the Sumas Valley, adjacent to the Unit 3/Unit 5 lobe.

4.2 Cross Valley Sections

A series of cross valley sections across the Sumas Valley was analyzed in order to identify lateral trends in the lithostratigraphic units. The series began with Transect B (Fig. 3.3) in the north, roughly parallel to the Vedder Canal, and extended south through Transects C,D,E,N, and L (Figs. 3.4, 3.5, 3.6, 3.15, and 3.13), finally terminating with Transect M (Fig. 3.14) near the town of Nooksack, Washington. In addition, Transects F, G, and K (Figs. 3.7, 3.8, and 3.12) cut through the valley at angles which encompassed portions of the valley not covered by the cross sectional and longitudinal transect grid.

The transects were grouped according to valley location into the following categories to facilitate interpretation:

Northern Valley--Transects B & K

Central Valley----Transects C, D, & E

Western Valley---Transects F & N

Southern Valley--Transects L & M.

The transect cross valley categories will be discussed in order from north to south to most easily illustrate the continuity of the subsurface units.

4.2.0 Northern Valley--Transects B & K

Transect B (Fig. 3.3), which parallels the Vedder Canal, and Transect K (Fig. 3.12), which cuts across the Sumas Prairie basin from north to south, display similarity in the assemblage of their subsurface lithostratigraphic profiles.

In the northern cross valley sections, the upper contact of Unit 1 is closer to the surface along the south flank of the valley, and considerably deeper towards the north flank. The southern cores (22-32-4 in Fig. 3.3 and 19-14-6 in Fig. 3.12) intersected Unit 1 at depths of -16 m (bmsl) and -7m (bmsl), whereas at the north end of the section, Unit 1 is present in cores adjacent to Transect B (Vedder Canal Bridge, Fig. 3.10) at -32 m (bmsl).

Lying above Unit 1, Unit 2 constitutes a large portion of the subsurface vertical profile in these sections. In both sections, Unit 2 extends from the Unit 1 boundary, up to a depth of about -5 m (bmsl) (Sumas Canal, Keith Wilson Bridge, Fig. 3.3; SV24, SV15, Fig. 3.12), with a slight rise in the elevation of the upper boundary 3 km west of Vedder Mountain (22-32-2, Fig. 3.3; SV16 & SV17, Fig. 3.12).

Transect B, the section closest to the Vedder River, displays a tapering wedge of Unit 4 gravel and sand extending from the southeast, while the mid-prairie basin section, Transect K, does not. Unit 4 tapers from a thickness of 16 m at 22-32-4 (Fig. 3.3) to 4 m at Keith Wilson Bridge before pinching out. Core data at 22-32-2 suggests that the gravel upwardly coarsens in this unit, and progressively grades to a more sand dominant matrix toward the north, as indicated by the sand-gravel interlayering sequence displayed at Keith Wilson Bridge.

Between Keith Wilson Bridge and Sumas Canal in Transect B (Fig. 3.3), Unit 4 gravel and sand is believed to grade into Unit 6 sand. Unit 6 displays initial upward coarsening in the core at Sumas Canal Bridge, followed by upward fining. Both upwards fining (SV15) and coarsening sequences (SV10, SV17, and SV16) are also observed in Unit 6 in Transect K, indicating a lack of continuity in the lateral grading pattern in this section.

Both northern sections are capped by a thin 1 m layer of Unit 9 silt along the north and south flanks of the valley (Sumas Canal, SV15, 19-14-6, Fig. 3.12).

4.2.1 Central Valley--Transects C, D, & E

Although the general assemblage of subsurface lithostratigraphic units in the central valley cross sectional transects is similar, significant differences in their spatial distribution exist in this region.

The central valley sections reveal that Unit 1 is deepest in the middle of the valley, found at a depth of -23 m (bmsl) at Sumas Air Strip (Fig. 3.4), and shallowest along the valley flanks (-3 m (bmsl) at 19-27-2, Fig. 3.4; -2 m (bmsl) at 19-15-6, Fig. 3.5). The depression in the upper boundary of Unit 1 which is visible in Transects C and D (Figs. 3.4 and 3.5) is not identifiable in Transect E due to the lack of deep core data in the mid-valley region in Fig. 3.6.

Unit 2, although less extensive than in the northern sections, still constitutes much of the valley fill in the central valley. Unit 2, in overlying Unit 1, displays its greatest thickness in the mid-valley region.

Subtle textural differences in Unit 2 occur between the three sections. The northern-most transect--Transect C (Fig. 3.4)-- displays mostly silt in Unit 2 (19-22-2, Sumas Air Strip) with minor upward fining sequences visible at SV27. In Transect D (Fig. 3.5) just south of Transect C, Unit 2 is composed of sands and silts which display initially upward coarsening sequences in some locations (19-16-10, 19-15-6, 19-10-4) and upward fining sequences in others (19-20-5, 19-20-6). The southern-most cross valley section--Transect E (Fig. 3.6)--exhibits a Unit 2 layer which is composed of mostly fine sand (Whatcom Road, 19-4-8). The overall trend within Unit 2 in the central valley sections, therefore, is one of lateral grading, with Unit 2 sediments becoming finer towards the north, and one of vertical grading, with Unit 2 sediments displaying primarily upward coarsening sedimentary sequences.

The most interesting element in the analysis of the distribution of central valley lithostratigraphic units is the occurrence of Unit 3 gravel and sand within this region. Although the Unit 3 layer is roughly the same thickness throughout the central valley (2 to 7 m) and is found at approximately the same elevation (the upper boundary of Unit 3 had an elevation of close to 3 m (amsl) in all locations), Unit 3 is found along the north flank of the valley in Transects C and D, and along the south flank in Transect E, leading to the suggestion that at some point between Transects D and E, Unit 3 crosses the valley. Unit 3 is not present at Transect B (Fig. 3.3) to the north and is therefore thought to pinch out at some point between these two transects.

Although Unit 3(a) (19-28-2) and Unit 3 (19-22-2, SV27, Sumas Air Strip) are located in close proximity to one another in Transect C (Fig. 3.4), they are separately classified due to lithology and elevation.[1] Unit 3(a) is situated immediately adjacent to Sumas Mountain.

Unit 5, which is positioned above Unit 3, is present in Transect E (Fig. 3.6) and Transect C (Fig. 3.4), but is not visible in Transect D (Fig. 3.5). Its upper boundary slopes from an elevation of 6 m (amsl) at 19-4-8 to 2.5 m (amsl) at SV29, thus causing Unit 5 to taper towards the valley centre. Although vertical and lateral grading characteristics are unknown within Unit 5 in this section, it is believed that Unit 5 grades to Unit 2 between Transects E and D just to the north (19-10-4, 19-15-6).

Unit 9, which is found in the mid-valley region of these transects, is deepest (8m) at 19-16-10 at Transect D (Fig. 3.5). The rise in elevation of Unit 9 at 19-7-10 (Fig. 3.6) is due to the presence of a surface dune at that location.

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[1]Unit 3(a) in this location is composed of shale according to well records while Unit 3 at SV27 is composed of volcanic clasts.

4.2.2 Western Valley--Transects F & N

Transects F (Fig. 3.7) and N (Fig. 3.15) are located in the western end of the Sumas Valley. The valley surface along these sections slopes from south to north--a pattern which also is reflected in the occurrence of subsurface lithostratigraphic units.

Only one core in the western cross valley sections displayed what is believed to be Unit 1 silty clay (16-11-7). Although Unit 1 is found at this location at an elevation of -17 m (bmsl), it is presumed to exist at depth elsewhere in the region, but was not intersected because of the shallowness of well records.

Also at 16-11-7 is the only trace of Unit 2 in this region--a 7 m thick layer positioned above Unit 1. Its distribution elsewhere in these sections is unknown.

Unit 3 predominates as the primary lithostratigraphic unit encompassing the western sections. Both sections clearly illustrate that the upper contact of this lithostratigraphic unit slopes from the south to the north. Transect F (Fig. 3.7) demonstrates this sloping trend best. The upper boundary of Unit 3 is located at an elevation of 10 m (amsl) at SV14, but drops to an elevation of -8 m (bmsl) nine kilometres north at 16-11-7.

Unit 3 is also believed to taper in thickness towards the north. Cores at SV25 (Fig. 3.15) and 16-2-16 (Fig. 3.7) display thicknesses of Unit 3 gravel and sand of 13 m and 17 m respectively. From these locations, Unit 3 can be traced to a 1 m thick occurrence of gravel at 16-11-7.

It was not possible to determine if lateral or vertical grading occurred within Unit 3 in these sections. Data from SV14 (Fig. 3.7) indicated a maximum clast diameter of 3 cm.

Included in Unit 3 are clay lenses, which can be observed at W36 and 16-2-18. The origin of these (often thick) silt lenses is not known, but they may represent ponding occurrences or extensions of Unit 8.

Unit 5 sand exhibits the same sloping configuration of Unit 3, above which it lies. The Unit 5 layer is less continuous in Transect F than in Transect N, but can still be identified at progressively lower elevations from south (14 m (amsl) at W41) to north (-4 m (bmsl) at 16-11-7) over 11.5 km.

Unit 5 generally demonstrates upward fining clastic sequences (W2, Fig. 3.15; SV14, 16-11-7, Fig. 3.7). Also, Unit 5 exhibits lateral grading, from predominantly coarse sand in the south (SV14, W36, W39, Fig. 3.7) to fine sand in the north (16-11-7, Fig. 3.7).

A significant aspect of the western sections is that of the presence of Unit 8. Unit 8, which is a surface clay deposit, is confined to the western portion of Sumas Valley. Its distribution is most extensive along Transect F (Fig. 3.7) where it is present at the surface for 10 km. Unit 8's thickness ranges from 4 m at W39 at the apex of the transect in the south to 14 m at 16-11-7 at the north end of Transect F. Peat is present at the surface at 16-11-6, but is also found in traces at lower elevations. One peat layer, found at an elevation of -10 m (bmsl) at 16-11-7, yielded a radiocarbon date of 8360±170 yr B.P.(see Table 5.0).

4.2.3 Southern Valley--Transects L & M

The southern cross valley sections are characterized by their high elevation and almost complete domination by Units 3 and 5. Transect M (Fig. 3.14) is the more southerly of the two transects and has a maximum elevation of 20 m (amsl), compared with Transect L (Fig. 3.13) which has a maximum elevation at 18 m (amsl).

Unit 3 gravel, while extensive in both sections, is closer to the surface in Transect M (Fig. 3.14) and in fact is found right at the surface at W12. In Transect L, Unit 3 is found between 1 and 15 m from the surface.

In these southern sections the upper boundary of Unit 3 displays elevational variation across the valley. In Transect L, records from SV23, W34, W14, and W36 indicate that gravel exists at an elevation of 0 m (amsl), in comparison to the adjacent cores of W35 and W15, where Unit 3 is located at an elevation of 12 m (amsl) A similar, but less pronounced trend is observed in Transect M, where two smaller depressions in the upper boundary of Unit 3 can be seen at SV13, and at W13 and W17.

Clast sizes within Unit 3 at SV13 (Fig. 3.14) display a subtle upwardly fining tendency. Maximum clast diameters within this unit range from 3 cm at the base to 2 cm and less near the top.

Unit 5 is more extensive in Transect L, which is the more northerly of the two cross valley sections. Unit 5 generally displays an upwardly fining clastic sequence (SV23, Fig. 3.13) although is occasionally capped by coarser sediments (W34, W14, W36, Fig. 3.13).

4.2.4 Cross Valley Sections--Summary

Analysis of the cross valley sections resulted in the following observations:

1) .In the northern Sumas Valley, the upper boundary of Unit 1 is deepest along the north flank of the valley. In the central Sumas Valley, however, Unit 1 is found at greater depths in the middle of the valley, and is shallower along both flanks.

2) Unit 2 is only observable in the northern and central valley cross sections where it constitutes a considerable proportion of the subsurface profile. The lateral grading pattern which predominates throughout Unit 2 in the cross valley sections is generally one of fining from sand to silt towards the north, while the vertical grading pattern within Unit 2 is one of upwardly coarsening clastic sequences.

3) Unit 3 gravel and sand, which constitutes most of the southern cross valley profiles, tapers in both width and thickness towards the north. The upper boundary of the Unit 3 gravel lobe dips towards the north and northeast. Between Transect E (Fig. 3.6) and Transect D (Fig. 3.5), Unit 3 crosses the Sumas Valley from the southern flank to the northern flank. Unit 3 tapers out between Transect C (Fig. 3.4) and Transect B (Fig. 3.3) in the northern portion of the valley.

The lateral grading pattern in Unit 3 appears to be one of fining towards the north, based on a comparison of maximum clast size. SV13 and SV14 in the southern end of the valley (Figs. 3.14 and 3.7) display clast sizes of 3 cm, whereas core from SV27 in the central valley at Transect C (Fig. 3.4) contains gravel with a maximum clast size of 1.5 cm. Unit 3 also displays subtle, upwardly fining clastic sedimentary sequences.

4) Unit 3(a), found along the northern flank of the Sumas Valley, is a localized gravel unit which is immediately adjacent to Sumas Mountain. It is distinguished from Unit 3 through lithology and elevation.

5) Unit 4 gravel and sand occurs only at the north end of the Sumas Valley, where it parallels the Vedder Canal. The Unit 4 lobe tapers in thickness from southeast to northwest, where it pinches out before reaching Sumas Mountain. Unit 4 displays lateral grading, with sediments fining from southeast to northwest, into Unit 6. Sediments within Unit 4 also show an upwardly coarsening clastic sequence.

6) Unit 5 sand, which overlies Unit 3, is found primarily in the southern and western cross valley sections, although it is also present, but less evident, the central valley sections.

As with underlying Unit 3 gravel, the upper boundary of Unit 5 sand slopes from south to north. Whereas Unit 3 composes most of the subsurface valley profile in the south, Unit 5 sand increasingly predominates the cross valley profiles towards the north.

Unit 5 sand clearly displays vertical and lateral grading characteristics. In addition to upward fining, it fines from south to north. Unit 5 sand is believed to grade into Unit 2 sand and silt in the central cross valley sections.

7) Unit 6 sand, as with Unit 4 gravel which underlies it, was encountered only in the northern cross valley sections. There appears to be a lack of continuity in the grading patterns in Unit 6, as both upward fining and upward coarsening clastic

sequences exist in these cross valley sections. The lobe of Unit 6 sand thickens and dips from the southeast to the northwest.

8) Unit 8 is clearly definable along the western flank of the Sumas Valley. Interlayered with peat at various depths, Unit 8 attains a maximum thickness of 14 m at the north end of Transect F (Fig. 3.7). The surface clay and silt of Unit 8 appears to be confined to a triangular region which lies between the town of Sumas in the south, the Sumas Way Interchange (Fig. 3.10) in the north, and Whatcom Road (Fig. 3.10) in the east.

9) Unit 7, as the least extensive sedimentary unit in these sections, is present only immediately adjacent to the Sumas River.

10) Unit 9, which is composed of fine sand and silt, is confined to the mid-valley region of the central cross valley cores. Its maximum depth is 8 m, and it is found at the valley surface over 3 to 5 km.

4.3 Discussion

Analysis of the longitudinal and cross valley sections, which were discussed in Sections 4.1 and 4.2, provided a description of the subsurface sedimentary architecture of the Sumas Valley.on which interpretations were based.

4.3.0 Unit 1

Unit 1, as a deep basement silty clay unit which displays distinct characteristics of colour and cohesiveness, probably underlies most of the Sumas Valley, although it was only encountered in the northern and central valley sections which were constructed for this study. Armstrong (1960, 1981, 1984) and Halstead (1961) described this deep (up to 300 m) silt and clay unit as a marine or glaciomarine formation, probably Fort Langley in origin based on the distribution of similar sediments elsewhere in the Central Fraser Valley.

Transects B (Fig.3.3) and C (Fig. 3.4) best illustrate the elevational variations of the upper boundary of Unit 1. Unit 1 is seen to be deepest along the north flank of

Transect B, and in the central valley in Transect C. The cause for the variation in Unit 1's upper boundary is not known. Because the silt and clay of this unit were probably deposited horizontally in a low energy environment, this cross valley variation in Unit 1's upper boundary could be due to the erosion of clay and silt by running water or by glacial ice, possibly during the advance of Sumas Stade ice after the deposition of Fort Langley sediments (Armstrong, 1960,1981, 1984). It should be noted, however, that no lag deposits were detected between Unit 1 clayey silt and the overlying sandy silt of Unit 2.

Alternatively, elevational differences in the upper boundary of Unit 1 could be depositional. One suggestion is that these clayey silts were simply deposited non-horizontally, as are deltaic or draped sediments on an irregular basement. Another explanation is that the variation of Unit 1's upper boundary is attributed to differential compaction of previously deposited silt and clay within the Sumas Valley basin.

4.3.1 Units 2, 3, and 5

When examined in longitudinal sections (Transect A, Fig. 3.2), Units 2, 3, and 5 clearly are related due to location and lithology (see Section 5.2) and thus will be discussed together.

The dominant sedimentation pattern that emerges in the southern half of the Sumas Valley is that of the stratigraphic succession of Units 3, 5, and 2. Unit 3 is a gravel and sand unit which encompasses much of the cross valley sections in the southern Sumas Valley. It grades both laterally to the north and vertically within cores to Unit 5, which is a sand unit of the same lithological composition as Unit 3. Unit 5 fines both vertically in core and laterally towards the northeast into Unit 2. Unit 2, which is a sand and silt unit, also laterally grades from predominantly fine sand in the south to silt in the north. However, rather than fining vertically, Unit 2 displays subtle upwardly coarsening sedimentary sequences.

The vertical and lateral succession of Units 3, 5, and 2 suggests that this assemblage of units represents the facies of a prograding wet alluvial fan or fan delta built by an alluvial system of decreasing competence (Rust, 1979, Galloway et al., 1983, Ritter et al., 1986). This suggestion is supported by the following evidence:

1) Clastic sediments are coarsest in locations most proximal to the Nooksack River at the south end of the Sumas Valley, and become finer in the most distal locations in the central valley. Because of lithology and location, Units 3 and 5 can be traced, therefore, to the Nooksack River, or to the Sumas River, which also originates south of the Sumas Valley.

2) The elevations at which Units 3 and 5 are found are highest in the southern valley (20 m (amsl) at W12, Fig. 3.14) and lowest in the central valley (2m at SV27, Fig. 3.4). The sloping surfaces are consistent with that of alluvial fan morphology.

3) Unit 3 tapers from a thickness of approximately 30 m (16-1-9, Fig. 3.2) to a thickness of 2 m at 19-22-2 (Fig. 3.4) before finally pinching out. Its lower boundary increases in elevation from at least -15 m (bmsl) (16-1-9, Fig. 3.2) to 1 m (amsl) (19-22-2, Fig. 3.4) in the north. This depositional pattern is consistent with that of a fan prograding into a depocentre--as the depocentre aggrades, the elevation of the base of the depositional units increases as well.

4) The alluvial fan is believed to be of the "wet" type (Galloway et al., 1983) because the degree of sorting and stratification of sediments is clearly an indication of a fluvially dominated depositional environment. Also, the low grade, elongate fan morphology is consistent with that of a wet alluvial fan. A fan of this type is often multi-channelled and resembles a braided alluvial plain (Walker & Cant, 1979; Galloway & Hobday., 1983). Alternatively, this geomorphic feature may be a fan delta, which displays the characteristics of an alluvial fan, but trancends from a subaerial to a subaqueous depositional environment.

5) The distal reach of the Unit 3 gravel lobe in the central cross valley sections delineates the location of the main channel of the fan. Because the Unit 3 gravel lobe crosses the valley between Transects E (Fig. 3.6) and D (Fig. 3.5), it is likely that the main alluvial channel followed this path. Because the Sumas River is present at the valley surface in this vicinity, it is believed that it is a remnant of the Nooksack fan's depositional system and continues to play a role in the distribution of sediment in the Sumas Valley.

6) The pattern of upward fining within vertical clastic sequences in Units 3 and 5 suggest a depositional system of decreasing competence with time. The fact that the Nooksack fan is presently inactive is a testament to this statement.

The reason for such a dramatic reduction in competency would have been the fluctuating hydrological and sedimentological conditions experienced by the region due to deglaciation, a phenomenon termed "paraglaciation" by Church and Ryder (1972). Initially, during and immediately following deglaciation, sediment supply and fluvial activity is high, but as sources of meltwater and sediments are reduced, so too is depositional activity. The role of paraglacial conditions on alluvial fan morphology has been documented by Ryder (1969, 1971a, 1971b). It is suggested that the paraglacial alluvial fan model is applicable to the evolution of the Nooksack fan in the Sumas Valley.

7) Unit 2, which is composed of interlayered sands and silt displays an upwardly coarsening clastic sequence. This vertical grading pattern is consistent with that of an alluvial fan prograding into a depocentre. The primarily silt component in the northern portion of Unit 2 represents the most distal reaches of the fan, perhaps as a shallow lacustrine environment or mudflat. As the fan prograded, increasingly coarser sediment was introduced to the depocentre as the distance between channel and depocentre was shortened.

Several cores exhibit a complete alluvial fan depositional sequence. One such core, seen in Transect A (Fig. 3.2) is SV19 which has core data to 40 m below sea level. The very fine sands of Unit 2 (no Unit 1 basement silt and clay was encountered at this location) coarsen gradually upwards to medium and coarse sand with traces of Unit 3 gravel at -6 m (bmsl) and -1 m (bmsl) Above the -1 m (bmsl) gravel layer, the sediments then fine upwards to Unit 5, from coarse sand to surface silt, to an elevation of 4.5 m (amsl). This grading pattern is reproduced at other mid-valley locations--SV11, 19-14-4, and 19-14-22 in Transect H (Fig. 3.9), 19-27-2 in Transect I (Fig. 3.10) and SV12 in Transect J (Fig. 3.11).

4.3.2 Unit 3(a)

Well records describe the gravel of Unit 3(a) as consisting of shale. Because this conforms with the lithological profile of Sumas Mountain, Unit 3(a) probably represents colluvium or alluvium from its slopes.

4.3.3 Units 4 & 6

Located in the northeastern region of the Sumas Valley, Unit 4, which is a gravel and sand unit, and Unit 6, which is a sand unit overlying Unit 4, represent a stratigraphic succession sequence and will be discussed together.

The distribution of Unit 4 and Unit 6 are best seen in Transects B (Fig. 3.3) and H (Fig. 3.9). In both these transects, the distribution and grading patterns of these lithostratigraphic units suggest the progradation of an alluvial fan into the Sumas Valley from the vicinity of the Vedder (Chilliwack) River. This conclusion is supported by the following evidence:

1) The upper boundary of Unit 4, which is found at the surface, slopes towards the Sumas Valley, from an elevation of 5 m (amsl) near the Vedder River to 1 m (amsl) at SV11 (Fig. 3.9) and Keith Wilson Bridge (Fig. 3.3). The gentle slope is therefore consistent with the morphology of an alluvial fan. It should be mentioned that

northeast of the Vedder Canal, this fan is more pronounced and can be identified on large scale topographic maps.

2) The thickness of the Unit 4 lobe decreases from 15 m at 22-32-4 to 5 m at Keith Wilson Bridge (Fig. 3.3) before pinching out to the west. A similar but less pronounced tapering pattern is also observed in Transect H (Fig. 3.9). Because the sediments within Unit 4 grade to finer Unit 6 sediments, the lateral grading pattern characteristic of alluvial fans applies--proximal sediments are coarser, and grade to finer sediments in more distal reaches.

3) All cores in which Unit 4 is present display upward coarsening clastic sequences, consistent with the model of fan progradation into a depocentre.

4) Unit 4 terminates abruptly at the Vedder Canal in the mid-valley section of the northern transects, yet is extensive north of the Vedder Canal. The cause for such an abrupt termination is unknown, but suggestions include the presence of a remnant ice block in the Sumas Valley as proposed by Armstrong (1961, 1981, 1984), or the excavation of previously deposited gravels by fluvial activity.

5) Unit 6 sand displays weak upward fining in only two cores (Sumas Canal Bridge, Fig. 3.3; SV15, Fig. 3.12), although lateral grading from east to west is evident. This observation leads to the suggestion that the fluvial system which deposited Unit 6 was still actively prograding at the time of the containment of the Vedder River into the Vedder Canal, and had not completed its alluvial fan cycle as had the Nooksack fan.

6) Unit 6 sand grades laterally into Unit 2 silt and sand in the central valley region from the northeast. Because Unit 5 also grades into Unit 2 from the south, it is suggested that Unit 2 represents a mudflat or shallow lacustrine depocentre for the progradation of both sets of distal sediments.

4.3.4 Unit 7

Due to its localized occurrence adjacent to the Sumas River, Unit 7 silt is identified as being a surficial overbank fluvial deposit.

4.3.5 Unit 8

The occurrence of Unit 8 clay is confined to a triangular region which lies between the Unit 3/5 gravel and sand lobe and the cliff of Sumas Drift delineating the western boundary of the Sumas Valley.

The presence of peat interspersed with the clay suggests that the depositional environment of Unit 8 was one of a swampy backwater or lake which experienced periodic subaerial episodes. Because Unit 8 is underlain by Unit 3 gravel (Fig. 3.7) this portion of the Sumas Valley may represent a ponding depositional sequence related to the aggradation of the valley by the Nooksack fan. The radiocarbon date of 8360 ± 170 yr B.P. of peat at the base of Unit 8 suggests a likely date for this region being cut off from the rest of the valley by the aggrading Unit 3 gravel lobe.

4.3.6 Unit 9

Classified as a surficial deposit left by Sumas Lake, Unit 9 is not extensive throughout the Sumas Valley. Unit 9 fine sand and silt is observable in the central valley transects of D and E (Figs. 3.5 & 3.6) to a maximum depth of 8 m.

However, Unit 9 overlies Unit 2 in the mid-valley region. It is tentatively suggested that Unit 9 may simply be the surficial exposure of Unit 2, and that Unit 2 deposits constitute those of an aggrading ancient Sumas Lake.

Historical accounts of Sumas Lake describe a shallow lake which underwent annual cycles controlled by the Vedder River, and occasionally the Nooksack River. During the spring freshet, water levels rose, followed by periods in the summer when the water levels dropped sufficiently to permit cattle to graze on the grass which grew on the exposed lake bed (Smith, n.d.). These depositional cycles can be seen in Fig. 3.16 which shows alternating layers of silt and sand at SV26. It is proposed that the sediments of Unit 2 represent a continuation of the depositional pattern of historical Sumas Lake. The depositional environment must have been one of some energy, as the sediments of Unit 2 do not resemble the deep varve-like silts seen in other proglacial lakes (Smith, 1975; Galloway & Hobday; 1983; Kostaschuk & Smith, 1983).

CHAPTER FIVE
GEOMORPHOLOGY AND PROVENANCE OF SEDIMENTS

The most significant aspect of the Sumas Valley's evolution in post glacial time was the progradation of two fans into a basin (possibly lake filled) left by the retreat of glacial ice. This conclusion, which was based on the analysis of the lithostratigraphic assembly of the units discussed in Chapter 4, is supported by the following additional geomorphic and sedimentological evidence

5.0 Topography

An examination of the general physiography of the Sumas Valley and its adjacent areas leads to two significant observations. The first is that despite their low relief, two fans can be identified as entering the Sumas Valley at either end. The second observation is that within the vicinity of the Sumas Valley surficial glacial deposits appear to have been subjected to extensive excavation by running water, thus significantly altering the landscape and complicating the interpretation of post-glacial events.

5.0.0 Fan Deposits

The surface topography of the valley floor itself reflects the growth of two fans into the Sumas Valley from the south and the northeast. An examination of surface contours (Fig. 1.5) indicates that the surface elevation of the south end of the valley, at the town of Everson on the Nooksack River, is 24 m (amsl). The elevation steadily decreases north from Everson to close to 0 m (amsl) in the central Sumas Valley. In other words, the continuity of the slope of the valley from the Cascades in the south is unbroken as it extends into the Sumas Valley to the north and reflects the extension of a fan northward.

The contour lines along the northeastern end of the Sumas Valley and the Fraser River floodplain to the north also clearly illustrate the extent of another alluvial fan issuing from the Cascade Mountains. Whereas the existence of a northward extending Nooksack fan has to be deduced from geomorphic evidence, the existence of a westward flowing Chilliwack River and the consequent deposition of a Chilliwack fan has been confirmed by observers (Sinclair, 1961). The fan is inactive at the present time due to the containment of the Chilliwack River within the Vedder Canal. The Chilliwack fan extends over much of the Fraser floodplain in the vicinity of Chilliwack, with only a portion of the fan discharging into the Sumas Valley. Its apex has an elevation of 24 m, roughly equivalent to that of the Nooksack fan as it enters the Sumas Valley in the south.

On the basis of surface topography alone, therefore, the extension of alluvial fans into the Sumas Valley at both ends can be seen, an observation which was also made by Mathews (1972).

5.0.1 Glacial Deposits

As previously mentioned, the occupation of the Sumas Valley by glacial ice in the late Wisconsinan is illustrated by plentiful erosional and depositional evidence. The presence of Sumas till on both sides of the Sumas Valley near Sumas, Wa. indicates the furthest limit of the Sumas ice lobe. In addition, the distribution of Sumas Drift which is found throughout the Central Fraser Valley is evidence of the extent of Sumas ice occupying the valley. The sharp escarpment composed of Sumas Drift, which delineates the western border of the Sumas Valley, rises 40 m above the present valley floor (Fig. 1.9). However, Sumas Drift is absent for the most part from the Sumas Valley, occurring only in two small exposures 40 m above the valley floor at the north ends of Vedder and Sumas Mountains.

The fact that Sumas Drift is mostly absent in the Sumas Valley, and where present, is exposed in thick, clean sections with little or no indication of collapse structures suggests the likelihood of the excavation of some of the drift by running water. Two possibilities for the source of this running water are: 1) meltwater from the retreating Sumas ice lobe, and later, its downwasting remnant, and 2) the fluvial system associated with the progradation of the Nooksack fan.

1) An examination of elevational variations in the Sumas Drift suggests three possible locations for the discharge of the meltwater from the Sumas lobe.

Mathews (1972) has identified the main meltwater channels of the Sumas ice lobe on the Abbotsford outwash plain, just west of the Sumas Valley. Based on the erosion of Sumas Drift at the south end of the Sumas Valley and the extensive distribution of Sumas outwash within the Nooksack floodplain (Easterbrook, 1963) most of the meltwater from the main Sumas ice lobe must have flowed south to Bellingham Bay across the Nooksack Lowland.

In addition, after the main retreat of the ice lobe north of Sumas Mountain, some meltwater from the still existing Sumas Valley lobe may have flowed north to the Fraser River. This channel cuts into Sumas Drift and runs through Abbotsford from the Sumas Valley to Matsqui Prairie west of Sumas Mountain (Fig. 1.5 and Appendix A(H)).

Armstrong (1981, 1984) has suggested that a stagnant ice block occupied the Sumas Valley after the main retreat of Sumas ice from the Fraser Valley. If the ice block in the Sumas Valley became separated from the main ice lobe in the Fraser Valley, then some of the meltwater may also have flowed towards the north along the southeastern side of Sumas Mountain, where the Sumas River presently flows. This conjecture is supported by the almost total absence of Sumas Drift along Sumas Mountain in this vicinity (with the exception of one exposure of Sumas Drift perched 40 m above the valley floor).

2) Although the melting Sumas ice lobe is believed to be responsible for much of the removal of glacial drift in the Sumas Valley, as indicated by the redistribution of

Sumas Drift into the Nooksack floodplain, the absence of Sumas outwash deposits within the valley itself, except as remnants high above the valley floor suggests that much of the drift must have been removed by a more recent fluvial system. The presence of Nooksack fan lithostratigraphic units reflects the occupation of the Sumas Valley by a northward flowing fluvial system, and it is therefore speculated that this system was responsible for much of the excavation of Sumas Drift within the Sumas Valley. Sumas River and Saar Creek are believed to be remnants of the fan's alluvial system.

5.1 Mineralogy and Lithology of Sediments

Providing further evidence, beyond that of geomorphology, of Nooksack and Chilliwack River fan progradation into the Sumas Valley is the lithological and mineralogical compositional differences of sediments derived from these fans.

5.1.0 Provenance of Sediments--Sumas Valley

Pebbles and sand grains of valley sediments were examined in the field and under a microscope for lithology and mineralogy to help determine provenance. Work previously done by Easterbrook (1963) and Armstrong (1981) on pebble provenance helped determine source regions for sedimentary lithologies found in the grains examined for this study. It was believed that knowledge of provenance, along with the lithostratigraphic profiles, would give some indication of the source areas for the sediments in the Sumas Valley, and would aid in the interpretation of their environments of deposition.

Cores were carefully scrutinized for any variation of mineralogical and lithological composition with increased depth which would indicate a provenance change. For consistency, medium sands were usually chosen for examination of mineralogy. It is recognized that because of the difficulty involved in the mineralogical identification of very fine sediments, some mineralogical variation may not have been recognized, particularly in the finer sediments of Unit 2 and Unit 9 in the north central basin of Sumas Valley. As far as could be determined, mineralogical composition remained relatively consistent vertically throughout cores.

Examination of the lithology and mineralogy of gravel and sand throughout the Sumas Valley resulted in the identification of three mineralogical regions which displayed distinction. The three regions were: 1) southwestern Sumas Valley, which contained Units 3 and 5, 2) northeastern Sumas Valley, composed of Units 4 and 6, and 3) the extreme northern tip of Sumas Valley, which contained Unit 2.

Clasts from samples taken from Unit 3 were overwhelmingly red and dark grey andesite with andesine phenocrysts, and black basalt with quartz veining constituting 80% of the samples taken. As the gravel of Unit 3 graded to sand of Unit 5 towards the north, the same lithological profile was maintained; light coloured felsic detritus was almost completely absent. The lithological suite of the subsurface gravels mirrors the geological composition of bedload presently carried by the Nooksack River, and indicates a Mount Baker provenance from the volcanic Cascade Range.

Gravel from Unit 4 and sand grains from Unit 6 also contained a substantial amount of of volcanic material, with red and grey porphyritic andesite and basalt constituting up to 40% of the samples taken . However, more lithological variety was observed in these sediments, with light coloured quartzite and quartz also being prominent, and muscovite being present in small amounts in the sand. The mineralogical composition of Unit 4 and Unit 6 sediments is very similar to that being presently carried by the Chilliwack River, which drains a region of geologic complexity (Figs. 1.2 & 1.3).

The northwestern corner of the Sumas Valley near Vedder Canal contained sediments which did not mineralogically resemble the majority of sediments found elsewhere in the valley. Sand grains (gravel was not found) were almost entirely felsic in nature, with an abundance of quartz, quartzite, and mica (biotite and

TABLE 5.0

LITHOLOGY AND MINERALOGY OF SAND AND GRAVEL

Tr Trace <1%   Mi Minor 1-5%   Ma Major >5%

SITE	DEPTH	INDEX MINERALS			INDEX ROCKS	
		Quartz	Muscovite	Biotite	Red Andesite	Basalt
SV10	0-25 m	Ma	Ma	Mi	Tr	Mi
SV11	2-8 m	Mi	Mi	Mi	Ma	Ma
SV12	6-43 m	Mi	Tr	Tr	Ma	Ma
SV13	1-12.5 m	Mi	Tr	Tr	Ma	Ma
SV14	0-14 m	Ma	Tr	Tr	Ma	Ma
SV15	1-5 m	Mi	Tr	Tr	Ma	Ma
SV16	0-2 m	Ma	Ma	Mi	Tr	Tr
	2-5 m	Tr	Tr	Tr	Ma	Ma
SV17	0-2 m	Ma	Ma	Mi	Tr	Tr
SV18	0-4 m	Tr	Mi	Tr	Ma	Ma
SV19	0-45 m	Mi	Tr	Tr	Ma	Ma
SV20	0-18 m	Ma	Ma	Mi	Tr	Tr
SV21	3-4 m	Tr	Tr	Tr	Mi	Ma
	5.5-6 m	Ma	Ma	Ma	Tr	Tr
SV22	2-6 m	Mi	Tr	Tr	Ma	Ma
SV23	1-17 m	Mi	Tr	Tr	Ma	Ma
SV24	1.5-26.5 m	Ma	Ma	Mi	Tr	Tr
SV25	1.5-20 m	Mi	Tr	Tr	Ma	Ma
SV26	2-17.5 m	Ma	Mi	Mi	Mi	Ma
SV27	0.5-6 m	Ma	Ma	Tr	Ma	Ma
SV28	2-5 m	Ma	Mi	Tr	Ma	Ma
SV29	4-5 m	Mi	Mi	Tr	Ma	Ma

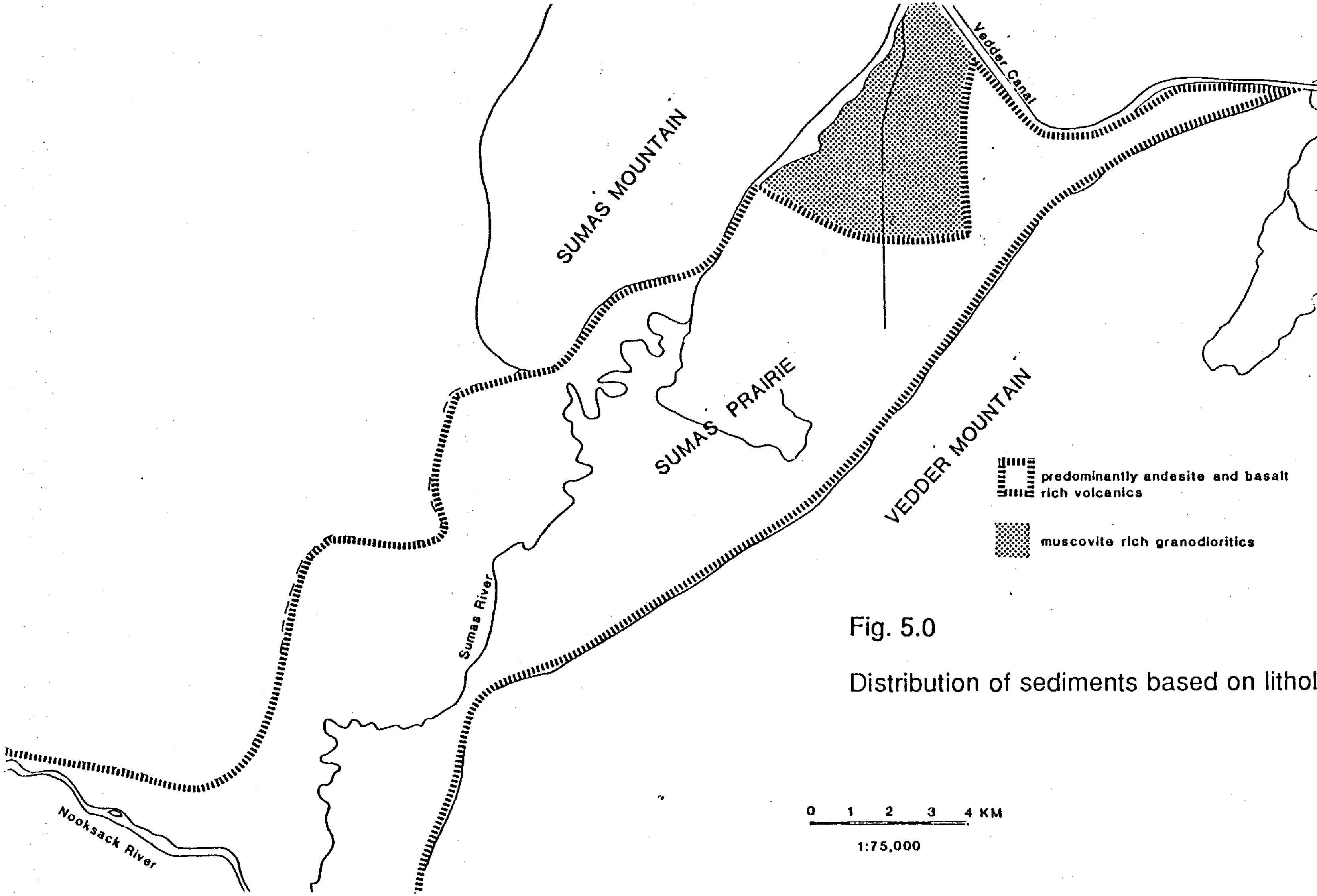


Fig. 5.0

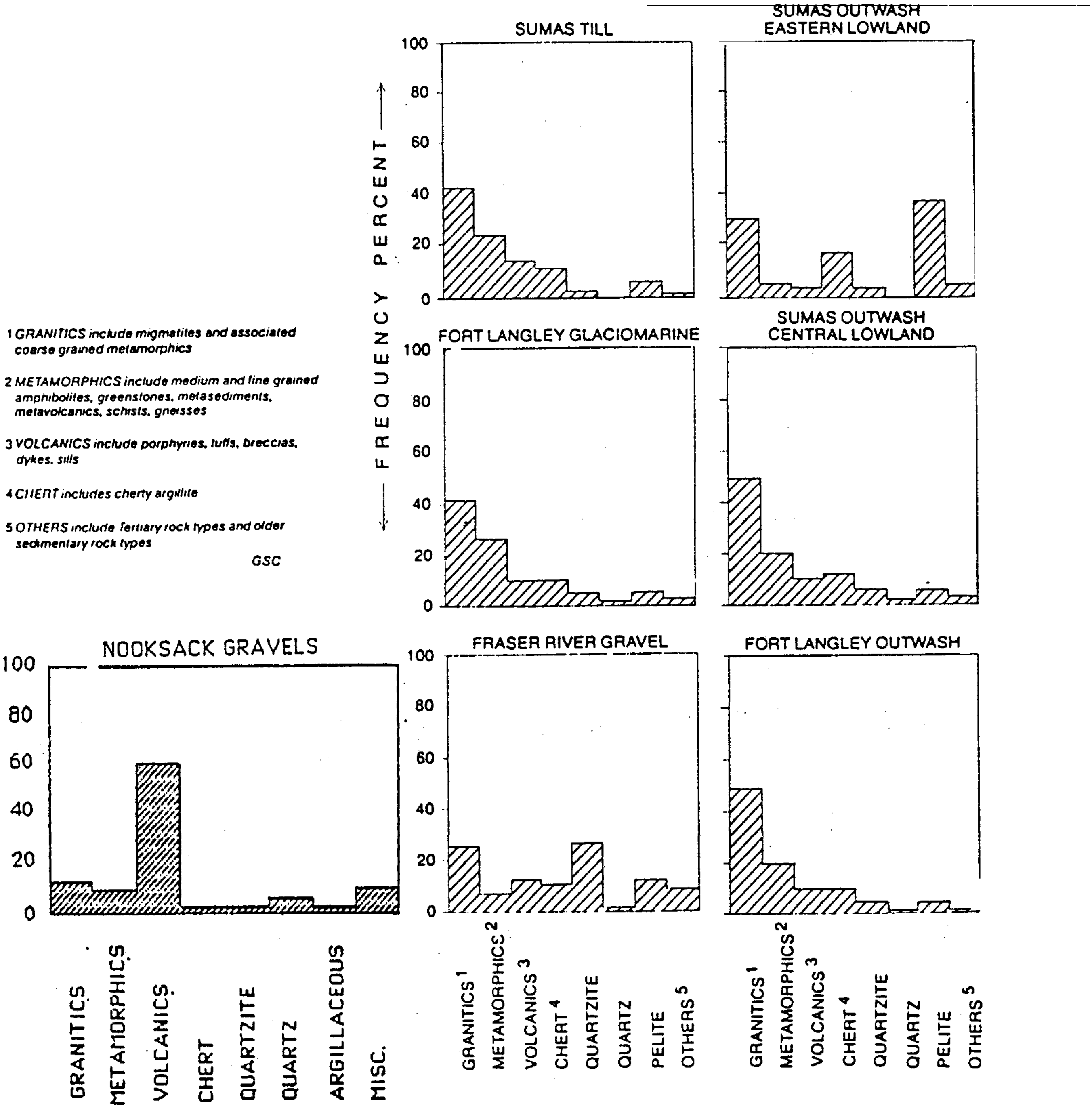
Distribution of sediments based on lithology muscovite) present. Less than 20% of these sediments were dark coloured, and the red andesites which were so strikingly obvious elsewhere in the Sumas Valley were only present in trace amounts in this region. This mineralogical assemblage resembles that found in the sand caps of gravel bars along the Fraser River at Chilliwack, just east of the study area (Fig. 5.0).

The felsic sediments in the northwest corner of the Sumas Valley are part of the Unit 2 lithostratigraphic unit. However, Unit 2 is not exclusively composed of these felsic sediments--it contains volcanic sediments as well, and is believed to be a mixture of all three lithological suites.

The lithological composition of sediments which are contained within the Sumas Valley contrasts sharply with the composition of sediments associated with Sumas Drift, which is well documented by Armstrong (1981). The differences are most pronounced in the proportion of volcanic sediments, which provide a lithological signature to illustrate provenance. Although volcanic sediments are present in Sumas Drift due to the contribution of ice from the Cascade Range to the Sumas ice advance, their proportion of the composition of the drift is much smaller than those sediments presently found within the valley (Fig. 5.1). Examination of data documenting the lithological differences of surficial sediments in the Central Fraser Valley region shows that the lithological composition of valley sediments more closely resembles that of the bedloads of the contemporary Nooksack, Fraser, and Chilliwack Rivers than of Sumas Drift. By extension, the sediments found at depth are more likely to be the result of deposition within Holocene time rather than associated with Sumas outwash.

A problem which must be addressed is the separation of sediments into mineralogical and lithological suites based on location within the valley. It is suggested that the sands and gravels which predominate in the portion of the Sumas Valley lying south of the Sumas Prairie basin originated either from the

Fig. 5.1 Provenance of Sediments



(from Easterbrook, Porter, Fulton, Armstrong, The Last Glaciation, 1975)

(from Armstrong, 1981)

Nooksack River or from the Sumas River, which also flows from the Nooksack Valley. The sands and gravels found in the northeast quadrant of the Sumas Valley can be traced to and can be presumed to have originated from the Chilliwack River Valley. The Sumas Prairie basin, containing very fine sediments which are difficult to identify mineralogically, is therefore presumed to have been the depository for the distal portions of these fans or fan deltas, reinforcing a suggestion which was made in the discussion of lithostratigraphic unit assemblage in Chapter 4. It is likely that the sediments in this central region are impossible to classify according to source region probably being interlayered with one another.

More difficult to explain is the abrupt abutment of felsic sediment in the northwestern quadrant of the valley against the largely volcanic sands and gravels found through the majority of the valley. This puzzle is compounded by the presence of very young (< 2000 yr B.P.) organic samples found at depths of up to 20 m in this region (SV 10). The mineralogical composition of sediments found in the north-east quadrant very closely resemble those presently found in the Fraser River floodplain at Chilliwack. However, the presence of an intact marine shell found at a depth of -9.7 m (bmsl) (SV24) suggests that the sediment deposited in this location could represent a mixture of present day Fraser River suspended sedimentary load and reworked glaciomarine sediment, excavated from exposures of Semiahmoo or Fort Langley sediment along the valley perimeter and transported a short distance. The sediment found in this location is almost entirely fine textured, usually fine sand interlayered with silt.

It is suggested that a barrier of some sort, either an ice block (kettle) as proposed by Armstrong (1981,1984) or the extension of the Chilliwack fan prevented the deposition of sediment in this area until the mid Holocene. When deposition was finally permitted, rapid sedimentation of fine material, possibly from reworked Fraser floodplain sediments during flooding events, occurred in the resulting basin. Periodic flooding of the Sumas Prairie basin by the Fraser River was observed by eye-witnesses prior to the construction of the Vedder Canal. In all likelihood, during flooding events the Fraser River was able to rise above the actively prograding distal Chilliwack fan and newly constructed Fraser River floodplain to supply sediment to the aggrading Sumas Valley. In the analysis of cores, it was not possible to distinguish if the surface silts were Fraser River overbank silts based on mineralogy. As with the fine sediments of the Nooksack and Chilliwack Rivers, it is likely that these surficial Fraser River silts have mixed with other fine sediments in the Sumas Prairie basin.

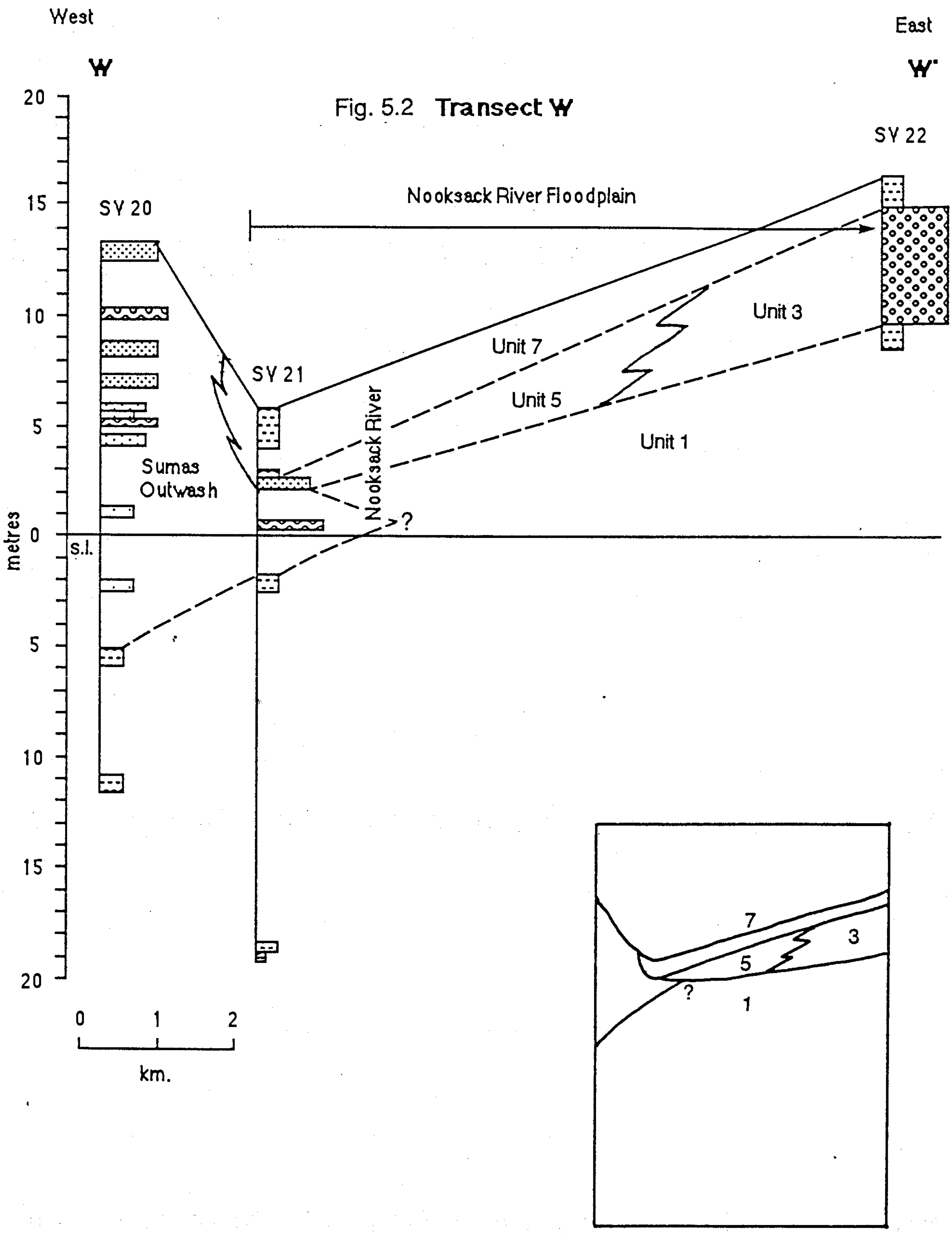
5.1.1 Custer-Ferndale Drill Holes

Three holes drilled west of the Sumas Valley, in Washington at Custer (SV 20), Ferndale (SV 21), and Lynden(SV 22) revealed profiles that varied considerably from those found in the Sumas Valley (Fig. 5.2). The hole locations were chosen to determine if clearly identifiable Nooksack and/or Fraser River sediments were present to help determine if either river could have followed a southwestern route to the ocean. Provenance of sediments, was used as a basis of distinguishing Nooksack or Fraser River origin.

Core from SV 20 at Custer, Wa. near Blaine contained no volcanic sediment, instead being composed of sediments of a felsic nature, with quartz being abundant. Pebbles, when present were clearly granitic, suggesting a north-northeastern provenance. Sediments coarsened upwards, from marine silty clays below a depth of 18 m(4m amsl) to gravels, possibly indicating deltaic advance. Easterbrook (1963) has classified the surficial sediments at this location as being Sumas outwash, with Bellingham Glaciomarine Drift also composing much of the regional surficial geology.

A hole drilled in the present Nooksack floodplain at Ferndale (SV 21) helped to delineate the extent of Nooksack sediments. The present bedload of the Nooksack

Fig. 5.2 **Transect W**



River contains a high proportion of red and black porphyritic andesite and basalt clasts, indicating Mt. Baker provenance.

The upper 3 m of the core contained Nooksack floodplain overbank silts and peat, and was underlain by Nooksack sands and gravels, clearly identified by the high proportion of andesitic and basaltic clasts. However, the shallow (4 m) layer of Nooksack sediments was immediately underlain by small (1 cm) gravels of varied lithological composition containing granitic and cherty clasts identical to the gravels seen at Custer (SV 20). The lithological composition of these lower gravels is consistent with that of Sumas outwash (Armstrong, 1981). Unconformably underlying the lower gravels was sticky marine silt of the type observed at SV 20.

The profile at the hole at Lynden in the Nooksack floodplain also helped to delineate the depth of Nooksack sediments. Two metres of Nooksack overbank silts were underlain by 4 m of Nooksack pea gravels. The gravels unconformably overlaid Unit 1 basement silt, with sand being entirely absent from the profile.

The purpose of investigating the lithology of these drill holes outside the confines of the study area was to seek evidence of previous fluvial activity which may have provided additional information regarding events affecting the Sumas Valley. The study of these profiles showed that sediment composed of volcanic material is confined to an area immediately adjacent to the present Nooksack River and that the layer of volcanic gravels tapers in depth from 4.5 m at Lynden to 0.5 m at Ferndale. Present floodplain deposits sit atop sediments which most likely originated as Sumas outwash based on their mineralogical profile. These observations lead to the suggestion that the early Nooksack River could have carried much of its bedload, not into the present Nooksack floodplain where volcanic deposits are limited, but into the Sumas Valley, where deposits of volcanic origin are extensive.

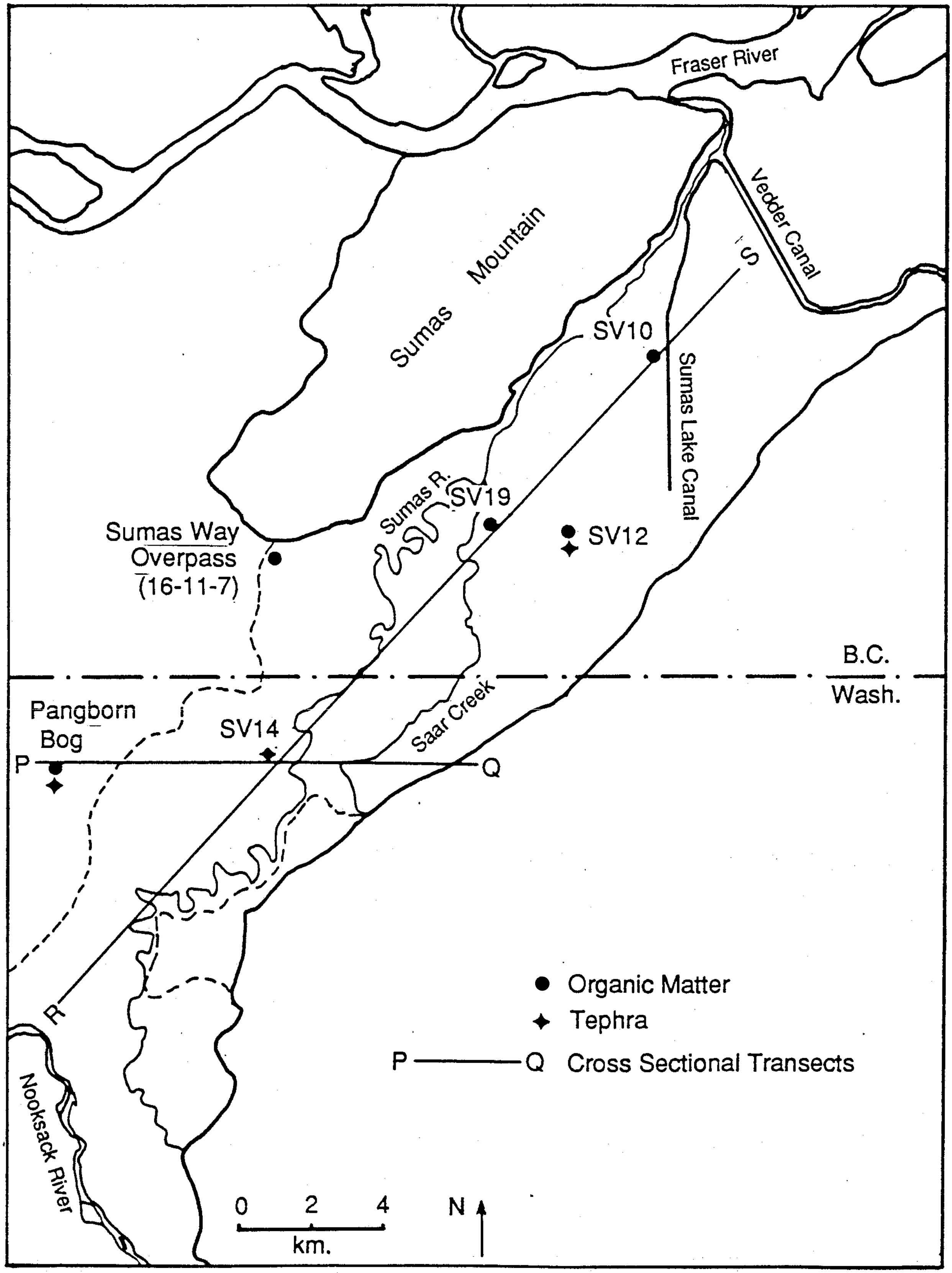


Fig. 5.3 Location of Dateable Materials

Fig. 5.4 Transect P - Q

Location and Age of Dateable Materials

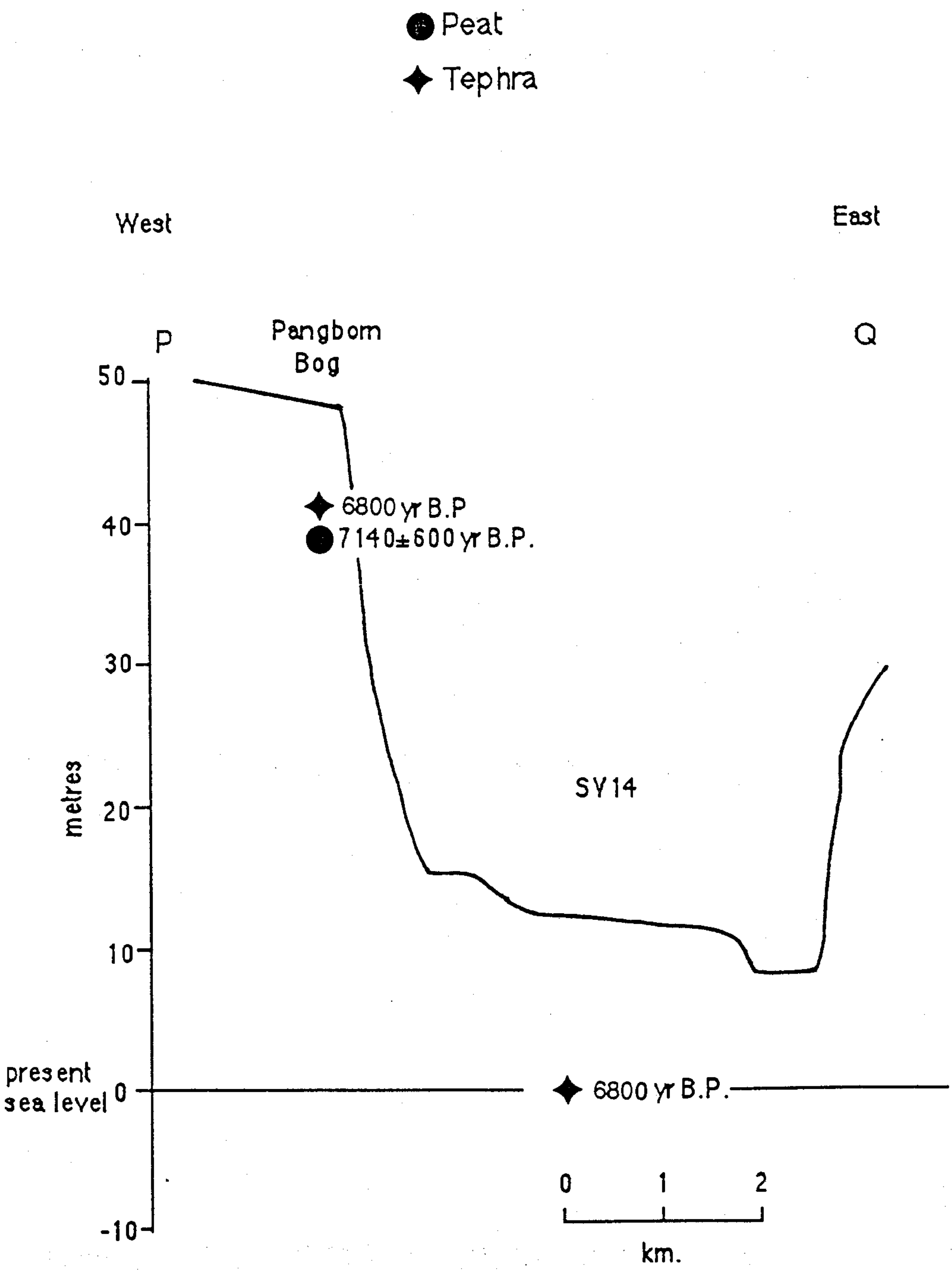
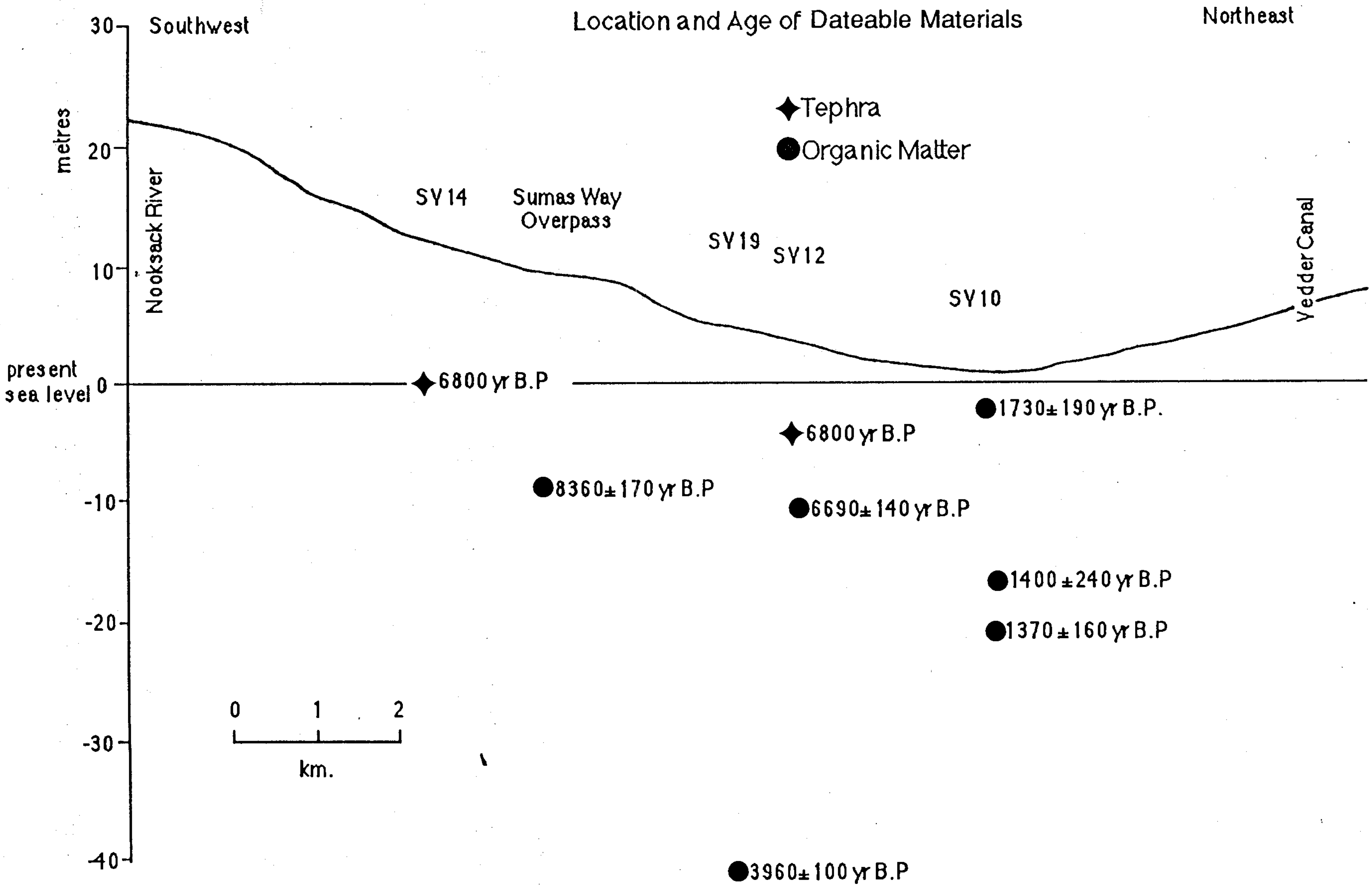


Fig. 5.5 Transect R - S

Location and Age of Dateable Materials



5.2 Tephra

The use of organic matter and tephra for the purpose of dating control was essential in the establishment of a geochronology of the Sumas Valley (Figs. 5.3, 5.4 and 5.5).

Tephra was found in two drill cores in the Sumas Valley. The tephra was positively identified using standard optical diagnostic techniques: samples were isotropic under cross polarized light and had low refractive indexes. Many samples contained trapped gas bubbles but did not exhibit the sharp shard like appearance characteristic of fresh tephras. The semi-rounded appearance of the sample grains suggests possible re-working by water.

A 1 cm thick layer of tephra was found in a silt layer at SV 14, located mid-valley just south of Sumas, Wa. The tephra layer was found at a depth of 13.6 m (approximately present sea level) beneath Unit 3 sand and gravel layers (Fig. 5.6). A 1 mm thick layer of tephra was also found at SV 12, located mid-valley approximately 9 km northeast of Sumas. This layer was found in Unit 5 medium sands at a depth of 8.42 m (approximately 4 m below present sea level).

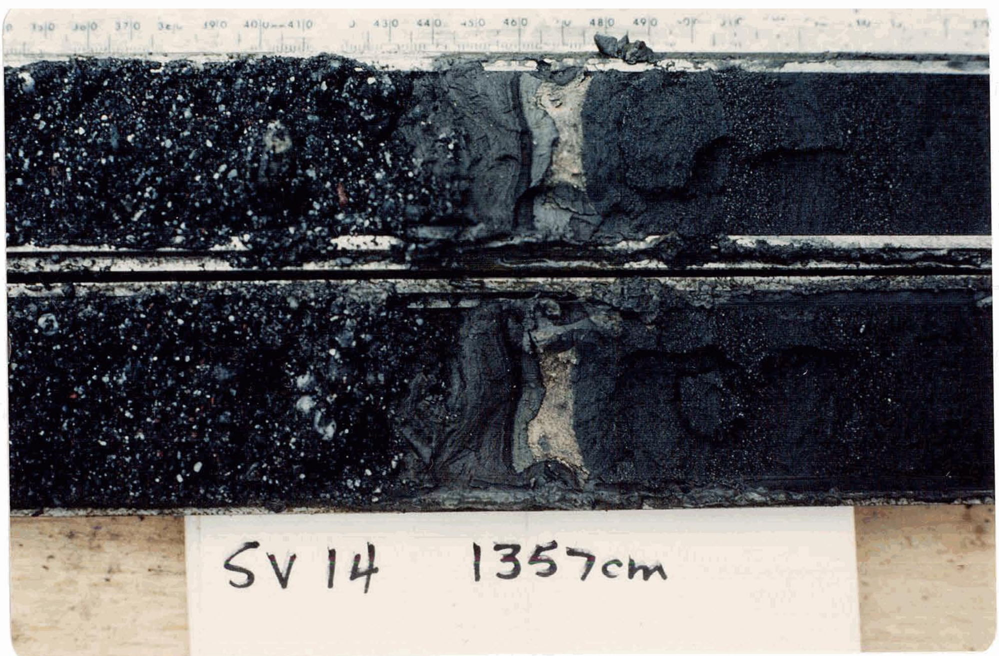


Fig. 5.6 Tephra beneath Unit 3

Intact ash layers have been previously identified in adjacent Pangborn Bog (Rigg, 1958, Hansen and Easterbrook, 1974). The bog is located in the Sumas Drift uplands 1.5 km west of the Sumas Valley and is believed to occupy an old kettle in the Lynden outwash plain. Ash within the bog was found at a depth of 4.25 m (approximately 38.5 m above present sea level). This ash layer has been tentatively identified as Mazama ash (6800 yr B.P.) based on a radiocarbon date of 7140 ± 600 yr B.P. on peat immediately below the layer.

Based on the descrption of the samples and given the proximity of Mazama ash in the Pangborn Bog, its is presumed that the tephra found in the Sumas Valley is also Mazama ash (Kettleman, 1973). Although it is possible that the ash may have originated from Mt. Baker, the stratigraphic relationship of the tephras to radiocarbon dated organic samples supports the identification of the ash as being Mt. Mazama The presence of a number of Mazama ash samples has permitted the clear delineation of the ashfall plume in southwestern British Columbia, whereas there is no evidence of extensive Mt. Baker ashfall (Clague, 1980, 1981).

The significance of the tephra layers within the Sumas Valley, in addition to their importance in establishing dating control, is their difference in elevation from the Mazama ash in Pangborn bog (Fig. 5.4). Whereas the ash in Pangborn bog is found in a closed depression in Sumas Drift at an elevation of 38.5 m above present sea level, ash at SV 14 and SV 12 was found at elevations of present sea level and 4 m below present sea level respectively. If ash in all three locations was deposited contemporaneously, then the Sumas Valley floor was established at its lower elevation prior to 6800 yr B.P., the estimated age of Mt. Mazama's eruption in Oregon (Bacon, 1983). Even if the ash within the Sumas Valley was not deposited in situ, and was redeposited from elsewhere, the young age of the sediments on the valley floor is still confirmed.

Also notable is the fact that the tephra surface between the two sites in the valley slopes towards the north. The drop in elevation of 4 m over 6 km is indicative of the depositional surface configuration at the time of Mt. Mazama's eruption. On the basis of tephra distribution, therefore, an inference can be made that a fan or delta was growing to the north at the time of ash deposition, and continued to aggrade vertically after the deposition of ash.

5.3 Organic Matter and Radiocarbon Dates

5.3.0 Wood and Peat

Organic matter was frequently found in sediments throughout the Sumas Valley in all lithostratigraphic units with the exception of Unit 1. The organic matter was usually found in the form of horizontal layers of comminuted wood fibres. Larger wood pieces (1 cm in length or greater) were rounded along their edges, were horizontally situated and had the appearance of being water transported. Wood pieces and wood fibres were found in all sediment types, but most commonly in horizontally laminated silty sand. Comminuted organic layers were generally less than 1 cm thick although in SV 19 a layer 12 cm thick (interspersed with fine silty sand) was observed.

Water well logs indicated the presence of peaty deposits in the silty clays of Unit 8 found along the western flank of the Sumas Valley (Transects F & G, Figs.3.7 & 3.8). Peat extended from the surface to a depth of 22 m (13 m below sea level).

The presence of peat indicates a swampy environment of deposition. Because the peat in Unit 8 was interlayered with silt and clay deposits, the triangular region in the western portion of the Sumas Valley where Unit 8 was found must have been a swampy backwater which experienced slow aggradation. The lithostratigraphic profiles analyzed in Chapter 4 indicate the presence of a Unit 3/5 gravel and sand lobe(which was probably the main distributary of the Nooksack fan), cutting off the western corner from the rest of the Sumas Valley. This low energy, ponded

TABLE 5.1

RADIOCARBON DATES

Date (yr B.P.)	Lab No.	Location/ Core	Depth Below Surface(m.)	Elevation (m.)	Material
1730±190	Riddl 769	SV10	3.86	-1.86	wood
1400±240	SFU 394	SV10	20.00	-18.00	wood
1320±160	SFU 393	SV10	23.00	-21.00	wood
6690±140	Riddl 770	SV12	15.57	-11.00	wood
3960±100	Riddl 1181	SV19	45.53	-41.03	wood
8360±170	GSC 225*	16-11-7	19.00	-9.00	peat
7140±600	I-2279**	Pangborn Bog	4.20	38.50	peat

* Armstrong, 1981

** Hansen & Easterbrook, 1974

environment would have been ideal for the deposition of fine silt, clay, and peat. A GSC radiocarbon sample of peat 9 m below sea level at the Sumas Way overpass (16-11-7, Fig. 3.10) yielded a date of 8360 ± 170 yr B.P. Because the dated peat layer was found at the base of the Unit 8 layer, just above Unit 3 gravel, this corner of the Sumas Valley must have been cut off from the rest of the valley at that time.

Lesser thicknesses of peat are also found adjacent to the Sumas River in the vicinity of Nooksack, Wa. These peat deposits are believed to be associated with the overbank deposits of Unit 7.

Both personal data collection and water well borehole logs revealed the presence of a large number of wooden logs below the surface. The logs were encountered over an 8 sq. km area in a recess in the bordering Sumas Drift 7-8 km southeast of Sumas, Wa. (SV 13, Transect M, Fig 3.14). The logs were found between 4-15 m below the surface in Unit 3 gravel. The concentration of logs in this portion of the valley suggests a debris flow or lahar from the Nooksack River Valley to the south, although the absence of large amount of ash in matrix would favour the former.

Several radiocarbon dates were determined from wood samples within the Sumas Valley, and are documented in Table 5.0. The presence of organic matter provided a maximum age for sediments at Sumas Way overpass (16-11-7), SV19, SV 12, and SV 10, and gave some indication of sedimentation rates within the Sumas Valley

The first observation that can be made about the sediments is their relative youth. Even the oldest date (8360 yr B.P.) is considerably younger than the age given to Sumas outwash (11,400 - 11,000 yr B.P.) by Armstrong, Easterbrook, and others. On the basis of these young radiocarbon dates, then, the sediments of the valley fill above the basement silts and clays are clearly Holocene in age.

As with the tephras, the stratigraphic relationship of dated organic matter supports the hypothesis of the growth of a Nooksack alluvial fan growing into the Sumas Valley. Assuming the law of stratigraphic superposition, sediments at SV 12 which are older than 6690 ± 140 yr B.P. would lie below -11 m bmsl where the dated wood sample was found. Therefore sediments at SV12 of an age contemporaneous with the wood sample at 16-11-7 (8360 ±170 yr B.P.) which had an elevation of -9.0 m (bmsl) would lie at some depth below -11 m(bmsl). Extending the chronological surface from 16-11-7 to SV 12 would therefore indicate a north sloping surface of uniform age, consistent with the surface of a fan (Fig. 5.5). The sedimentation rate for 16-11-7 and SV12 is 0.23 cm/yr.

The much younger dates at SV 10 and SV 19, which are only 6.5 km and 2 km from SV 12 respectively , indicate a far more recent environment of deposition and a much more rapid rate of sedimentation (1.43-1.74 cm/yr.). The dates and the depths at which wood was at SV 10 found are more consistent with Fraser River floodplain aggradational dates than with the sediments which predominate elsewhere in the valley (Morningstar, 1987). This suggestion is supported by the fact that the sands in which these organic samples are found are mineralogically similar to Fraser River floodplain sediments, and differ dramatically from the primarily volcanic sediments in which the other organic samples were found.

5.3.1 Forams

Sediments were examined under a binocular microscope for evidence of marine forams: none were found.

5.4 Sea Level Fluctuation

The interpretation of geomorphic events in the Fraser Lowland during the Late Quaternary requires an evaluation of the sea level changes which occurred at that time. Information on sea level changes and the processes which control them is important because: 1) sea level changes helped to determine the environment of sedimentary deposition (eg. marine, deltaic, terrestrial), and 2) fluvial processes would have been controlled by fluctuating sea level.

During the Fraser glaciation, the land was sufficiently isostatically depressed to cause sea level to rise to 200 m above present (Fig. 5.7). As the ice melted, isostatic rebound resulted in a rapid fall in sea level to 12 m below present sea level by about 8000 yr B.P. From 8000 yr B.P. to the present, sea level rose gradually, approaching present sea level 2250 yr B.P. (Easterbrook, 1963; Mathews et al., 1970; Armstrong, 1981; Clague et al., 1982, Williams & Roberts, 1989).

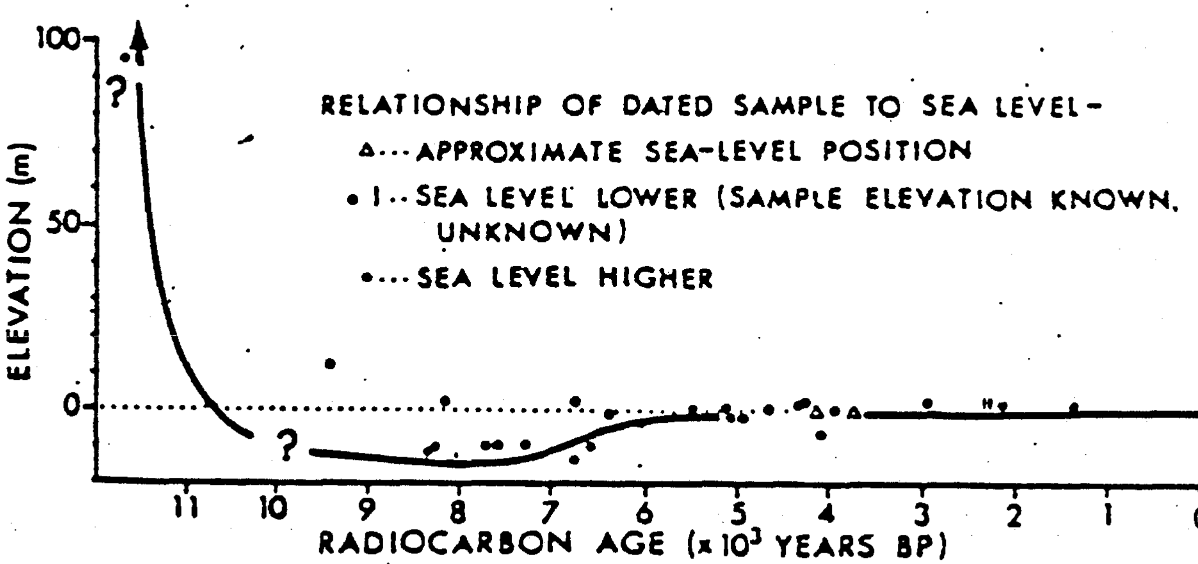


Fig. 5.7 Sea level fluctuations--Fraser Lowland
(from Clague et al., 1982)

Sea level fluctuations significantly influenced the sedimentary environment of the Sumas Valley. The marine incursion caused by isostatic depression during the Fraser Glaciation resulted in the extensive deposition of Fort Langley glaciomarine sediments throughout the Central Fraser Valley. These sediments are found beneath

Sumas Drift immediately west of the Sumas Valley.[1] However, Fort Langley glaciomarine silt was not observed by the author along the walls of the Sumas Valley, although Armstrong (1980) has mapped small exposures of this unit at elevations of 83 m and 166 m on the western side of Sumas Mountain.

Armstrong (1980, 1984) has speculated that glaciomarine Fort Langley sediments and/or earlier sediments may constitute the basement silt which underlies the Sumas Valley. This conjecture requires an explanation for the absence of Fort Langley silt between the suggested upper and lower occurrences of this unit. One possibility is that a portion of the Fort Langley silt unit was eroded by advancing Sumas ice and/or proglacial fluvial action. However until the upper and lower silt units are positively identified as Fort Langley sediment, all explanations concerning its distribution are speculative.

The most significant aspect of sea level fluctuation is with respect to the theory that the Fraser River may have flowed through the Sumas Valley to Bellingham Bay after deglaciation. If the Nooksack fan, which today presents a topographic barrier for any southward flow of water out of the Sumas Valley, was indeed a recent addition to the valley's landscape, the possibility of Fraser River sediments underlying the Nooksack fan sediments would be reasonable. However, if this was the case, the ancestral Fraser River would have been graded to sea level, which was never lower than 12 m below present sea level after the Fraser Glaciation, according to the forementioned research. Therefore had the Fraser River flowed through the Sumas Valley, its sediments, if present, would not be found greatly below that elevation.

At several sites throughout the Sumas Valley cores extending well beyond the -12 m (bmsl) elevation contained only the volcanic sands of the Nooksack or Sumas

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[1]The absence of Fort Langley Formation sediments in the eastern Fraser Lowland has been attributed to the Lowland occupation by ice during the Fort Langley time interval (Armstrong, 1981). Sumas Drift north east of the Sumas Valley is underlain instead by older Semiahmoo glaciomarine sediments. Fossil marine shells from an exposure of Semiahmoo silt at the Bailey Pit near Vedder Crossing have yielded a date of 34,000 yr B.P. (Armstrong, 1977, 1984).

Rivers, with no evidence of the felsic Fraser River sediments. In one location--SV 19--volcanic sands were found to a depth of -40 m (bmsl). In addition, the Unit 3/5 gravel lobe in the south end of the Sumas Valley, which is clearly an extension of sediments from further upstream on the Nooksack River, is found at depths which exceed -12 m bmsl (eg. Transect N, SV 25 and Transect L, W 15) and would present a barrier to the southward flow of water. Therefore, on the basis of sedimentary evidence, the theory that the Fraser River flowed through the Sumas Valley within the Holocene must be rejected.

CHAPTER SIX

EVOLUTION OF THE SUMAS VALLEY

Based on available data, the following sequence of events describing the geomorphic evolution of the Sumas Valley is proposed.

6.0 Late Wisconsinan Glaciation

6.0.0 Fort Langley Time Interval 11,000-13,000 yr B.P.

Sea level was 250 m higher than present at the end of the Fraser glaciation due to isostatic depression (Armstrong, 1981; Clague et al., 1982). As the ice occupying the entire Fraser Valley, including the Sumas Valley, retreated to the northeast during an interstade 13,000 - 11,400 yr B.P., a thick layer of Fort Langley glaciomarine sediments, mostly silt, was deposited throughout much of the Fraser Lowland. These sediments were classified as "Bellingham Glaciomarine Drift" in Washington by Easterbrook (1963).

Speculation on geomorphic events within the Sumas Valley during the Fort Langley Time Interval is contingent on the positive identification of Fort Langley sediments within the valley. It has been suggested that Fort Langley sediments occur both perched on Sumas Mountain, at an elevation of 166 m., and beneath the surface of Sumas Valley (as the lithostratigraphic unit classified as Unit 1 in this study) (Armstrong, 1981, 1984). Confirmation of these silts as being Fort Langley in origin would indicate the extensive distribution and subsequent erosion of this sedimentary unit. However, the absence of additional silt exposures between these two occurrences may refute the possibility that they were originally part of the same unit.

Fort Langley sediments are not found east of the Sumas Valley because the ice front retreated no farther east than the vicinity of Agassiz (Armstrong, 1981). The absence of Fort Langley sedimentary exposures throughout the Sumas Valley may require that this assertion be reconsidered--perhaps the presence of the ice lobe prevented the depostion of Fort Langley sediment in the Sumas Valley as well.

6.0.1 Sumas Stade 11,000-11,400 yr B.P.

After 11,400 yr B.P., the Fraser Lowland experienced rapid isostatic rebound, with sea level correspondingly dropping to close to present day levels (Armstrong, 1981; Clague et al., 1982, Williams & Roberts, 1989). Concurrently, glacial ice advanced in the eastern Fraser Valley from a frontal position near Agassiz (Fig. 6.a). A lobe advanced down the Sumas Valley as far as the town of Nooksack, Wa., its furthest limit indicated by the presence of Sumas till on both sides of the valley (Armstrong, 1960a; Easterbrook, 1963; Armstrong et al., 1965).

The main evidence of the advance of the Sumas lobe is the distribution of Sumas Drift. This unit underlies much of the Central Fraser Valley to the west of the Sumas Valley and overlies Fort Langley sediments in the same region. Sumas Drift is found at a maximum elevation of 213 m above sea level on Sumas Mountain (Armstrong, 1980b). It is therefore concluded that the Sumas lobe, due to its relative shallowness, did not override Sumas and Vedder Mountains. It should be noted that, because the Sumas ice advanced when the land was isostatically rebounding, its deposits were terrestrial in nature and were not overlain by any marine deposits (Armstrong, 1981, 1984).

The advance of the Sumas lobe was localized in the eastern Fraser Valley, and therefore, no other glaciation was present in the Lower Mainland during its advance. Past studies have indicated that at the time the Sumas lobe was advancing, the Cascade Range to the south supported only alpine glaciation (Easterbrook, 1963).

The retreat of the small Sumas lobe was as rapid as its advance (Armstrong, 1981). It is believed that the Fraser Valley in the vicinity of Chilliwack was ice-free by

Sequence of Glacial Retreat and Sedimentation Pattern and Suggested Dates

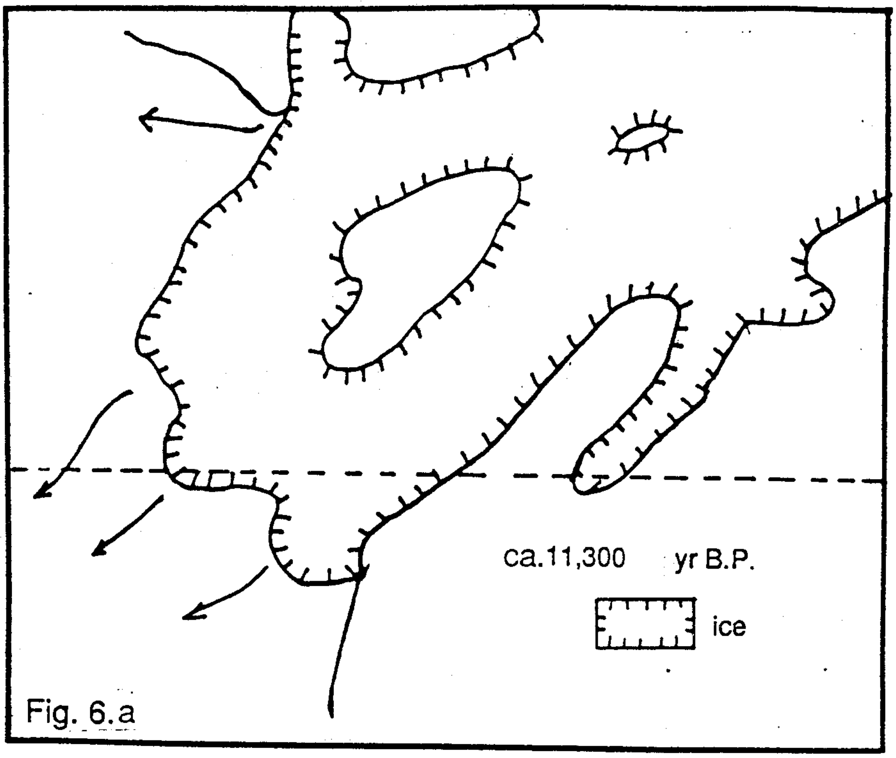


Fig. 6.a

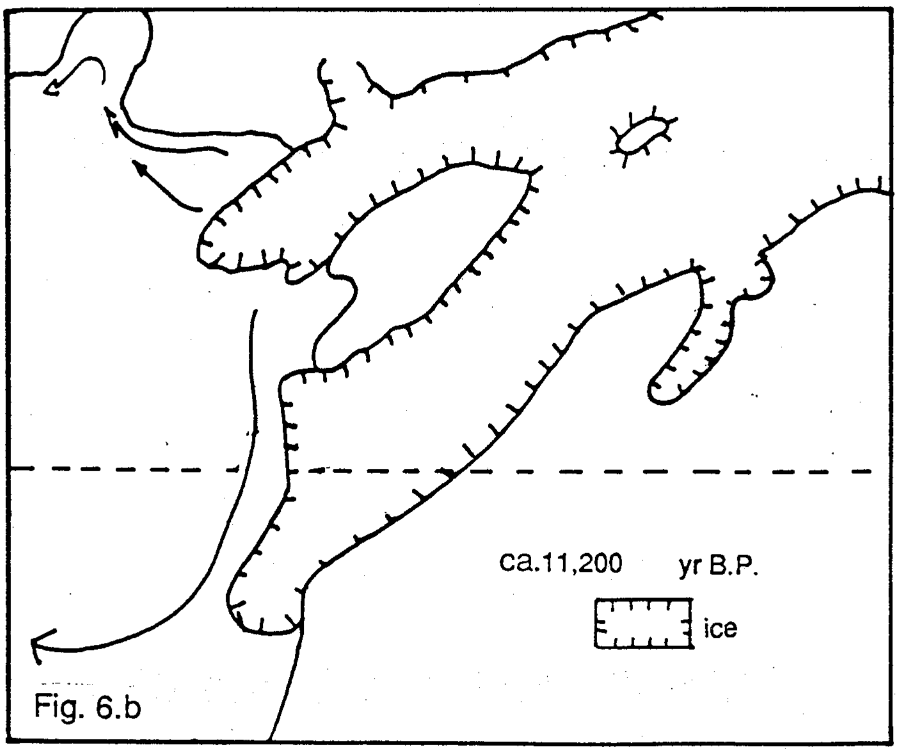


Fig. 6.b

11,000 yr B.P. (Saunders et al., 1987). However, it has been suggested by Armstrong (1981, 1984) that a remnant block of ice continued to occupy the Sumas Valley after the main retreat of the Sumas ice lobe from the Fraser Lowland. If such an ice block was indeed present, it would help explain why the meltwaters of the Sumas lobe did not flow to the south, because the Nooksack and Chilliwack fans at that time (11,000 yr B.P.) would not have provided a barrier to the southward flow of water. In any event, ice would have melted at a slower rate in the Sumas Valley than in the rest of the Fraser Valley, because the valley would have been shaded by Vedder ~~Mountain~~ Mountain, as it is today (Fig. 6.b).

Meltwater from the Sumas lobe was instrumental in the deposition of Sumas outwash in the Puget Lowland to the south (Easterbrook,1963). In addition, some of the meltwater from the Sumas Valley may have drained to the north to the then fledgling Fraser River via a small meltwater channel cut into the Sumas Drift west of Sumas Mountain. If an ice block in the Sumas Valley became separated from the main retreating Sumas ice lobe, as suggested by Armstrong (1981, 1984), then some melting along the eastern edge of the ice lobe would have also occurred, and meltwater would have flowed to the young Fraser River (Fig. 6.c).

The ice surface within the Sumas Valley eventually downwasted past the surface of the Sumas Drift, causing the small, northern meltwater channel to be abandoned. The main outlet for meltwater discharge continued to be to the south, permitting the excavation of the glacial drift bank along the Sumas Valley's western wall. In addition, the ice block began to melt back towards towards the northeast. During these waning stages of ice occupation, it is believed that ice along the north flank of the Sumas Valley was the first to melt because this side of the valley would have received the most insolation. Once the north flank of the Sumas Valley became ice free, meltwater would have then flowed along it towards the northeast.

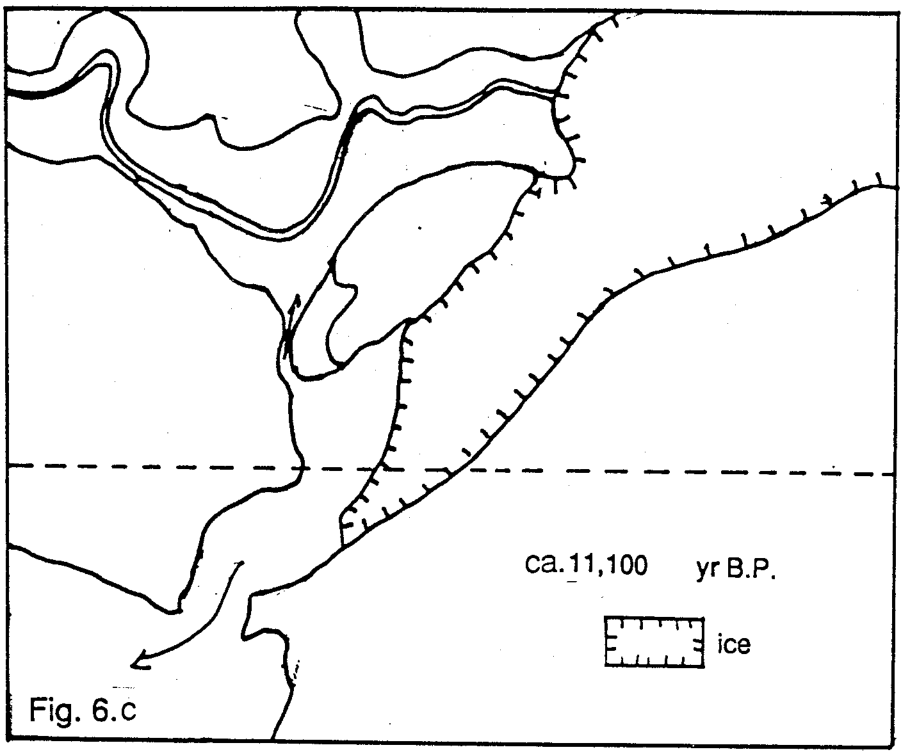


Fig. 6.c

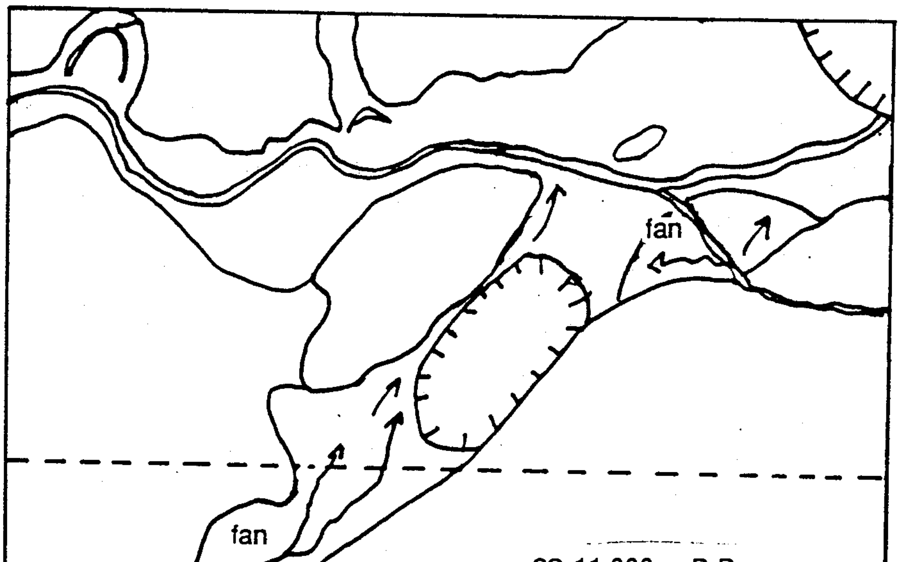


Fig. 6.d

This flow would have been responsible for the excavation of much of the Sumas Drift along the valley's flank.

6.1 Early Holocene 10,000 yr B.P.

6.1.0 Nooksack Fan Progradation

At some point during the wastage of the ice lobe which occupied the Sumas Valley, the Nooksack River (or a greatly enlarged Sumas River) from the Cascade Mountains to the south, began to build an alluvial fan towards the Sumas Valley. The exact timing of this event is not known due to the lack of data beneath the Nooksack sediments. However, the lithological evidence assembled for this study clearly indicates the aggradation of a fan from the north to the south within the Holocene (Fig. 6.d).

The Nooksack fan, which was a fan delta or "wet" type alluvial fan, likely resembled a braided alluvial plain. Its bedload consisted of gravels and sands which graded from proximal to distal reaches.

The Sumas Valley may or may not have been ice free at the time the Nooksack fan began its progradation into the valley. If a wasting ice lobe was still present at the time of fan progradation, then the reduced discharge from its meltwaters was not strong enough to deflect the advancing front of the alluvial fan from the south, especially when sedimentary deposition on the fan was fortified with sediment from periodic lahars from the Mount Baker (Hyde & Crandell, 1975).

The Nooksack fan advanced to such an extent that it cut off the southward flow of water from the Sumas Valley. With both of its outlets dammed, the only direction for accumulating water (possibility meltwater) to flow was to the northeast along the northern flank of the Sumas Valley. The northward flow of the Nooksack fluvial system helped to erode much of the Sumas Drift not already eroded by Sumas lobe meltwater.

The concentration of alluvial gravel in the mid-western and northern segments of the Sumas Valley supports the hypothesis of a remnant ice block occupying the valley. Its distribution (see Fig. 3.17) suggests that the ice block deflected the main fan channel (considered to be the ancestor of the present day Sumas River) towards the north side of the valley, and that as the valley floor continued to aggrade, the flow pattern remained established. As with all fans, flow probably exhibited erratic patterns during progradation.

As the Nooksack fan prograded into the Sumas Valley, the western flank of the valley became separated from the rest of the valley by the fan's apex. This western region became a swampy backwater, judging from the presence of silty clay deposits interlayered with peat. (Figs. 3.7, & 3.10). A radiocarbon date of 8360±170 yr B.P.taken from peat at the base of this silty clay layer suggests that the Nooksack fan had aggraded sufficiently to cut off the western flank of the valley by this time.

6.1.1 Chilliwack Fan Progradation

The Fraser Valley was ice free by 11,000 yr B.P. in the vicinity of Chilliwack northeast of the Sumas Valley (Saunders, 1985, Saunders et al, 1987) As the Sumas lobe began to retreat from this area, a fan from the ice free Chilliwack Valley began to form. The Chilliwack fan began to prograde and aggrade into the newly forming Fraser River floodplain and may have contributed to the deflection of the Fraser River to the north side of the valley.

As the Sumas Valley became ice free, the Chilliwack fan began to prograde into the basin which remained. However, the progradation of the Chilliwack fan into the area was a slightly later event than the Nooksack/Sumas fan progradation into the valley, because ice would have remained in the north portion of the Sumas Valley as the southern ice front retreated and would have obstructed the deposition of Chilliwack fan material.

As the Chilliwack fan prograded west towards Sumas Mountain, the Fraser River floodplain was also forming. Armstrong (1981, 1984) asserted that the Fraser River did not enter the Sumas Valley because while the Fraser River was forming its floodplain on the eastern side of the Fraser Valley adjacent to the Sumas Valley, the ice block remained an obstacle. However, even without a protective ice block, the Sumas Valley would have been partially protected from an incursion on the Fraser River by the prograding Chilliwack fan. Nevertheless, the Fraser River periodically flooded the basin by breaching the Chilliwack fan--a process that was witnessed at the time of European settlement in the area.

6.2 Mid Holocene

When the ice melted completely, a slackwater basin remained. Into this basin the distal portions of both the Chilliwack and Nooksack/Sumas fans were able to prograde. Unit 2 interbedded silt and sand was deposited in this low energy environment (Fig. 6.e). The young age of radiocarbon dated organic matter suggests that the aggradation of the slackwater basin occurred more recently than the aggradation of the rest of the Sumas Valley.

A theory which must be entertained is that if a remnant ice lobe did indeed exist in the valley after the main retreat of Sumas ice from the eastern Fraser Valley, it is possible that Unit 1 clayey silt represents the lacustrine sediment which was deposited in its dammed meltwater. Pollen analysis of Unit 1 may provide dateable evidence which would support this theory.

As the Chilliwack fan prograded across the northeast end of Sumas Valley, it acted as a dam containing what eventually became Sumas Lake. A similar fan damming process has been documented at Tulare Lake, California (Atwater, et al., 1986).

Eventually, the basin aggraded to close to present levels. Reduced sediment supply due to decreasing stream competence from the Nooksack/Sumas fan systems

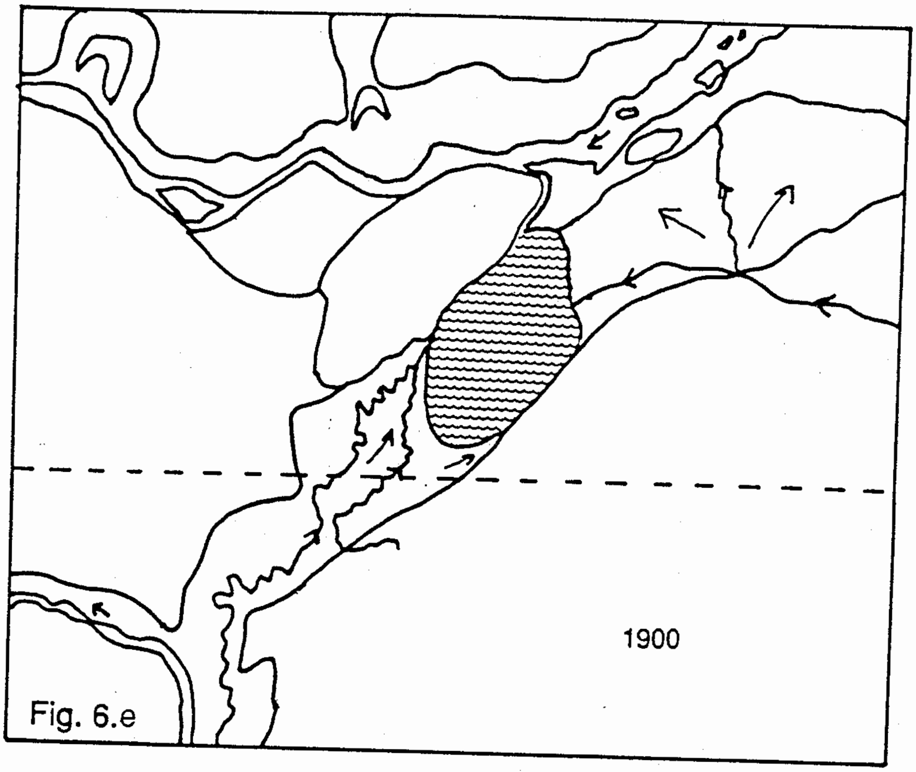


Fig. 6.e

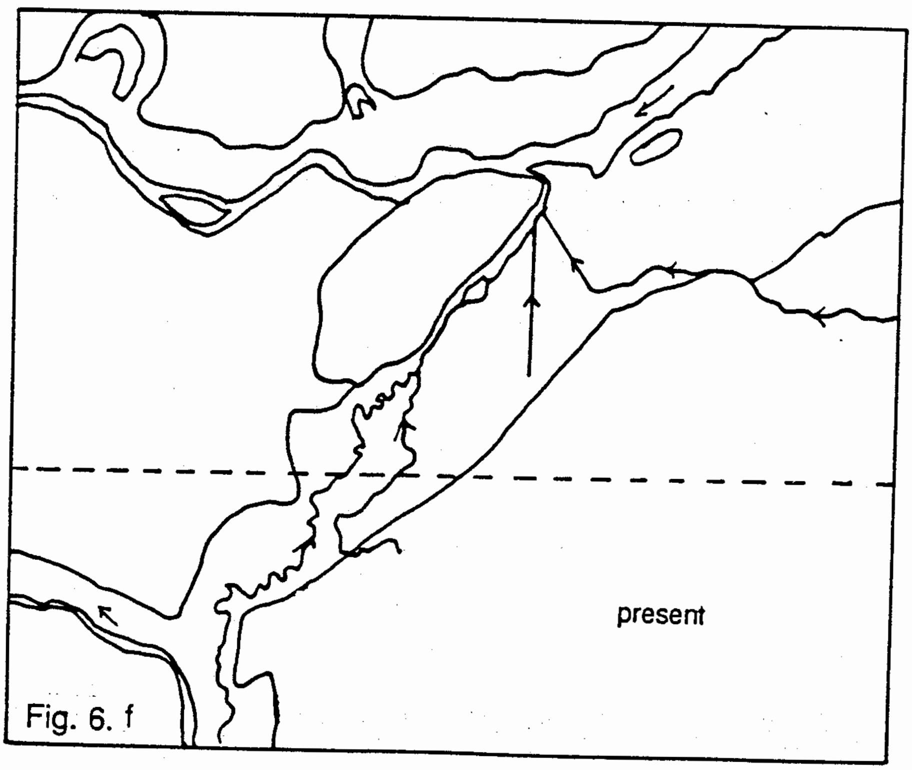


Fig. 6. f

resulted in the deposition of mostly fine sediment from the south. However, the Chilliwack fan continued to be active up to the time of settlement into the region.

6.3 Late Holocene

The Nooksack River at present does not flow into the Sumas Valley, unlike the Sumas River and its tributaries . If the Nooksack River was the major source of sediment from the south into the Sumas Valley, it obviously must have subsequently avulsed to its present northerly course. The reason for this directional change can only be speculated upon, and could have been as mundane as the normal channel changes that occur on most alluvial fans, or as catastrophic as an earthquake. It is also possible, however, that the Sumas River was at one time much larger than it is at present and was responsible for much of the deposition in the Sumas Valley. In either case, until recently, the majority of the sediment carried from the Nooksack River to the south ended up in the Sumas Valley rather than in the present Nooksack floodplain.

By the time of European settlement, the Sumas Valley basin was almost completely filled in with sediment. The valley, dammed by two fans, contained a shallow lake that filled with water during the spring freshet and dried during the summer, permitting grazing by animals on grasses which grew on the exposed lake bed (Sinclair, 1961). Sumas Lake continued to be inundated by Fraser and Nooksack River floodwaters occasionally, and by Chilliwack River floodwaters annually, until the construction of the Vedder Canal in 1924 (Sinclair, 1961). If left to nature, the area would have eventually filled to the same level as the Fraser River floodplain. Because the Vedder Canal was built before this was achieved, much of the Sumas Valley has an elevation close to sea level and still floods periodically due to rising groundwater levels.

CHAPTER SEVEN

SUMMARY AND CONCLUDING REMARKS

7.0 Summary

The objectives of this study were: 1) to attempt to reconstruct the late Quaternary, primarily post-glacial geomorphic history of the Sumas Valley, and 2) to address the question of whether the Fraser River could have flowed through the Sumas Valley in post-glacial time.

The analysis of the subsurface sedimentary architecture of the Sumas Valley, together with topography, sediment lithology, mineralogy, tephrochronology, and radiocarbon dating, supports several conclustions.

1) The nature and origin of Unit 1 silt and clay remains unknown. As the deepest and most extensive lithostratigraphic unit in the Sumas Valley, Unit 1 is presumed to be the oldest unit encountered in this study, possibly representing Fort Langley glaciomarine silt. However, the possibility of a post-glacial lacustrine origin for this unit has not been discounted.

2) Sumas Drift from the Sumas ice lobe is almost completely absent from the Sumas Valley. The absence of these sediments is attributed to their excavation by Sumas meltwater, and by fluvial activity associated with the Nooksack alluvial fan.

3) The most significant aspect of the post-glacial geomorphic evolution of the Sumas Valley was the progradation of two alluvial fans into the valley--the Nooksack fan from the south and the Chilliwack fan from the north. Evidence of the progradation of these fans was seen in the lithostratigraphic profile of the valley.

The Nooksack fan, which is the larger of the two fans, encompasses the southern half of the Sumas Valley. It exhibits the characteristic lateral and vertical grading facies of a prograding alluvial fan having a fluvial system of decreasing competence.

The Chilliwack fan is smaller than the Nooksack fan, but still exhibits the lateral and vertical grading characteristics of a prograding fan. This fan was active until the Chilliwack River was contained in the Vedder Canal in 1924.

It is believed that both fans began prograding into the Sumas Valley shortly after the withdrawal of glacial ice.

3) Deposition of clay and silt along the western flank of the Sumas Valley occurred when this area was separated from higher energy fluvial environments by the aggrading Nooksack alluvial fan.

4) Tephrochronology and radiocarbon dating indicate much of the valley fill to be clearly Holocene in age and not associated with Sumas outwash, as had been suggested previously.

5) The two alluvial fans damming the Sumas Valley provided a slackwater depocentre for their fine textured distal sediments as well as for the fine sediments of the Fraser River during flooding events. Aggradation in this basin continued until Sumas Lake was drained, and the Vedder Canal and Fraser River were dyked.

6) The theory that the Fraser River flowed through the Sumas Valley enroute to the ocean in the Holocene is rejected. This conclusion is based on the presence of a lobe of Nooksack alluvial fan gravel and sand in the south portion of the valley which would have provided a formidable obstacle to any southward flow of water. In addition, Fraser sediments were not found in the Sumas Valley, except in a limited region in the extreme northern tip of the Sumas Valley.

but then, neither [illegible]

7.1 Suggestions for Future Research

Several opportunities for future research exist within the Sumas Valley.

The greatest challenge lies in determining the nature and scope of the underlying basement silts. Establishment of the origin of this basement sedimentary unit as lacustrine or marine will help address some of the outstanding questions which still exist in the reconstruction of the geomorphic evolution of the Sumas Valley. A concentrated search for forams and pollen would be an integral part of the analysis of this basement silt unit. X-ray diffraction may be helpful in assessing the silt's mineralogical composition.

One problem encountered in the analysis of subsurface sedimentology was the inference of subsurface units based on the extension of units found in cores. Shallow seismic surveying may provide a more continuous profile of subsurface units. However, because the presence of gravels poses a problem for shallow seismic surveying, this technique may meet only limited success and may be only confined to areas were gravel units do not predominate. Seismic surveying would also determine depth to bedrock, for which no information exists.

7.2 Conclusion

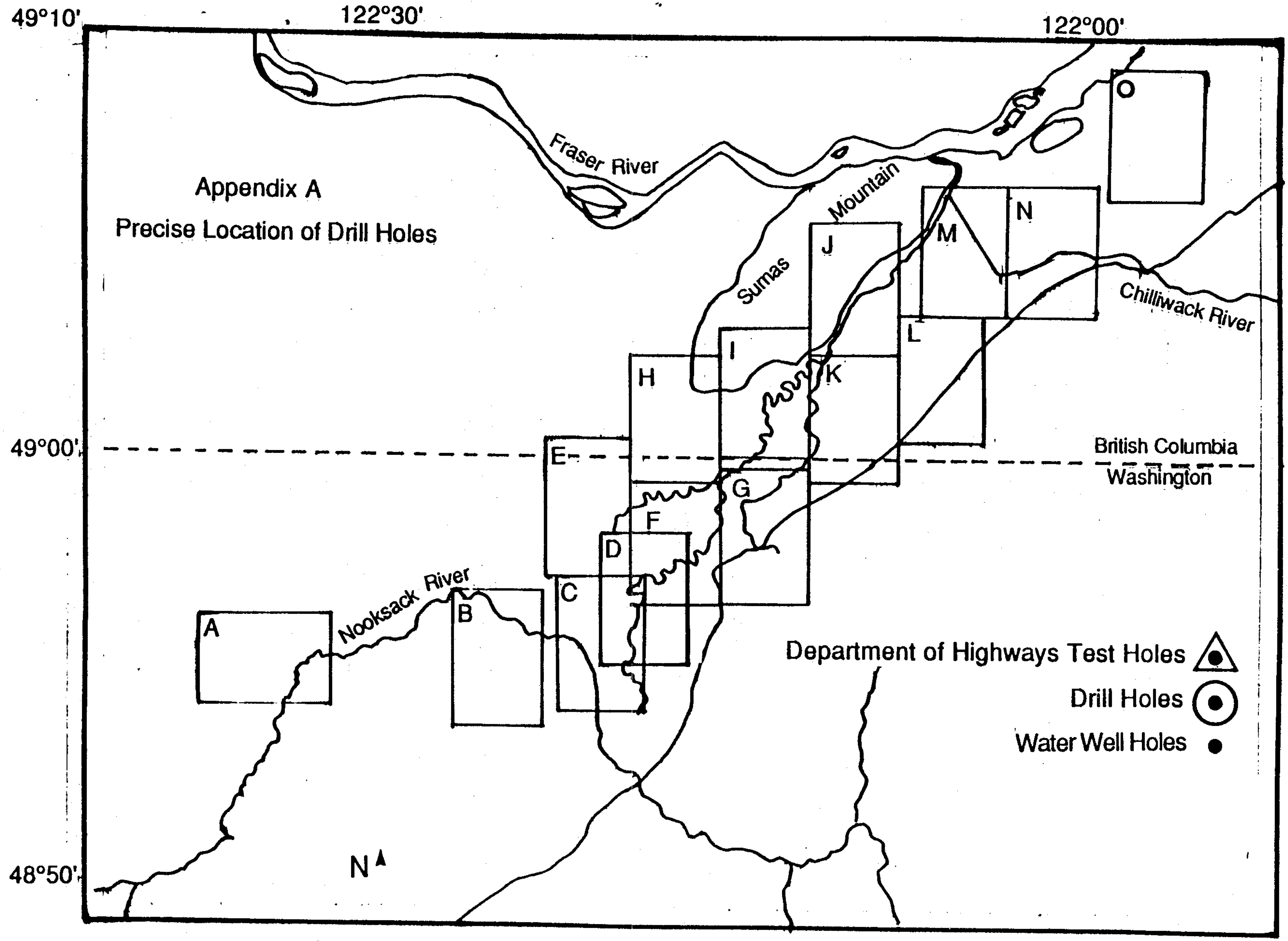
Research conducted during the course of this study has indicated that the subsurface sedimentology of the Sumas Valley is more complex than originally believed. Belying the low relief of its surface is a fascinating assemblage of sedimentary units. It is hoped that this study will have both practical value, in the delineation of aquifers and subsurface sedimentary units for engineering purposes, and academic value, in that the results and conclusions discussed here will contribute to other research being conducted into the geologic and gemorphic evolution of the Fraser Lowland.

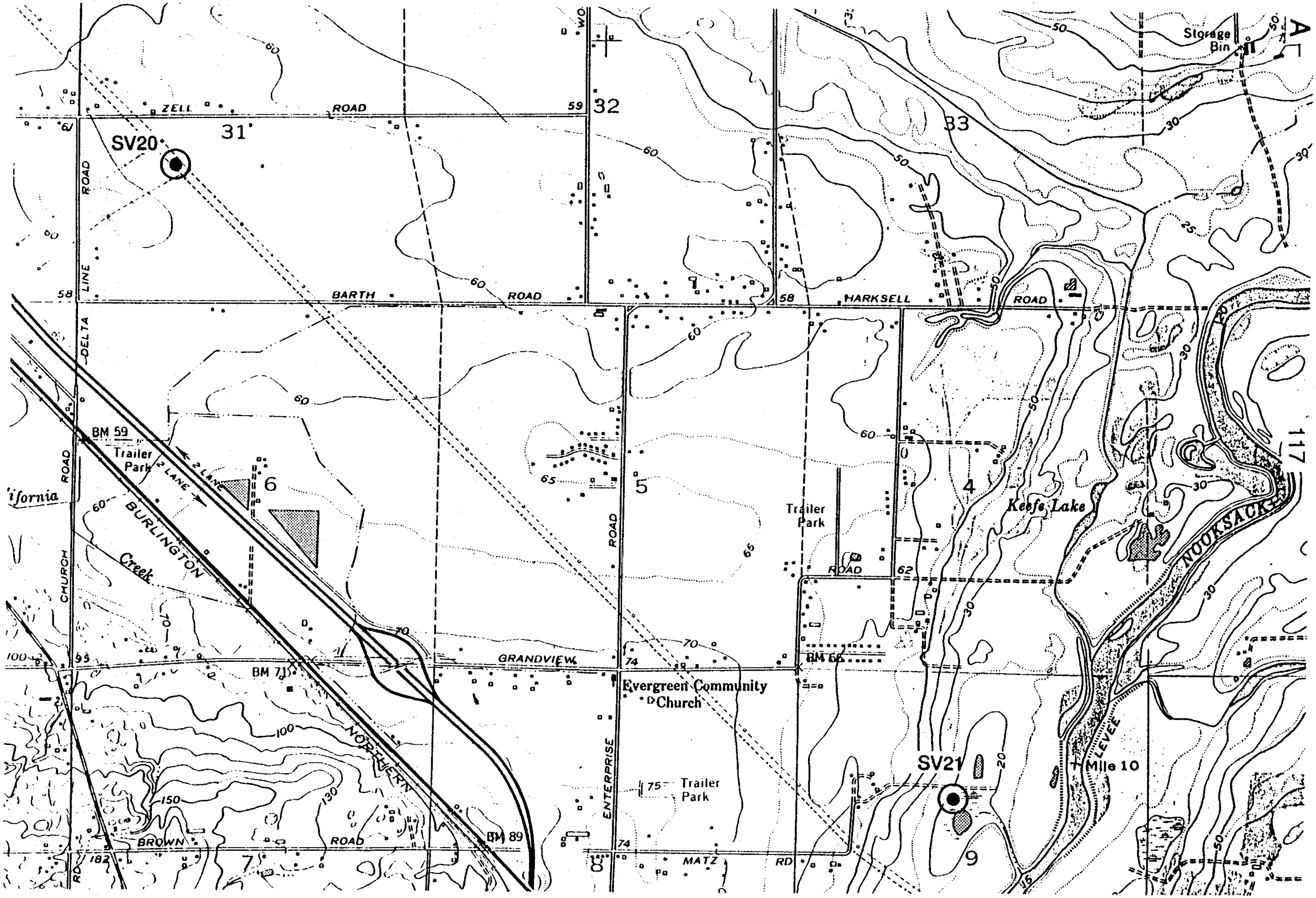
APPENDIX A

Precise Location of Cores

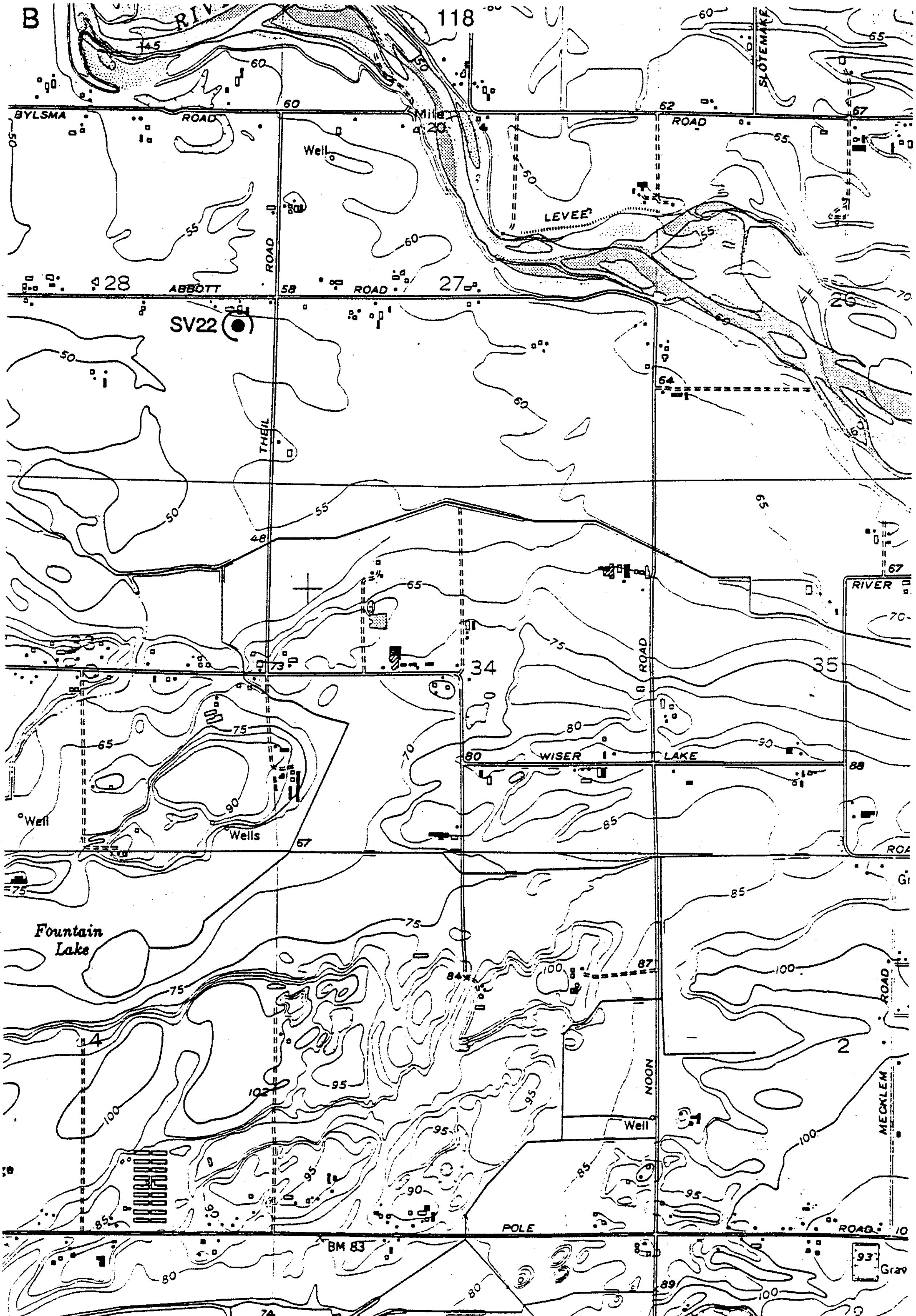
Appendix A

Precise Location of Drill Holes



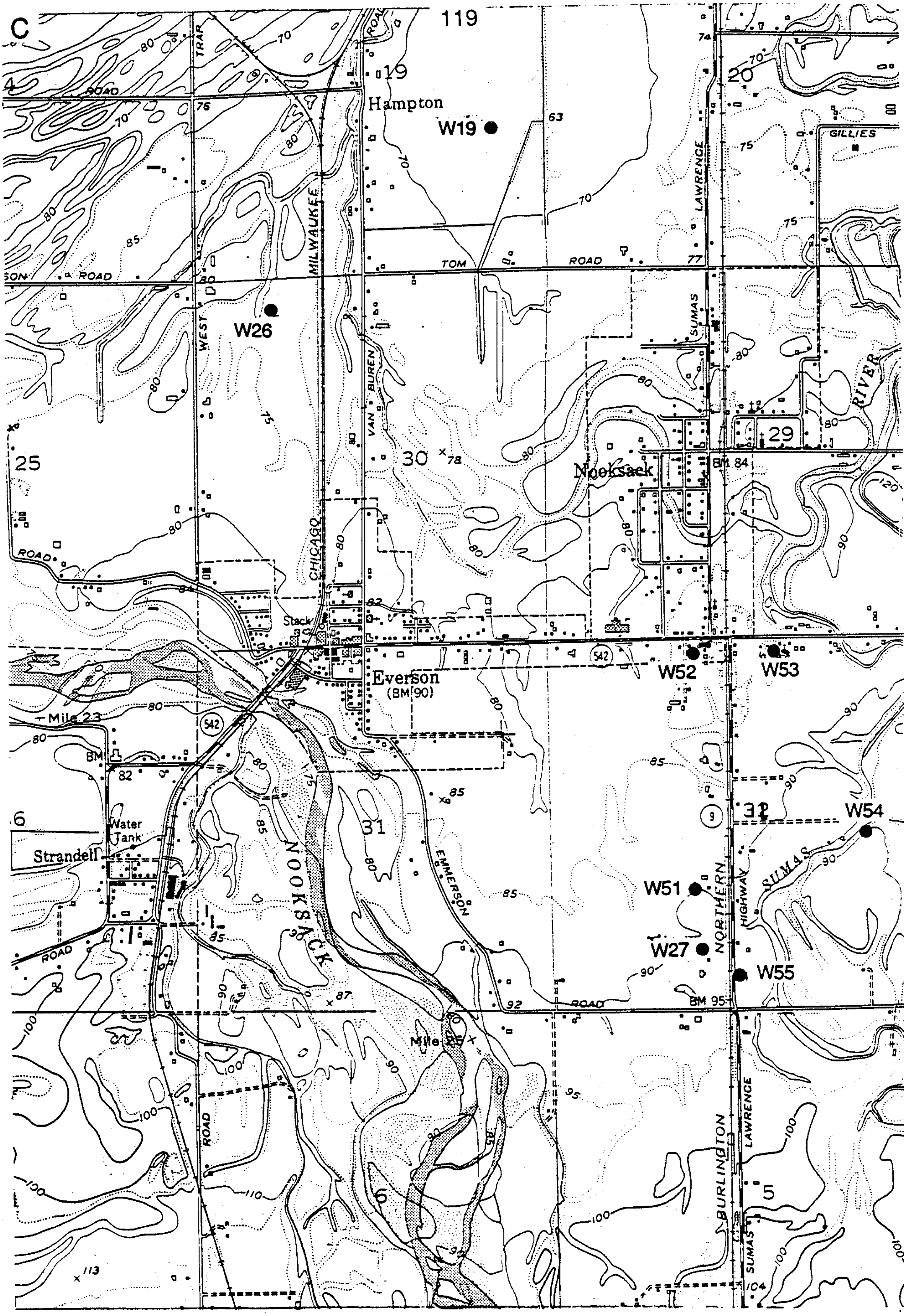


A
Storage Bin
SV20
SV21
ZELL ROAD
BARTH ROAD
HARKSELL ROAD
DELTA LINE ROAD
CHURCH ROAD
GRANDVIEW
ENTERPRISE ROAD
BROWN ROAD
MATZ RD
BURLINGTON NORTHERN
Trailer Park
Evergreen Community Church
Keefe Lake
NOOKSACK
LEVEE
Mile 10
Creek
BM 59
BM 71
BM 89
BM 66
2 LANE
31
32
33
4
5
6
7
8
9
117

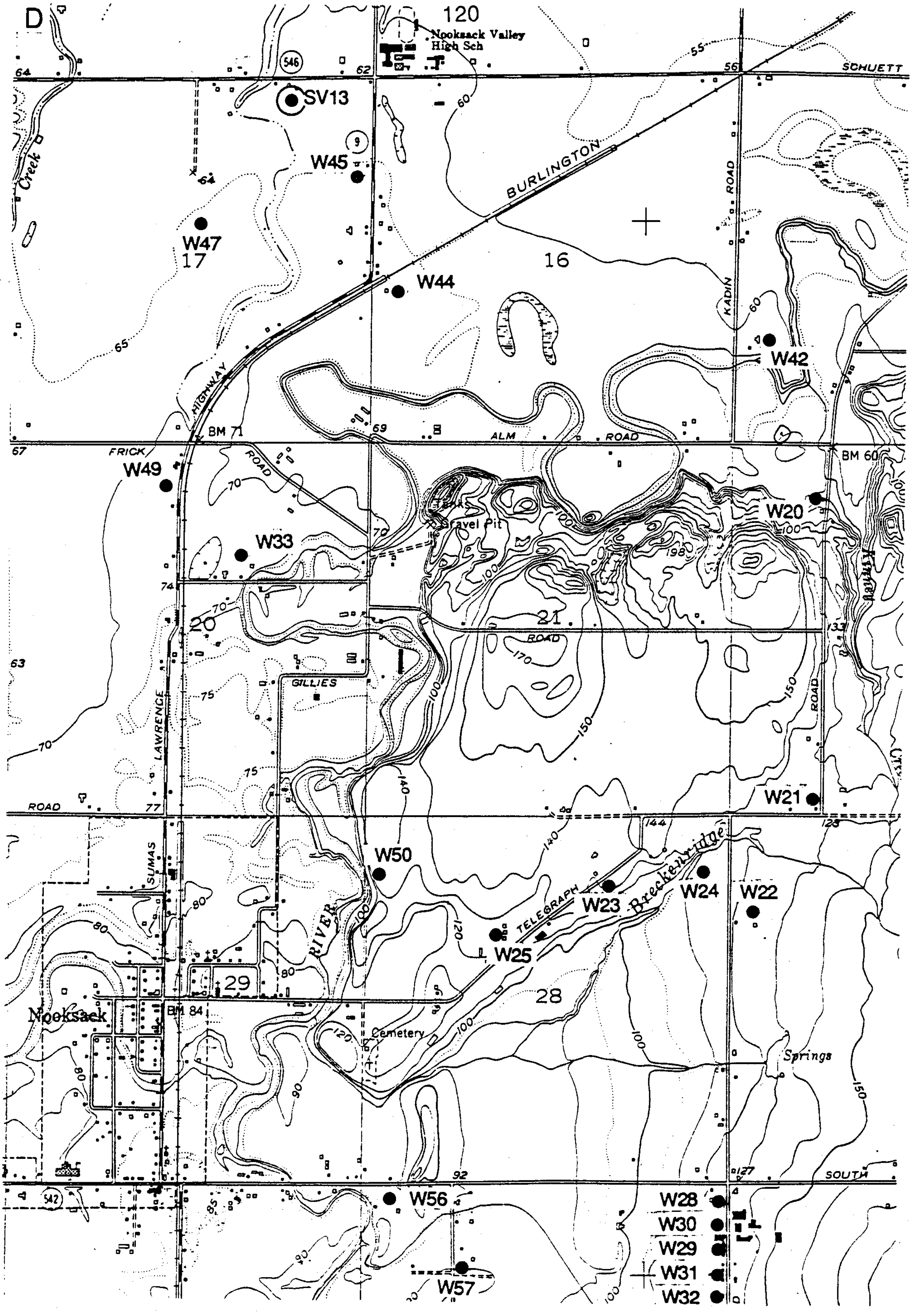


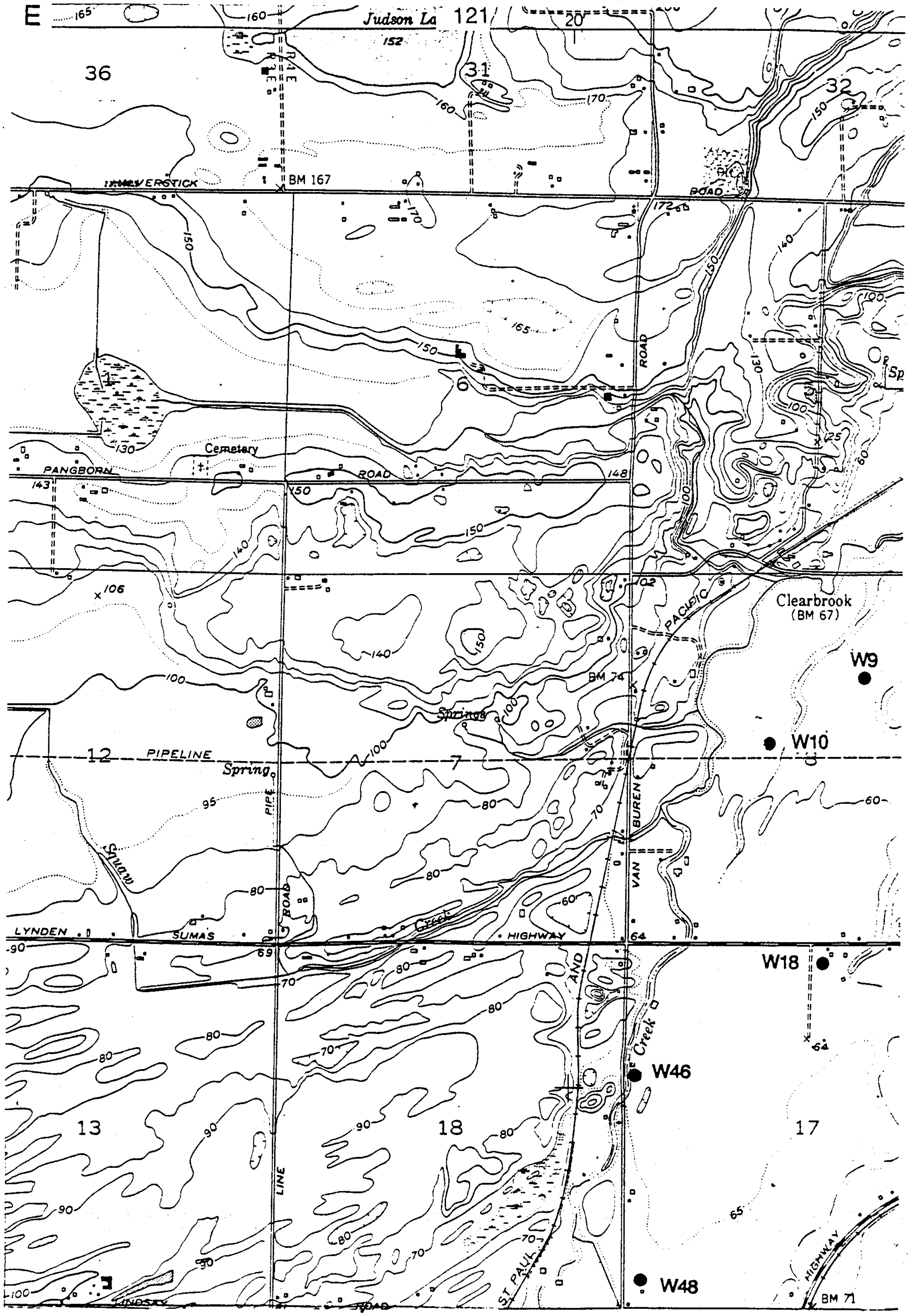
B
118
SLOTEMAKER
BYLSMA ROAD
ROAD
Mile
20
Well
LEVEE
ABBOTT ROAD
28
27
26
SV22
THEIL
ROAD
RIVER
34
35
WISER LAKE
ROAD
Well
Wells
Fountain Lake
NOON
MECKLEM
2
4
Well
POLE ROAD
BM 83
Grav
Green Lake

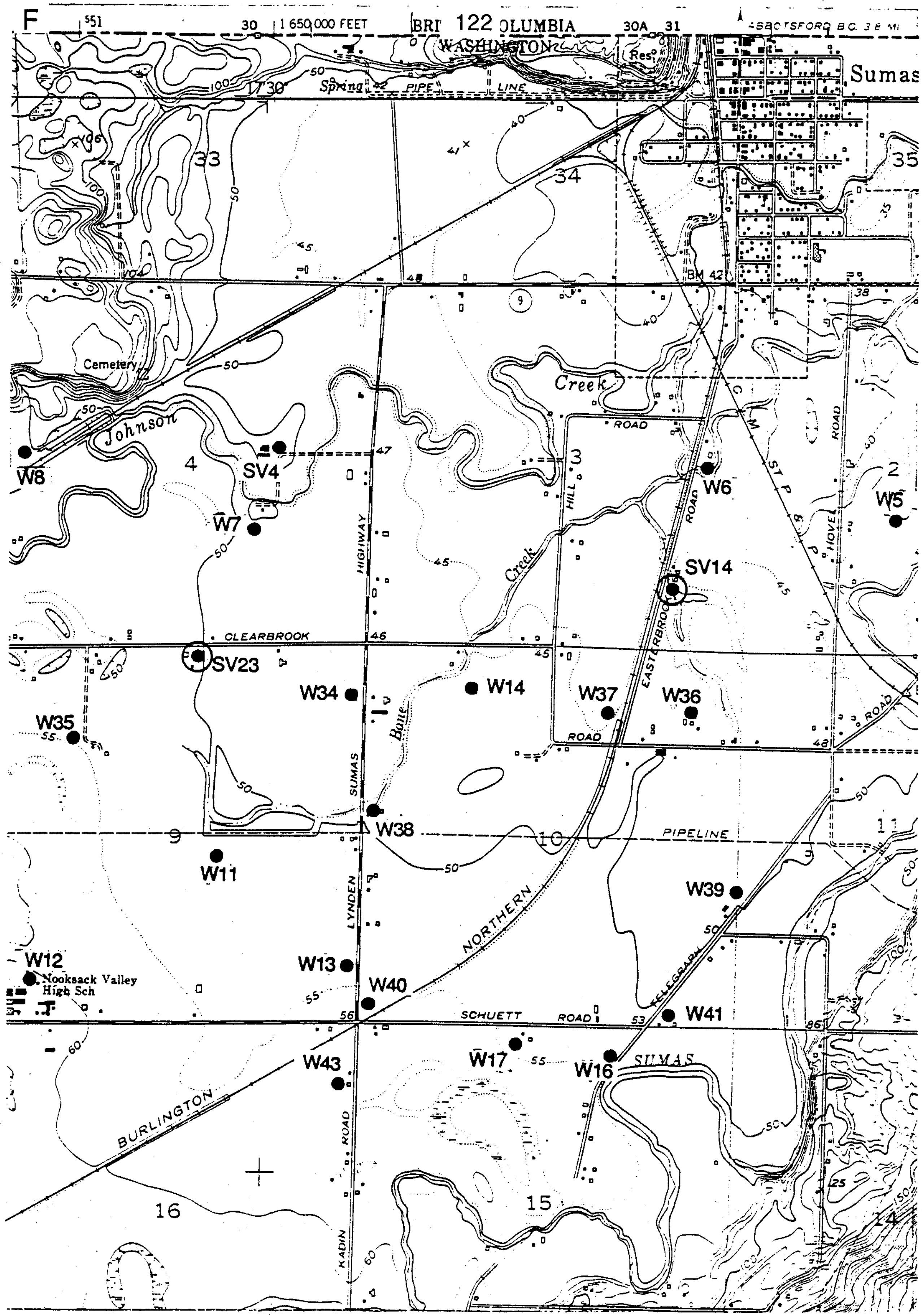
C



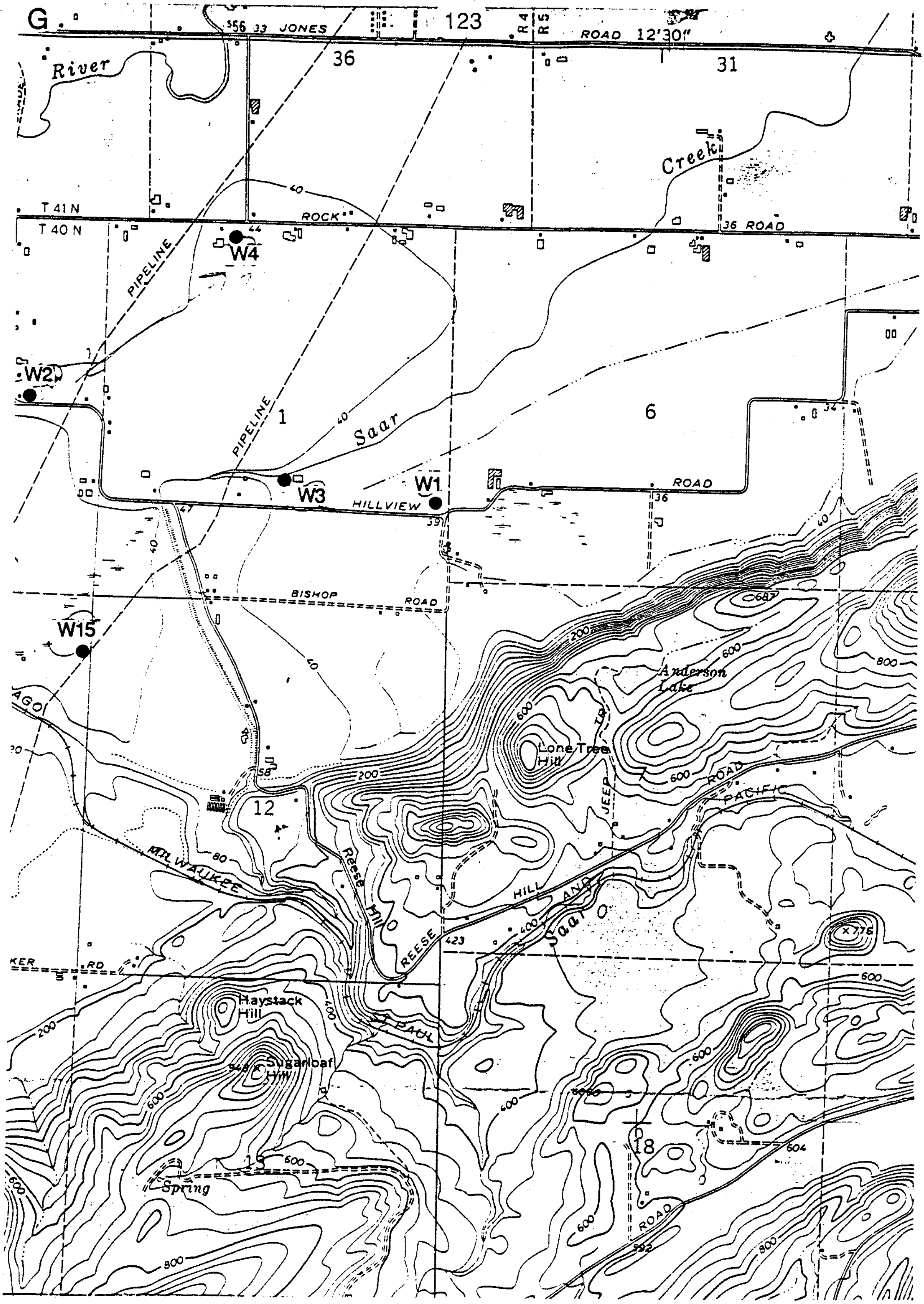
119
Hampton
W19
W26
TOM ROAD
GILLIES
LAWRENCE
SUMAS
RIVER
MILWAUKEE
WEST
VAN BUREN
CHICAGO
30
29
25
Nooksack
BM 84
Stack
Everson
(BM 90)
542
W52
W53
Mile 23
BM 82
Water Tank
Strandell
NOOKSACK
EMMERSON
31
32
9
W54
NORTHERN
HIGHWAY
SUMAS
W51
W27
W55
ROAD
BM 95
Mile 25
BURLINGTON
LAWRENCE
SUMAS
5
6


D
120
Nooksack Valley High Sch
546
SV13
9
W45
W47
17
16
W44
BURLINGTON
SCHUETT
KADIN ROAD
W42
HIGHWAY
BM 71
FRICK ROAD
ALM ROAD
BM 60
W49
W20
Tanks
Gravel Pit
W33
20
21
ROAD
GILLIES
LAWRENCE
ROAD
W21
SUMAS
W50
RIVER
TELEGRAPH
Breckenridge
W23
W24
W22
W25
29
28
Nooksack
BM 84
Cemetery
Springs
SOUTH
542
W56
W28
W30
W29
W31
W32
W57

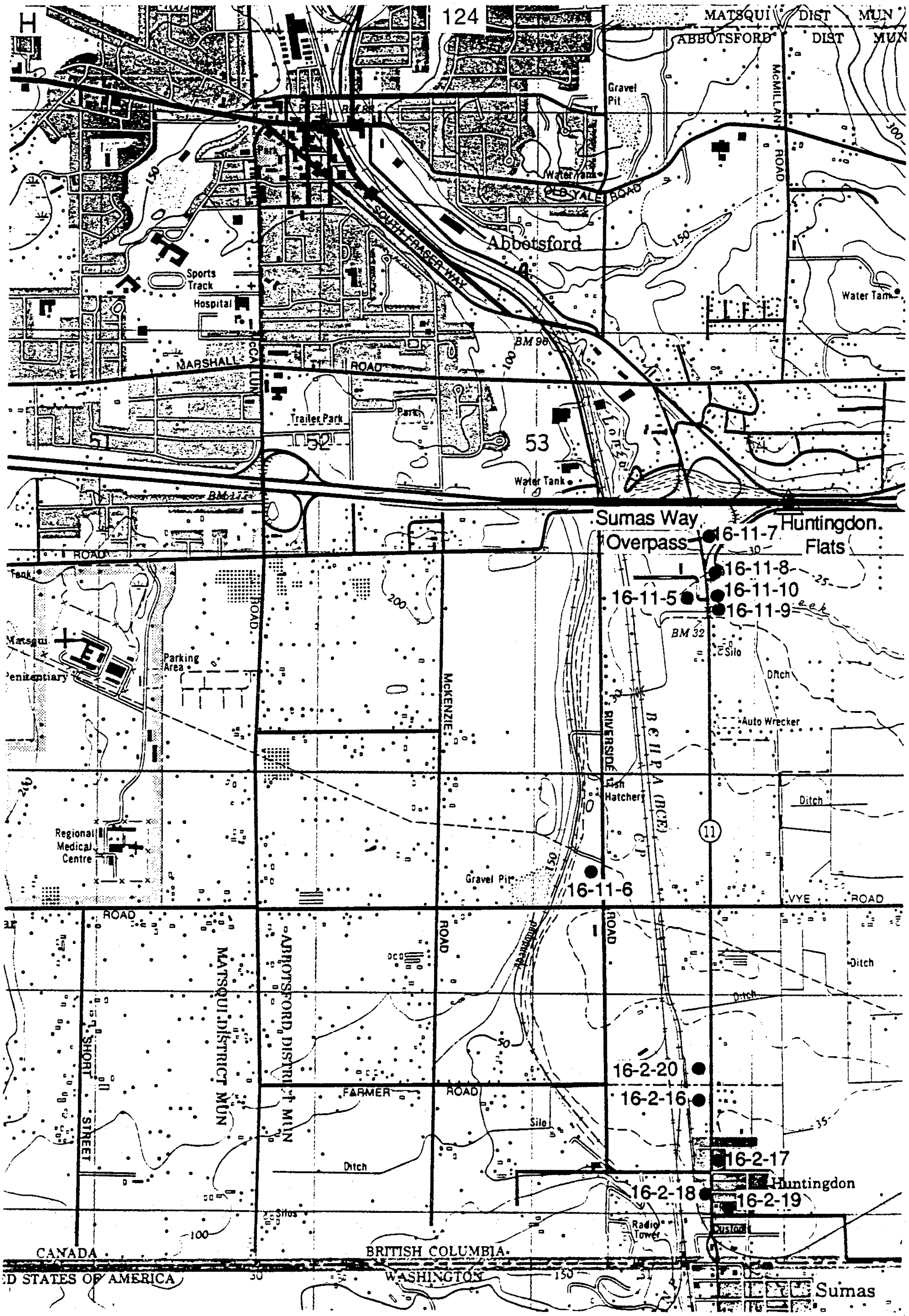

E
Judson La
121
20
36
31
32
R 4 E
R 3 E
BM 167
HAVERSTICK
ROAD
172
165
160
170
150
152
140
130
100
125
60
Sp
6
Cemetery
PANGBORN
ROAD
143
148
106
Clearbrook
(BM 67)
PACIFIC
BM 74
Springs
Spring
12
PIPELINE
7
W9
W10
95
80
70
Squaw
Creek
PIPE
ROAD
VAN
BUREN
LYNDEN
SUMAS
HIGHWAY
69
64
90
W18
AND
Creek
W46
13
18
17
LINE
65
ST PAUL
HIGHWAY
W48
BM 71
LINDSAY
ROAD

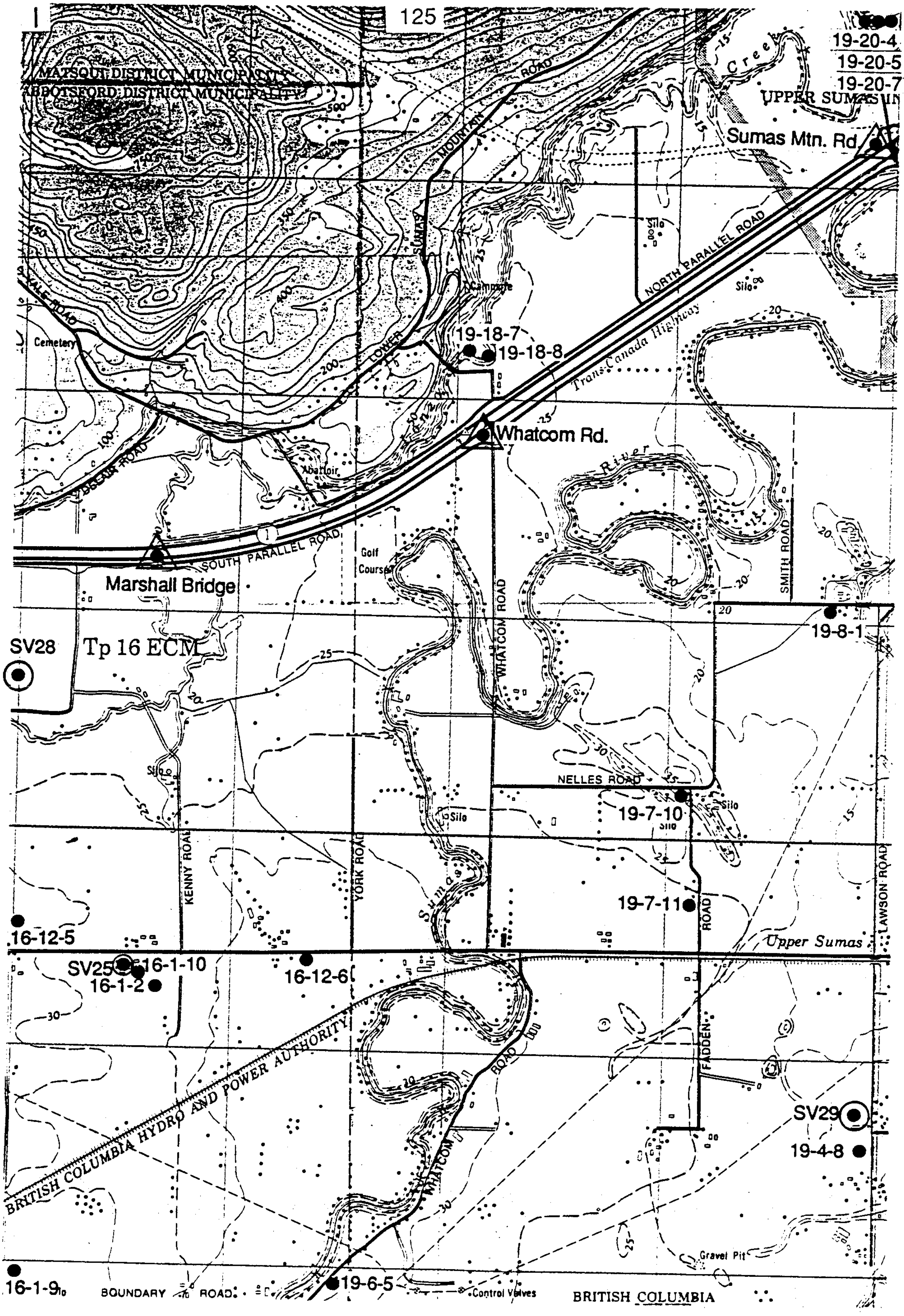


F
551
30
1 650 000 FEET
BRITISH COLUMBIA
122
WASHINGTON
30A
31
ABBOTSFORD B.C. 3.6 MI
Sumas
Res
Spring
PIPE LINE
17'30"
33
34
35
Cemetery
Johnson
Creek
ROAD
HILL
3
4
2
BM 42
W8
SV4
W7
W6
W5
SV14
EASTERBROOK ROAD
HOVEL ROAD
C M ST P & P
HIGHWAY
CLEARBROOK
SV23
W34
W14
W37
W36
W35
Bone
SUMAS
ROAD
W38
PIPELINE
9
10
11
W11
W39
LYNDEN
NORTHERN
TELEGRAPH
W12
Nooksack Valley
High Sch
W13
W40
SCHUETT ROAD
W41
W43
W17
W16
SUMAS
BURLINGTON
KADIN ROAD
16
15
14

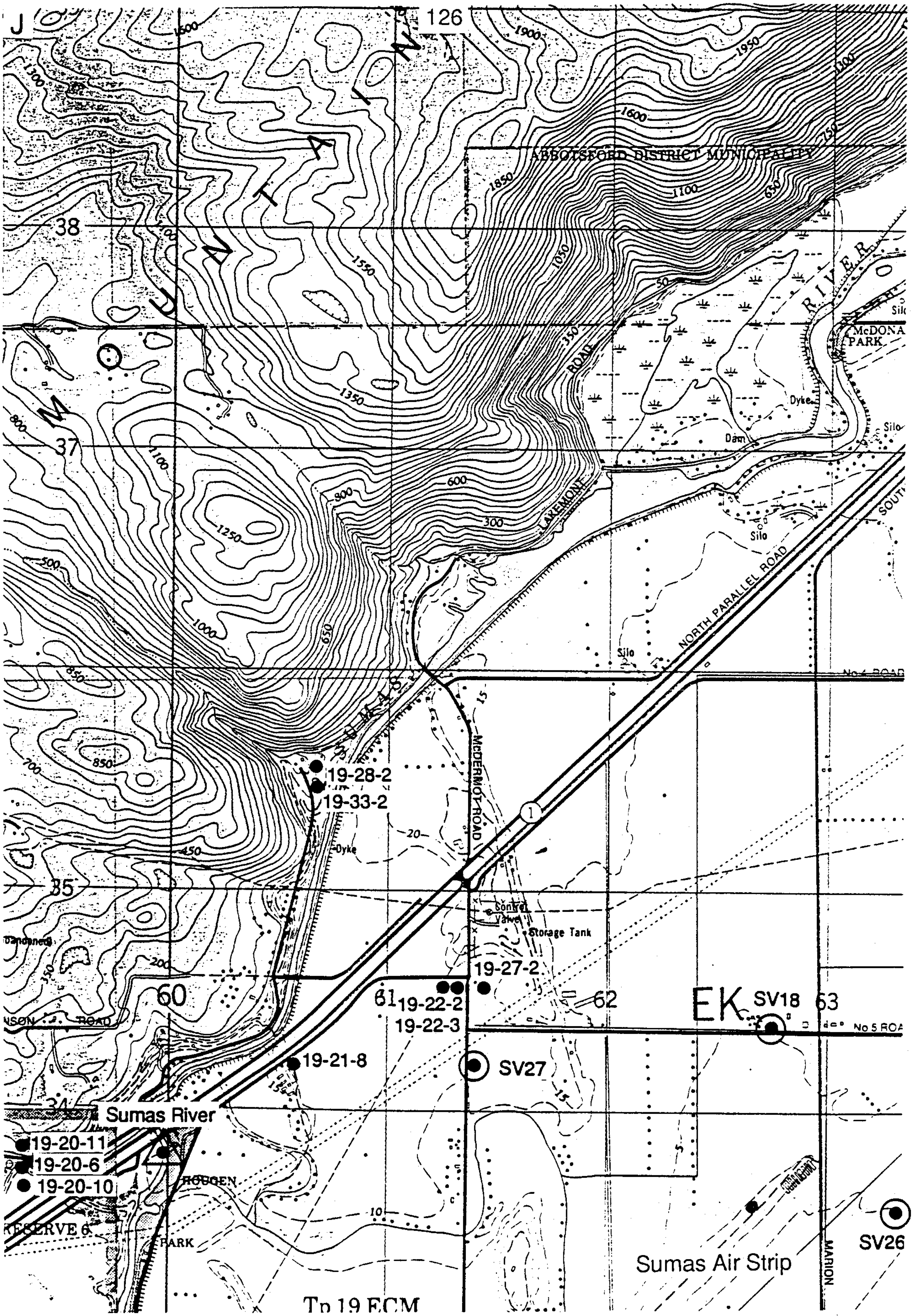


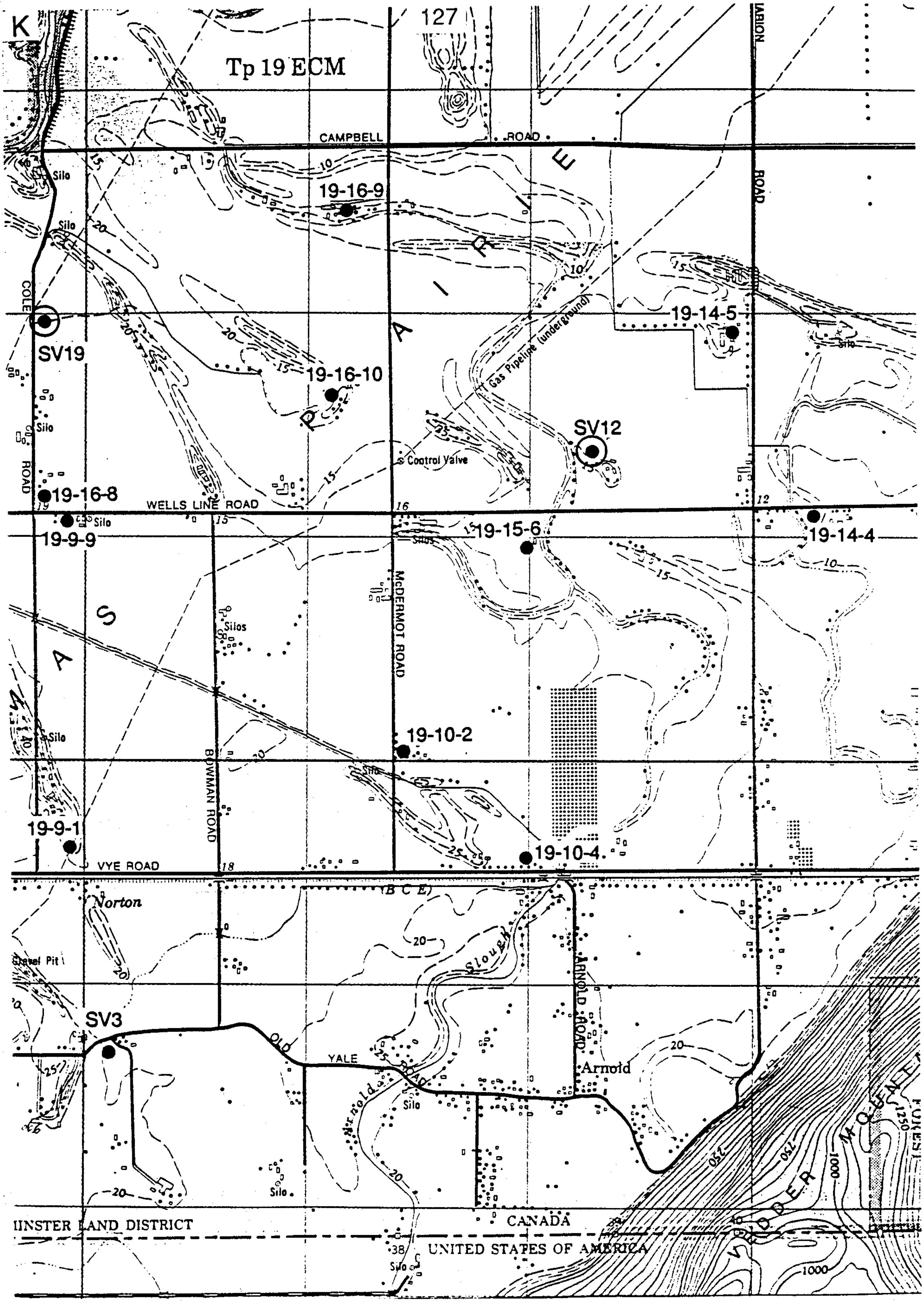
G
556
33 JONES
123
R4
R5
ROAD 12'30"
36
31
River
Creek
T 41 N
T 40 N
ROCK
36 ROAD
44
W4
PIPELINE
W2
1
6
PIPELINE
40
Saar
34
W3
W1
ROAD
HILLVIEW
47
39
36
40
BISHOP
ROAD
W15
40
687
200
600
800
Anderson Lake
600
Lone Tree Hill
JEEP TR
600
ROAD
PACIFIC
58
200
12
80
Reese Hill
MILWAUKEE
HILL AND
Saar
REESE
423
400
X776
KER RD
600
Haystack Hill
400
ST PAUL
200
948 X
Sugarloaf Hill
600
600
400
18
604
600
Spring
600
ROAD
600
592
800
800

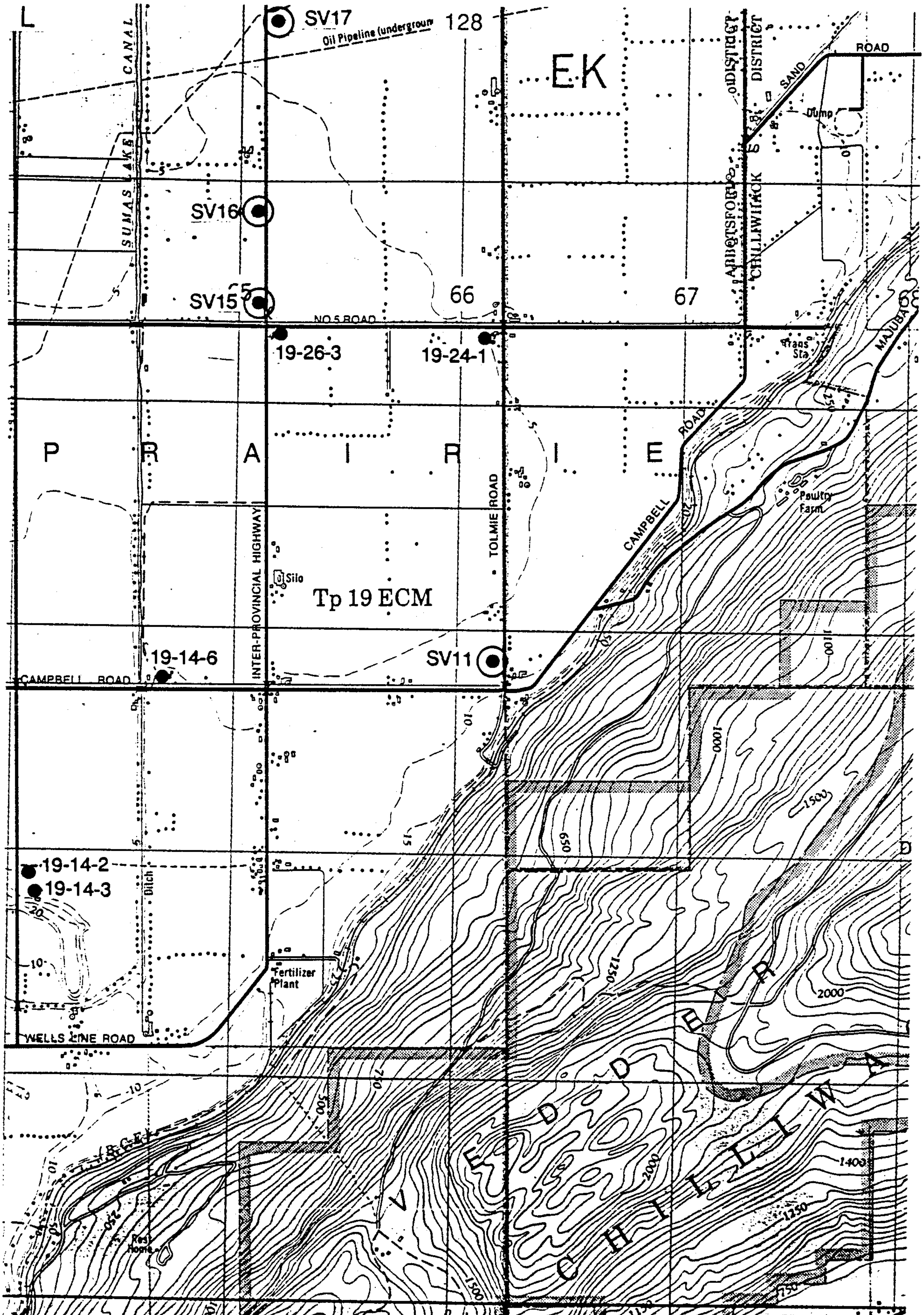

H
124
MATSQUI DIST MUN
ABBOTSFORD DIST MUN
Gravel Pit
McMILLAN ROAD
Water Tank
OLD YALE ROAD
SOUTH FRASER WAY
Abbotsford
Sports Track
Hospital
Park
Water Tank
BM 96
MARSHALL ROAD
Trailer Park
Park
52
53
Water Tank
Sumas Way Overpass
16-11-7
Huntingdon Flats
16-11-8
16-11-5
16-11-10
16-11-9
BM 32
Silo
Ditch
ROAD
Matsqui Penitentiary
Parking Area
McKENZIE
RIVERSIDE
Fish Hatchery
Auto Wrecker
Ditch
11
Regional Medical Centre
Gravel Pit
16-11-6
VYE ROAD
ROAD
ROAD
ROAD
Ditch
MATSQUI DISTRICT MUN
ABBOTSFORD DISTRICT MUN
SHORT STREET
FARMER ROAD
16-2-20
16-2-16
Silo
Ditch
16-2-17
Huntingdon
16-2-18
16-2-19
Silos
Radio Tower
Customs
CANADA
BRITISH COLUMBIA
UNITED STATES OF AMERICA
WASHINGTON
Sumas



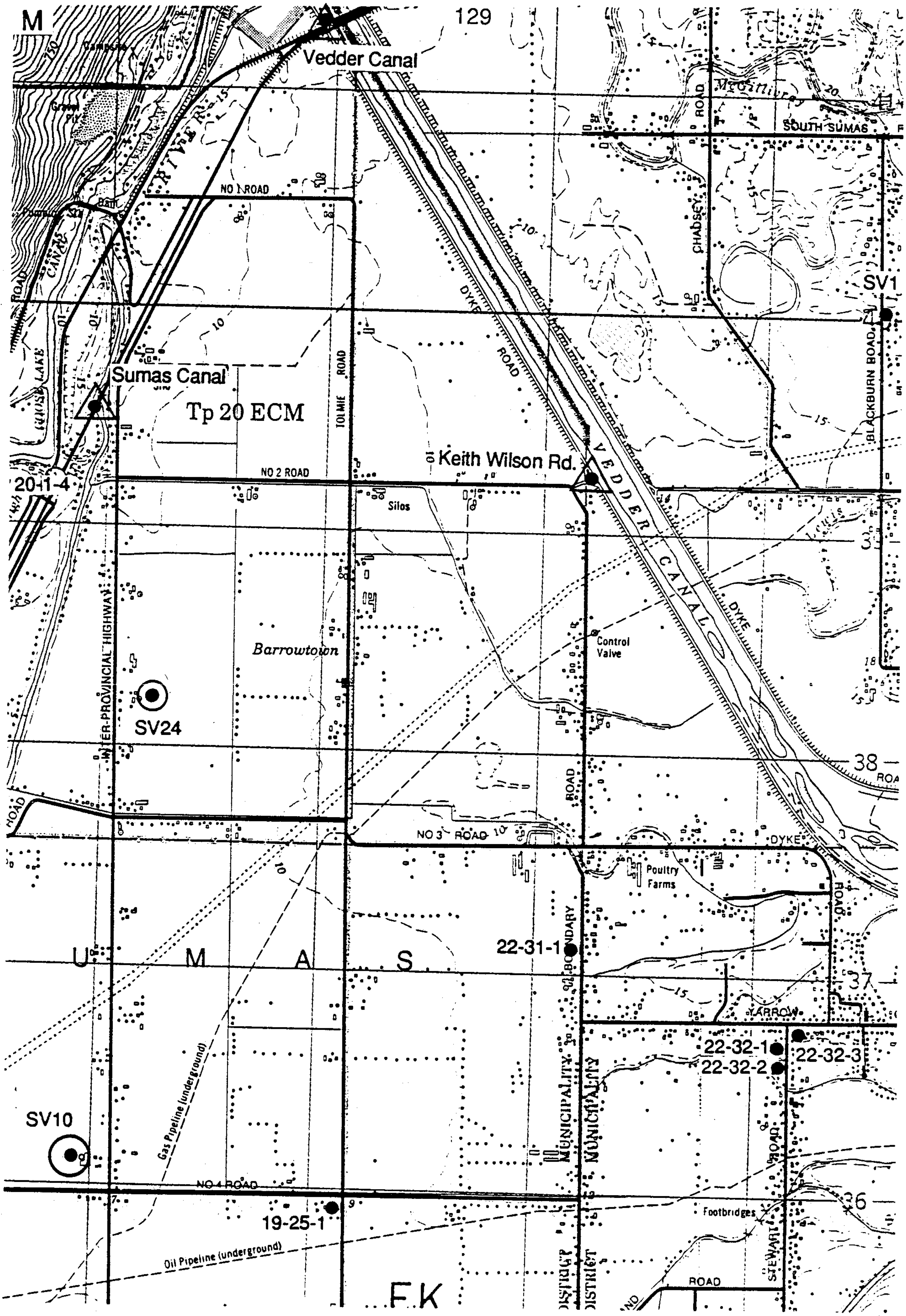
125
MATSQUI DISTRICT MUNICIPALITY
ABBOTSFORD DISTRICT MUNICIPALITY
19-20-4
19-20-5
19-20-7
UPPER SUMAS IN
Sumas Mtn. Rd.
Creek
MOUNTAIN ROAD
SUMAS
NORTH PARALLEL ROAD
Trans-Canada Highway
Silo
Campsite
Cemetery
LOWER
19-18-7
19-18-8
Whatcom Rd.
River
Abattoir
SOUTH PARALLEL ROAD
Golf Course
Marshall Bridge
SMITH ROAD
WHATCOM ROAD
19-8-1
SV28
Tp 16 ECM
NELLES ROAD
19-7-10
KENNY ROAD
YORK ROAD
Sumas
19-7-11
ROAD
LAWSON ROAD
Upper Sumas
16-12-5
SV25
16-1-10
16-1-2
16-12-6
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY
ROAD
FADDEN
WHATCOM
SV29
19-4-8
Gravel Pit
16-1-9
BOUNDARY ROAD
19-6-5
Control Valves
BRITISH COLUMBIA

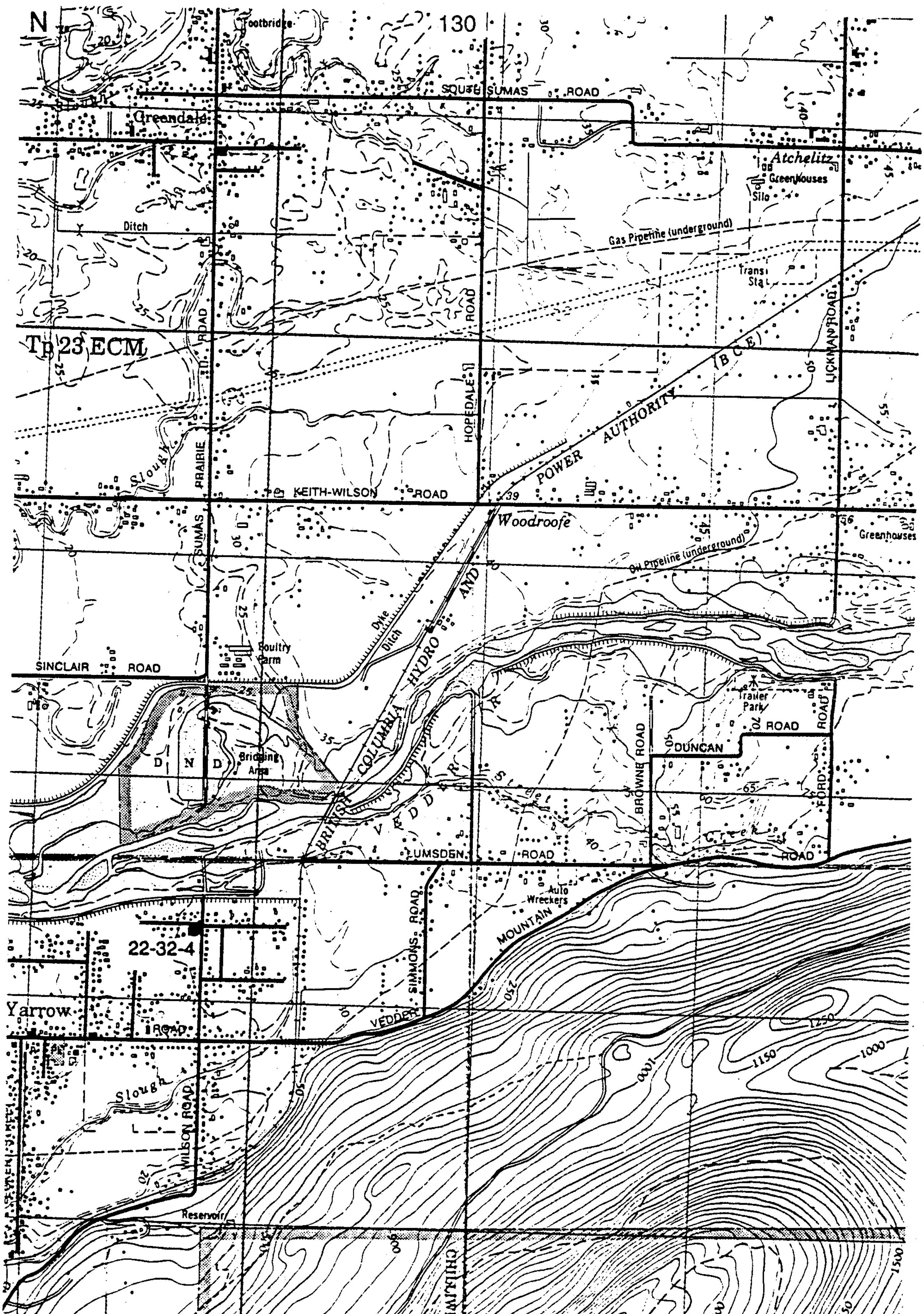

J
126
MOUNTAIN
ABBOTSFORD DISTRICT MUNICIPALITY
38
37
35
34
RIVER
McDONALD PARK
Dyke
Dam
Silo
LAKEMONT ROAD
NORTH PARALLEL ROAD
No 4 ROAD
SUMAS
McDERMOT ROAD
19-28-2
19-33-2
Dyke
Control Valve
Storage Tank
19-27-2
60
61
19-22-2
19-22-3
62
EK
SV18
63
No 5 ROAD
19-21-8
SV27
Sumas River
19-20-11
19-20-6
19-20-10
HOUGEN
PARK
RESERVE 6
Sumas Air Strip
MARION
SV26
Tp 19 ECM


K
127
Tp 19 ECM
CAMPBELL
ROAD
MARION
ROAD
Silo
19-16-9
COLE
ROAD
SV19
19-16-10
19-14-5
Gas Pipeline (underground)
SV12
Control Valve
19-16-8
WELLS LINE ROAD
19-9-9
19-15-6
19-14-4
McDERMOT ROAD
Silos
19-10-2
BOWMAN ROAD
19-9-1
VYE ROAD
19-10-4
(B C E)
Norton
Gravel Pit
Slough
ARNOLD ROAD
SV3
OLD
YALE
ROAD
Arnold
WESTMINSTER LAND DISTRICT
CANADA
UNITED STATES OF AMERICA
VEDDER MOUNTAIN
FOREST

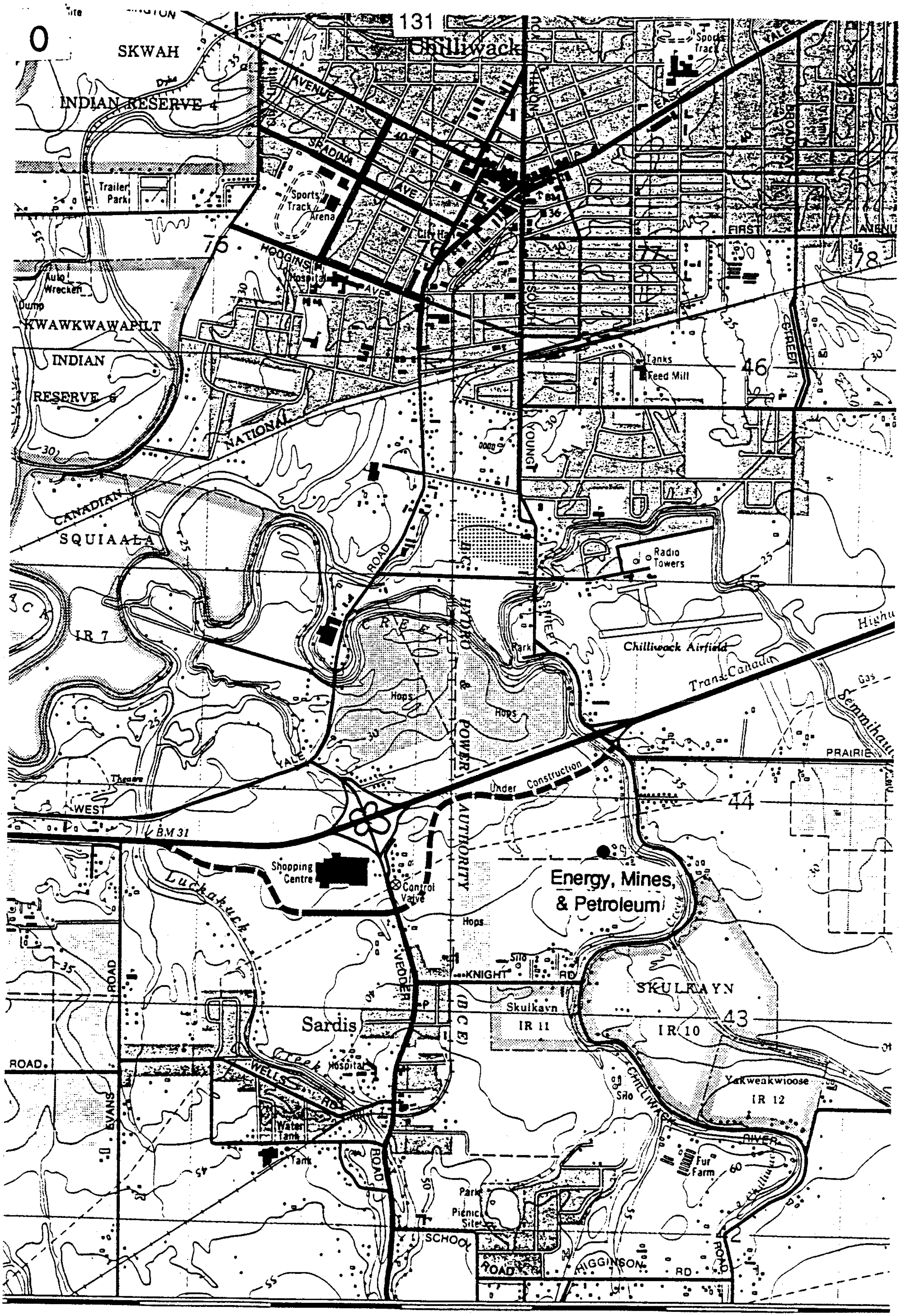


SV17
Oil Pipeline (underground
128
EK
SUMAS LAKE CANAL
ABBOTSFORD DISTRICT
CHILLIWACK DISTRICT
SAND ROAD
Dump
SV16
SV15
66
67
NO 5 ROAD
Trans Sta
19-26-3
19-24-1
P R A I R I E
CAMPBELL ROAD
Poultry Farm
INTER-PROVINCIAL HIGHWAY
TOLMIE ROAD
Silo
Tp 19 ECM
19-14-6
SV11
CAMPBELL ROAD
19-14-2
19-14-3
Ditch
Fertilizer Plant
WELLS LINE ROAD
Rest Home
V E D D E R
C H I L L I W A
1000
1500
2000
1250
1400


M
129
Vedder Canal
NO 1 ROAD
SOUTH SUMAS
CHADSEY ROAD
SV1
BLACKBURN ROAD
DYKE ROAD
Sumas Canal
Tp 20 ECM
TOLMIE ROAD
Keith Wilson Rd.
NO 2 ROAD
20-1-4
Silos
VEDDER CANAL
INTER-PROVINCIAL HIGHWAY
Control Valve
Barrowtown
SV24
38
ROAD
NO 3 ROAD
DYKE
Poultry Farms
22-31-1
BOUNDARY
U M A S
37
YARROW
22-32-1
22-32-2
22-32-3
MUNICIPALITY
Gas Pipeline (underground)
SV10
NO 4 ROAD
19-25-1
36
Footbridges
STEWART ROAD
Oil Pipeline (underground)
DISTRICT
ROAD



N
130
Footbridge
SOUTH SUMAS ROAD
Greendale
Atchelitz
Greenhouses
Silo
Ditch
Gas Pipeline (underground)
Transf Sta
Tp 23 ECM
PRAIRIE ROAD
HOPEDALE ROAD
LICKMAN ROAD
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY (BCE)
Slough
KEITH-WILSON ROAD
Woodroofe
Greenhouses
SUMAS
Oil Pipeline (underground)
Dyke
Ditch
Poultry Farm
SINCLAIR ROAD
D N D
Bridging Area
VEDDER
Creek
Trailer Park
ROAD
DUNCAN
BROWNE ROAD
FORD ROAD
LUMSDEN ROAD
ROAD
Auto Wreckers
MOUNTAIN
SIMMONS ROAD
22-32-4
Yarrow
ROAD
VEDDER
WILSON ROAD
Slough
Reservoir
CHILLIWACK
1250
1150
1000
1500
1650
2400



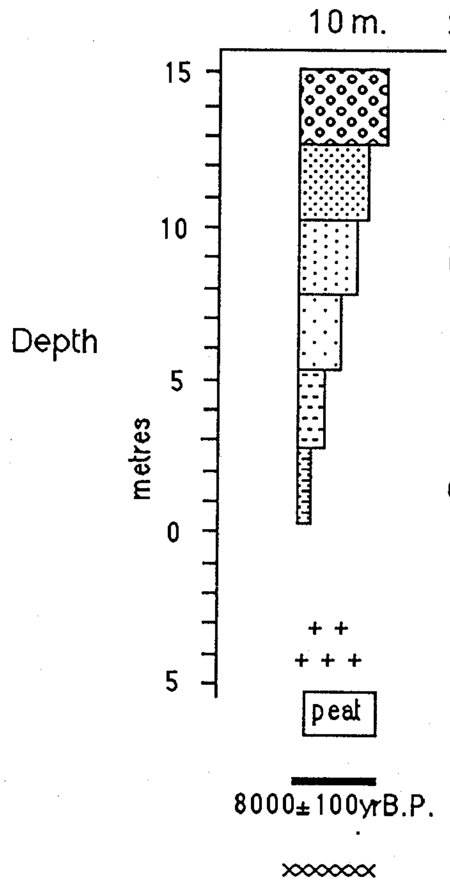
0
131
Chilliwack
SKWAH
INDIAN RESERVE 4
Trailer Park
Sports Track
Arena
City Hall
Hospital
AVENUE
SPADINA AVE
HODGINS AVE
Auto Wrecker
Dump
KWAWKWAWAPILT
INDIAN
RESERVE 6
NATIONAL
CANADIAN
SQUIAALA
IR 7
Sports Track
VALE
BROADWAY
FIRST AVENUE
YOUNG
SOUTH
STREET
Tanks
Feed Mill
46
Radio Towers
Chilliwack Airfield
Trans Canada
Highway
Gas
Semmihault
PRAIRIE
ROAD
Hops
Hops
B.C. HYDRO & POWER AUTHORITY
(B C E)
Under Construction
44
WEST
BM 31
Theatre
Shopping Centre
Control Valve
Energy, Mines, & Petroleum
Luckakuck Creek
Hops
Silo
KNIGHT RD
SKULKAYN
Skulkayn IR 11
IR 10
43
VEDDER
Sardis
Hospital
WELLS RD
ROAD
EVANS
Water Tank
Tank
ROAD
Yakweakwioose IR 12
Silo
CHILLIWACK RIVER
Fur Farm
Park
Picnic Site
SCHOOL ROAD
HIGGINSON RD
ROAD
75
76
77
78

APPENDIX B

Core Descriptions

APPENDIX B

KEY TO CORE DESCRIPTIONS



Surface Elevation

Gravel

Coarse Sand

Medium Sand

Fine Sand

Silt

Clay

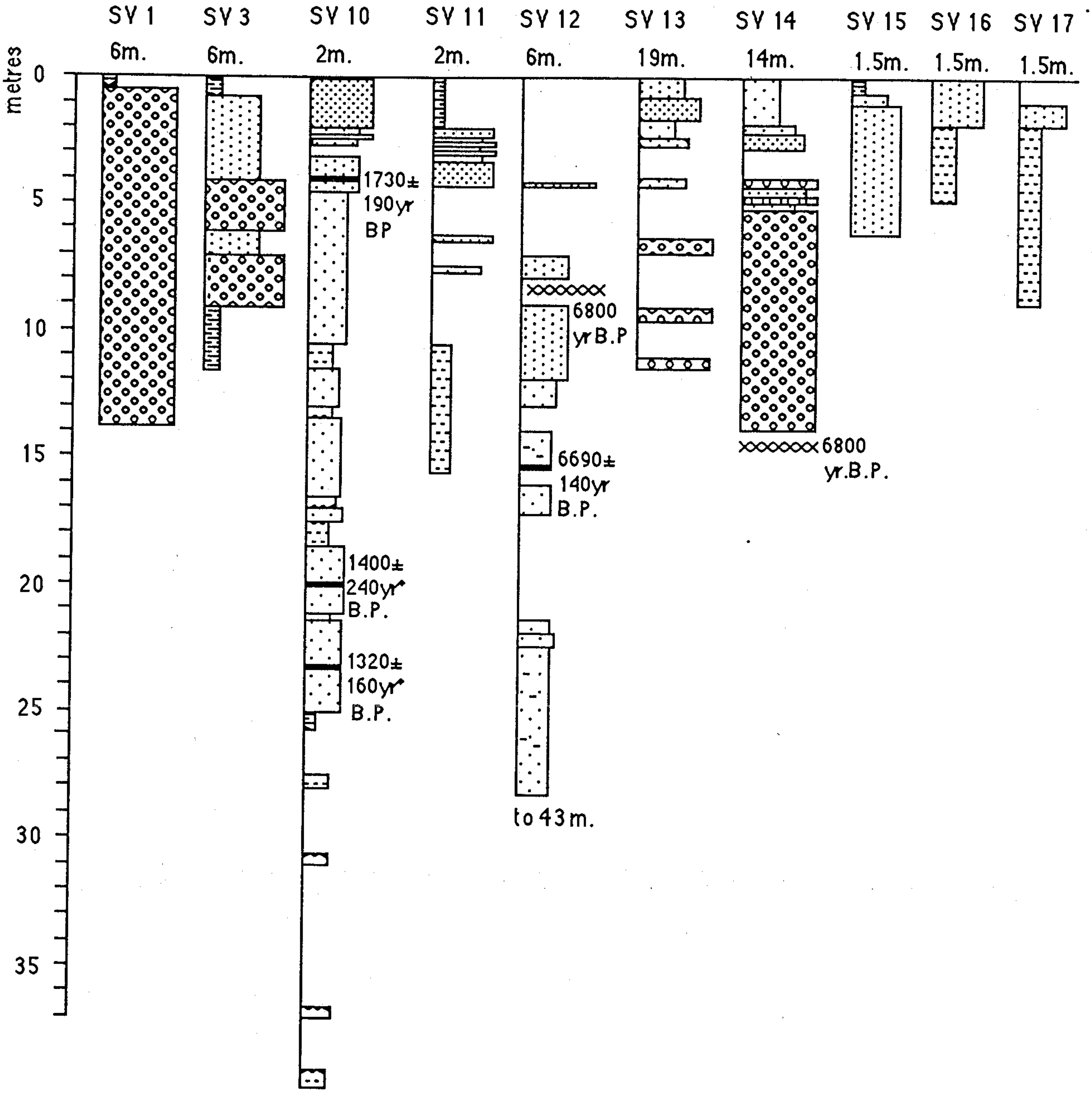
Bedrock

Peat

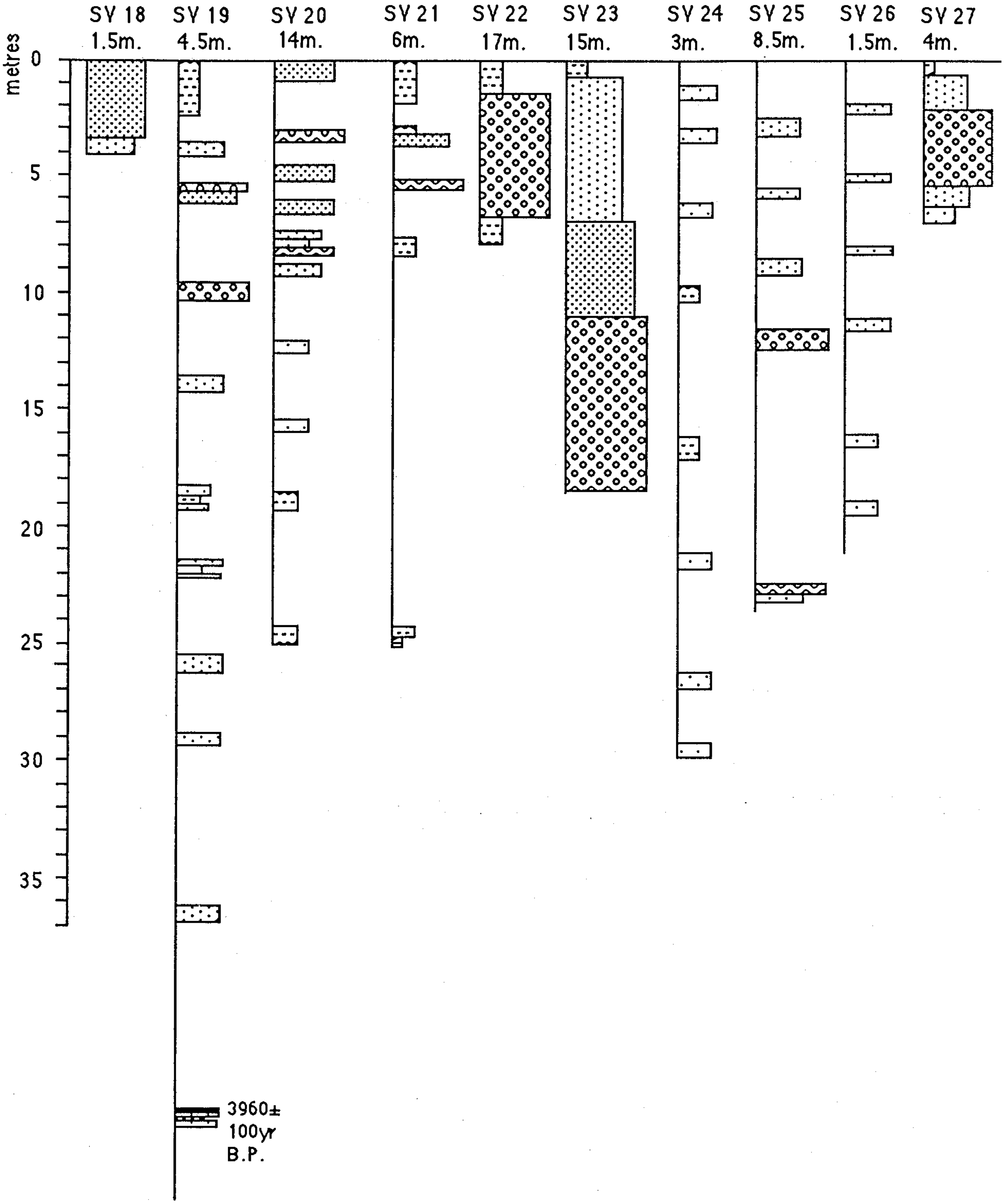
Dated Organic Matter

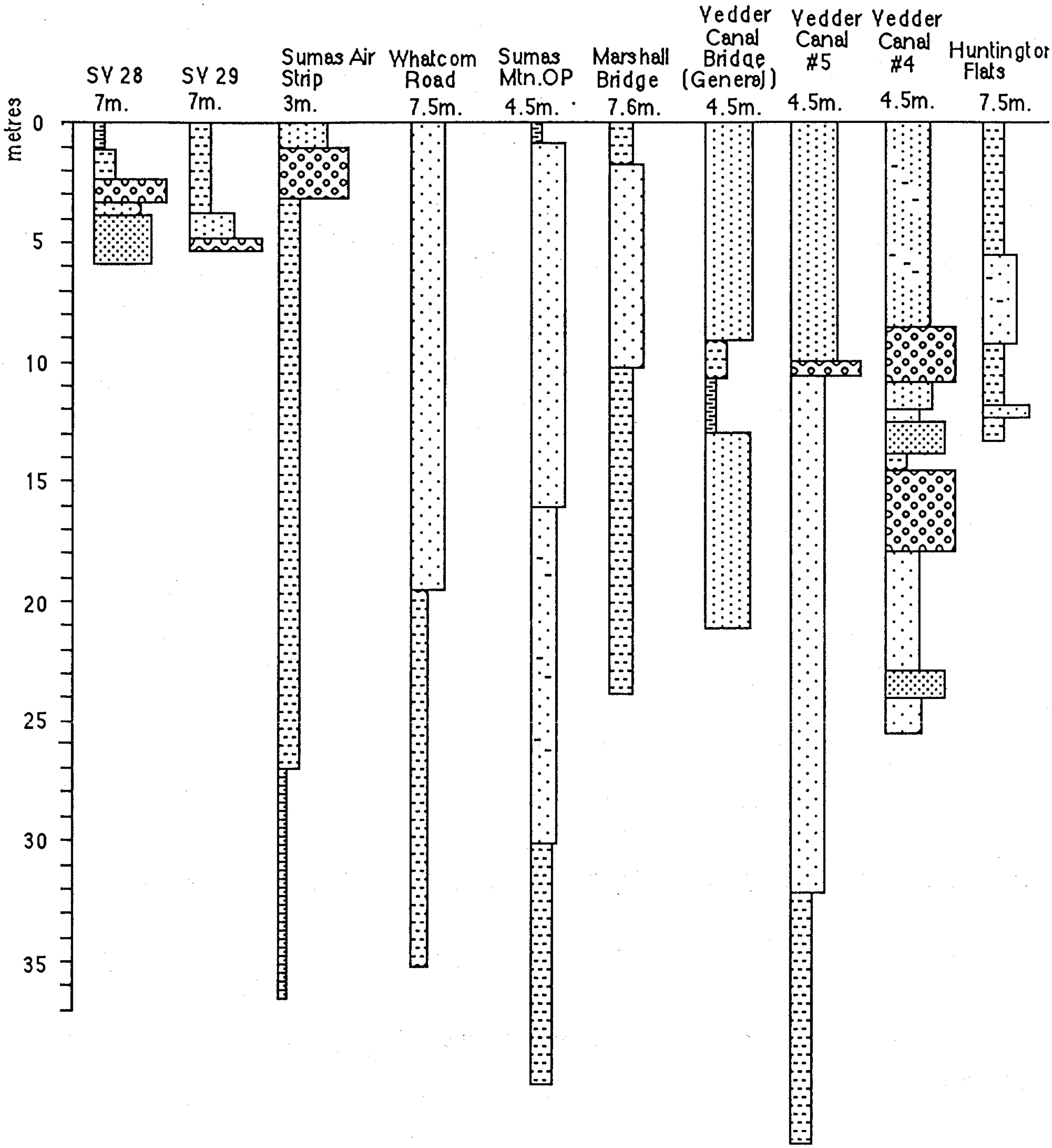
Tephra

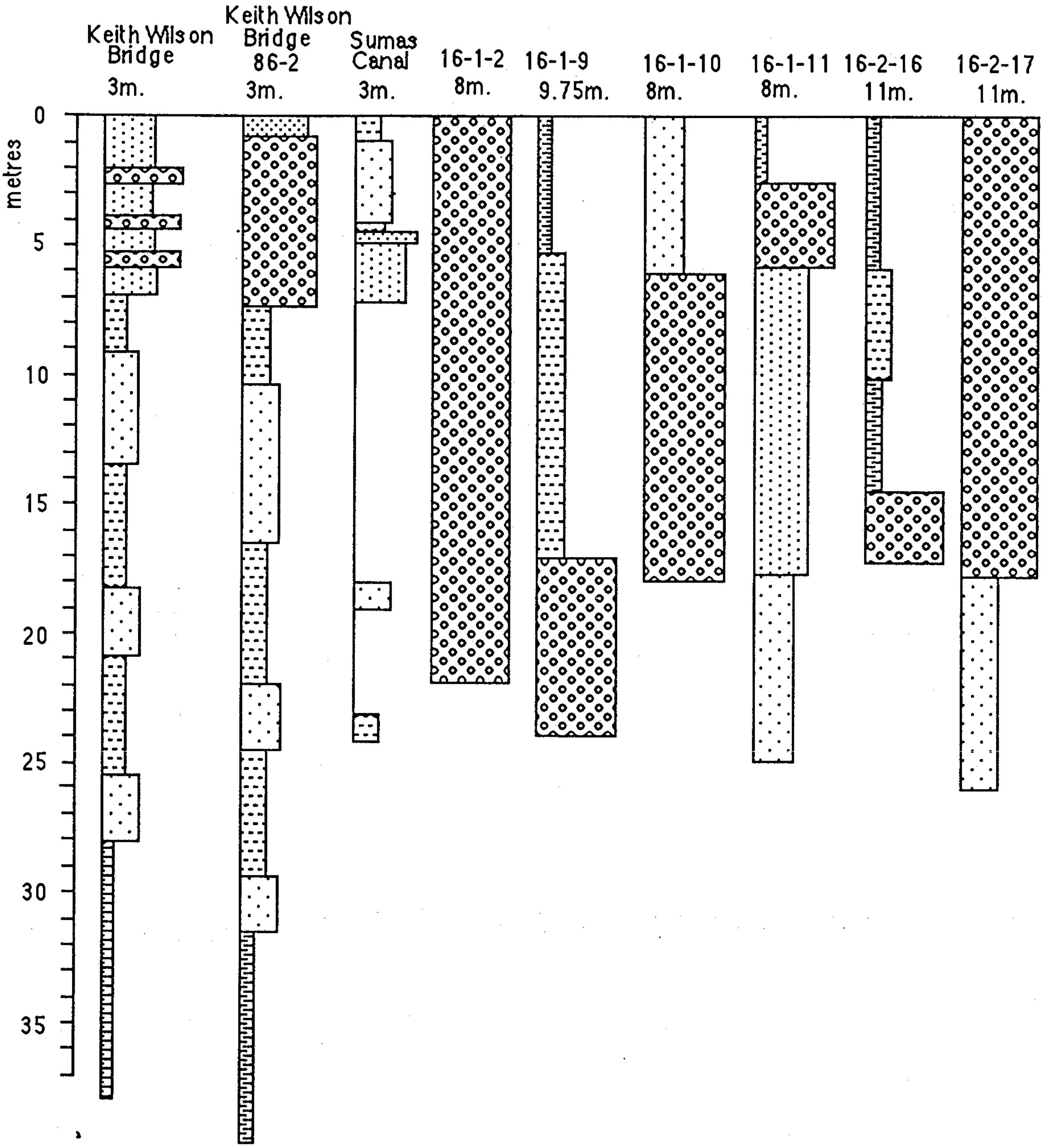
SV 19	Study Drill hole
Whatcom Rd.	Highways Test Hole
16-11-7	B.C. Water Well
W41	Washington Water Well

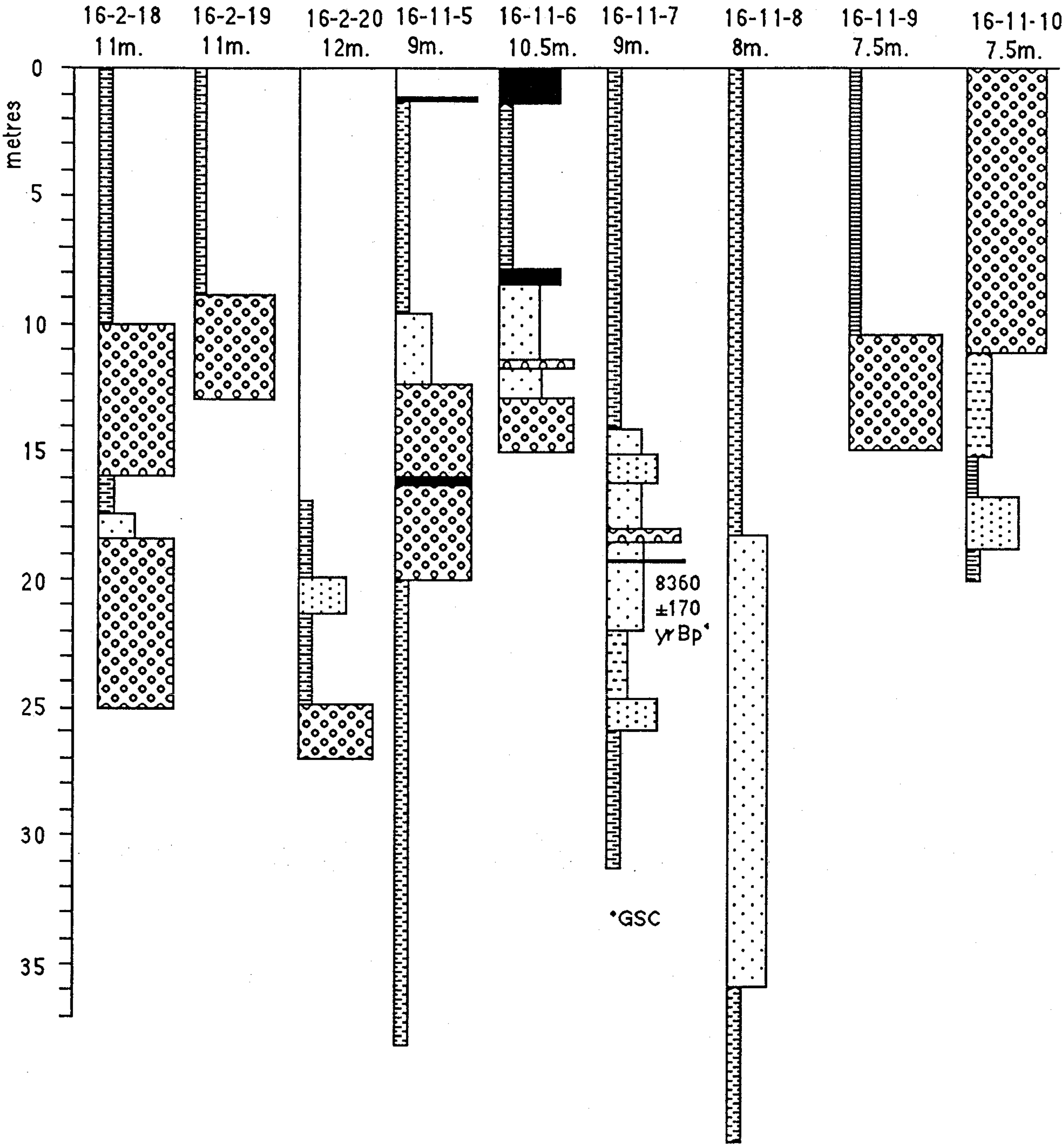

SV 1
6m.
SV 3
6m.
SV 10
2m.
SV 11
2m.
SV 12
6m.
SV 13
19m.
SV 14
14m.
SV 15
1.5m.
SV 16
1.5m.
SV 17
1.5m.
metres
0
5
10
15
20
25
30
35
1730± 190yr BP
1400± 240yr* B.P.
1320± 160yr* B.P.
6800 yr B.P
6690± 140yr B.P.
to 43 m.
6800 yr.B.P.

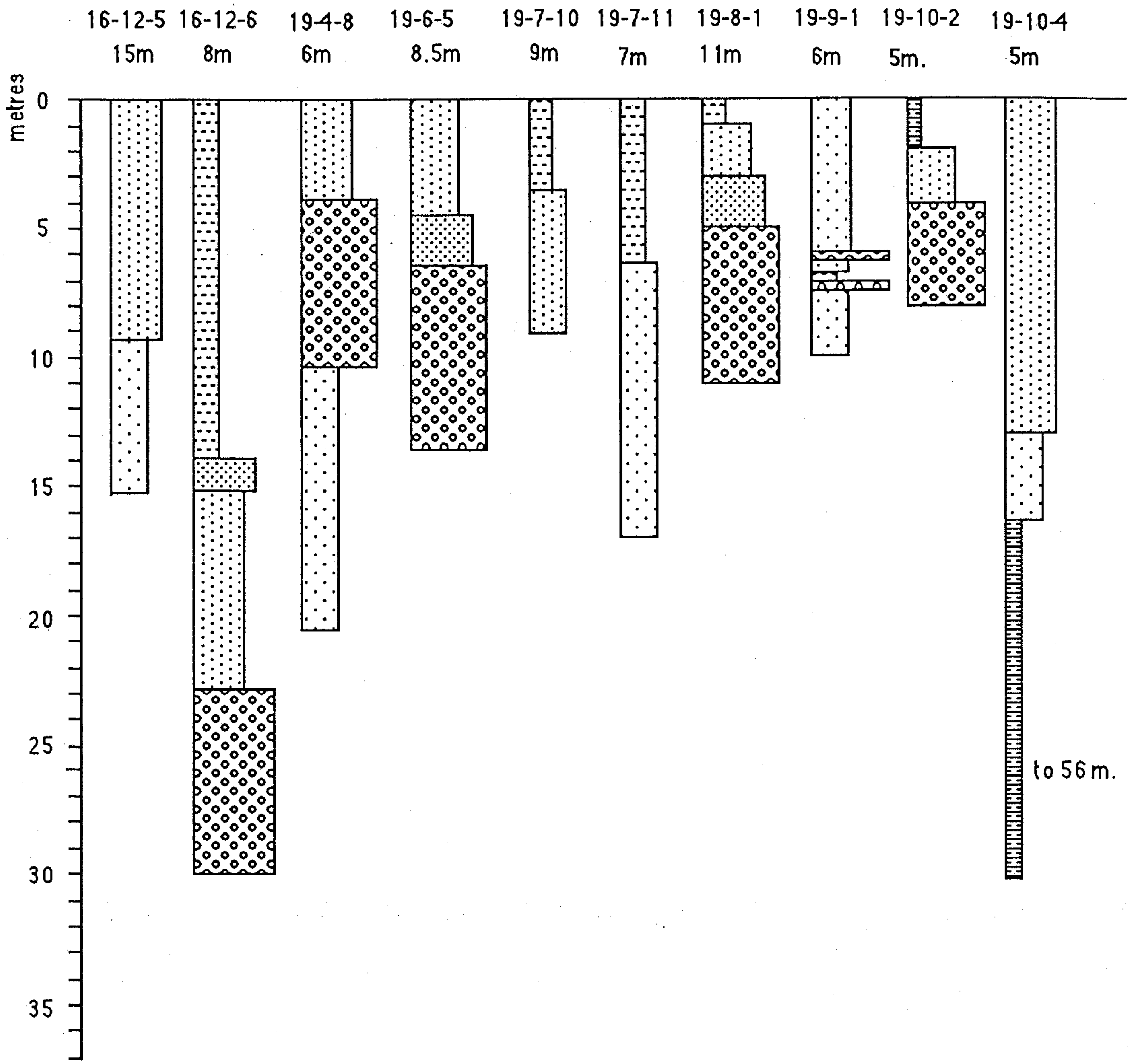
*M.C.Roberts

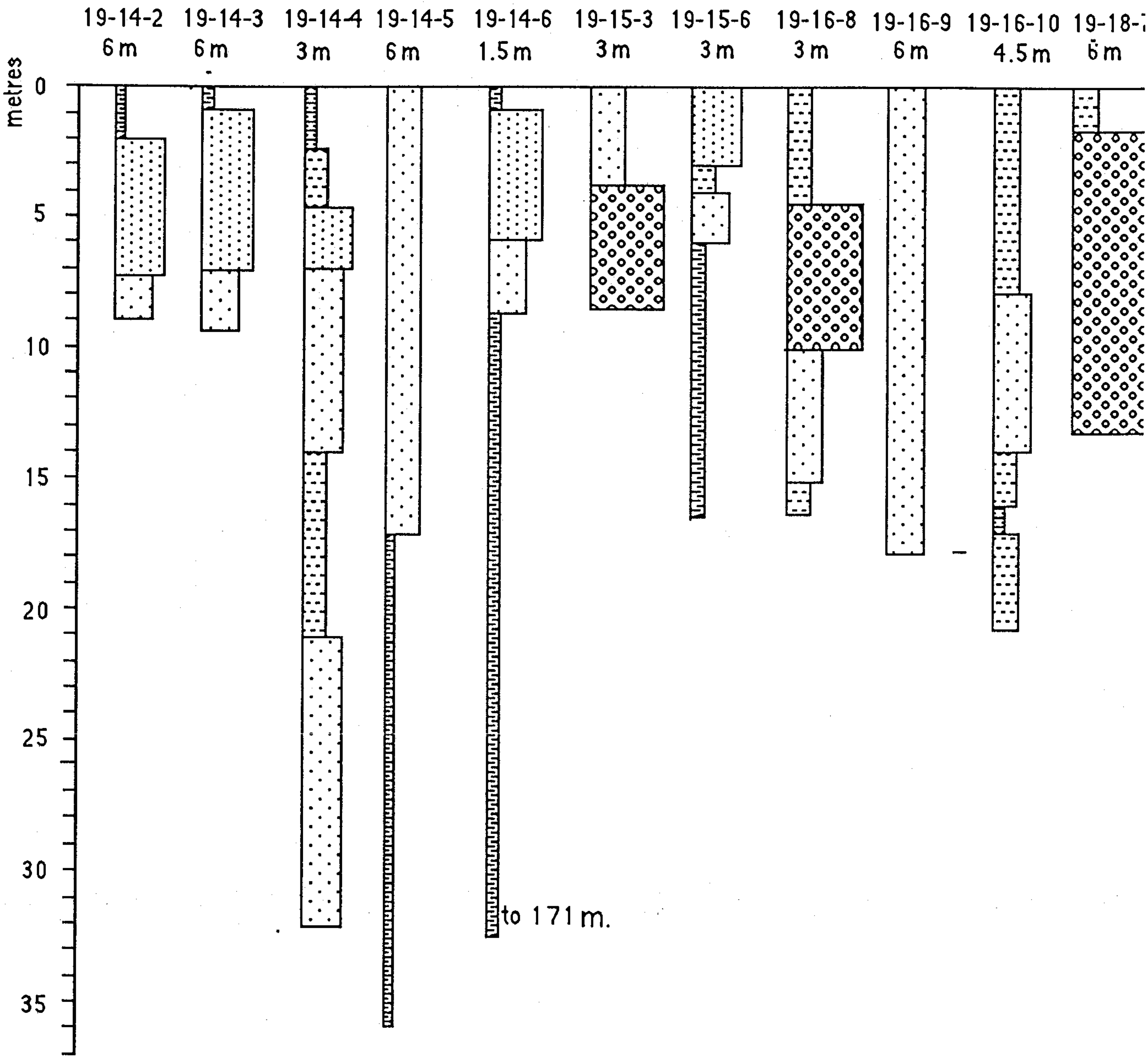

SV 18
1.5m.
SV 19
4.5m.
SV 20
14m.
SV 21
6m.
SV 22
17m.
SV 23
15m.
SV 24
3m.
SV 25
8.5m.
SV 26
1.5m.
SV 27
4m.
metres
0
5
10
15
20
25
30
35
3960±
100yr
B.P.

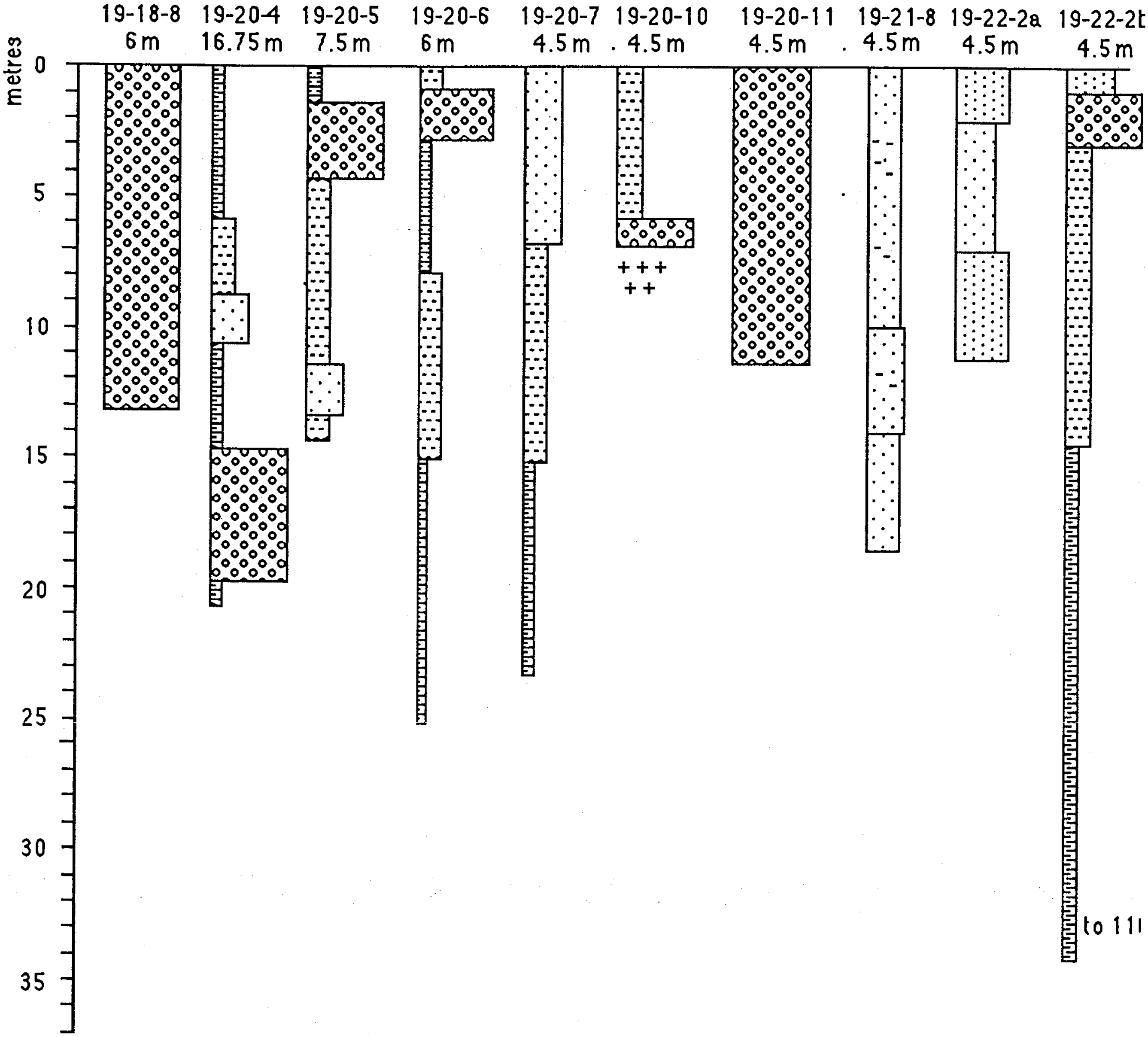

SV 28
7m.
SV 29
7m.
Sumas Air Strip
3m.
Whatcom Road
7.5m.
Sumas Mtn.OP
4.5m.
Marshall Bridge
7.6m.
Vedder Canal Bridge (General)
4.5m.
Vedder Canal #5
4.5m.
Vedder Canal #4
4.5m.
Huntington Flats
7.5m.
metres
0
5
10
15
20
25
30
35

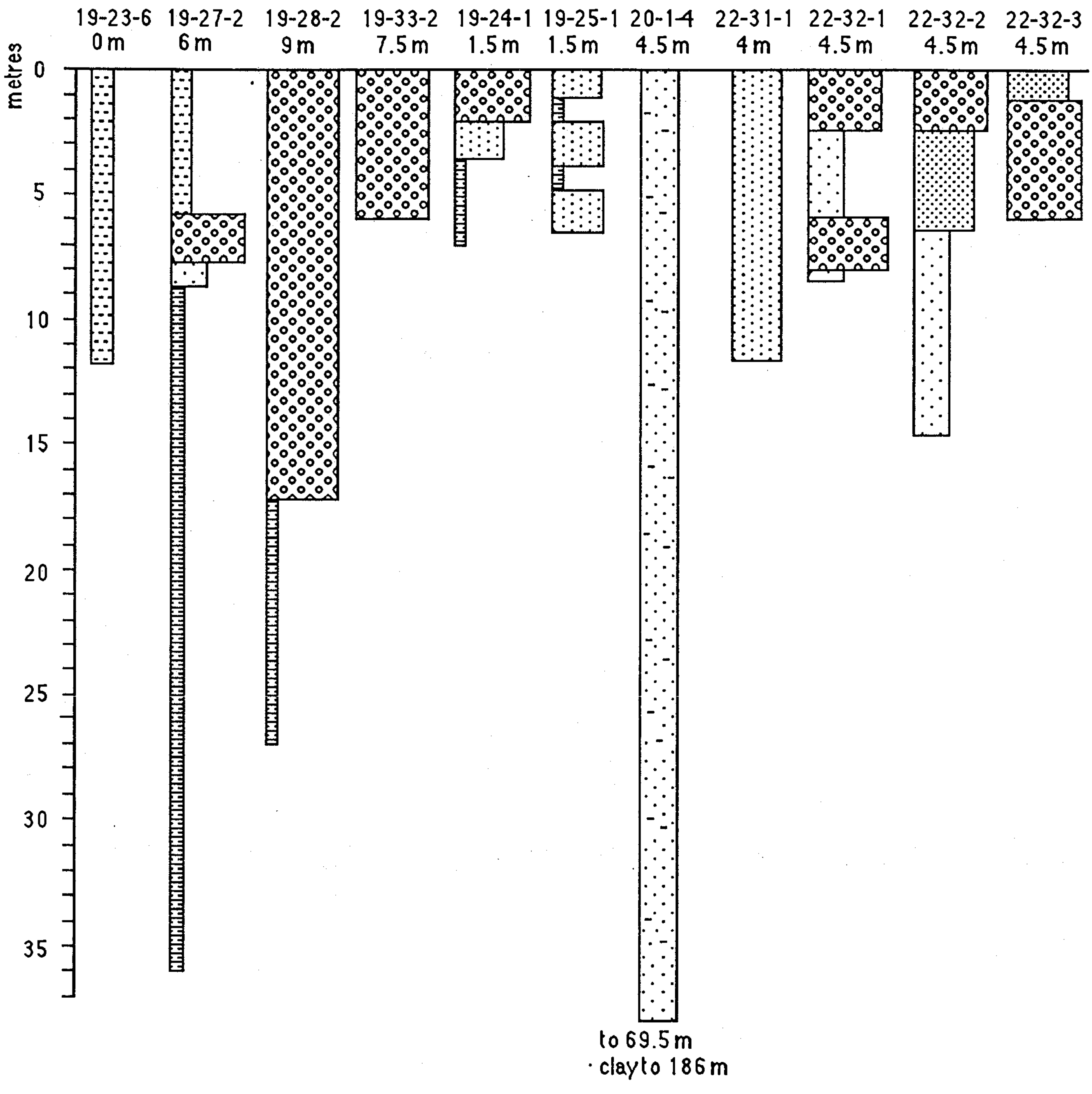

Keith Wilson Bridge
3m.
Keith Wilson Bridge
86-2
3m.
Sumas Canal
3m.
16-1-2
8m.
16-1-9
9.75m.
16-1-10
8m.
16-1-11
8m.
16-2-16
11m.
16-2-17
11m.
metres
0
5
10
15
20
25
30
35

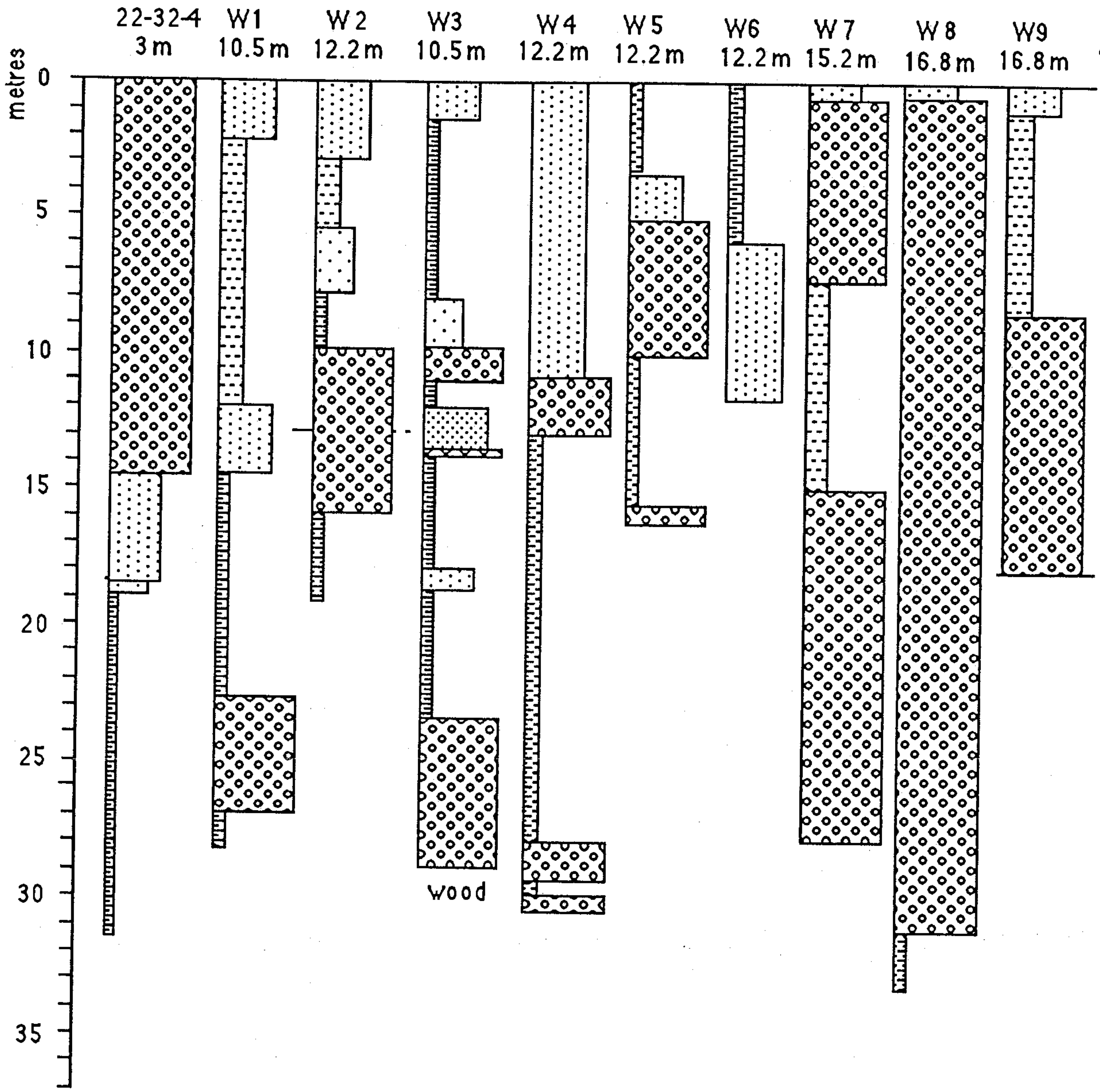

16-2-18
11m.
16-2-19
11m.
16-2-20
12m.
16-11-5
9m.
16-11-6
10.5m.
16-11-7
9m.
16-11-8
8m.
16-11-9
7.5m.
16-11-10
7.5m.
metres
0
5
10
15
20
25
30
35
8360
±170
yrBp*
*GSC

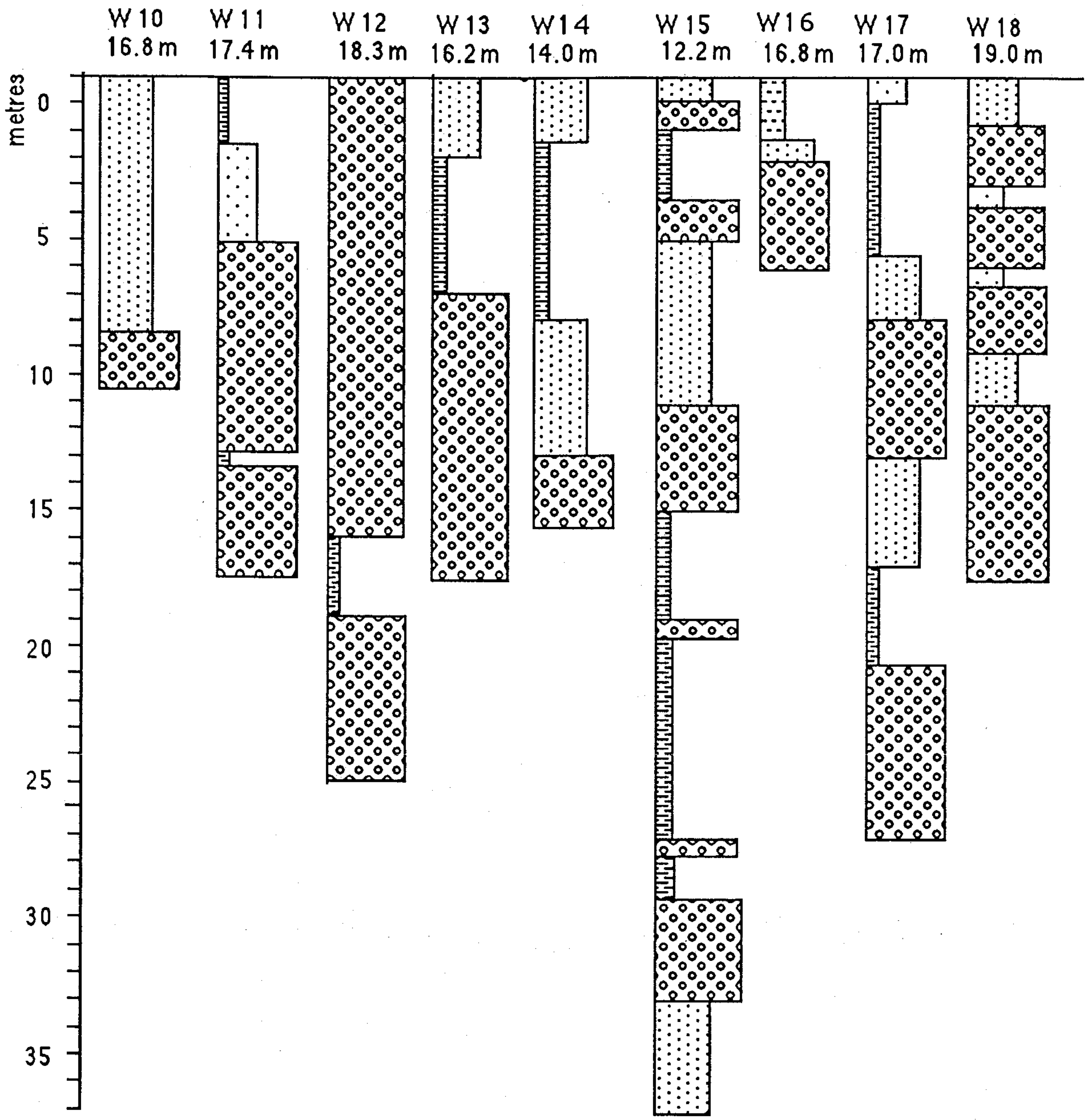

16-12-5
15m
16-12-6
8m
19-4-8
6m
19-6-5
8.5m
19-7-10
9m
19-7-11
7m
19-8-1
11m
19-9-1
6m
19-10-2
5m.
19-10-4
5m
metres
0
5
10
15
20
25
30
35
to 56m.

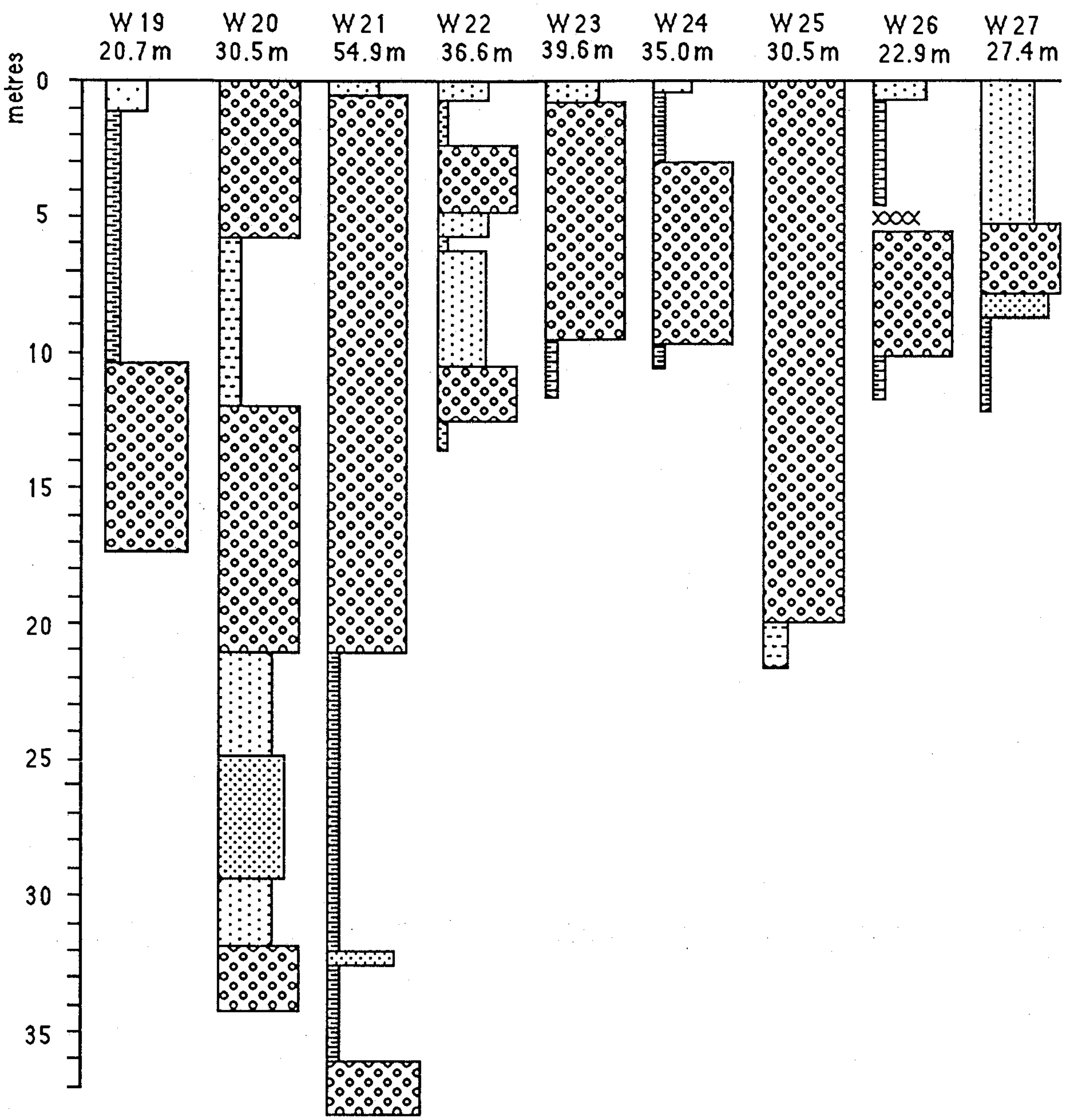

19-14-2
6m
19-14-3
6m
19-14-4
3m
19-14-5
6m
19-14-6
1.5m
19-15-3
3m
19-15-6
3m
19-16-8
3m
19-16-9
6m
19-16-10
4.5m
6m
metres
0
5
10
15
20
25
30
35
to 171 m.

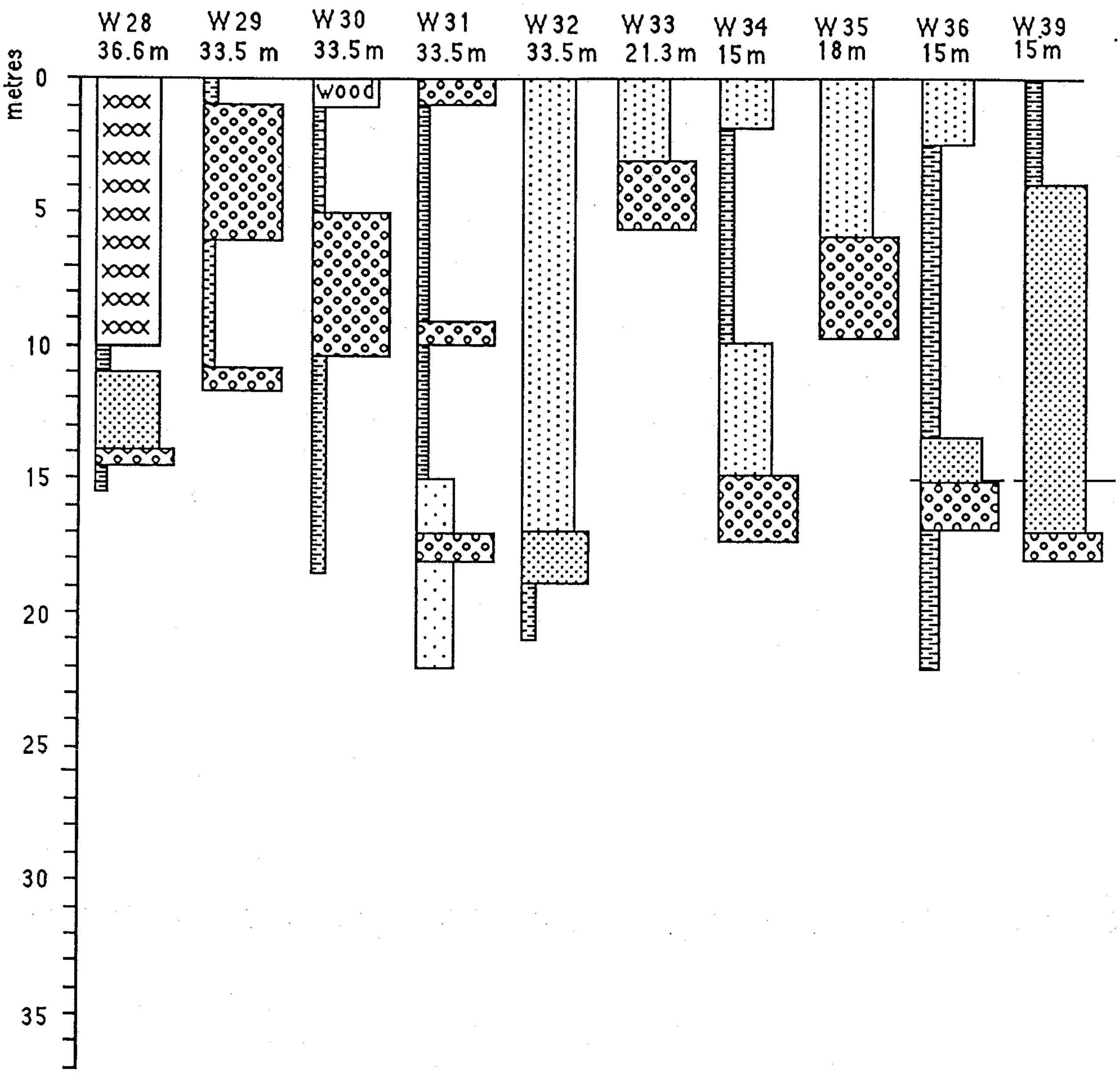

19-18-8
6 m
19-20-4
16.75 m
19-20-5
7.5 m
19-20-6
6 m
19-20-7
4.5 m
19-20-10
4.5 m
19-20-11
4.5 m
19-21-8
4.5 m
19-22-2a
4.5 m
19-22-2t
4.5 m
metres
0
5
10
15
20
25
30
35
to 111

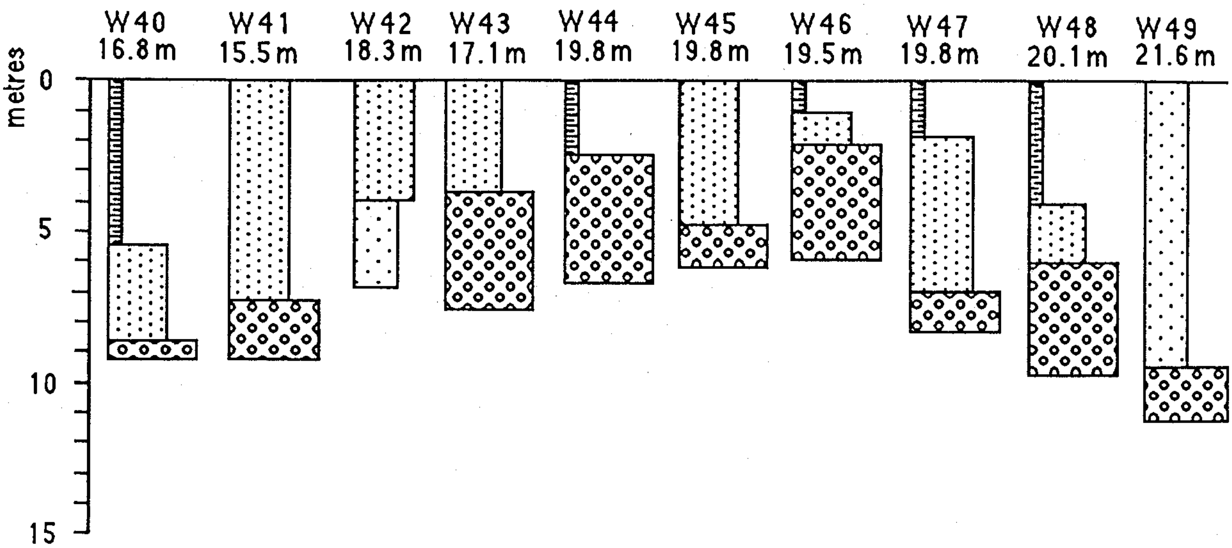

19-23-6
0m
19-27-2
6m
19-28-2
9m
19-33-2
7.5m
19-24-1
1.5m
19-25-1
1.5m
20-1-4
4.5m
22-31-1
4m
22-32-1
4.5m
22-32-2
4.5m
22-32-3
4.5m
metres
0
5
10
15
20
25
30
35
to 69.5m
clay to 186m

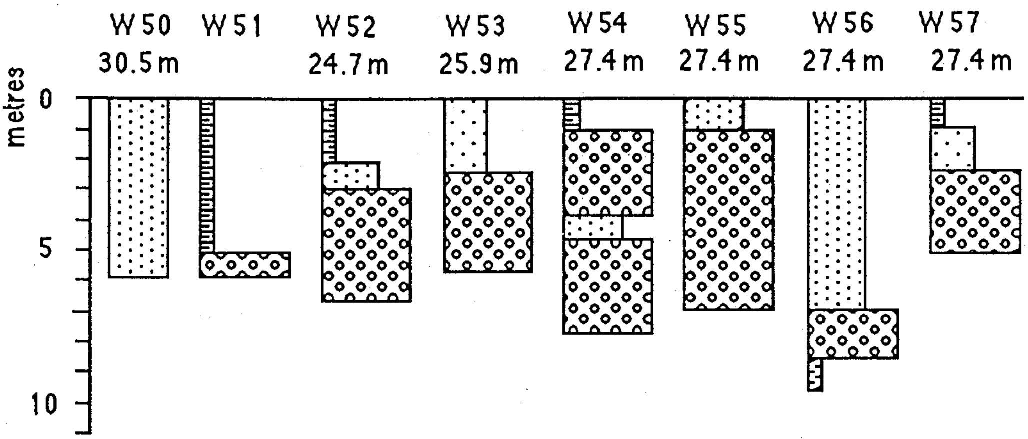

22-32-4
3m
W1
10.5m
W2
12.2m
W3
10.5m
W4
12.2m
W5
12.2m
W6
12.2m
W7
15.2m
W8
16.8m
W9
16.8m
metres
0
5
10
15
20
25
30
35
wood


W 10
16.8 m
W 11
17.4 m
W 12
18.3 m
W 13
16.2 m
W 14
14.0 m
W 15
12.2 m
W 16
16.8 m
W 17
17.0 m
W 18
19.0 m
metres
0
5
10
15
20
25
30
35


W 19
20.7 m
W 20
30.5 m
W 21
54.9 m
W 22
36.6 m
W 23
39.6 m
W 24
35.0 m
W 25
30.5 m
W 26
22.9 m
W 27
27.4 m
metres
0
5
10
15
20
25
30
35


W 28
36.6 m
W 29
33.5 m
W 30
33.5 m
W 31
33.5 m
W 32
33.5 m
W 33
21.3 m
W 34
15 m
W 35
18 m
W 36
15 m
W 39
15 m
metres
0
5
10
15
20
25
30
35
wood


W40
16.8m
W41
15.5m
W42
18.3m
W43
17.1m
W44
19.8m
W45
19.8m
W46
19.5m
W47
19.8m
W48
20.1m
W49
21.6m
metres
0
5
10
15


W50
30.5m
W51
W52
24.7m
W53
25.9m
W54
27.4m
W55
27.4m
W56
27.4m
W57
27.4m
metres
0
5
10

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