BASIN ARCHITECTURE OF THE NORTH OKANAGAN VALLEY FILL, BRITISH COLUMBIA

by

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ABSTRACT

The North Okanagan Valley occupies an elongate basin (~45 km long by ~3 km wide) situated in the Cordilleran physiographic region of the southern Interior of British Columbia. Depth to bedrock in the North Okanagan Basin is at least 680 m below the valley floor and 2200 m below the surrounding Thompson Plateau and Shuswap Highlands. The volume of sediment stored within the basin is estimated to be about 49 km^3 and the study findings suggest that the basin fill was mainly deposited after ~19 ka during late Wisconsin glaciation and deglaciation. Analysis of 16 km of high resolution reflection seismic profiles and 30 lithologic logs was carried out to delineate and interpret the basin architecture of the valley fill and provide an interpretive framework for basin architectures of other glaciated Cordilleran valleys. The main objective of this study was to establish the three-dimensional basin architecture of the North Okanagan Valley.

The seismic and lithologic data were integrated using a depositional systems approach which revealed four distinct depositional systems that characterize the basin architecture: the Fluvio-Glacial, Glaciolacustrine, Alluvial Fan, and Fluvial Systems. The clastic fill of the basin shows an overall fining upward trend from basal, coarse-grained, stratified and poorly stratified sand and gravel of the Fluvio-Glacial System to the Glaciolacustrine System. The Glaciolacustrine System is exposed at the surface and fines upward from glaciolacustrine fine sand to silt and clay. The Alluvial Fan System interfingers the Fluvio-Glacial and Glaciolacustrine Systems and plays an important role in the overall geometry of the basin architecture. Channel sand and silt of the Fluvial System are incised into the upper part of the Glaciolacustrine System.

From this data a three-dimensional model is proposed for the North Okanagan Basin that defines the architecture of the basin fill and highlights the geomorphic environment during deglaciation. The model illustrates that during ice advance and retreat thick sequences of coarse-grained, stratified sediments were deposited adjacent to the glacial ice. Blockage of the Okanagan Valley and formation of Glacial Lake Penticton resulted in thick accumulations of glaciolacustrine silt and clay in a setting which was relatively free of stagnant ice complexes. During, and soon after deglaciation, alluvial fans were deposited into the basin by mass movement processes that redistributed unstable glacigenic sediments. On the valley floor, the Shuswap River is incised into the glaciolacustrine sediments and is representative of contemporary geomorphic processes.

DEDICATION

This work is dedicated to my nieces, Kelsy and Kayla,
for the happiness you bring to me.

ACKNOWLEDGMENTS

I would like to thank my senior supervisor, Dr. Michael C. Roberts, for his guidance, friendship, and criticism; I have benefited from the practical experience you passed along to me 'in the field' and will not forget the soggy summer of '91. Drs. Edward (Ted) J. Hickin and Dirk Tempelman-Kluit provided valuable advice and comments throughout the course of this study. Special thanks also goes out to Drs. Jim Hunter and Rolf Mathewes, whose comments were helpful and appreciated. Drs. Sue Pullan and Jim Hunter of the Geological Survey of Canada, Terrain Sciences Division, permitted the use of the Vernon seismic lines and provided computer and plotting facilities for preparation of the final printouts. Special thanks is also extended to the staff of the Geography Department and landowners in the North Okanagan Valley.

Financial support was provided by a National Science and Engineering Research Council of Canada (NSERCC) Operating Grant and a Simon Fraser University Special Research Grant for investigating the "Tertiary-Quaternary Fill of the Okanagan Valley", both awarded to Dr. Roberts. Funding was also provided in the form of a Graduate Entrance Scholarship, Graduate Fellowships, and a President's Research Grant awarded to the author. I would also like to thank the British Columbia Ministry of Environment, Groundwater Division, for the provision of well logs and core samples.

This dissertation would not have been possible without exceptional field crews - special thanks to David Lye, Steve Deichman, and Mike and Ev Roberts. Your strong backs, determination, and enthusiasm were greatly appreciated during those 'dog day' Okanagan afternoons. My good friend Dr. Harry Jol provided invaluable assistance during initial seismic testing in the Vernon area.

To my buddies Olav Lian, Don McPhee, and Dr. Gregory Brooks, thanks for all the 'shop talk' over beers and during hikes; Arnie nights and Jack Daniels forever! Tanya Lukie provided many useful editorial comments on various drafts of the thesis and assisted in final preparation of the document. Many thanks for your kindness, moral support, and for showing up at the right time in my life.

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

The southern Cordillera of British Columbia is an extensive mountainous region containing numerous plateaus, plains, and deep elongate basins. Many of the basins are occupied by major lakes and rivers such as the Columbia River, and Kootenay, Arrow, Okanagan and Shuswap lakes in the Interior, and Lillooet and Harrison Lakes to the west (Figure 1.1). These basins often contain thick sedimentary fills that are potentially invaluable for reconstructing local paleo-depositional environments of the southern Cordillera (Cohen and Johnson, 1991).

Present understanding of the sedimentary architecture and age of Tertiary-Quaternary intermontane basin fills in the Cordillera is fragmentary at best. This can be attributed to the complexity of the geomorphic processes that have shaped the Cordillera and to the fact that sediments in deep, elongate structural basins are not very accessible. The region has been subjected to at least two glaciations (Fulton, 1984) and older deposits are eroded or reworked by glacial processes. Most information relates to deposition associated with the last major ice advance. In addition, our lack of understanding results from a lack of continuous outcrop and the difficulties and high costs of subsurface surveys.

Most previous studies of southern Cordilleran basin fills lack detailed analysis of the subsurface fill. For example, Eyles et al., (1990, 1991) and Mullins et al., (1990) discuss the basin fill and bedrock topography of Okanagan

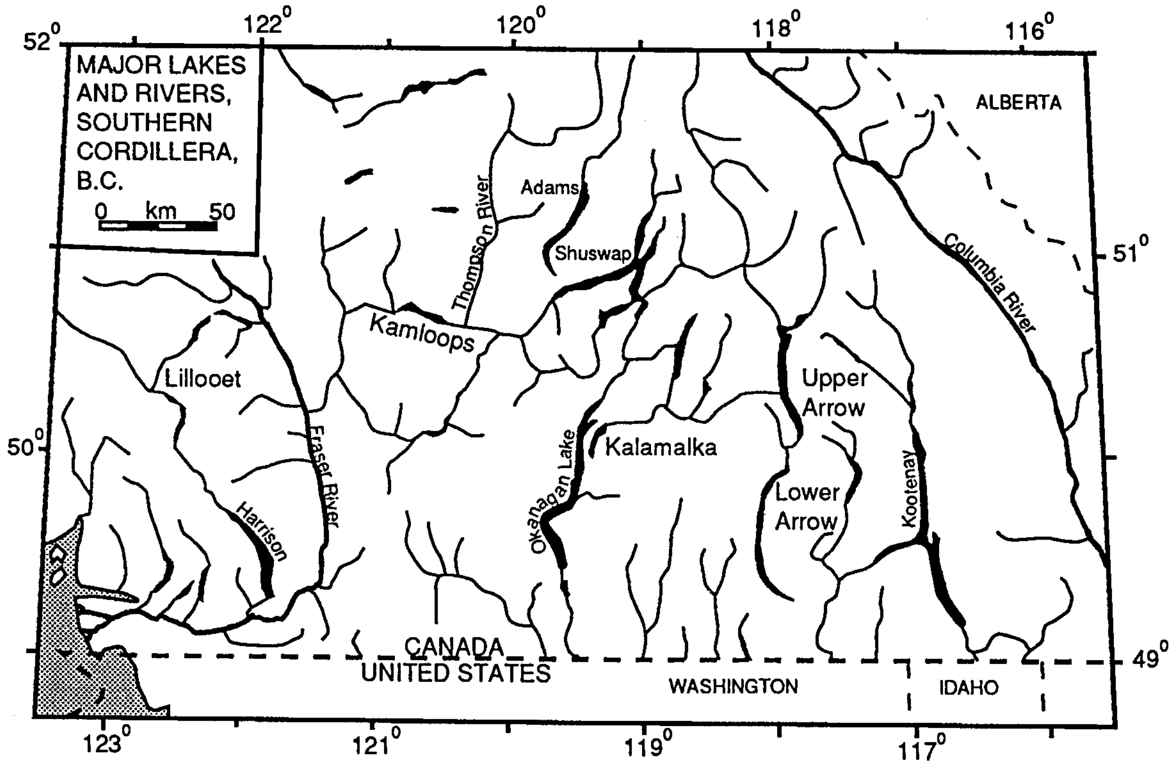


Figure 1.1 Major lakes and rivers of the Southern Cordillera, British Columbia.

and Kalamalka Lake basins in terms of the seismostratigraphy but lack adequate lithologic control. Similar investigations of Lillooet (Gilbert, 1975) and Harrison Lake basins (Desloges and Gilbert, 1991) are also based on seismostratigraphic analysis with minimal lithologic information.

Fulton (1969,1975); Fulton and Smith (1978); Shaw (1975, 1977); and Shaw and Archer (1978, 1979) described the Quaternary deposits and sedimentology of the Thompson and Okanagan valley fills based only on the analysis of exposed valley-fill sediments. Subsurface research in the North Okanagan Valley is limited to a seismic refraction study of the bedrock topography (MacAulay and Hobson, 1972), a groundwater assessment report (Okanagan Basin Committee, 1974), and to a preliminary interpretation of the valley fill (Fulton, 1972).

Clearly, subsurface investigations of Tertiary-Quaternary Cordilleran basin fills are limited in scope and few in number. While many studies emphasize seismostratigraphic and bedrock relationships using the exposed valley fill for lithologic correlations, few studies employ detailed analysis of subsurface lithologies. A greater understanding of the relationships between basin architecture and geomorphic processes in Cordilleran valleys can best be attained through the use of an integrated research approach using high resolution seismic surveys and detailed subsurface lithologic control; this approach has been adopted here to examine the basin architecture of the North Okanagan Valley. The study was designed to determine the depositional systems and architecture of the basin and to account for the depositional history of the basin fill.

1.2 The North Okanagan Valley: Previous Investigations

North Okanagan Valley is an ideal research area because the valley floor between Vernon and North of Enderby is not occupied by any large water bodies, the basin fill is intact, and the region is accessible for a land based seismic and drilling survey (Figures 1.2 and 1.3). Eyles et al., (1991) identified a 792 m thick sediment fill in the Okanagan Lake basin south of Vernon. On this basis it was reasoned that a thick basin fill might be preserved in the North Okanagan Valley.

From an examination of seismic refraction profiles, drillhole logs, and outcrop, Fulton (1972) proposed a three-part model for the North Okanagan Valley fill. Although based on limited lithologic data and chronologic control, his model suggests a complex sedimentary succession consisting of post-glacial sediments overlying Fraser Glaciation proglacial sediments, glacial tills (?), and non-glacial sediments interpreted as Olympia Interglacial deposits. Fulton suggested that the latter are preserved because subsequent glaciations were unable to scour the deep bedrock floor of the valley. These Olympia Interglacial sediments consist of medium-grained sand, fine and coarse gravel, and fine-grained silt and sand. The sediments are thickest in mid-valley positions with coarser-grained units restricted to the valley sides. The possibility that these units may originate from mass movement slope processes was not addressed. According to Fulton (1972, p.13), till was found only in boreholes on the valley sides and in tributary valleys. 'Till-like' material was not present in the deeper fill of North Okanagan Valley.

A sequence of glacial deposits consisting of glaciolacustrine silt and clay with some sand overlies the succession of Olympia Interglacial sediments. Fulton (1972) classified these as Fraser Glaciation proglacial sediments, variously deposited as lake or deltaic sediments, stratified ice contact deposits

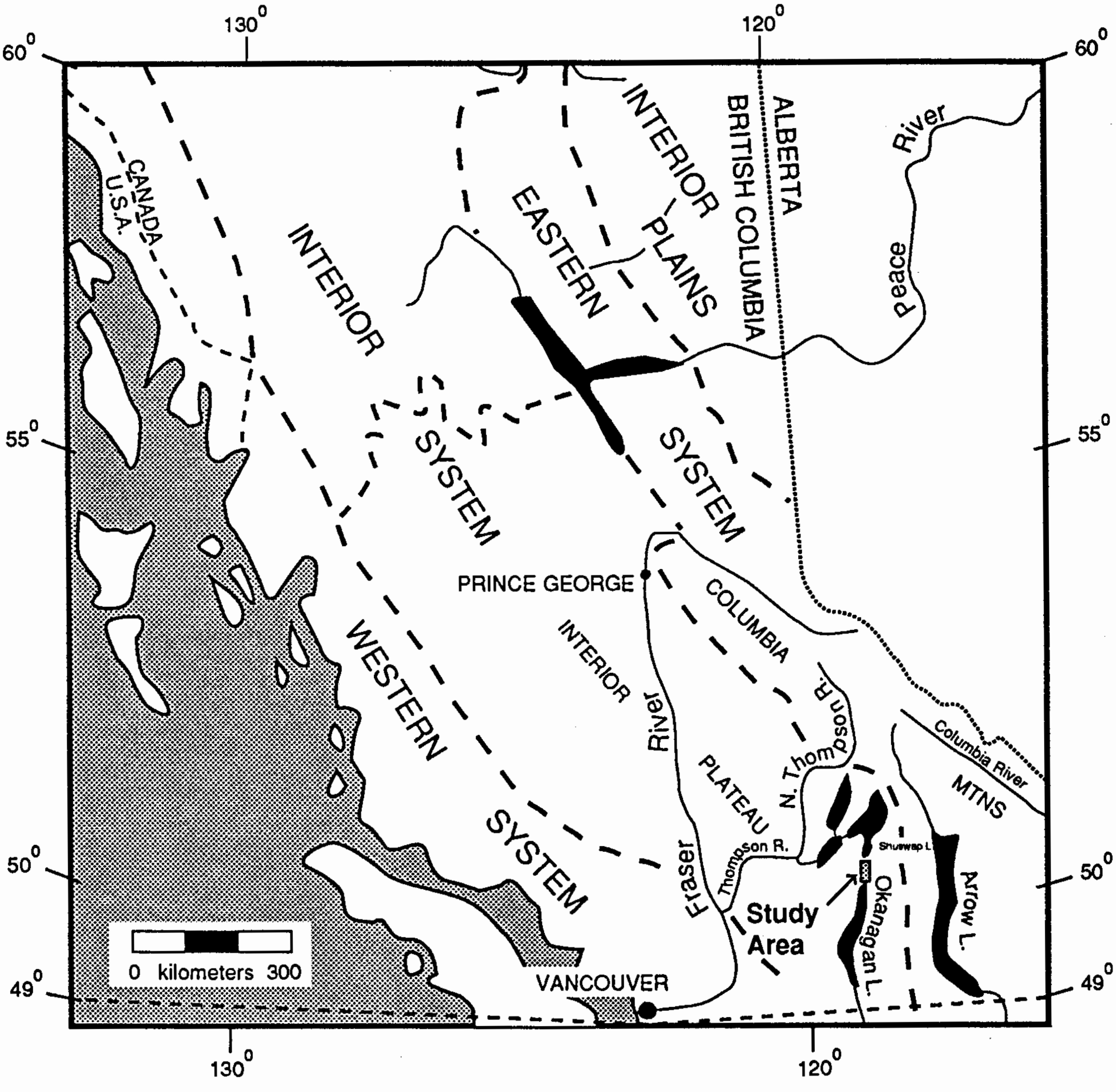


Figure 1.2 Major physiographic divisions and location of the study area in southwestern British Columbia.

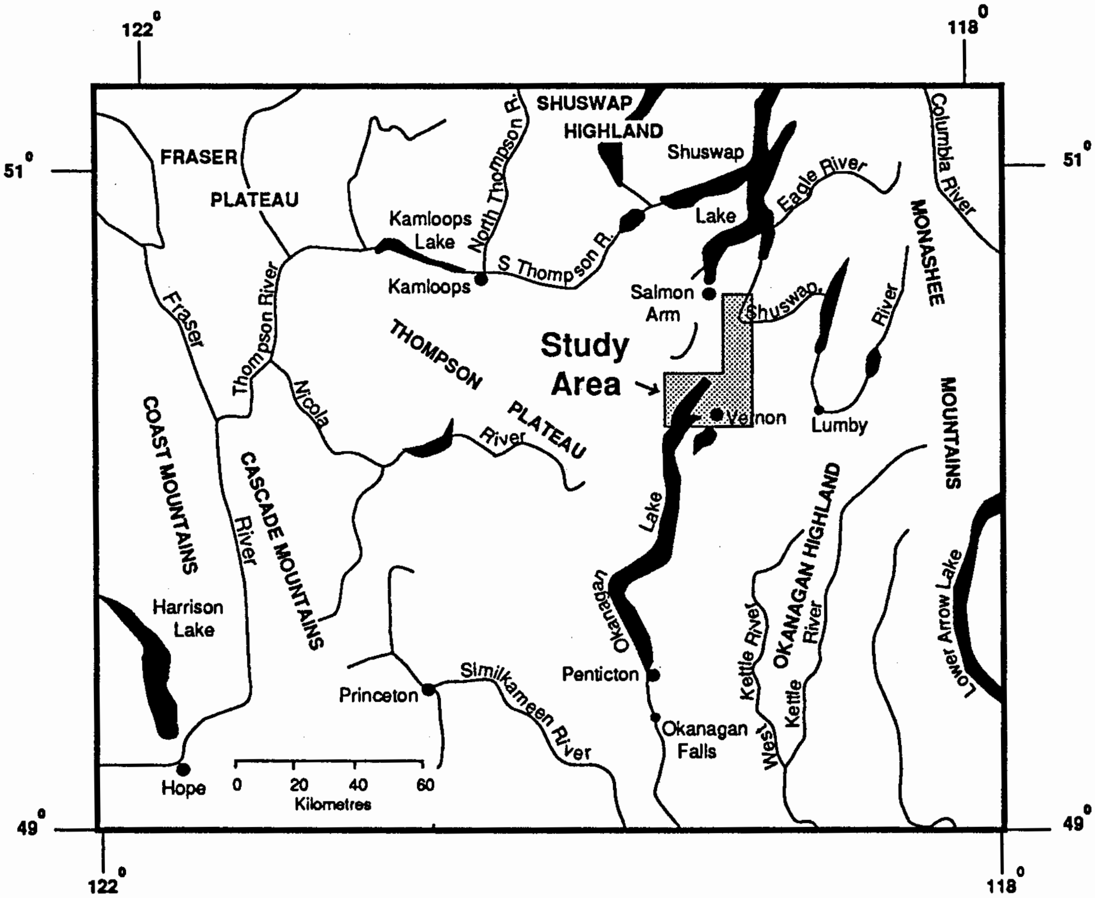


Figure 1.3 Location of study area in the Southern Interior Plateau, British Columbia.

or glacial tills. The proglacial sediments are overlain by post-glacial silt, sand, and gravel, interpreted in turn as lake, delta and thin alluvial fan deposits.

It would seem from this discussion of the North Okanagan Valley fill that a rather detailed Quaternary sequence has been constructed from available seismic and borehole data. Many of Fulton's correlations; however, are based on a comparison of generalized drill logs with outcrop elsewhere in Okanagan Valley. Fulton (1972, p.16) acknowledged this limitation of his analysis when he stated: 'it (the sedimentation model) is a highly simplified version of what actually would be found.' He further noted that 'the seismic survey defined the boundaries of the prism of unconsolidated (Quaternary ?) sediment; but, because of the gross similarities of lithologies and the complex nature of sedimentation units, it provided little information of stratigraphic value.' Fulton's (1972) pioneering interpretation is founded on limited lithologic and seismic control, and on speculative interpretations of the depositional history and stratigraphy of the basin fill. A detailed lithologic and seismic investigation of the basin fill would allow a more accurate delineation of the architecture and depositional history of the North Okanagan Valley.

1.3 Basin Architecture of the North Okanagan Valley

To fully appreciate the spatial and chronological arrangement, or architecture, of a basin fill one must have an understanding of the stratigraphy, geometry of the major facies associations, seismic facies, and bedrock topography of the basin (Ricketts, 1991). Hence, this study involves an examination of the relationships among the geomorphic and sedimentary processes affecting the stratigraphy of the North Okanagan Basin and the bedrock topography.

Structurally, the North Okanagan Basin occupies the northernmost portion of a deep, narrow basin produced by Tertiary extension (Parish et al., 1988; Okulitch, 1984; Tempelman-Kluit and Parkinson, 1986; Brown and Journeay, 1987; Journeay and Brown, 1986; Bardoux, 1985; Eaton, 1979, 1982; Ross, 1981; Davis, 1979; Thornbury, 1965) (Figure 1.4). It has been argued that the structure and style of tectonism in North Okanagan Valley is similar to that which occurred in the Basin and Range Province of the Western United States. Tempelman-Kluit and Parkinson (1986) describe the middle Eocene extension of North Okanagan Valley and suggest about 90 km of offset. Typically, extensional basins have deep floored valleys prior to modification and infilling and exhibit a dominant longitudinal component (Eaton, 1979, 1982; Ross, 1981).

Tectonic formation of the North Okanagan Basin was coeval with early to mid-Tertiary volcanism and late-Tertiary fluvial incision (Jones, 1959). The occurrence of at least two Quaternary glaciations (Fulton, 1984) may have caused additional bedrock and stratigraphic modification that likely affected the basin morphology and stratigraphy. Although the influence of Quaternary glaciations on the pre-glacial fills of intermontane valleys is not well understood, Leech (1966) suggested that late Wisconsin glaciation of the Rocky Mountain Trench may not have significantly altered earlier glacial, and perhaps Tertiary, deposits. Some researchers, including Fulton (1969, 1975) and Nasmith (1962), have postulated that Tertiary sediments may also be preserved in the North Okanagan Basin.

Models developed for predicting the basin fill architectures of extensional basins such as North Okanagan Valley are largely based on the geology of large scale structural basins located in arid climate regions. (Thornbury, 1965; Stewart, 1978; Hunt, 1979; Eaton, 1982; Frostick and Reid, 1987; Hempton and

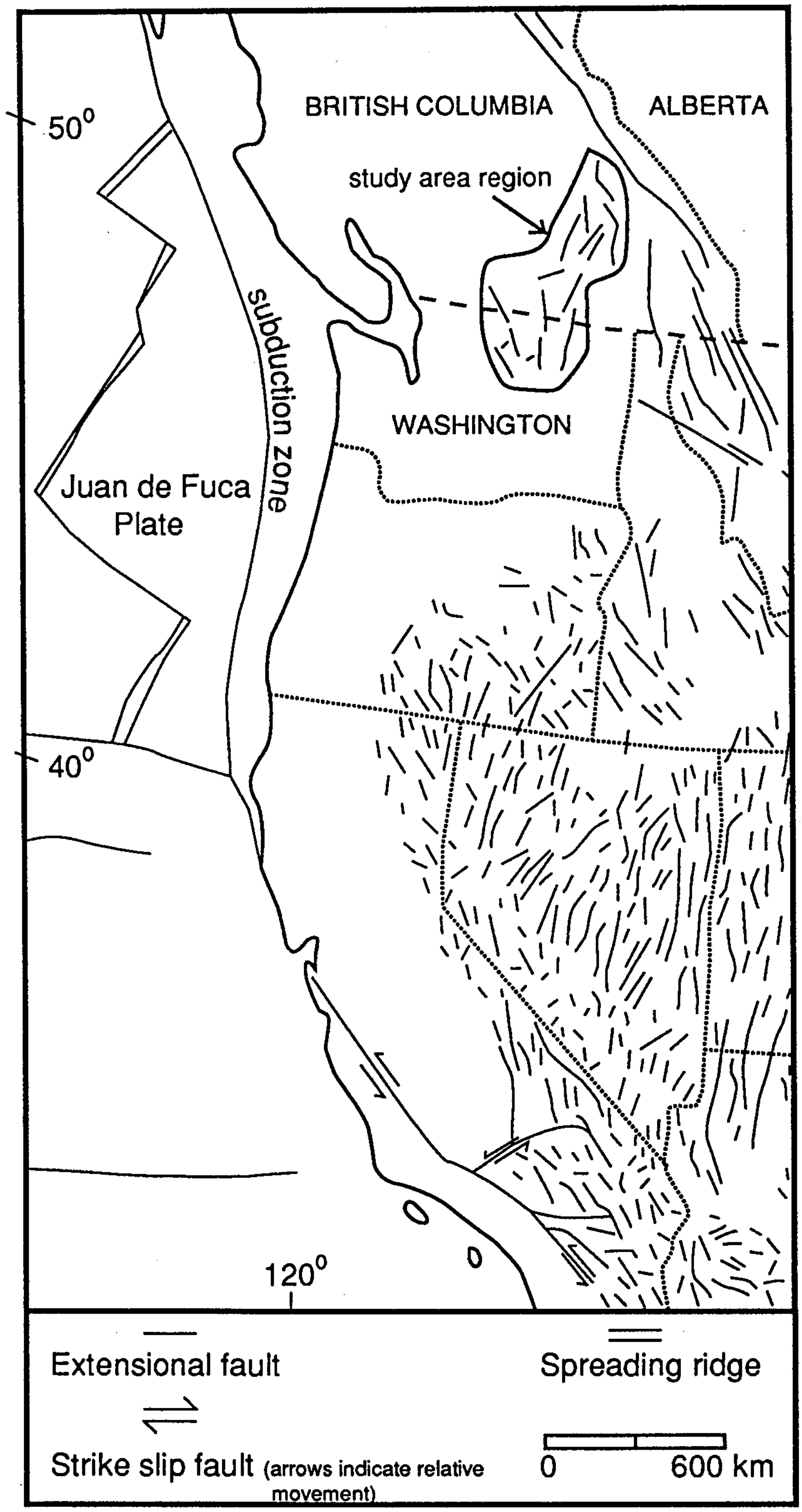


Figure 1.4 Distribution of Cenozoic faults in the Pacific Northwest and current plate boundaries (after Stewart, 1977).

Dunne, 1984). Sedimentation in these basins is thought to be a function of prevailing tectonic processes; as extension and uplift occurs sediments are deposited into the basin. The stratigraphic models usually exhibit the following properties: thick sediment sequences relative to basin dimensions (i.e. deep, narrow valleys with thick fills), rapid sedimentation rates, asymmetrical facies and facies associations, basin geometries with a dominant longitudinal component, and sediment textural trends that reflect tectonic and geomorphic events (Hempton and Dunne, 1984). Thick (hundred to thousands of metres) Basin and Range basin fills exhibit stacked sets of interdigitated, fine-grained lacustrine and fluvial deposits, and coarser-grained alluvial fan and braided fluvial deposits, called "cyclothems" (Blair and Bilodeau, 1988; Eaton, 1982; Hunt, 1979; Stewart, 1978; Thornbury, 1965).

Interfingered fine and coarse-grained units appear as vertically stacked, wedge shaped, asymmetrical depositional units in cross-basinal view (Figure 1.5). This arrangement reflects the interaction between bedrock valley sides, mass movement processes, and deposition of material in the basin. Typically, the coarse-grained units (frequently alluvial fans deposited by debris flows) thin towards the basin axis and exhibit lens to wedge-shaped morphologies (Selley, 1988). Basin fills characterized by stacked coarse/fine units have been observed in numerous arid valleys in the Basin and Range Province (Hempton and Dunne, 1984; Eaton, 1982; Hunt, 1979; Stewart, 1978; Thornbury, 1965) and in arid pull-apart basins (Frostick and Reid, 1987) (Figure 1.5).

The model proposed by Heller et al., (1988) is based on a facies analysis of non-marine, half graben basins. They suggest that the facies distribution is a function of the interaction among tectonic events, grain-size distribution, and fluvial processes (Figure 1.5, basin A). During times of active faulting the basin subsides rapidly and coarse-grained material is deposited on the proximal faulted side of the basin; finer sediments are deposited farther towards the basin axis. Periods of tectonic quiescence are marked by a dominance of erosional processes that transport coarse grained material into more distal portions of the basins; the sediments are derived from reworked coarse-grained deposits and eroded fault material. The model implies that the proximal coarse-grained sequence records the onset of faulting whereas the more distal coarse-grained component represents cessation of tectonic activity and a dominance of erosional processes in the thrust region.

Investigations of fault controlled half grabens by Frostick and Reid (1987) provide detailed descriptions of the nature and depositional processes of sedimentation in extensional basins (Figure 1.5, basin B). Typically, half graben basins are steep-sided valleys that show a dominant scarp face. The basin fill is asymmetrical in cross-sectional view because of the one-sided faulting and related differences in the model facies on either side of the basin. Frostick and Reid's model postulates that, during times of tectonic activity, coarse sediments in the form of alluvial fans build out from the valley side opposite the scarp face and even coarser material is deposited from scarp face streams that deposit coarse fans or fan-deltas. The coarse-grained units are interbedded with, and overlie, fine-grained deposits that represent sedimentation during tectonic inactivity. Evaporite deposits may also develop during intervals of tectonic quiescence and indicate past drier climates and lower lake levels.

Blair and Bilodeau (1988) present a model for sedimentation in extensional basins similar to that of Heller et al., (1988). Blair and Bilodeau's model shows that the cross-sectional geometry of the basin is asymmetrical due to the dominance of tectonic activity along one basin margin (Figure 1.5, basin C). In their model coarse-grained sediments are restricted to the faulted margin

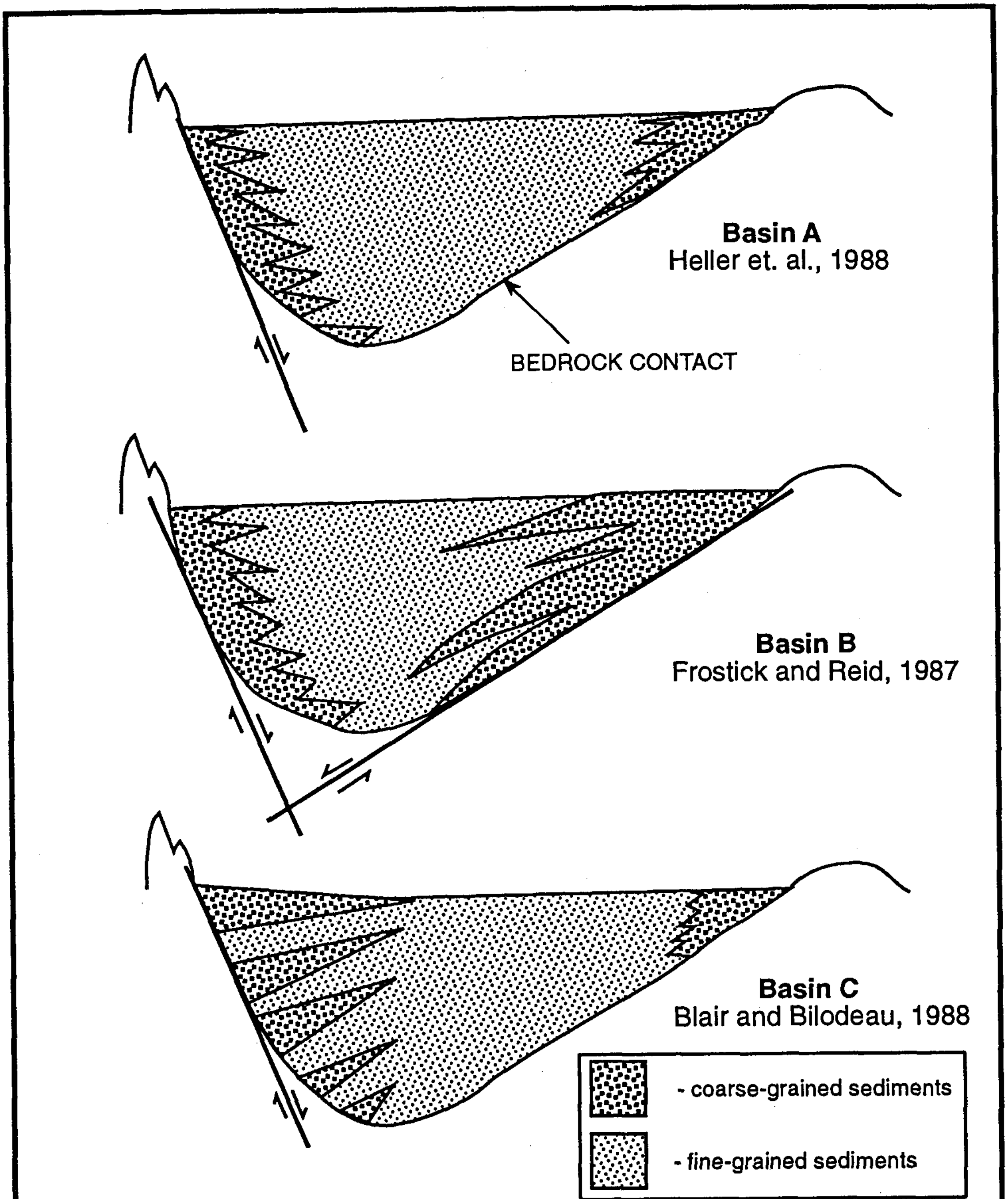


Figure 1.5. Selected models of unglaciated sedimentary basin fills. Notice the interfingered coarse and fine-grained sediments or 'cyclothems'. **Basin A** shows coarse-grained sediments, deposited during tectonic activity, that are restricted to the basin margins. **Basin B** exhibits an asymmetrical distribution of coarse-grained sediments resulting from tectonic activity along both margins of the basin. **Basin C** also shows an asymmetrical distribution of coarse-grained sediments again resticted to the faulted margin of the basin.

and fine-grained material is interbedded with coarse-grained sediments and deposited in mid-basin positions. The major difference between this model and that of Frostick and Reid (1987) is that faulting is restricted to one side of the basin. This results in stacked sequences of coarse and fine-grained sedimentary units adjacent to the scarp face. Coarser sediments are deposited during periods of tectonic activity and finer-grained units during periods of basin subsidence; the coarse-grained units thin distally towards the basin axis.

Although these useful models of tectonically active, extensional basin fills in arid climates may apply elsewhere, none has been tested in Tertiary-Quaternary, glaciated, intermontane basins. Generally, the existing tectonic models fail to address the effect of climatically driven geomorphic processes, such as glaciations, on the three-dimensional arrangement of basin sediments. Previous studies also tend to rely on speculative and generalized subsurface data and lack detailed seismic, drill hole, and geophysical information. Furthermore, it can be argued that basin models are site specific and that their application and use as a predictive tool in other geomorphic settings consequently is limited (Paola, 1988). The literature is replete with investigations of mega-scale, ancient marine basins (Ingersoll, 1988; Helwig, 1985; Bois et al., 1982; Dickinson, 1974; Kleime, 1971a, 1971b) that emphasize the role of tectonic controls on basin architecture, but there is a significant gap in the literature dealing with Quaternary, non-marine basin fills.

Considering the tectonic and glacial history of North Okanagan Valley, examination of the preserved basin fill of this unique geomorphic and geologic setting will further our understanding of Cordilleran valley fills and address the effects of Quaternary geomorphic processes on the basin architecture.

1.4 Objectives of the Study

Deep lake basins and elongate valleys may often contain thick sedimentary fills that yield important geomorphic and depositional information that span extensive periods of geologic time. If sedimentation rates are rapid, the potential for sedimentary preservation of information relating to the geomorphic, tectonic, and climatic history of the basin is relatively high.

The primary objectives of this study were to develop a three-dimensional model of the North Okanagan Basin architecture and to provide a reconstruction of depositional environments. This study is based on an integrated approach in the field, involving high resolution-shallow reflection seismic profiling, drilling, downhole geophysical logging (Spontaneous Potential, Resistivity, and Gamma), outcrop logging, and the collection and analysis of existing subsurface information (groundwater logs). Although common in hydrocarbon exploration programs and engineering investigations, only within the last six years have relatively low cost technology and portable field computing facilities allowed the earth scientist to implement an integrated research approach of this nature.

This research of the North Okanagan Basin will fulfill the following objectives:

1) To establish the three-dimensional basin architecture of the North Okanagan Valley. This objective will be met through the use of seismic profiling, drilling, geophysical logging, and surficial mapping. Specific tasks will include specifying the basin stratigraphy, determination of the relationships between bedrock valley sides and geomorphic processes, and estimation of the volume of sediment stored in the basin.

2) To reconstruct the depositional environments based on the findings in (1).

3) To establish an initial chronology of basin fill processes; to date only limited C^{14} dates are available for North Okanagan Valley.

4) Synthesize all data from (1) (2) and (3) in a three-dimensional model of North Okanagan Valley basin architecture representative of Cordilleran basin fills. This model will be compared with existing models of non-glaciated intermontane basins.

CHAPTER TWO

PHYSICAL SETTING AND PREVIOUS RESEARCH

2.1 The Study Area

The North Okanagan - South Shuswap Valley is a relatively narrow (~3 km average width), elongate (~45 km), north-south trending basin situated within the Okanagan and Shuswap drainage systems (Figure 2.1). Although located within two drainage basins, the region is referred to as the North Okanagan Valley. The 187 km^2 study area is situated between 50° 37' N to 50° 19' N and 119° 5' W to 119° 22' W and is part of the Interior Plateau physiographic region that is bordered by the Coast Mountains to the west and Columbia Mountains to the east.

The highlands and intermontane valleys of the Interior Plateau are remnants of an uplifted and dissected Tertiary erosional surface (Holland, 1964). Regional elevations of the moderately sloped plateau surface range from 1520 masl to over 2,117 masl. Valley floor elevations range from 390 masl near Vernon to 353 masl north of Enderby. Near Enderby the valley floor is dissected by the northward flowing Shuswap River.

North of Vernon the valley bifurcates into the main basin of Okanagan Valley and a smaller, parallel basin that contains Swan, Kalamalka, and Wood Lakes. Interestingly, Bardoux (1984) pointed out that Okanagan Valley has the lowest elevations of any geomorphic feature between the west coast of British Columbia and Saskatchewan.

The region lies within the rainshadow of the Coast Mountains and has a dominant north-south climatic gradient. Annual precipitation in this semi-arid

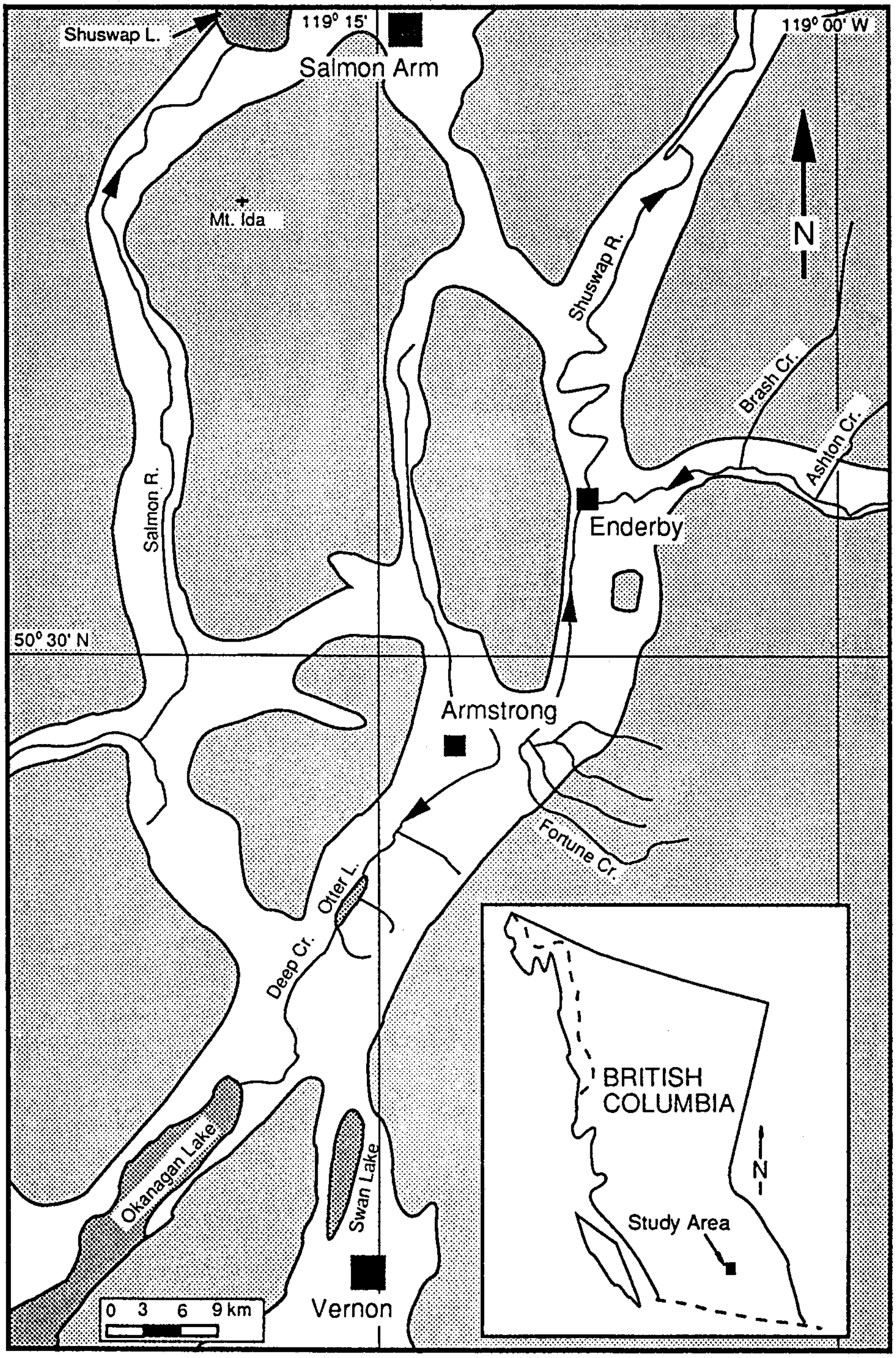


Figure 2.1 Detailed location map of the study area in North Okanagan Valley.

region ranges from 43.6 cm/a at Armstrong to 27 cm/a at Oliver. Similarly, the number of frost free day ranges from 114 days/a at Armstrong to 152 days/a at Oliver.

2.2 Previous Geological Investigations, Tectonics, and Geology of the Study Area

2.2.1 Previous Geological Investigations

The geology and tectonic history of the Omineca Crystalline Belt in southern British Columbia (Figure 2.2) has been the focus of numerous geologic investigations, and comprehensive reviews of recent works are provided by Parrish et al., (1988) and Okulitch (1984).

The earliest bedrock geology interpretation in the vicinity of North Okanagan Valley was that done by Dawson in 1879. In this pioneering work Dawson mapped the Shuswap "Series" metamorphic rocks near Shuswap Lakes and suggested that they were correlative with Archean rocks of the Canadian Shield. Later work by Brock (1903) attempted to correlate similar metamorphic rock complexes between Okanagan and Kootenay Lakes with the Shuswap Series and suggested a late Paleozoic to early Mesozoic age for the strata. Cairnes (1932) elaborated on Brock's (1903) interpretations and suggested Mesozoic contact metamorphism for the entire Shuswap Terrane. Detailed lithologic analysis and field mapping by Jones (1959) led him to the separate the Shuswap Terrane into the Monashee, Mount Ida, and Chaperon Groups. He also proposed an Archean age for the strata and orogenesis of the terrane similar to that first proposed by Dawson in 1879.

More recent studies, up to the early 1970's, of the bedrock geology in southwestern British Columbia continued to provide informal and inconsistently applied interpretations of the region as a metamorphic complex (Okulitch, 1984)

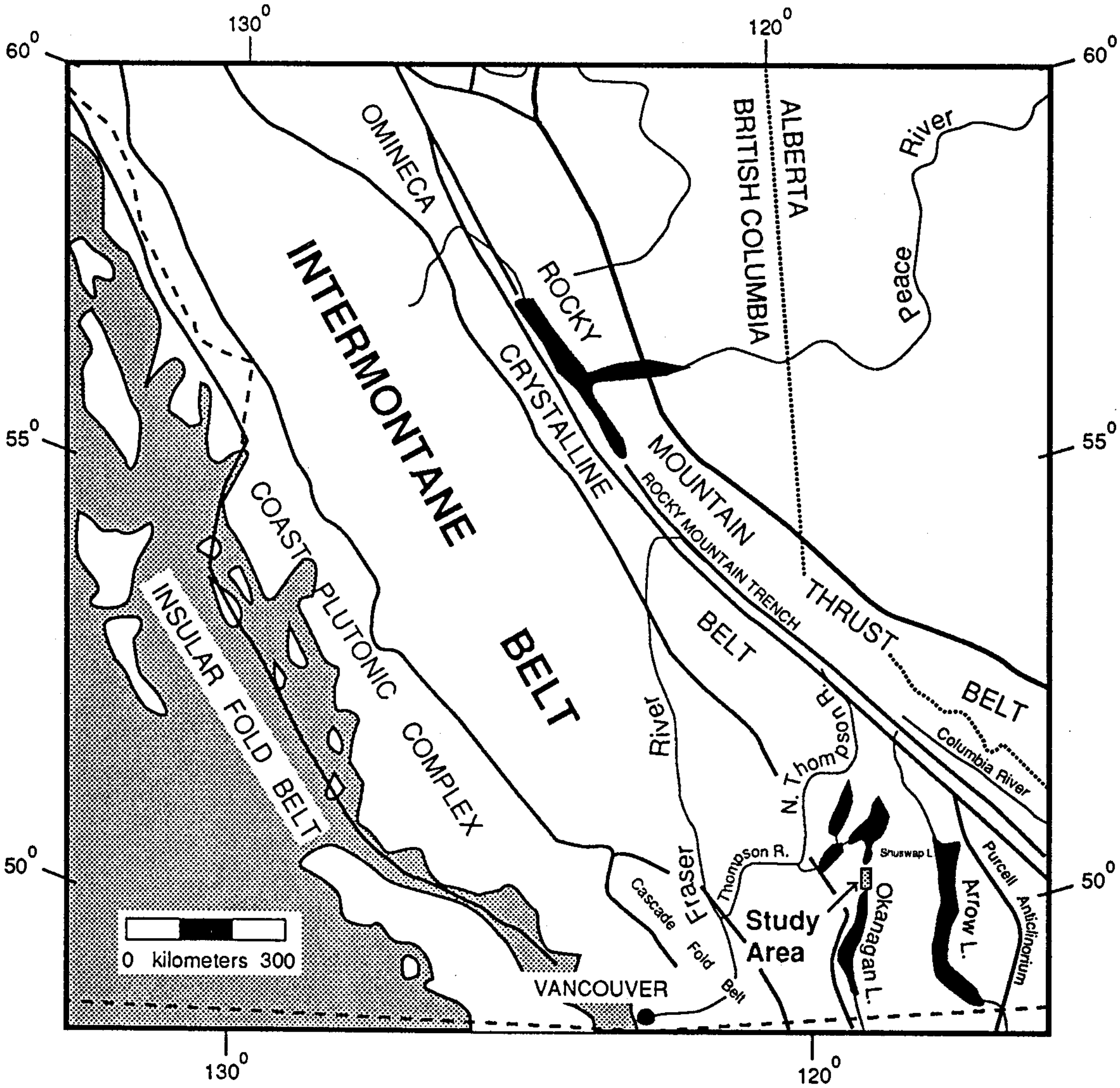


Figure 2.2 Major tectonic belts of southwestern British Columbia (tectonic belts after Douglas et al., 1972).

Research during the last ten years has served to better define the complex relationships, ages, and timing of tectonic processes in the Shuswap Metamorphic Complex (Okulitch, 1984).

2.2.2 Tectonics

Recent studies indicate that the geology between Okanagan and Kootenay Lakes contains a complex mix of metamorphic rocks, plutons, and sedimentary and volcanic rocks of late-Paleozoic, Triassic, Jurassic, and Paleogene ages (Parish et al., 1988; Okultich, 1984). This discussion will be restricted to Tertiary tectonics and geology of the North Okanagan Valley region. Reviews of the pre-Tertiary tectonic history and geology of southwestern British Columbia are found in Parrish et al., (1988) and Okulitch (1984, 1985).

The North Okanagan Valley is situated in the Okanagan Complex of the larger Shuswap Metamorphic Complex (Okulitch, 1984; Figure 2.3). Recent work by Okulitch (1984) has shown that the Okanagan Complex extends north from the 49th parallel to Okanagan and Kootenay Lakes (Figure 2.3). The present geologic architecture of this Complex in the southern portion of the Omineca Crystalline Belt is the result of Eocene extensional processes (Parrish et al., 1988; Tempelman-Kluit and Parkinson, 1986; Brown and Journeay, 1987; Journeay and Brown, 1986; Bardoux, 1985; Ross, 1981). During the mid-Eocene, two plates, an upper and a lower, were simply pulled apart or 'unthrust' (Tempelman-Kluit and Parkinson, 1986; Figure 2.4). This early to mid-Tertiary deformation (younger than 51 Ma) caused approximately 90 km of slip across the shear zone (Parrish et al., 1988), resulting in juxtaposed bedrock composition on either side of a 150 km long south-trending normal fault, named the Okanagan Valley fault (Brown and Journeay, 1987).

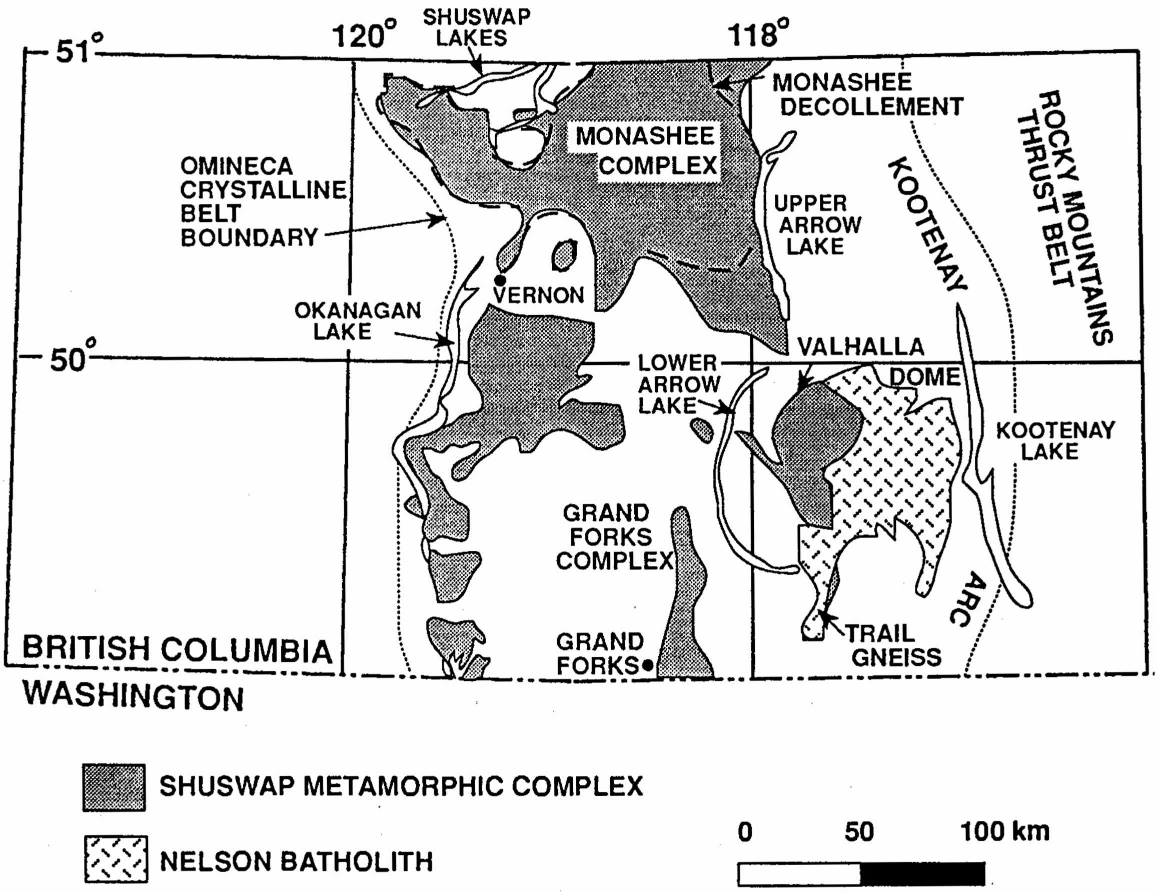


Figure 2.3 Map of the Shuswap Metamorphic Complex in the study area showing geographic and major geologic features (after Okulitch, 1984).

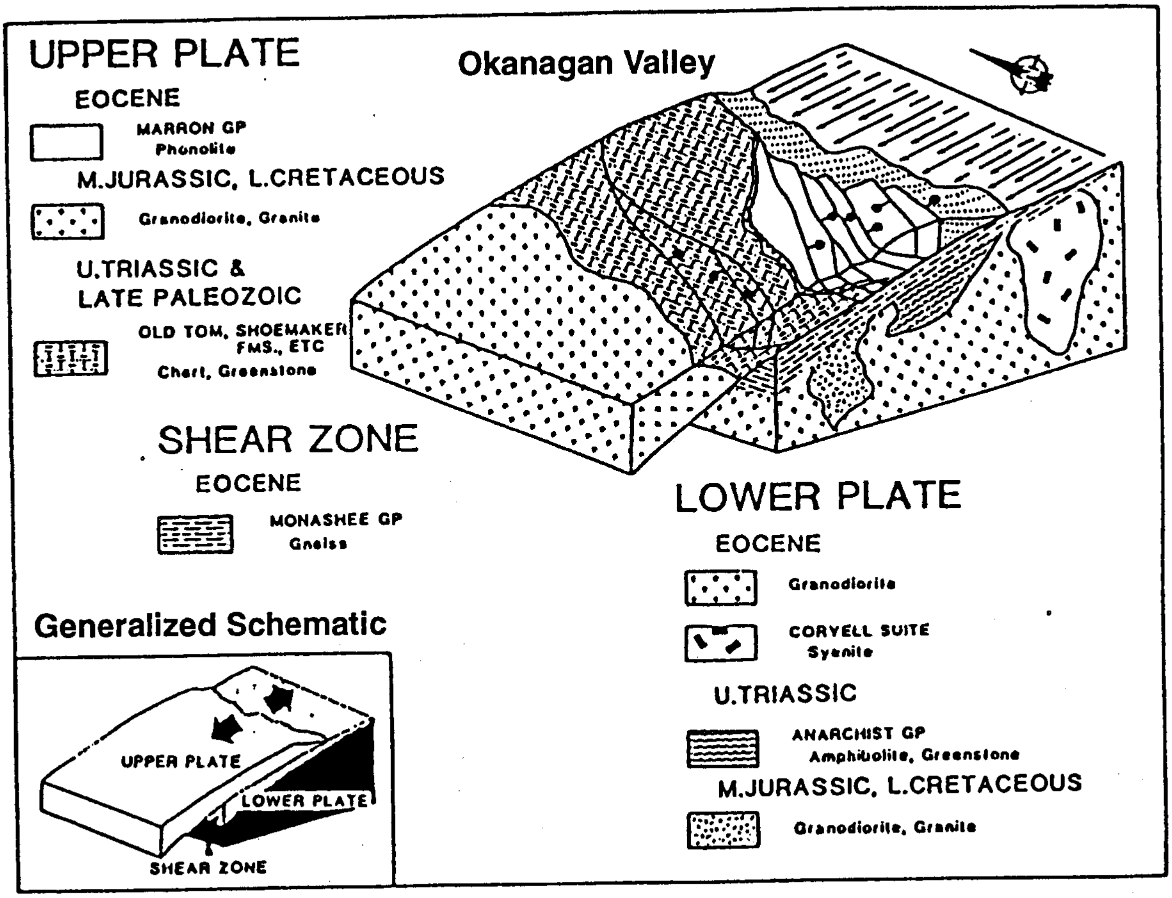


Figure 2.4 Tectonic formation of the Okanagan Valley (after Tempelman-Kluit and Parkinson, 1986).

The Tertiary extension of southern British Columbia is considered to be similar, in terms of style of formation, to extensional geologic structures in the Basin and Range Province, Western United States. However, Okulitch (1984) indicates that although the styles of tectonism were similar, the amount of extension is at least an order of magnitude less than that proposed for the Basin and Range Province. Furthermore, Basin and Range extension occurred during late-Tertiary time (late Miocene) from about 13-7 Ma (Okulitch, 1984).

Although the magnitude and timing of extensional processes in the two regions were different, investigations of extensional basin fills in the Basin and Range Province can provide interpretive frameworks for basin fills in similar tectonic settings. Many authors including Eaton, (1982, 1979); Nelson, (1981); Hunt, (1979); Stewart, (1978); have described the general characteristics of valleys formed by extensional processes. These valleys exhibit physiographic similarities characterized by parallel, north-south trending elongate mountain ranges that are separated by arid basins. The extensional valleys are essentially linear basins containing sediment accumulations ranging in thickness from several hundred to over 3,000 m (Eaton, 1982; Nelson, 1981; Hunt, 1979; Stewart, 1978).

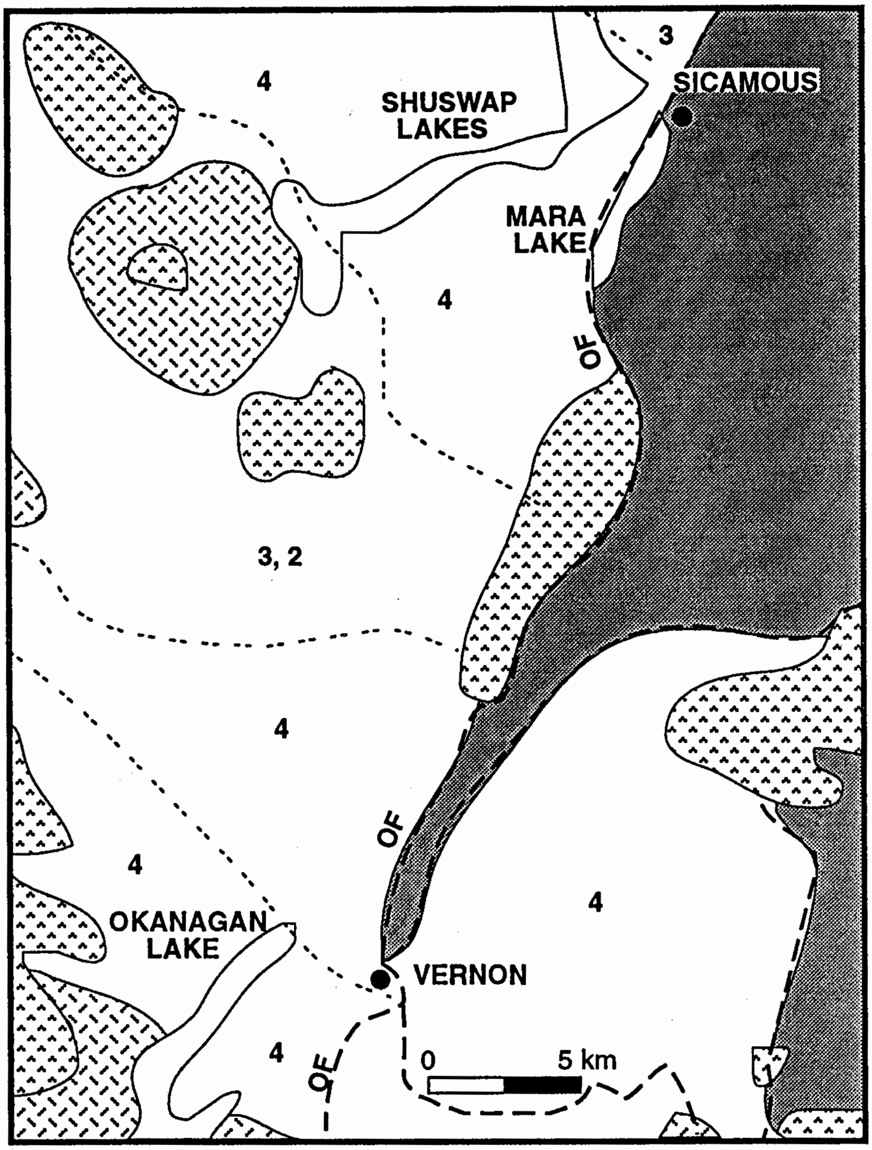
The fills of these extensional basins typically exhibit two facies: 1) coarser-grained fan-like deposits along valley margins and 2) coarser-grained deposits that grade into finer-grained lacustrine/fluvial facies towards the valley axis (Eaton, 1982; Thornbury, 1965). Detailed analysis of extensional basin fills show complex relationships between coarse-grained valley margin deposits that interfinger with fine-grained lacustrine, floodplain, evaporite, or flood basalts (Eaton, 1979). This information serves to illustrate the possible complex arrangement or 'geometry' of sedimentary units that comprise the basin fill.

2.2.3 Geology of the Study Area

Recent work in the Okanagan Complex and fault zone has shown considerable variation in the tectono-stratigraphic composition of the hanging wall and footwall rocks of the Okanagan Valley fault (Parrish et al., 1988; Okulitch, 1979) (Figure 2.5). West of the Okanagan Valley fault, and in the southeast portion of the map area near Vernon, the lithology consists of stratified middle Jurassic granitic and plutonic rocks, stratified late Paleozoic to early Mesozoic rocks, and stratified middle Eocene volcanic and sedimentary rocks. The Eocene volcanic and sedimentary rocks consist of andesite, basalt, dacite, trachyte flows, dykes, breccia, tuff, agglomerate; and sandstone, conglomerate, and shale with minor amounts of coal, tuff, and arkose (Okulitch, 1979).

East of the Okanagan Valley fault the structure and geology of the Okanagan Complex is intricate and not as well understood (Parrish et al., 1988). The lithology consists of Shuswap Metamorphic Core Complex paragneiss, minor orthogneiss and granitic rocks of uncertain age, fossiliferous upper Paleozoic to Triassic rocks, and Eocene metasedimentary and metavolcanic rocks (Figure 2.5). The complexity of the geology and structure is partly attributed to numerous superimposed faults in the region and eruptions of volcanic rock between periods of faulting.

Detailed structural geology, lithology, and economic mineral maps of the Thompson, Shuswap, and Okanagan regions are provided by Okulitch (1979).



Metamorphic Core Complex - paragneiss, minor orthogneiss: age uncertain

Granitic Plutonic Rocks - Middle Jurassic granitic rocks

STRATIFIED ROCKS

Middle Eocene - volcanic, sedimentary rocks

4 **Late Paleozoic -Early Mesozoic** - allochthonous terrane

3 **Paleozoic rocks of North American affinity**

2 **Windermere Supergroup**

STRUCTURAL SYMBOLS

Eocene regional normal faults of moderate dip

Middle Jurassic to Paleocene thrust fault

OF Okanagan Valley Fault

Figure 2.5 Tectonic map and general geology of the study area (after Parrish et al., 1988)

2.3 Quaternary Deposits, Stratigraphy, and Holocene Deposits

2.3.1 Quaternary Deposits and Stratigraphy

At least 2 interglacial and glacial geologic-climatic intervals are recorded in Quaternary deposits of the Okanagan region: the Westwold and Olympia Interglaciations and the Okanagan Centre and Fraser Glaciations, respectively. (Table 2.1).

Westwold Interglaciation deposits are the oldest recorded Quaternary sediments preserved in the Okanagan region and are represented by the Westwold Sediments lithostratigraphic unit (Table 2.1). The type section, located northwest of Vernon in the Falkland Valley, exhibits 19 m of marl, silt, sand, and clay overlying coarse, stratified sand containing fossil ice-wedge casts (Figure 2.6). The deposits are dated as older than 51,000 BP and are correlated with Highbury Non-Glacial Interval deposits of the Fraser Lowland (Fulton, 1975, 1976; Fulton and Smith, 1978).

Okanagan Centre Glaciation deposits represent the oldest Quaternary glacial sediments recorded in the Okanagan region (Table 2.1). The Okanagan Centre Drift lithostratigraphic unit is composed of stratified outwash, a till (?), glacial lacustrine, and glacial fluvial deposits that overlie Westwold Sediments. This unit is widely distributed throughout North Okanagan Valley and radiocarbon dates indicate an age older than 51,000 BP. The type section is on the east side of Okanagan Lake near the village of Okanagan Centre (Figure 2.6). The 60 m section consists of a lower stratified, bouldery outwash unit overlain by till (?), and an upper 7 m of glacial lacustrine, glacial fluvial and beach sediments (Fulton, 1975, 1976; Fulton and Smith, 1978). The sediments represent the oldest documented early Wisconsin glacial deposits in south-central British Columbia; the Okanagan Centre Glaciation is correlated with the Semiahmoo Glaciation of the Fraser Lowland.

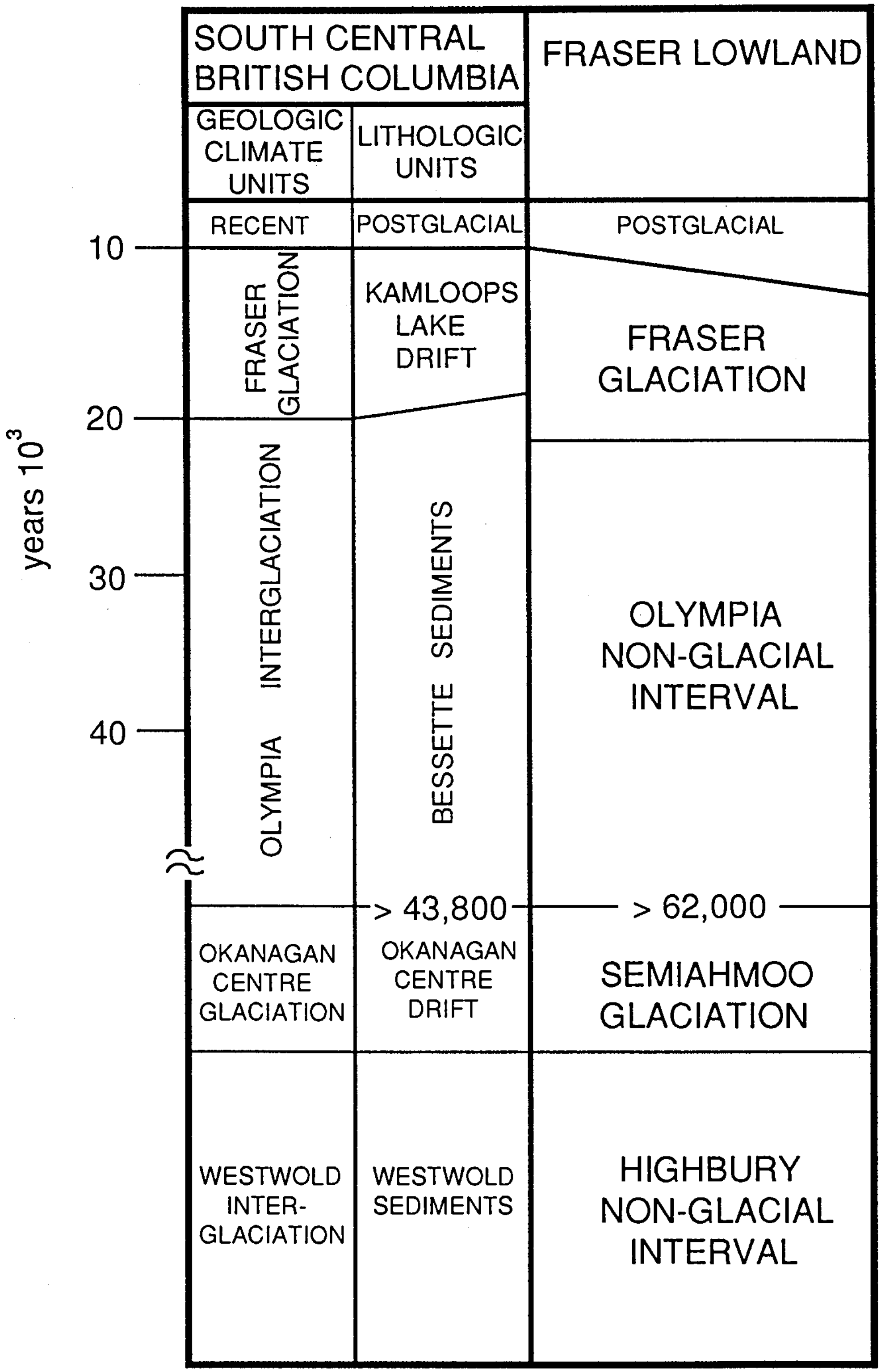


Table 2.1 Stratigraphic units for south-central British Columbia and correlation with the Fraser Lowland (after Fulton and Smith, 1978).

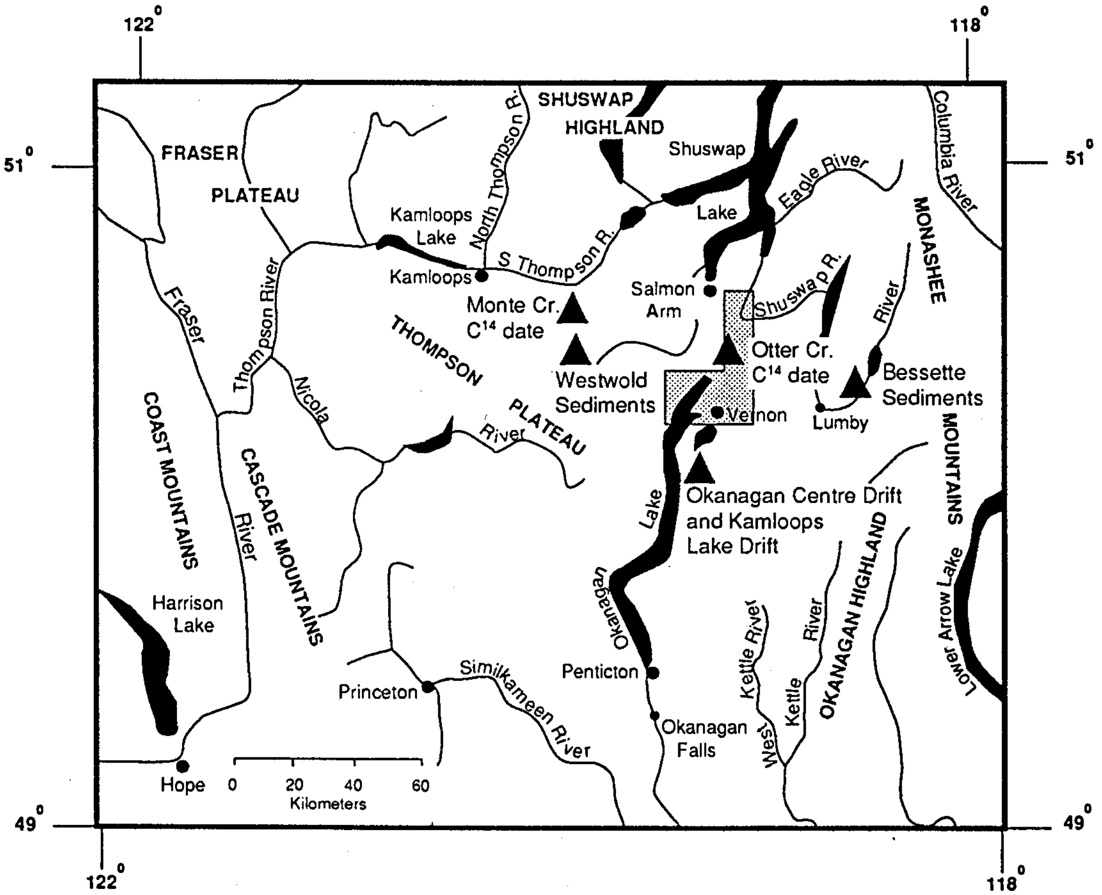


Figure 2.6 Locations of Quaternary formation type sections and radiocarbon dates cited in this dissertation. Locations are indicated by shaded triangles.

Olympia Interglaciation deposits are represented by the Bessette Sediments lithostratigraphic unit that is observed throughout the North Okanagan Valley (Table 2.1). These non-glacial, middle Wisconsin, fluvial, lacustrine, eolian, and tephra deposits range in radiocarbon age from 43,800 BP to 19,100 BP (Fulton and Smith, 1978). The type section, located north of the village of Lumby near Bessette Creek (Figure 2.6), exhibits 20 m of organic rich, interbedded silt, sand and gravel interbedded with two tephra layers. The lower tephra, identified as the Riggins Road Tephra, is about 1 cm thick and approximately 30,000 years old (Westgate and Fulton, 1975). An overlying tephra, identified as the Cherryville Tephra, is 5 cm thick and thought to be about 25,000 years old (Westgate and Fulton, 1975). The ages were determined from radiocarbon dates obtained from peat immediately above and below the tephra layers. Bessette Sediments are considered to be representative of depositional environments and climatic conditions similar to current conditions in the Okanagan Valley (Fulton 1976; Fulton and Smith, 1978), and are correlative with Olympia Interglaciation deposits in the Fraser Lowland.

Fraser Glaciation deposits are the most recent Quaternary sediments observed in Okanagan Valley and are represented by the Kamloops Lake Drift lithostratigraphic unit (Table 2.1). Kamloops Lake Drift sediments are the most extensive Quaternary sedimentary assemblage in south-central British Columbia. The unit is composed of at least 150 m of subaerially exposed glacial lacustrine and ice stagnation sediments. At numerous localities the unit overlies a relatively thin (15 m) section of till (?) and glacial outwash. Radiocarbon dates indicate the lithostratigraphic unit ranges in age from about 19,100 BP to 10,000 BP (Fulton and Smith, 1978). Kamloops Lake Drift is correlated with Fraser Glaciation deposits of the Fraser Lowland.

2.3.2 Holocene Climate and Surficial Sediments

Holocene vegetation and climate change in the Okanagan Valley is inferred from fossil pollen assemblages collected from a bog near Kelowna, British Columbia (Alley, 1976). During the drainage of Glacial Lake Penticton a pine (*Pinus*) and spruce (*Picea*) forest colonized the valley sides. This was followed by a warmer, dry interval correlated with the Hypsithermal period. Common plant species during this interval were arid grasses (*Graminae*) and sagebrush (*Artemisia*). A cooling interval after 6,600 BP was followed by three moister phases associated with the various stades of Neoglaciation in south-central British Columbia (Alley, 1976). A bog-bottom date of 8,410±100 BP (GSC-1867) is consistent with the date of about 8,900 BP proposed for ice and glacial lake free conditions in Okanagan Valley (Fulton, 1969).

The earliest discussion of surficial sediments in North Okanagan Valley was provided by Nasmith (1962). Later work by Fulton (1975) is summarized in a series of surficial sediment maps for the North Okanagan Valley region (Fulton, 1975, Maps 1392A and 1391A; Figure 2.7).

The valley floor between Vernon and Enderby largely consists of glaciolacustrine sediments (Figure 2.7). North of Enderby glaciolacustrine sediments interfinger with modern alluvium from the Shuswap River. Mixed, unconsolidated, coarse-grained valley margin deposits and alluvial fans comprise the remainder of the surficial fill from Vernon to North of Enderby.

An abandoned meltwater channel is first observed 3.6 km south of Enderby and extends to the north arm of Okanagan Lake west of Vernon (Figure 2.7). The channel represents the largest erosional landform in the North Okanagan Valley. Elsewhere, the sediments are intact and it appears that limited erosion of the fill has occurred since deglaciation.

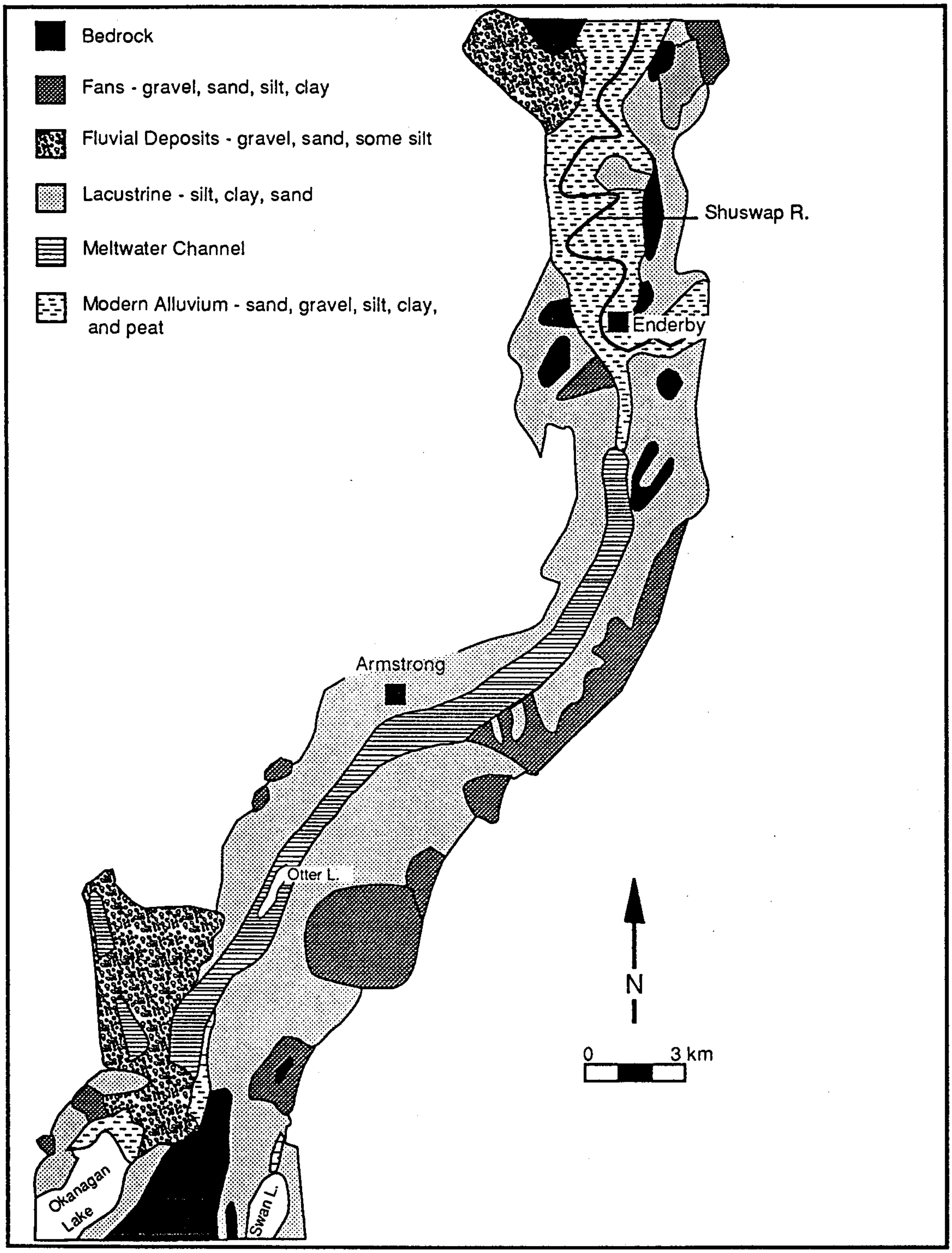


Figure 2.7 Geomorphology and surficial sediments of North Okanagan Valley (after Fulton, 1975).

2.4 Glaciation, Glacial Lakes and Silt Deposits

2.4.1 Styles of Glaciation

The nature of the late Pleistocene sedimentary record of south-central British Columbia is closely related to the style of glacier decay. The stagnation of large ice masses in the Okanagan and adjacent valleys formed extensive lakes and the accompanying deposition of lacustrine sediments. It is in this context that the work of Davis and Mathews (1944) is instructive, because they provided a comprehensive description of the various stages of Cordillera Ice Sheet build up and decay.

Cordilleran glaciation began as alpine glaciers advanced and amalgamated to form ice caps. The ice caps then flowed from the uplands to form piedmont lobes that coalesced to form ice sheets (Davis and Mathews, 1944). During the ice sheet phase the glacial ice was no longer influenced by the underlying topography. As a result, glacial ice flowed southward, overriding eastern and western mountain systems of the Columbia Plateau region. At this time the ice accumulation zone was centered over the central interior of the Cordillera. Jackson and Clague (1991) provide a comprehensive review of the development and state of scientific inquiry pertaining to the Cordilleran Ice Sheet in British Columbia and the Yukon.

In Okanagan Valley, the stages of ice sheet growth and decay probably closely followed the various stages proposed by Davis and Mathews (1944). Ice initially flowed southward from the Interior Plateau and eastward from the Coast Mountains into southwestern British Columbia. During the early phases of glaciation the Interior and Coast Mountain ice masses coalesced with a large lobe of westward flowing ice from the Coldstream Valley, southeast of Vernon, and a smaller lobe from the Salmon River Valley west of Vernon. This large piedmont lobe, called the 'Okanagan Lobe', then flowed south into Washington

State (Nasmith, 1962). Ice sheet coverage of the south-central Interior of British Columbia occurred for the final time at about 17,000 BP. A large terminal moraine, the Winthrop Moraine, bordering on Grand and Moses Coulees some 50 km south of the Columbia River, delineates the southern extent of the Okanogan Lobe into the Columbia Plateau during late Pleistocene time (Easterbrook, 1976).

Although the genesis and early phases of ice build-up in the Cordillera are somewhat speculative (Fulton, 1991), the pattern of deglaciation is better understood. Deglaciation of the Cordillera was generally characterized by the recession of glaciers to their alpine accumulation zones, but in the Okanagan Valley deglaciation usually took the form of stagnation. Fulton (1991) believes that the underlying physiography of the ice sheet influenced the decay of the Interior ice so that thicker ice masses were located in the valley bottoms. This, in combination with rapid climatic amelioration and the failure of the ice sheet to recede to alpine accumulation zones, resulted in *in situ* ice stagnation in the valley bottoms. Upland areas rapidly emerged through the ice sheet and isolated ice lobes downwasted in deeper valley bottoms. Drainage from meltwater channels was diverted along the margins of stagnating ice masses and coarse-grained debris was transported down valley. Frequently, debris transported by ice marginal channels combined with coarse-grained tributary valley sediments and stagnant ice to obstruct drainage. These processes led ultimately to the impoundment of meltwater and the formation of glacial lakes in the Okanagan Valley (Fulton, 1969).

2.4.2 Glacial Lakes

Numerous glacial lakes were formed during late Wisconsin time in the Okanagan Valley. Nasmith (1962) provided the first detailed account of the glacial lake history in Okanagan Valley and used the name 'Lake Penticton' to refer to a lake that extended from Penticton to Enderby in the north. He suggested that during deglaciation southward drainage of the Okanagan Valley was controlled by a 'plug' of clastic debris and buried ice. The blockage, located near Okanagan Falls south of Penticton (Figure 2.6), was the mechanism responsible for impounding meltwater drainage and the formation of Glacial Lake Penticton. Both the sediment 'plug' and differential isostatic tilting controlled lake levels and the gradual drainage of Glacial Lake Penticton (Nasmith, 1962).

For the Okanagan Valley, Fulton (1969) took Nasmith's (1962) work on Glacial Lake Penticton and developed a more detailed picture of it's various stages. He proposed that Glacial Lake Penticton be sub-divided into four stages: 1) Long Lake Stage; 2) Grandview Flats Stage; 3) B.X. Stage; and 4) O'Keefe Stage (Figure 2.8).

Long Lake Stage developed as glacial ice retreated from the Kalamalka Lake region south of Vernon. During this stage ice remained in the Okanagan Valley, but a meltwater channel formed along the west valley side between Armstrong and Vernon. Evidence for Long Lake Stage is found in the form of delta terraces and extensive silt deposits near Armstrong. Lake levels during this stage were from about 486 to 517 masl.

Grandview Flats Stage is of particular interest to this dissertation because it represents the first glacial lake stage to occupy the entire North Okanagan Basin (Fulton, 1969). Geomorphic evidence including non-glacial deltas and valley side terraces suggest a relatively stable shoreline at approximately 486 masl. Moreover, ice remained in various valley locations during this stage. Knowledge of the various ice and water positions are important considerations when reconstructing depositional environments. For

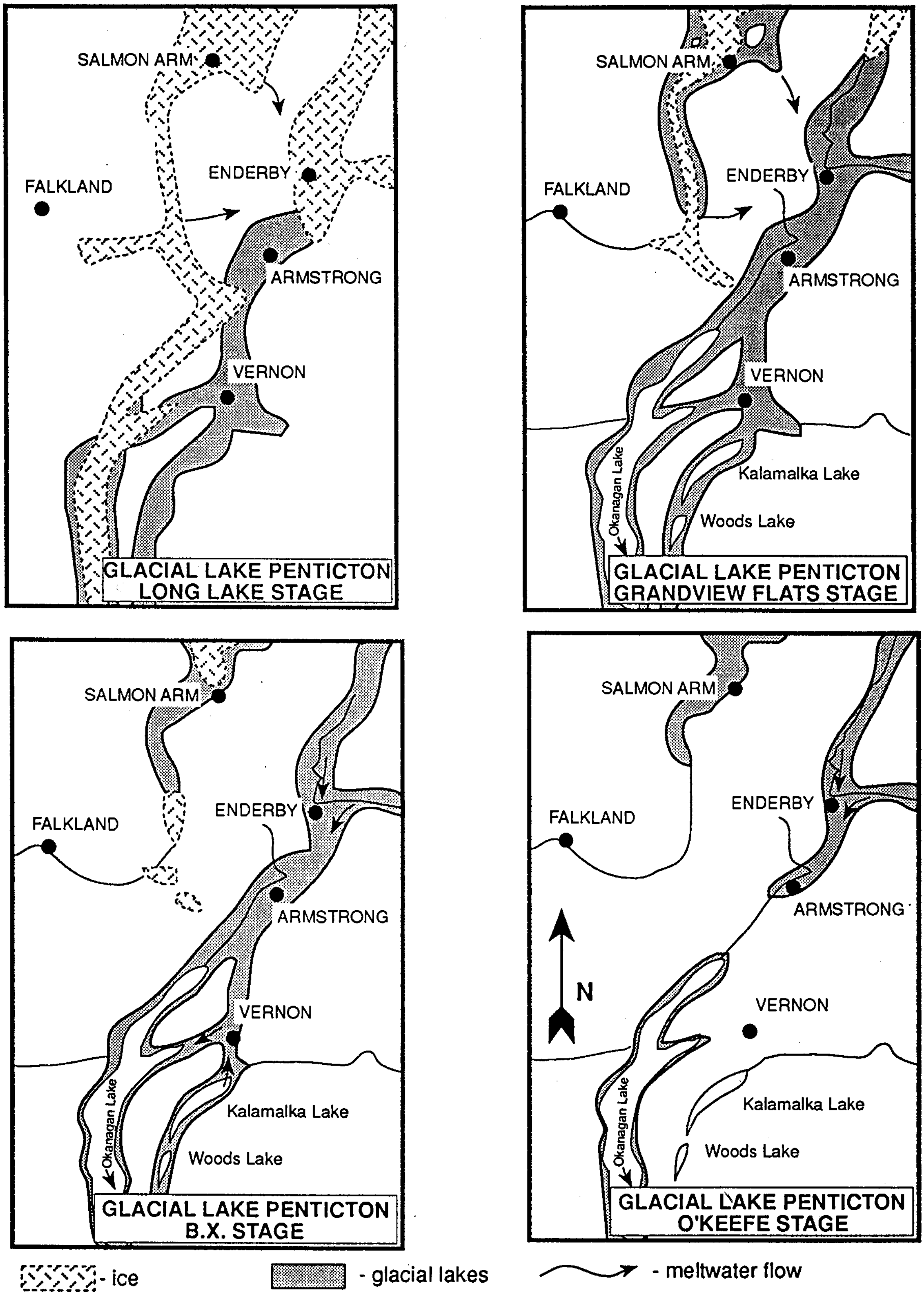


Figure 2.8 Stages of Glacial Lake Penticton in the North Okanagan region (after Fulton, 1969).

example, it may be necessary to determine if deposition was occurring in dynamic ice proximal or more quiescent ice distal environments. As indicated in Figure 2.8, at locations north and west of Enderby, ice existed in the form of retreating, or stagnant and dead ice masses.

B.X. Stage was the most extensive stage of Glacial Lake Penticton. During this stage lake shorelines extended from Okanagan Falls north into Mara Lake Basin; perhaps into the present Shuswap Lake Basin (Fulton, 1969). The stage is defined by numerous deltas and terraces constructed at the mouths of several tributary valleys, and by weakly developed southward dipping shorelines. Lake levels during B.X. Stage stabilized at approximately 425 masl and Nasmith (1962) reports a southward tilt of about 0.67 cm/km for the paleo-shorelines. Between B.X. and O'Keefe Stages the Otter Creek meltwater channel formed between Enderby and the present location of the north shore of Okanagan Lake.

The onset of Glacial Lake Penticton - O'Keefe Stage was marked by a rapid drop in shoreline elevations to about 354 masl. This reduction in lake levels is attributed to gradual north-south isostatic tilting and the melt of buried ice in the sediment plug at Okanagan Falls. By the end of O'Keefe Stage drainage separation between North Okanagan Valley and Shuswap Valley had occurred. This ultimately formed the drainage divide between the two basins, currently the divide is located immediately south of Armstrong.

The chronology of the sequence of glacial lake stages observed in the Okanagan Valley are poorly constrained due to a paucity of radiocarbon dates. Fulton (1969) proposes that deglaciation of the region was well advanced by about 10,000 BP. His interpretation is based on a radiocarbon date of 9,750 ± 170 BP (GSC-526) collected from wood deposited in a glacial lake outlet channel at an altitude of about 914 masl. At this site the paleo-channel enters the Thompson Valley at Monte Creek (Figure 2.6). The date suggests the uplands above 914 masl were deglaciated by about 9,800 BP and vegetation had sufficient time to establish in the region. A radiocarbon date of 8,900±150 BP (GSC-193) collected from the floor of the Otter Creek abandoned meltwater channel, south of Armstrong, provides a minimum date for deglaciation in the region (Figures 2.6 and 2.7). By this time deglaciation was complete, all glacial lakes were drained, shoreline positions were similar to contemporary shorelines, and modern drainage was established (Fulton, 1969).

2.4.3 Lacustrine Silt

Thick, laterally extensive glaciolacustrine silt is found throughout the Nicola, Thompson, Okanagan, and Columbia Valleys of the Cordillera (Fulton, 1965). Dawson (1879) first recognized their distinctiveness and origin, noting "The benches or terraces on the south Thompson ... formed of hard, fine, white silts, which have been deposited in the bottom of a lake formerly filling the valley."

Flint (1935) provided a detailed account of the silts in Okanogan Valley, eastern Washington State. He attributed the silts to sedimentation in an ice-dammed lake in the Okanogan Trench during late Pleistocene time. Deformation structures observed in the silt exposures were associated with the *in situ* melt of buried ice masses (Flint, 1935).

Meyer and Yenne (1940) made the first petrographic examination of the silts. They concluded that the mineralogy is distinctive for the South Thompson and Okanagan Valleys and suggest local source areas for the sediments. Grain angularity and presence of texturally immature feldspars provided evidence of limited stream transportation and rapid deposition (Meyer and Yenne, 1940). Early discussions of the origin of Okanagan Lake and related depositional environments of the silt are given by Schofield (1943) and Mathews (1944). Nasmith (1962) provided the first comprehensive description of the Okanagan Valley silt as sediments that were deposited in a glacial lake during ice retreat.

Fulton (1965) studied the silt in Thompson Valley, east of Kamloops, British Columbia. He noted varved layers up to 610 cm thick that exhibit an upward decrease in thickness. The silts were interpreted as locally derived deposits from glacial meltwater channels that flowed along receding ice margins. Interestingly, Fulton (1965) first noted the interfingering of gravel and sliderock with glacial silt along valley margins in the North Thompson Valley, however, no further discussion was made regarding the implications of the interfingered coarse and fine-grained sediments on the geometry of the basin fill.

Recent investigations of the glaciolacustrine silts have focused on examining the relationships between ice retreat, ice stagnation, and the presence of coarse sediments interbedded with fine-grained silt. These investigations, by Shaw (1975, 1977) and Shaw and Archer (1978, 1979), provide detailed accounts of the physiographic and sedimentological characteristics of the silts near Penticton, British Columbia. Shaw (1975) describes a complex association of gravel, sand, horizontally laminated silt, and diamict that comprise a deltaic succession. He interprets the sediments as the result of the progradation of a Gilbert-type delta with steep forsets into a deep lake basin situated in the Okanagan Valley.

Subsequent work by Shaw (1977) and Shaw and Archer (1978) describe the properties of both grainflow and turbidity flow in Glacial Lake Penticton and use this information to develop three seasonal models for sedimentation in an alpine lake. The model emphasizes the importance of changing depositional processes, distance from the ice margin, and the effect of the melt out of buried ice masses on the final attitude of glaciolacustrine sediment complexes. Finally, Shaw and Archer (1979) suggest a conceptual framework of deglaciation and glaciolacustrine sedimentation in the Penticton region. They indicate that the considerable degree of deformation and faulting evident in the glaciolacustrine sediments suggests deposition over stagnant ice. A depositional model stemming from their study proposes a complex sequence of stagnant ice overlain by debris, glacial lake formation over the stagnant ice and debris, and the subsequent undermelting of the ice and lowering of lake levels.

CHAPTER THREE

RESEARCH METHODS

3.1 Introduction

Research in the North Okanagan Valley was conducted during three field seasons: the summers of 1988, 1989 and 1990.

During the summer of 1988 an eight week reconnaissance of the surficial geology of the North Okanagan Valley was carried out. Exposed deposits and stratigraphic type sections in the Okanagan valley were observed and recorded in order to develop a general understanding of the basin fill and Quaternary stratigraphy of the study area. At the same time site, accessibility was evaluated for a shallow reflection seismic survey. Site considerations included accessibility, nature of the surficial deposits for seismic shooting, and the potential to integrate valley cross-sections (east-west) with longitudinal profiles (north-south).

A high resolution-shallow reflection seismic survey was conducted during the summer of 1989. Initially, four weeks of subsurface testing was conducted to determine the optimum common offset and to locate the most suitable sites for seismic profiling. This work was followed by the collection of shallow reflection profiles at the predetermined sites in the North Okanagan Valley. In the subsequent fall and winter seasons the seismic lines were processed and plots were correlated with existing borehole data.

Drilling in the study area was conducted during the summer of 1990. Prior to the drilling season, existing British Columbia Environment Groundwater well logs were collected and interpreted for the study sites in the North

Okanagan Valley. Drilling was conducted at selected sites only after careful consideration of the seismic data, groundwater logs, time constraints, equipment limitations, and drilling costs. Following the acquisition of land access privileges site preparation required two days, followed by up to three weeks for completion of each drill hole (depending on depth).

Laboratory analysis of drill cores and cutting samples collected during the drilling season included detailed stratigraphic interpretation, photography, and detection of organic material. Additional analyses involved X-Ray Diffraction (XRD), oxygen isotope determinations, and radiocarbon dating.

3.2 Seismic Methods

3.2.1 Reflection Seismic Profiling

A key advantage of shallow reflection seismic profiling is the ability to obtain high resolution subsurface information. High resolution data, produced by low cost engineering seismographs, portable field computers, and relatively 'safe' and low cost energy sources has extended the applicability of shallow reflection surveys for detailed Quaternary investigations (Roberts et al., 1992; Sharpe et al., 1992; Jol and Roberts, 1992; Steeples and Miller, 1990). The common-offset seismic technique was used in this study (Hunter et al., 1984; Hunter and Pullan, 1989).

3.2.2 Common Offset Technique

The shallow reflection-common offset technique is based on the principle of the "optimum window". The optimum window is the range of source-geophone separations that allows for reflected events to be observed with minimum interference from signal generated disturbances such as the effects of ground roll (Rayleigh or surface waves) and ground coupled airwaves (Hunter et al., 1984; Figure 3.1). The limits of the optimum window are specified by the onset of signal interference and study objectives (e.g. depth to bedrock).

Having identified the optimum window, a source-geophone separation is selected within the window that portrays the target reflectors with minimum signal generated noise. This source-geophone separation is known as the "optimum offset" and the offset distance is maintained for the entire survey, so great care must be taken in the selection of the offset (Jol, 1988). In this study an offset of 72 m was used.

A 12-geophone array is typically used during an optimum offset survey and each channel is shot individually while maintaining the optimum offset between each geophone and shot point (Figure 3.2). For each spread of 12 geophones a multi-channel reflection record is collected in addition to the common offset record. The multi-channel record is collected with the shot-point positioned at the mid-point of the source-geophone separation or into the third shot point position. These records are subsequently used for velocity analysis and normal moveout corrections (Hunter et al., 1989).

3.2.3 Data Processing

After the collection of the raw common offset records, data processing is applied prior to the production of the seismic profiles. Data processing improves the appearance of the final plots and reduces the effects of signal generated interference. In the field, raw data collected during the day is down loaded from the seismograph to a microcomputer. Data processing includes file back-up, filtering, and preliminary plotting on a dot matrix printer.

Initial data processing involves the application of static corrections to each trace of each spread. Commonly, the first arrival on each trace is a

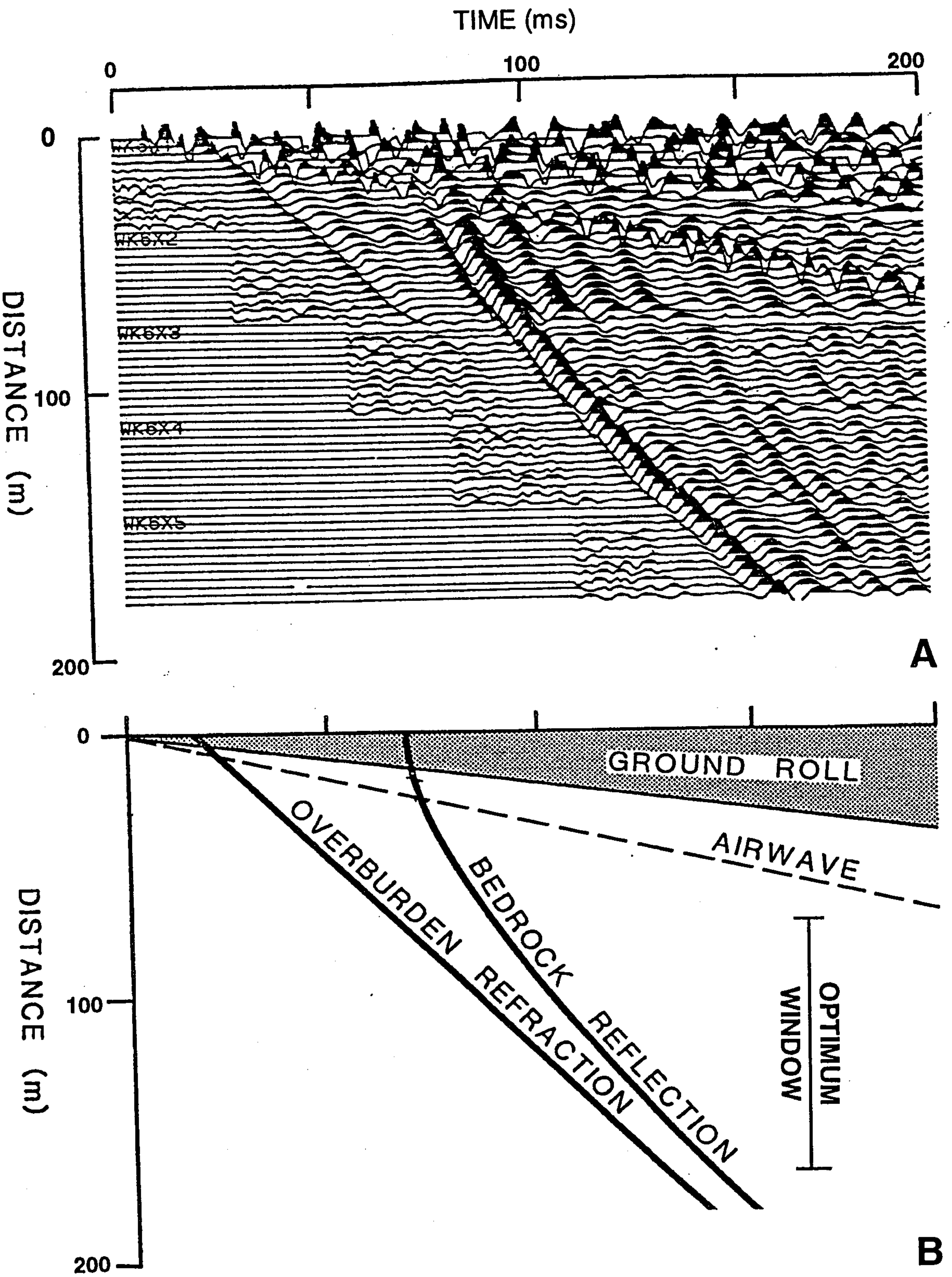


Figure 3.1 Determining the optimum window using the common offset technique (after Hunter et al., 1984). **A** shows uninterpreted multi-channel record, **B** indicates interpreted acoustic events and optimum window.

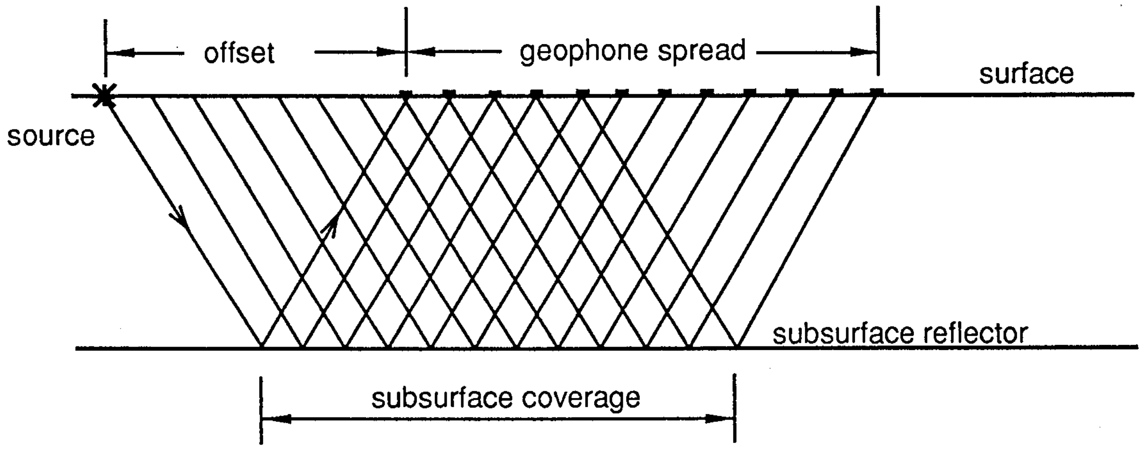


Figure 3.2 Geophone arrangement and subsurface coverage using the Common Offset technique.

refracted event generated from the interaction of the ray path along the water table. By aligning each of these first arrival events to a common datum the effects of the low velocity layer (LVL) above the water table can be eliminated (Hunter et al., 1989). Therefore, the origin for the depth scale on each seismic line represents the boundary between the basin fill and the LVL.

Digital band pass filtering is then applied to the data to standardize the frequency spectra of the records. Digital filtering is followed by the application of an automatic gain control (AGC) that standardizes trace to trace variations in wave amplitude and enhances weak reflectors. Linear gain tapers are used to enhance target reflectors and minimize interference within predetermined time windows (Figure 3.3). Processing parameters used in this study will be discussed later in the chapter.

3.3 North Okanagan Valley Seismic Survey

3.3.1 Introduction

A total of 16 line km of shallow reflection seismic profiles were recorded in the North Okanagan Valley. A key design objective of the survey was to collect both depositional strike (east-west) and dip (north-south) seismic sections of the North Okanagan Basin fill. Approximately 9 km of Simon Fraser University, Department of Geography (SFU) seismic lines were collected. These were supplemented by 7 km of Geological Survey of Canada (GSC), Terrain Sciences Division (Seismic Section) seismic lines (Pullan et al., 1992).

The seismic lines are numbered randomly and are described relative to the Vernon, Armstrong, and Enderby sites (Section 3.4). Locations of all seismic lines used in this study are found in Appendix C (Figure C-2).

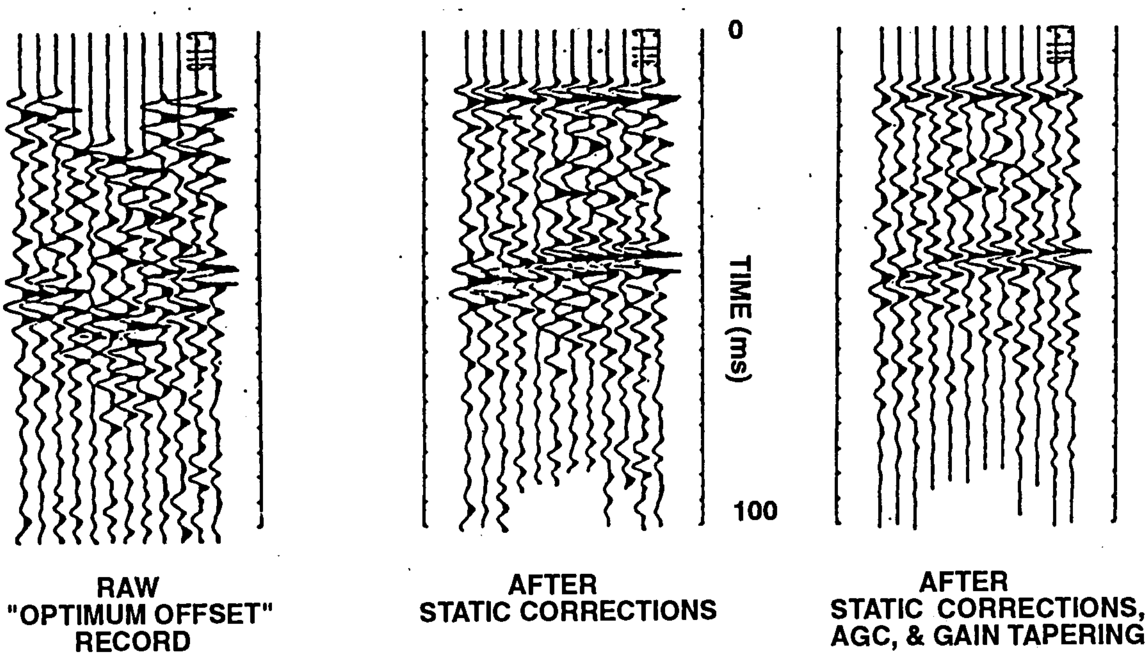


Figure 3.3 Effects of data processing on raw optimum offset records (after Hunter et al., 1989).

3.3.2 Seismic Crew

The seismic survey was conducted in the North Okanagan Valley during the summer of 1989. The seismic crew consisted of the author and two undergraduate research assistants. Standard operation involved the seismograph operator working inside a 1/2 ton panel van, and two assistants firing shots and setting geophones. At each site seismic line shot points and geophone positions were surveyed, marked, and shot holes were augured where necessary. On a typical day, when all shot holes were augured and water tamped, approximately 8, 36 m spreads were collected.

A base camp was established at Swan Lake campground north of Vernon. Computer facilities were housed in a trailer modified to provide desk and computer space. Each day data were downloaded each day from the seismograph to a personal computer (Apple IIe), files were backed-up, filtered, static corrections applied, and seismic lines printed to verify that the system was functioning normally.

3.3.3 SFU Seismic Parameters

The optimum offset was determined to be 72 m. High frequency 50 Hz geophones in marsh casings were used with a 3 m geophone interval along a 12-channel linear geophone array. Data were initially filtered in the field by the high frequency geophones and by 75-1000 Hz analog filters in a Bison 8012A engineering seismograph. Additional filtering using 75-800 Hz filters and static corrections were applied to the data prior to the preparation of final plots. Final plots were prepared by the author at the Geological Survey of Canada, Terrain Sciences Division Seismic Laboratory (Ottawa), using a Tektronix 4663 Interactive digital plotter.

The energy source was a 12-gauge "Buffalo Gun" (Pullan and MacAulay, 1987) using 1.25 oz lead slugs. Most lines were shot with a 500 ms two-way travel time (sweep); no signal delays were applied. A 60 Hz notch filter was used when overhead transmission lines were encountered.

The aforementioned parameters were used for all SFU lines with the exception of SFU Line 900 which was shot using a 66 m offset and a 200 ms sweep. Line 900 was collected along a previously surveyed section of SFU Line 100 in order to obtain greater detail in the near surface. Additional seismic plotting parameters and survey notes are listed in Appendices A and B, respectively.

3.3.4 GSC Seismic Parameters

In the summer of 1984, the Geological Survey of Canada, Terrain Sciences Division, Seismic Section, conducted tests of the shallow reflection-optimum offset technique in the Okanagan Valley north of Vernon (Pullan et al., 1992). The main objectives of the GSC study were to assess the applicability of the technique in thick basin fills and evaluate the utility of various energy sources.

The water table was observed at 5 m depth during the GSC survey. Optimum offsets from 150 to 225 m were selected using 50 Hz geophones and a 3 m geophone spacing. Data were recorded on a Nimbus 1210F engineering seismograph and Nimbus G724S tape recorder. A variety of energy sources were used and included a 16 lb sledge hammer, a 65 kg weight drop, and 8 and 12-gauge 'Buffalo' guns (Pullan and MacAulay, 1987).

All other recording parameters, equipment, and data processing were similar to those used in the SFU North Okanagan Basin study (Section 3.3.2 and Appendix A).

3.3.5 Velocity Analysis

Based on the analysis of the multi-channel spreads, acoustic velocities of 1300 m/sec for the low velocity layer (LVL) and 1700 m/sec for the fill below water table were determined. A low velocity layer is common in the upper 0 to 30 m of an unconsolidated basin fill. Refraction velocities ranging from 304 m/sec to 580 m/sec were reported by MacAulay and Hobson (1972) for the near surface zone in the study area. The velocity of 1700 m/sec correlates with modal refraction velocities of 1570 m/sec for the North Okanagan Valley fill (MacAulay and Hobson, 1972) and velocities of 1600 m/sec to 2000 m/sec obtained for the Okanagan Lake Basin (Eyles et al., 1991). Pullan et al., (1992) determined a near surface velocity of 1500 m/sec and a lower basin fill velocity of 1800 m/sec for the North Okanagan Valley. Below 400 m depth the 1800 m/sec velocity was assumed to be constant down to the overburden-bedrock contact.

3.3.6 Site Conditions and Seismic Adjustments

Preliminary testing in the early summer of 1989 found that surficial sediments in the study area were extremely dry and compact. In light of these findings minor adjustments were required in order to conduct the common offset seismic survey. Firing points were augured to 0.80 m depth and water tamped to enhance the source-formation coupling. The calculated common offset distance of 150 m was reduced to 72 m due to insufficient source-receiver signal return. Energy source attenuation was attributed to the extremely dry surficial sediments encountered at the seismic sites. Dry surficial sediments were likely the result of a dry winter preceding the hot, dry summer of 1989. Reduction of the common offset to 72 m resulted in source generated air waves observed at approximately 220-225 ms on some of the seismic profiles shot with a 500 ms sweep.

Geophones were planted so that the top of the geophone casing was flush with the ground surface to improve signal to noise ratio and ensure maximum receiver-formation coupling. In some instances the geophones were covered with a thin layer of top soil to further reduce noise generation. Similar techniques were implemented in seismic investigations of the Fraser River delta (Jol and Roberts, 1988).

3.4 Seismic Sites

Three sites were selected within the study area for the collection of seismic lines and drillhole data. The sites yielded favorable seismic test results in representative geomorphic settings of the North Okanagan Valley. The three sites were named after the nearest towns - Vernon, Armstrong and Enderby.

3.4.1 Vernon Site

The Vernon site is situated on a gentle, southward sloping lacustrine plain near the north end of Okanagan and Swan Lakes known locally as the Spallamacheen Prairie (Figures 3.4, 3.5). This 6.9 km wide portion of the North Okanagan Valley is divided by a prominent north-south trending bedrock ridge (Figure 3.6 and 3.7). To the west of the ridge lies the northernmost extension of Okanagan Lake and its confluence with an abandoned meltwater channel (Nasmith, 1962). East of the ridge lies the northern portion of a narrow basin that parallels the main Okanagan Valley and contains Swan, Kalamalka, and Wood Lakes.

Surficial sediments in the Vernon area include lacustrine silts and

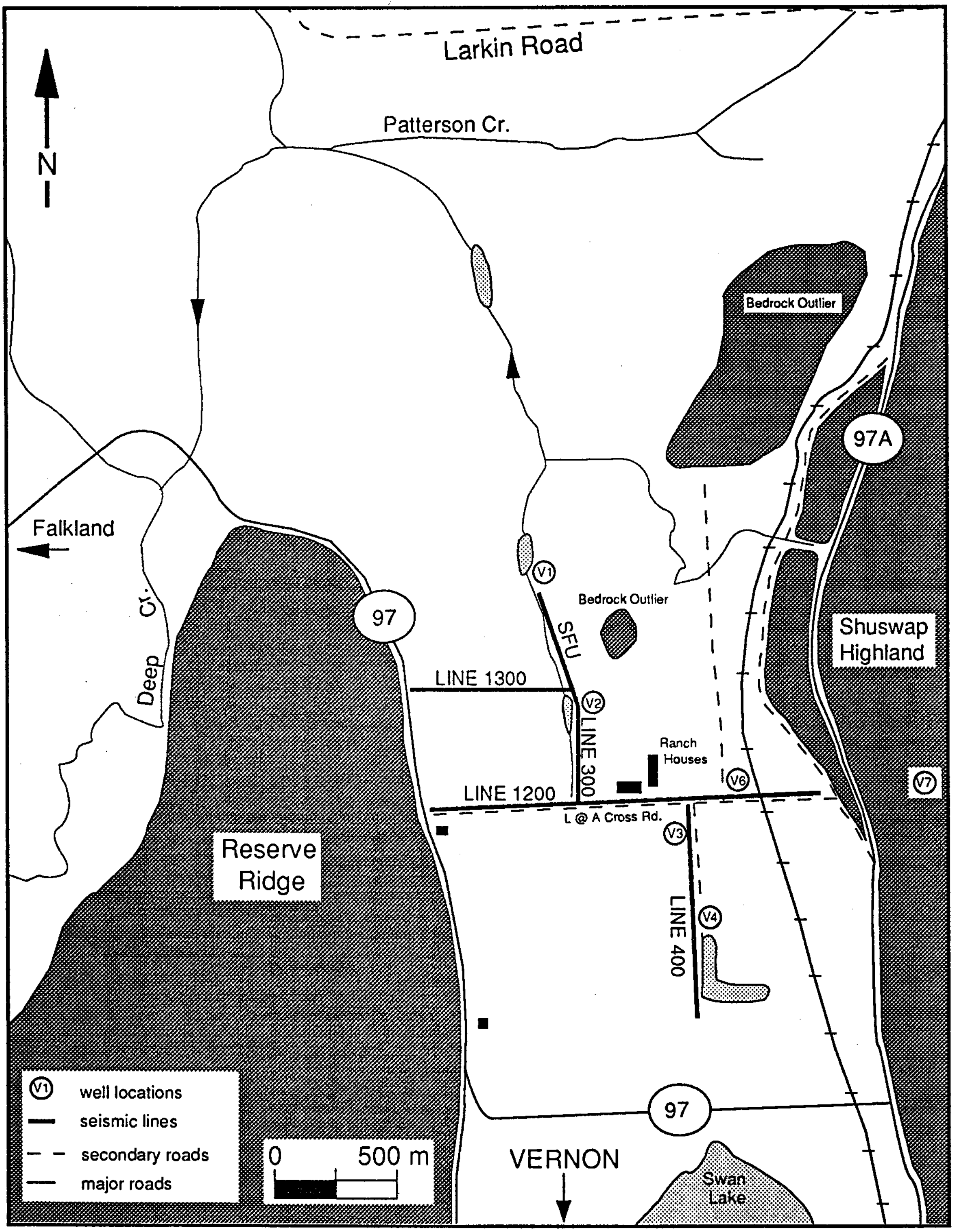


Figure 3.4 Location of Vernon site seismic lines and well logs.

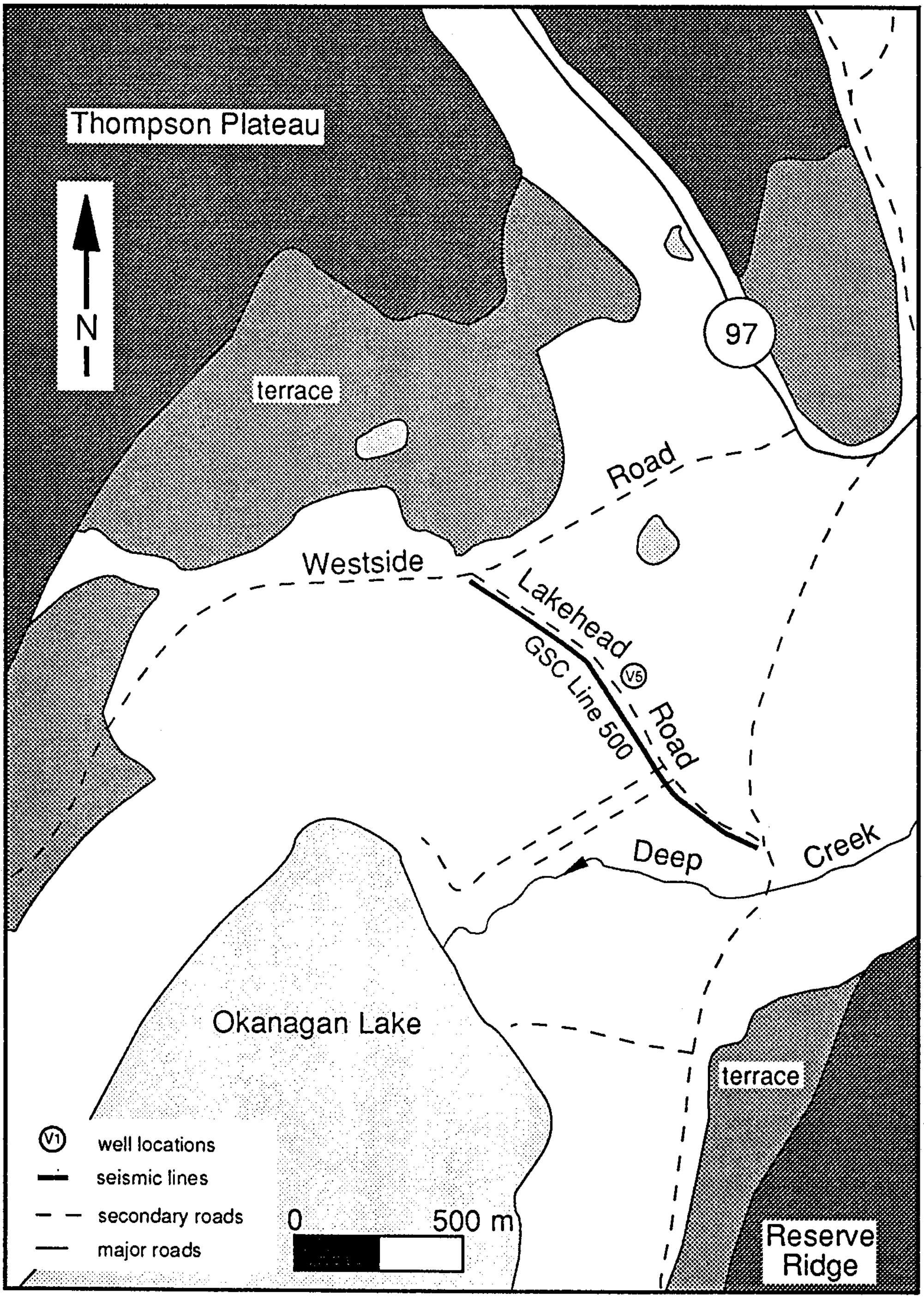


Figure 3.5 Location of GSC Line 500 and well log V5 north of Okanagan Lake.

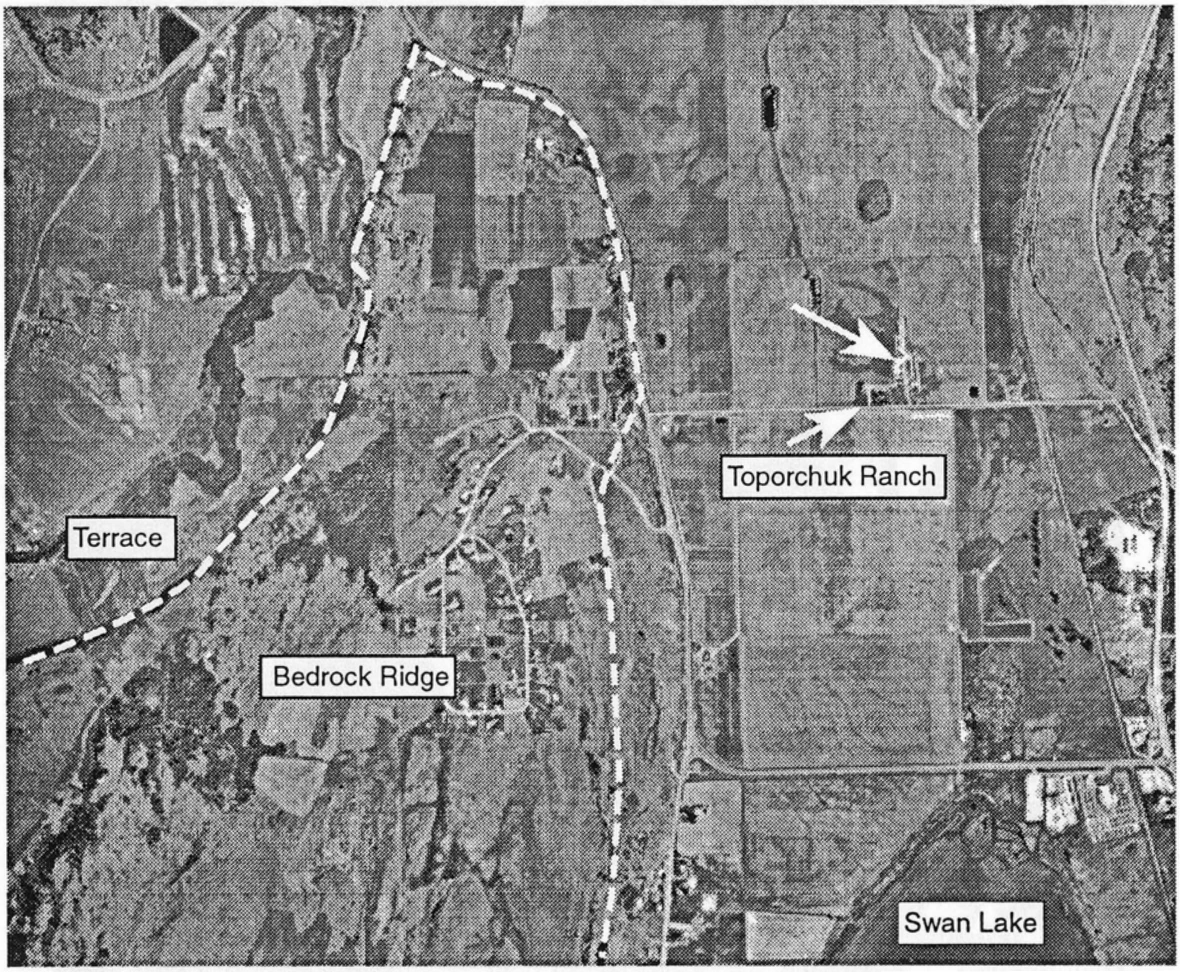


Figure 3.6 Bedrock ridge located west of Toporchuk Ranch that separates Vernon and Okanagan Lake sites (dashed line defines perimeter of ridge).

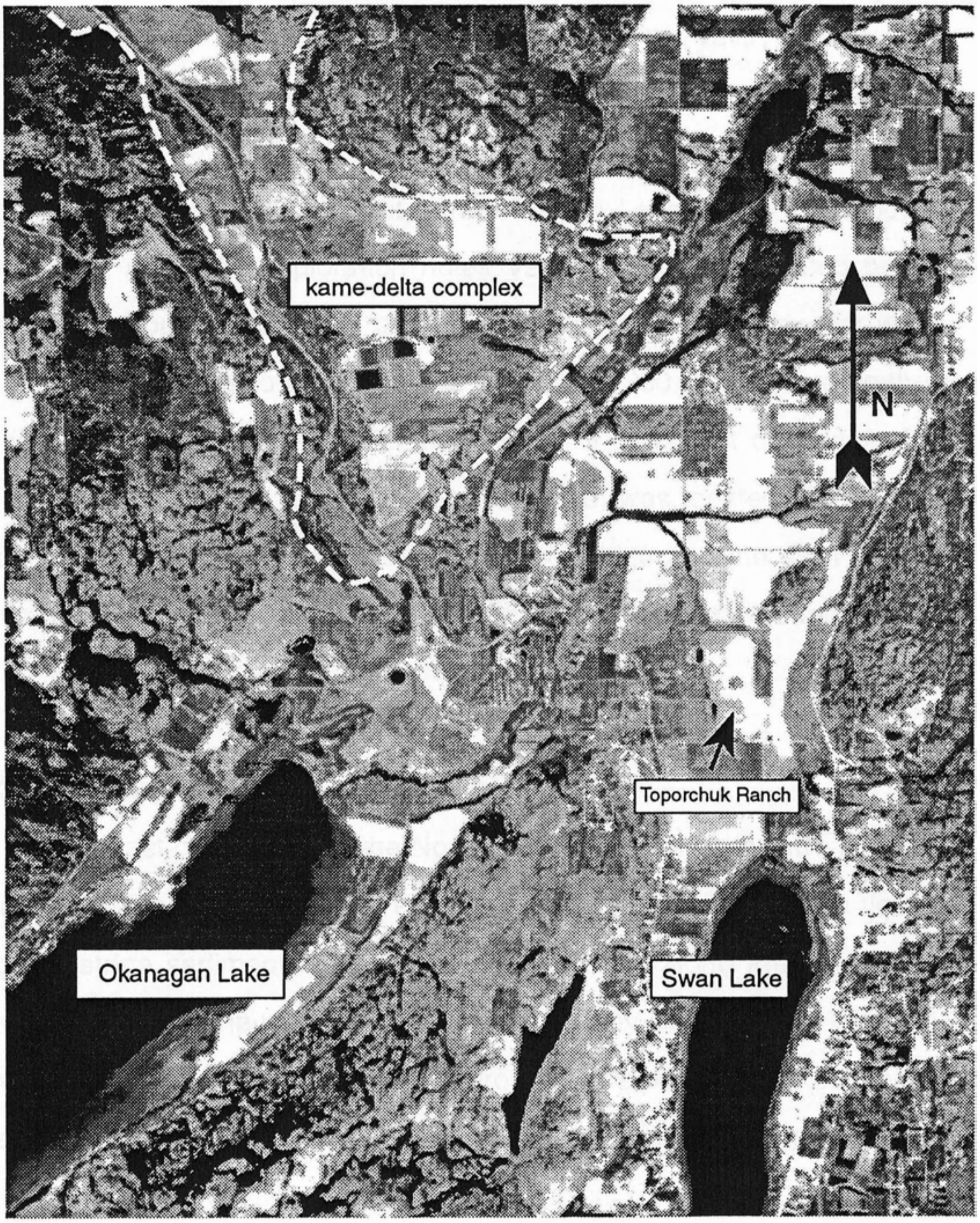


Figure 3.7 Confluence of the Salmon River Valley with North Okanagan Valley west of Toporchuk Ranch (dashed line delineates perimeter of the kame-delta complex).

alluvial fan deposits. West of Swan Lake a large kame-delta complex enters the valley from the Salmon River Valley (Figure 3.7). Bedrock rises steeply on all valley margins and a bedrock outlier crops out in mid-valley position north of the Toporchuk Ranch buildings (Figures 3.8 and 3.9).

Approximately 3.8 km of seismic lines were shot in the Vernon area, including 2.4 km of SFU line shot north of Swan Lake. SFU Lines 300, 400, 1200, 1300, and SFU exploration holes V2 and V4, were located north and south of the Toporchuk Ranch buildings (Figure 3.4). Groundwater well logs V1, V3 and V7 were also located at this site. Lines 300 and 400 are north-south trending dip sections; Lines 1200 and 1300 are east-west depositional strike profiles. GSC Line 500, a 680 m east-west line, was located along the north shore of Okanagan Lake between the bedrock ridge and the west valley side (Figure 3.5). Groundwater well log V5 was located mid-way between GSC Line 500.

3.4.2 Armstrong Site

Northeast of Armstrong, the North Okanagan Valley narrows to about 2.8 km and has a meltwater channel eroded along the axis of the valley floor. Flat lying lacustrine sediments and alluvial fans outcrop along the valley margins (Figure 2.7). The surface elevation of the east valley side is approximately 20 m above the meltwater channel floor. Bedrock rises steeply on the east and west valley sides and a large bedrock outlier crops out to the north (Figure 3.10).

During the summer of 1984 the Geological Survey of Canada shot 6.4 km of shallow reflection seismic lines northeast of Armstrong. The seismic lines are integrated in this study with an SFU seismic line. In total, approximately 7.3 km of seismic line were available for analysis at the Armstrong site. These included SFU Line 500 and GSC Lines 100, 300, and 700 (Figure 3.11).

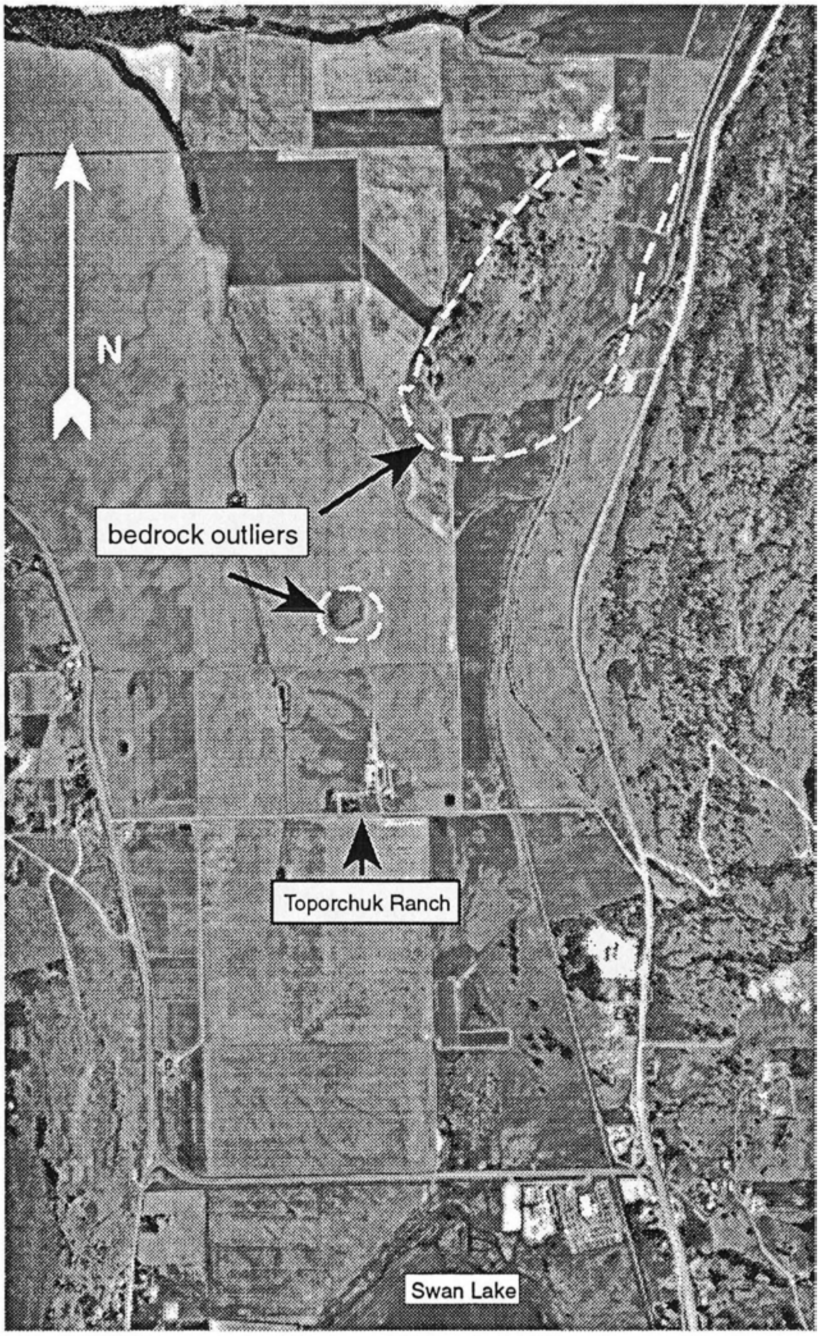


Figure 3.8 Bedrock outliers located near the Toporchuk Ranch site north of Vernon.

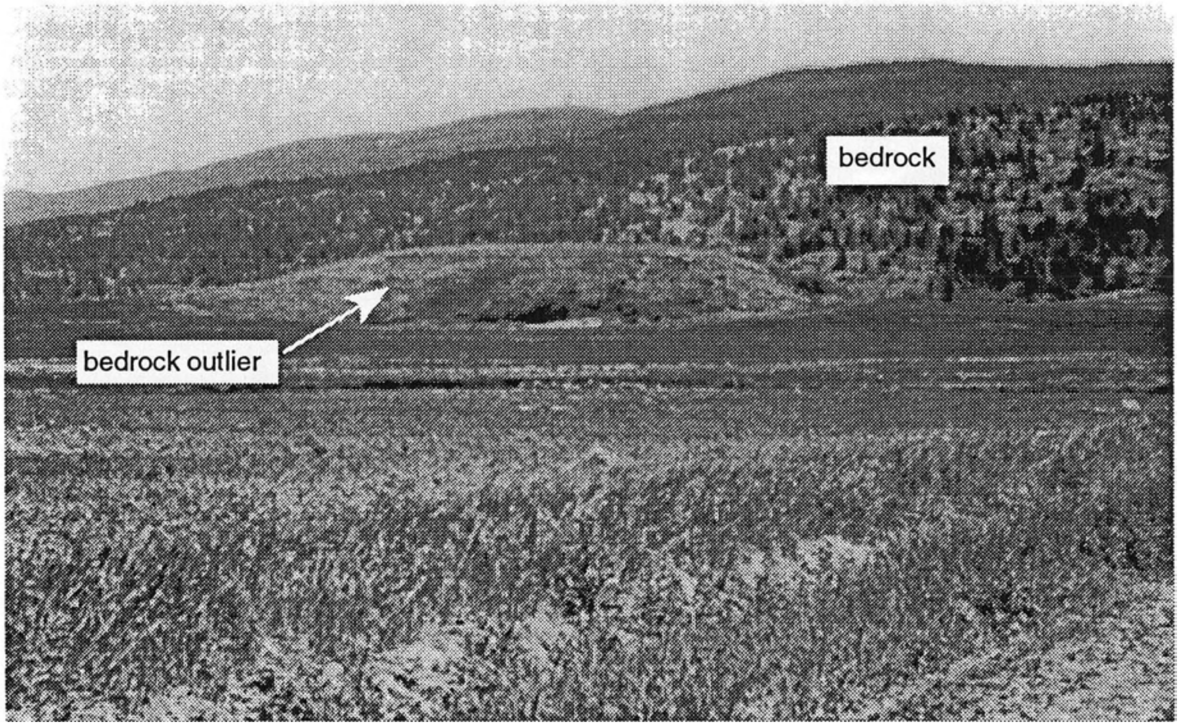


Figure 3.9 Bedrock outlier located approximately 800 m northeast of SFU drill hole V2 at the Vernon site. The eastern bedrock margin of the North Okanagan Valley is visible in the background.

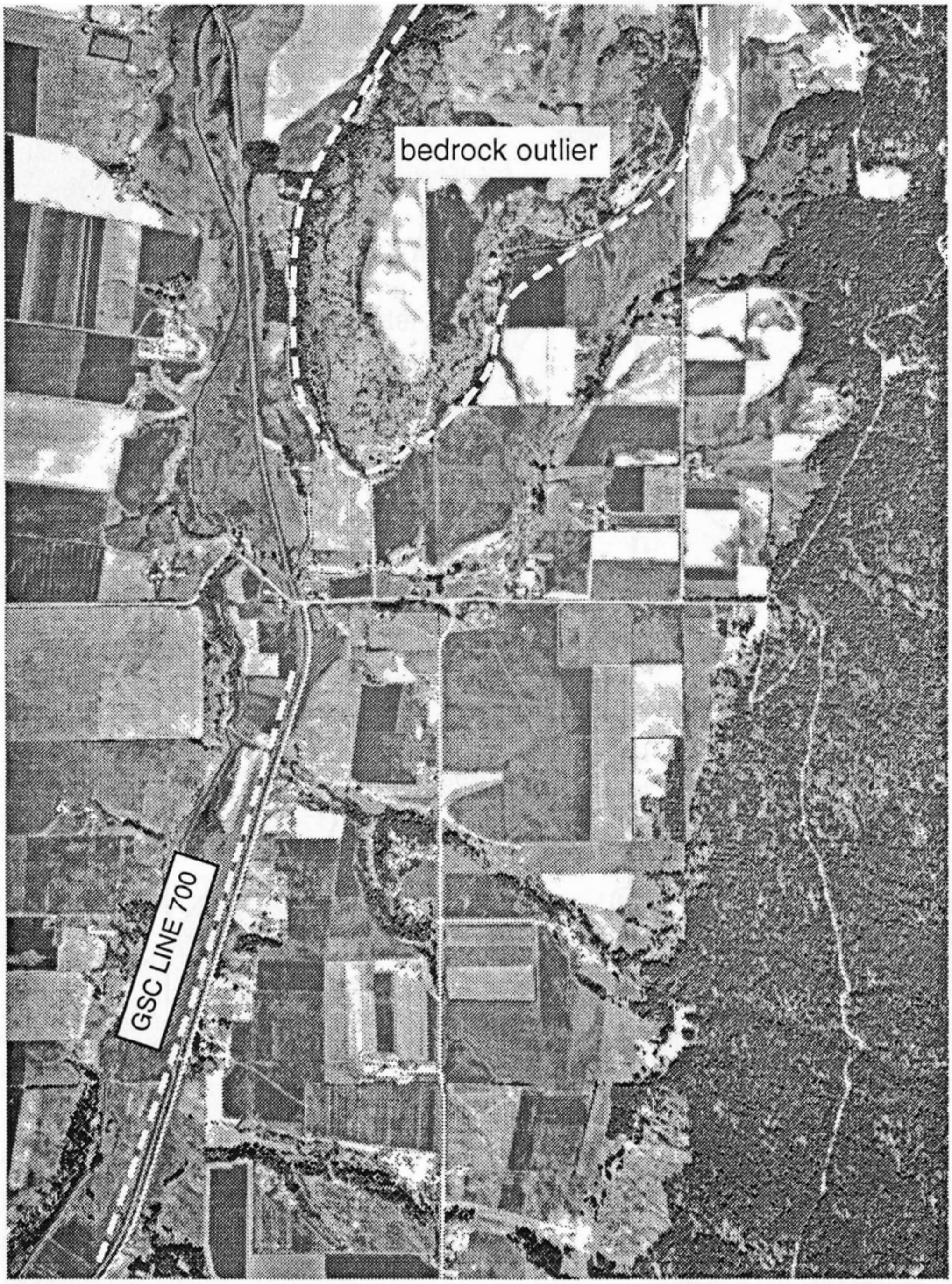


Figure 3.10 Bedrock outlier located north of GSC Line 700 at the Armstrong site.

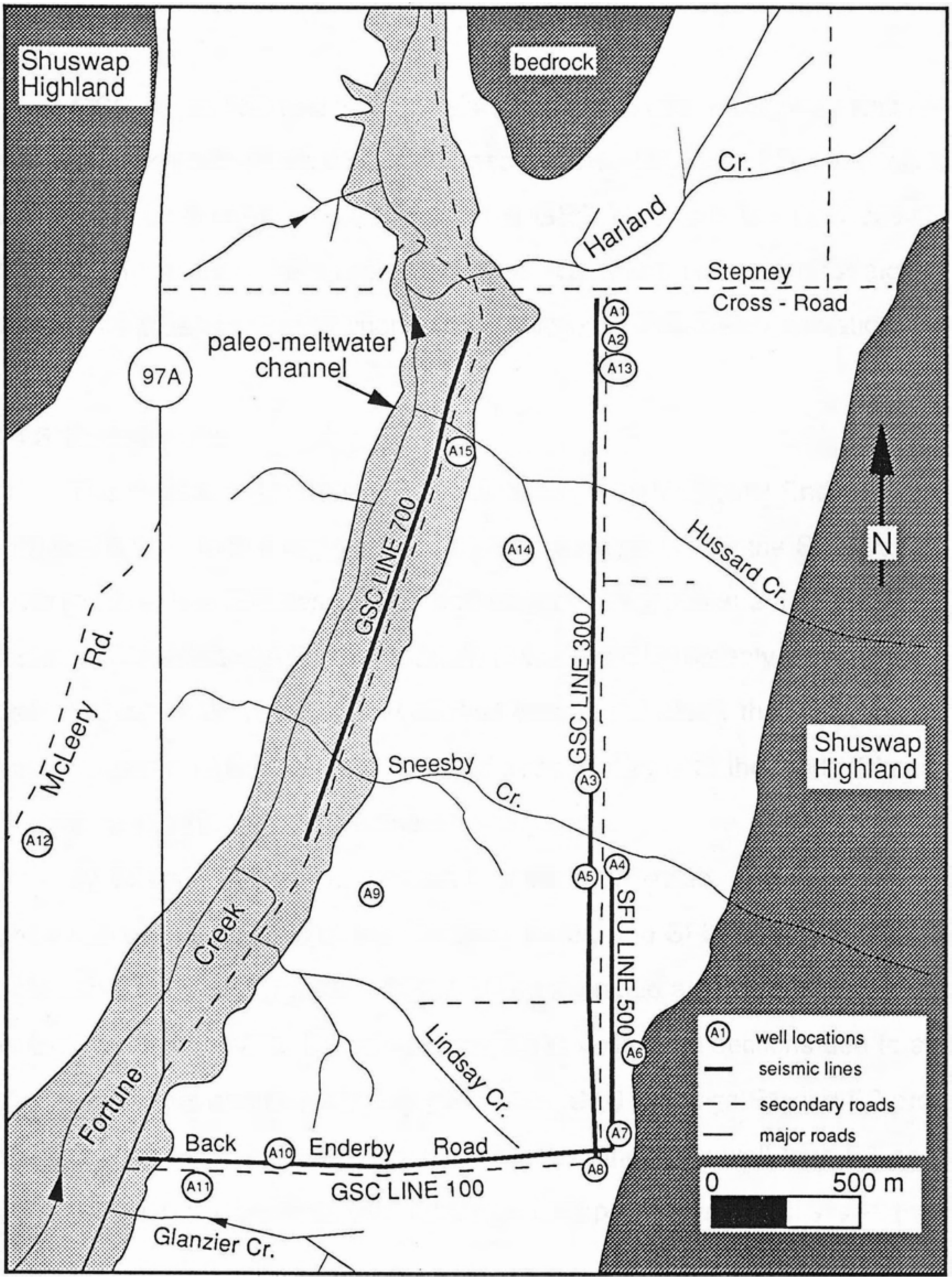


Figure 3.11 Location of Armstrong site seismic lines and well logs.

Detailed lithologic control is provided by SFU drill log A5 with groundwater well logs A1 to A4 and A6 to A15 used as supplementary lithologic sources (Figure 3.11).

GSC Lines 100 and 300 are situated on the east valley side and follow east-west and north-south directions, respectively. SFU Line 500 was collected along the same north-south transect as GSC Line 300 but provides more detailed information of the upper basin fill. GSC line 700 was shot along the base of the paleo-meltwater channel that follows a NNE-SSW orientation.

3.4.3 Enderby Site

The third survey site was located north of the Village of Enderby (Figure 3.12 and 5.12). In this region of the North Okanagan Valley the Shuswap River flows north to the Shuswap Basin and subsequently into the Thompson River system. The Shuswap River floodplain is bordered by steeply dipping bedrock walls, lacustrine sediments, and alluvial fans found along the valley margins. The confluence of the Gardom Creek tributary valley with the North Okanagan Valley is located in the northwest corner of the site.

At this site 4.9 km of seismic line were collected. This includes SFU Lines 700 and 1000 west of the Shuswap River, and SFU Lines 100 , 800 and 900 east of the river (Figures 3.12). All lines collected at the Enderby site follow an east-west alignment. It was not possible to collect dip sections due to a lack of suitable roads and accessibility problems. SFU drill logs E1 and E2 provide detailed lithologic information for the site. Groundwater well logs E3 and E4 were also used in seismic and lithologic interpretations for this site (Figure 3.12).

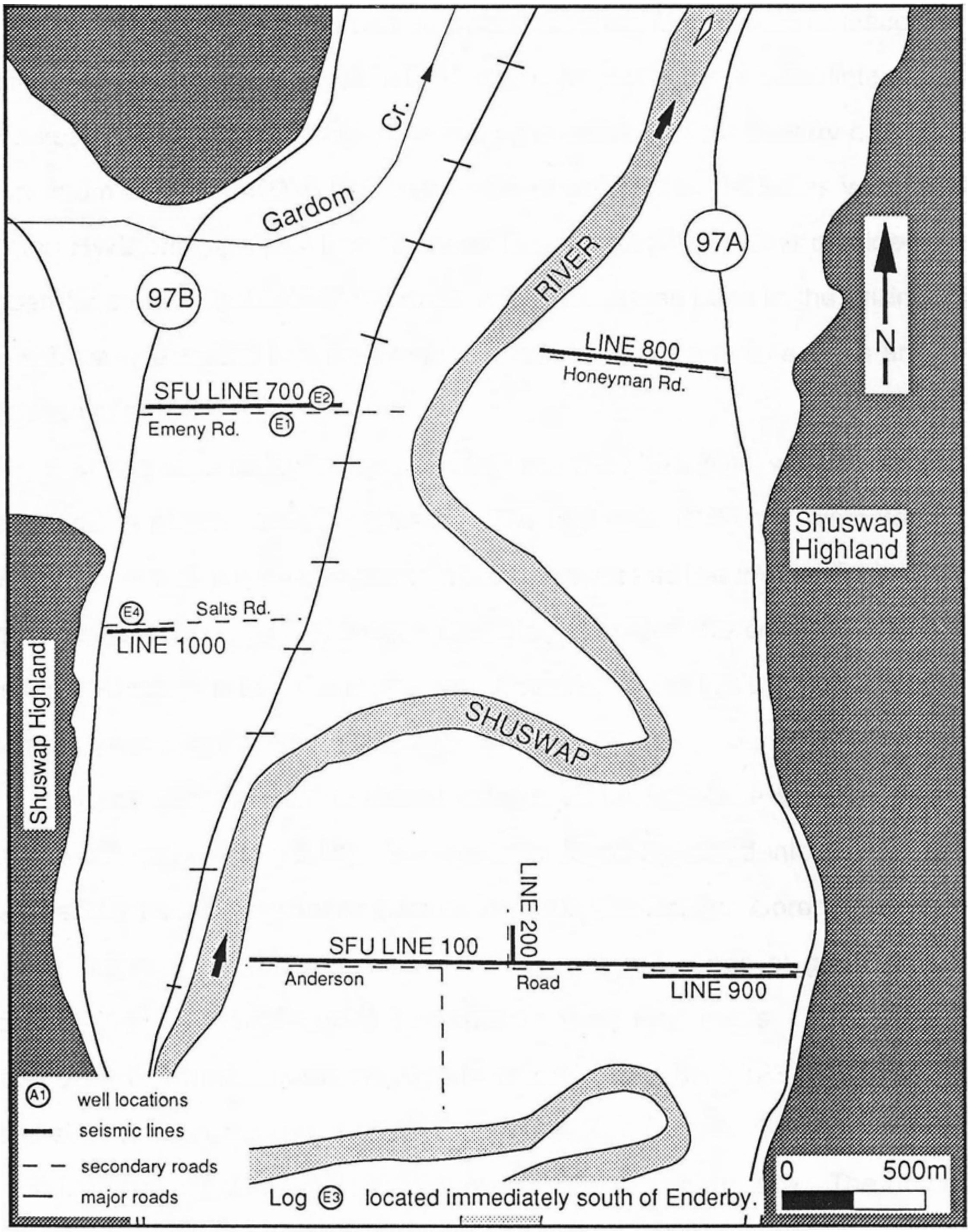


Figure 3.12 Location of Enderby site seismic lines and well logs.

3.5 Drilling and Well Logs

3.5.1 Mud-rotary Drilling

Lithologic information was collected using the Department of Geography, Simon Fraser University, Mobile B-53 drill rig mounted on a 5-ton International Harvester truck (Figure 3.13). The drill rig is capable of mud-rotary drilling to a maximum depth of 400 m in unconsolidated sediments. All holes were drilled using HWL drill pipe (3.5 inch diameter thin walled pipe) with a carbide-tipped open faced bit. 'Quick-Gel" bentonite drilling mud was used in the drilling fluid which was desanded in a mud tank and recirculated (to reduce costs and limit environmental impact).

When core sampling was carried out the HWL pipe was 'broken' and clamped in place. Smaller diameter BW drill pipe (2.5 inch diameter thick walled pipe) with a core sampler was then lowered into the HWL drill pipe to the desired sample depth. The open faced bit permitted the core sampler to be inserted through it into the formation. Essentially, the HWL pipe served as a temporary casing during the extraction of core samples.

Core samples were collected using a 60 cm split-tube sampler attached to the BW rod (Figure 3.14). The sampler was hammered into the formation with a 150 pound hammer or pushed in to it hydraulically. Core was collected more frequently in the upper 70 m of the drill holes than at greater depths because of the exponential increase in time and costs. For example, approximately 4 hours were required to extract a core from 123 m depth at SFU drill site A5 but, only 30 minutes for a core at 30 m depth. The deepest cored hole in the study, SFU drill hole A5, was at the Armstrong site. The drill hole bottomed out at 128 m depth and took a total of 3 weeks to drill.

Five SFU drill holes were located in the North Okanagan Valley. Detailed information provided by these holes was used to correlate and better

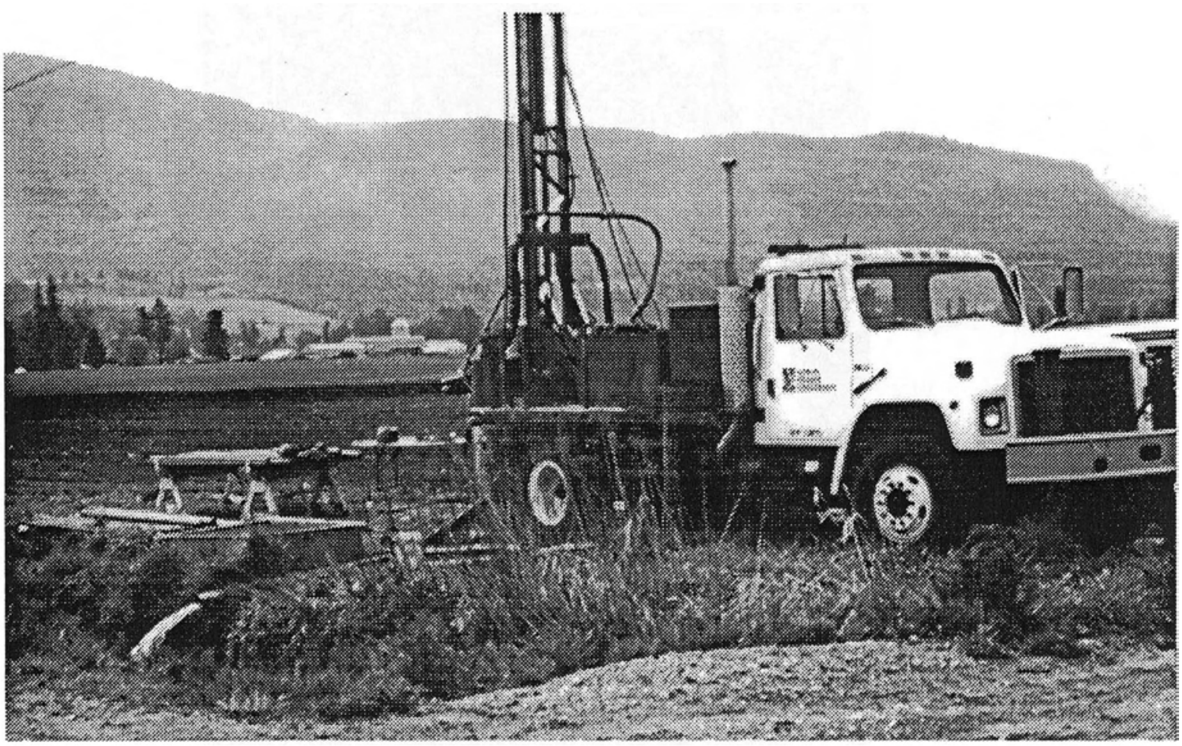


Figure 3.13 Simon Fraser University, Department of Geography Mobile B-53 mud-rotary drill rig at Enderby site. View from west to east.

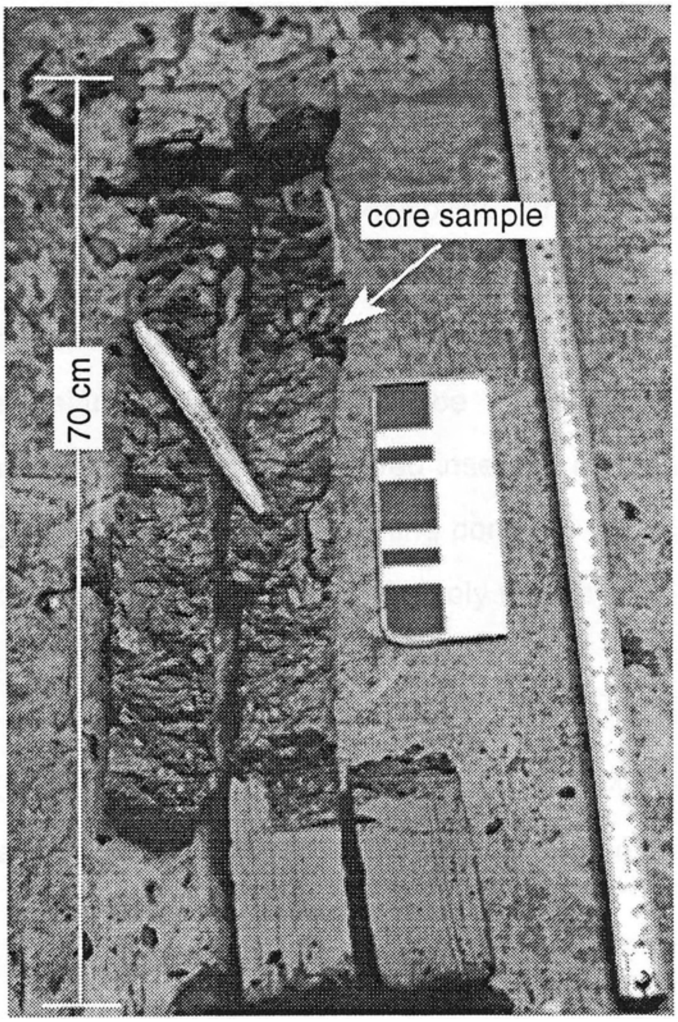


Figure 3.14 Example of 'split-tube' in situ core sample collected from SFU drill hole E1 at the Enderby site.

define generalized groundwater log descriptions. In total, 30 well logs were analyzed for the study.

3.5.2 Artesian Well Control

After numerous discussions with local water well drillers, and analysis of well data for the North Okanagan Valley (Johanson, 1976), I felt that artesian flow in the study area was a distinct possibility. Artesian flows exceeding 440 litres per minute, located within 30 m of the surface, are not uncommon in the Valley. Therefore, it was decided to modify the standard drilling technique to insure that artesian water flows could be contained. To this end, site preparation in artesian flow areas involved inserting 8 inch diameter HW (thick walled) casing to 8 m depth. Quick setting concrete was then poured outside the casing and allowed to set for approximately two days (Figure 3.15). A well-cap fitting was machined for capping the HW casing in the event of artesian flow.

Indeed, at SFU drill site E1 artesian flow of 374 litres per minute was encountered at only 12.8 m depth but, casing had been set and the flow was controlled.

3.5.3 Core Logging

Core samples were logged in the field for lithologic characteristics that included textural changes, presence and type of sedimentary structures, color and organic content (hammer blow counts recorded during core sampling were analyzed for density information). Sediment grain size determinations were made using an American/Canadian Stratigraphic grain size chart and a 20 power hand lens. Lithologic characteristics and sedimentary structures observed in the core samples were photographed and sketched.

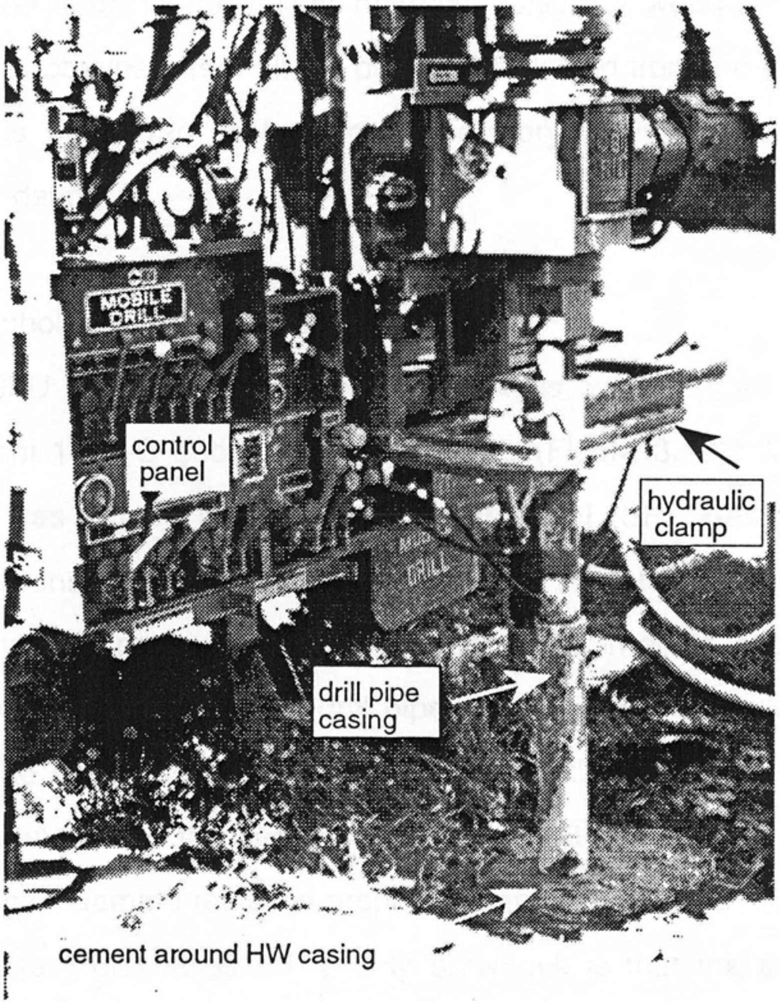


Figure 3.15 Photograph of drill site preparation at Toporchuk Ranch site north of Vernon. Note cemented layer around the HW casing.

As previously indicated, all core samples were carefully scanned for *in situ* wood samples. If wood samples were not readily detectable, predetermined intervals of the core were disaggregated and dispersed in distilled water to check for organic material. Only one wood sample, SFU OV-500 S.3, was obtained from all the drill core collected from the drill holes. This sample was submitted to Isotrace Laboratory, University of Toronto, for accelerator dating.

3.5.4 Downhole Geophysical Logging

All SFU drill holes, and cased water wells, were logged using a Mount Sorpis Model 1000-C geophysical well logger (Figure 3.16). When possible, each hole was logged for Spontaneous Potential (SP), Resistivity (R), and Gamma responses. Spontaneous Potential and Resistivity measurements rely on the formation's passive electrical properties but, in order to prevent the drill hole from collapsing, the HWL drill pipe remained in place during downhole logging. The HWL casing prevented the conduction of any passive electrical responses emitted by the sediments, therefore, it was not feasible to collect electrical logs. Gamma radiation properties can be measured in either cased or open (uncased) drill holes. The only drawback is that the casing tends to suppress the response curve observed on the log printout. For these reasons mainly Gamma response logs were collected.

The logs were used in conjunction with borehole and seismic data to further define sediment texture and improve lithologic control. Well logging further reduces the need for costly and time consuming core sampling, supplements lithologic data, and provides useful information from existing water wells. Theoretical considerations and applications of geophysical logging are discussed in detail by Merkel (1979); Galloway and Hobday (1983);

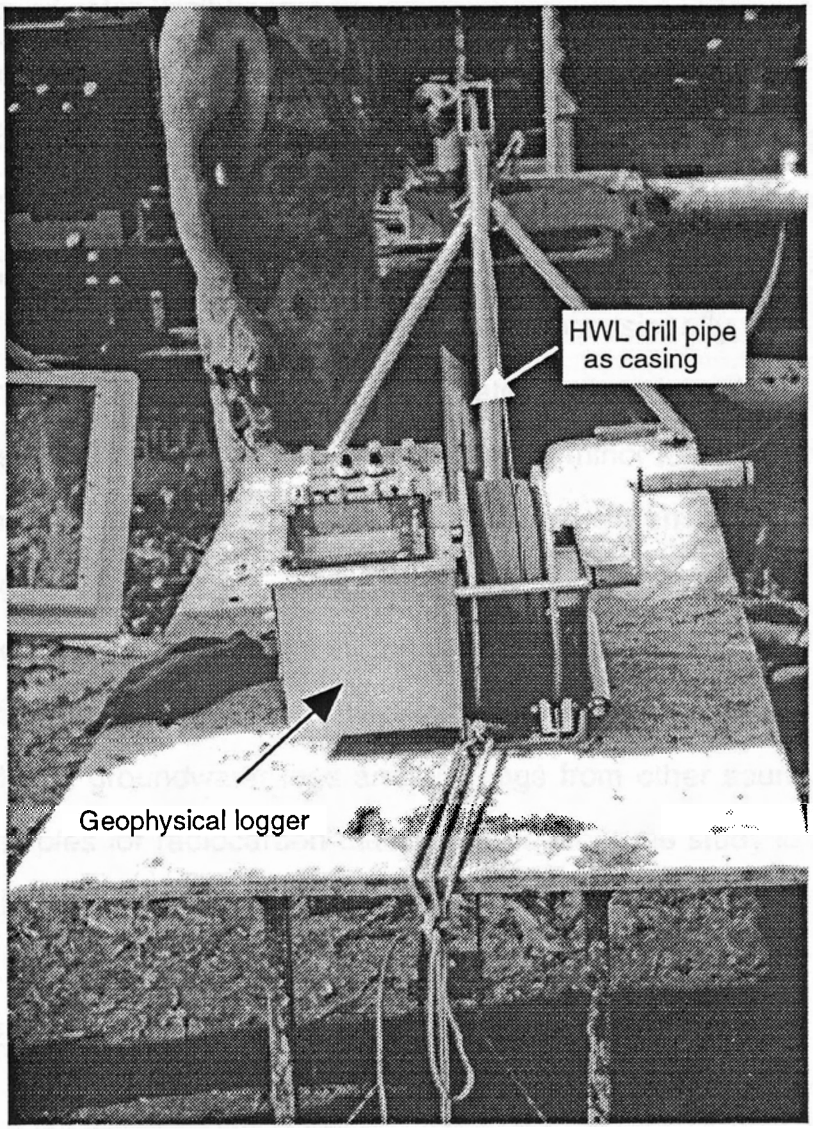


Figure 3.16 Mount Sorpis 1000 geophysical logger in use at SFU drill hole V2 at the Toporchuk Ranch (Vernon site). Logging procedure involved mounting the instrument to the table top and lowering gamma probe into the cased drillhole.

Schlumberger (1987); Serra (1984, 1985, 1986); Serra and Sulspice (1975); Serra and Abbott (1982).

3.5.5 Groundwater Well Logs

Numerous groundwater well logs were obtained from the Groundwater Section, British Columbia Ministry of Environment. The drill logs used in the study were situated along or near the seismic lines collected at the Vernon, Armstrong, and Enderby sites. The logs provided generalized descriptions of lithologic variations, water table depths, and occasionally, depth to bedrock values. In the descriptions of the groundwater wells, minimal attention was paid to the presence of sedimentary structures and to minor textural variations. Thick gravel and cobble sequences were collectively referred to as 'tills' on the driller's logs.

One of the primary reasons for the establishment of SFU drillholes was to ensure lithologic control, provide detailed subsurface information that could be correlated with groundwater logs and well logs from other sources, and collect organic samples for radiocarbon dating. Throughout the study logs obtained by me are referred to as SFU drill logs and BC Environment logs are referred to as groundwater or 'well' logs. Locations and proper designations for all SFU drill logs and BC Environment well logs are presented in Appendix D.

3.5.6 Drill Hole Locations

The drill sites were selected after seismic line analysis and evaluation of existing well logs. In addition, SFU drilling locations were a function of land access, potential artesian flow problems, and water availability. At the Enderby site, after encountering artesian flow at SFU drill sites E1 and E2, drilling was terminated.

Analysis of lithologic information gathered from drill and well logs is presented in Chapter Six.

CHAPTER FOUR

SEISMIC LINE DESCRIPTIONS

4.1 Introduction

In this chapter 14 seismic lines collected from the Vernon, Armstrong, and Enderby sites in the North Okanagan Valley are described. Field notes and data processing parameters are presented in Appendices A and B. Plots of the seismic profiles, including seismic unit interpretations, are found in Appendix C (Plates 1 to 14).

4.2 Vernon Site

4.2.1 SFU Line 300 (Plate 1)

SFU Line 300 (Plate 1) is a 852 m north-south line shot west of the Toporchuk Ranch buildings (Figure 3.4). The south end of Line 300 (spread OV-324) ties into the north end of SFU Line 400; combined, the two lines provide a longitudinal profile of the basin fill north of Vernon. SFU drill hole V2 was located along Line 300 near spread OV-310, while well hole V1 is located 72 m north of spread OV-301.

The seismic information of the upper 25 ms of Line 300, from 50 to 75 ms, is limited because of high signal to noise levels resulting from the shallow occurrence of bedrock observed around 45 m (see SFU drill log V2). Based on the refraction data acquired by MacAulay and Hobson (1972) a shallow bedrock depth was not anticipated in this region. It became apparent that a 500 ms sweep was too deep for this site. Between 50 and 75 ms the profile is characterized by low amplitude, horizontal reflections; the reflections deteriorate north of spread OV-304 where extremely dry surface sediments were encountered. The lower portion of the seismic section, from 75 ms to about 115 ms, shows a series of moderate to high amplitude, semi-continuous reflections. The reflections are particularly well defined between spreads OV-310 and OV-304. These reflections dip at about 4.4^{o} from SFU drill log V2 at 45 m to 78 m at well log V1 (north of spread OV-301). Again, continuity of the record is limited north of spread OV-304.

The seismic refraction study by MacAulay and Hobson (1972) indicate that depth to bedrock in the vicinity of Line 400 exceeded 85 m depth. It seems likely that there is considerable local variation in relief on the bedrock surface. For example, at SFU drill site V2 the drill hole bottomed out at 45 m depth, whereas only 700 m to the northeast of the drill site, bedrock crops out at the surface (Figure 3.8).

4.2.2 SFU Line 400 (Plate 2)

SFU Line 400, a 648 m north-south line, provides another seismic profile of the basin fill north of Vernon (Figure 3.4). The line is located on Toporchuk Ranch immediately south of L and A Cross Road. Lithologic control is provided by SFU drill hole V4 and well hole V3. The site of well log V3 is between spreads OV-403 and OV-404. SFU drill site V4 is located at the south end of the profile adjacent to spread OV-418.

The upper component of the profile, from 50 ms to about 137 ms, shows a set of 6 horizontal, continuous to semi-continuous reflections. This seismic zone ranges in depth from 54 m at well log V3 to about 70 m at SFU drill log V4. From 110 to 125 ms (between spreads OV-404 and OV-406) the horizontal reflections onlap underlying seismic units. The upper unit correlates with horizontally-bedded fine-grained sediments observed in SFU drill log V4 and well log V1.

Underlying the upper section of the profile is a unit characterized by reflections with low to moderate amplitudes that dip southward at 2° to 4°. The unit extends from 165 ms below spread OV-404 to 180 ms below OV-416. North of spread OV-404, and south of spread OV-417, the continuity of the reflections is limited due the dry surficial sediments and reduced signal return. The upper contact of the unit is less distinct towards the south end of the profile. The unit correlates with coarse grained sediments observed in the log of SFU drill hole V2 at 70.2 m depth.

The lower part of Line 400 is characterized by a series of continuous, moderate to high amplitude reflections that dip to the south at 1.5°. The reflections are clearly defined between spread OV-411 (at 165 ms) to OV-417 (at 171 ms) and OV-404 (at 165 ms) to OV-407 (at 171 ms). The reflections correlate with bedrock observed at 73 m in well log V3 and 90 m in SFU drill log V4. The combined profiles of SFU Lines 300 and 400 show a longitudinal bedrock profile with a minimum bedrock depth of 45 m observed below SFU drill hole V2; from this position bedrock slopes to the north and south at 4.5° and 1.5°, respectively.

4.2.3 SFU Line 1200 (Plate 3)

SFU Line 1200 is a 1.4 km line that represents an east-west, depositional strike section of the North Okanagan Valley (Figure 3.4). The line originates and terminates near the valley margins where bedrock crops out nearby. Line 1200 parallels L and A Cross Road and several gaps occur on the profile (between spreads OV-1214 to OV-1216 and OV-1231 to OV-1240). The gaps occur because the surficial sediments were extremely dry and compact, consequently, auguring and geophone planting were not possible. Well hole V6 is located west of spread OV-1205. SFU drill hole V2 is located approximately 750 m north of spread OV-1226.

Depth to bedrock values observed along Line 1200 were, again, shallower than expected. Shallow bedrock augments strong reflections at the fill-bedrock interface that tend to mask all other reflections. For this reason the bedrock surface is profiled at the expense of near surface data. This resulted in an almost reflection free upper portion of the profile between 55 and 75 ms except for 1-2 low amplitude, horizontal, semi-continuous reflections that are observed between spreads OV-1226 to OV-1229. This unit correlates, to some degree, with horizontally-bedded, fine-grained sediments observed in the log of SFU drill hole V2 from the surface to about 40 m depth. The horizontal reflections onlap underlying reflections (between spreads OV-1228 to OV-1230) at 60 to 70 ms. Towards the east and west margins of the profile the upper unit is characterized by strong reflections originating at the fill-bedrock contact. A maximum thickness for the unit of about 41 ms is observed from 55 to 96 ms below spreads OV-1227 and OV-1228.

The lowermost portion of the seismic profile is characterized by a series of high amplitude reflections that dip at about 7^{o} from the west and 32^{o} from the east towards the basin axis (Figure 4.1). The reflections originate on the west end of the profile below spread OV-1240 (at 75 ms) and at 75 ms (below spread OV- 1202) to the east. Although a 459 m separation exists between spreads OV-1214 to OV-1226, lateral continuity of the reflections is maintained by correlation with bedrock observed in SFU drill hole V2. Bedrock depths range from surface outcrops on the valley margins to about 55 m below spread OV-1228. The bedrock reflections are overlain by a 12.5 ms reflection free unit observed between spreads OV-1209 and OV-1229. The unit correlates with coarse-

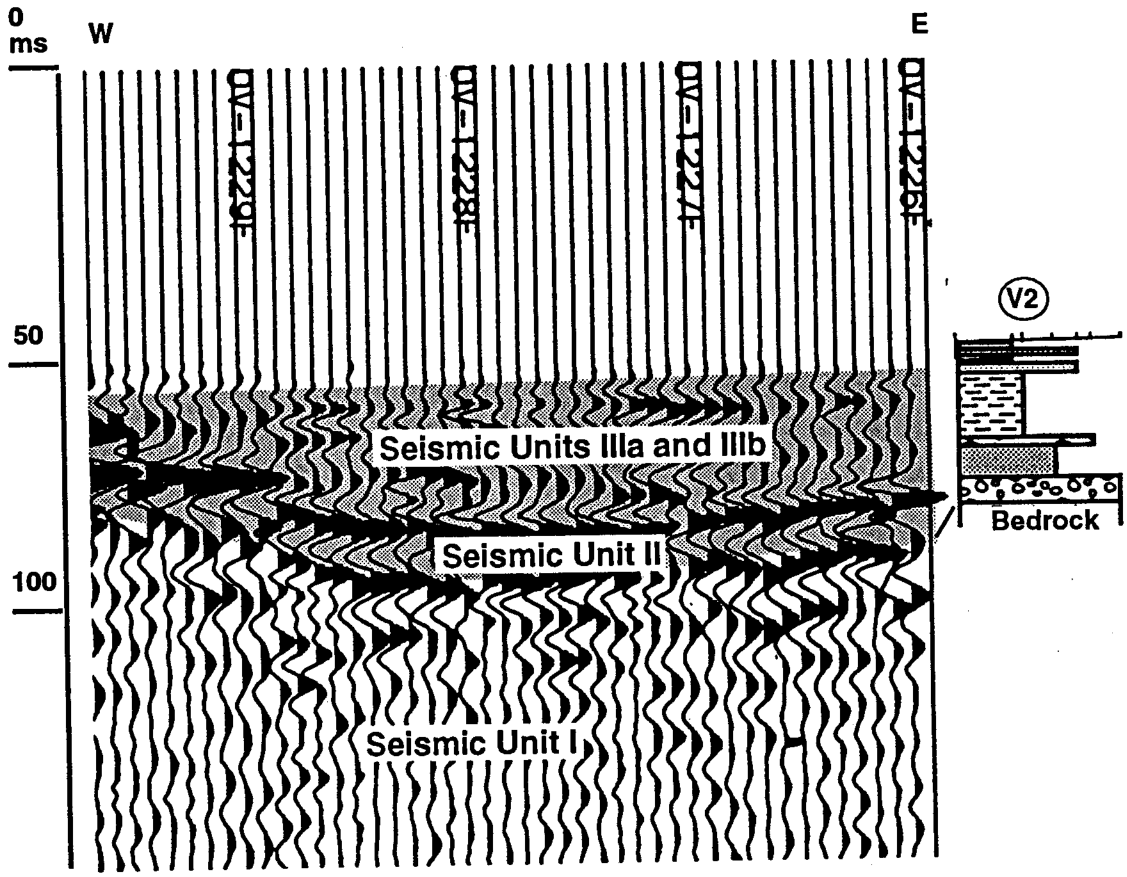


Figure 4.1 Shallow basin observed north of Vernon at the Toporchuk Ranch. Shaded area delineates the basin and seismic units.

grained sands and gravels observed in the logs of SFU drill hole V2 and well hole V6. The upper contact of the unit is characterized by a series of high amplitude, continuous reflections.

The profile of Line 1200 represents the northernmost extension of the shallow basin that contains Swan, Kalamalka, and Wood Lakes. The basin roughly parallels the deeper Okanagan Lake Basin west of Vernon.

4.2.4 SFU Line 1300 (Plate 4)

SFU Line 1300 is a short 288 m profile extending from SFU drill hole V2 east of spread OV-1310 to the west valley margin (Figure 3.4). Spread OV-1301 ties into SFU Line 300 at spread OV-310. The upper portion of the profile, from 64 to 90 ms (below spread OV-1304), exhibits faint horizontal, semi-continuous reflections between spreads OV-1303 to OV-1305. A lower unit of the profile shows a series of moderate amplitude, continuous reflections that are overlain by high amplitude, continuous reflections. This unit is observed between spreads OV-1303 to OV-1305 from 93 to 110 ms. The lowermost reflections dip basinward (east) at about 2.2^{o} and correlate with bedrock observed at about 45 m depth below SFU drill site V2. The overlying, high amplitude reflections correspond with a fine sand to gravel transition observed in drill log V2 at 42 m depth. Towards the east and west valley margins, the correlation is tenuous due to a lack of reflection continuity.

4.2.5 GSC Line 500 (Plate 5)

GSC Line 500 is a 680 m southwest-northwest trending profile that was shot immediately north of Okanagan Lake (Figure 3.5). The upper unit of the profile, from 160 to 260 ms, shows a series of high amplitude, horizontal, continuous to semi-continuous reflections. This unit is continuous between spreads V-496 to V-514. Below this, a zone extending from 260 to 460 ms, is characterized by less continuous, horizontal, moderate amplitude reflections. At about 450 ms a series of very gently dipping reflections extends westward from spread V-506 to V-514. The log of groundwater well V5 shows a strong correlation between the horizontal reflections from the surface to 302 m depth and horizontally-bedded, fine-grained sediments.

A series of westward dipping, high amplitude reflections are visible near the east end of the profile from 475 to 500 ms below spread V-496 and V-600 to 625 ms below spread V-505. These reflections are interpreted to correspond with the subsurface extension of a bedrock ridge that separates the Okanagan Lake Basin from the shallower basin containing Swan, Kalamalka, and Wood Lakes (Pullan et al., 1992) (see Figure 3.6). The reflections dip westward at 17° and diminish in continuity west of spread V-505; Pullan et al., (1992) attribute this to the attenuation of energy in the overlying sediments. A high frequency event that dips to the east is observed from 850 to 900 ms between spreads V-509 to V-514. The events "may" be related to acoustical interference resulting from the considerable bedrock relief of the western basin margin observed at this site (Pullan et al., 1992).

4.3 Armstrong Site

4.3.1 GSC Line 100 (Plate 6)

GSC Line 100, a 1.5 km east-west line, reveals a thick sediment fill at this site in the North Okanagan Valley. The line was shot from the edge of the alluvial fill at spread V-97 on the east valley side to mid-valley position at spread V-138 (Figure 3.10 and 3.12). The profile incorporates 5 groundwater well logs that are used for lithologic correlations (logs A8, A9, A10, A11, and A12). Well

Log A12 is located on the west valley side 1.4 km west of spread V-138 and shows bedrock at 126.5 m depth.

The upper zone of the profile shows a series of up to 11 parallel, continuous, moderate amplitude reflections that extend from the surface at 125 ms below spread V-97 to about 440 ms below spread V-138. This 315 ms unit attains a maximum thickness of about 330 m below spread V-138. The reflections pinch out to the east and onlap a series of lower reflections between spreads V-110 to V-123 and spreads V-97 to V-123 (Pullan et al., 1992). This is particularly evident below spread V-110 at about 310 ms. The well logs indicate that this zone correlates with horizontally-bedded, fine-grained clay and silt overlying coarse gravel.

An underlying seismic unit is characterized by basinward dipping, semi-continuous to divergent, moderate amplitude reflections that lie unconformably over lower seismic units. The unit is up to 120 m thick below spread V-117 (from 340 to 420 ms) and internal reflections tend to flatten and lose their continuity to the west. A series of truncations are apparent at 390 ms below spreads V-123 to V-127 where a convex, mounded series of reflections overlie the truncations. Generally, the reflections exhibit a wedge-shaped morphology that pinches out laterally. Reflection boundaries of this unit downlap onto the lowermost seismic units (below spreads V-109 to V-111) at about 325 ms. The unit reduces to less than 5 m thick on the west end of the profile between spreads V-133 to V-144 at 440 ms. Poorly defined internal reflections are also visible in the wedge-shaped feature.

The quality of the reflections diminishes towards the base of the profile. This is partly attributed to the greater than 450 m depth of fill and coarse sediments that attenuate energy and reduce signal return. The record also deteriorates to the west as noise levels associated with Highway 97 increased

(Pullan et al., 1992). The lower unit of Line 100 is characterized by a lack of continuous reflections and numerous point-source reflections, combining to create an irregular mass of seismic reflections. Interpretation of the unit is made possible through the correlation of seismic and lithologic data that shows alternating layers of cobble sized gravel to medium and coarse sand overlying bedrock (see well logs A9, A10, and A12). The unit pinches out to the east below spread V-120 at 450 ms and thickens to the west. Below spread V-128 the unit is 121 m thick (from 450 to 590 ms).

The lowermost reflections of the profile are characterized by basinward dipping, continuous, high amplitude reflections indicating the bedrock-basin fill contact. The reflections dip to the northwest at about 19° from spreads V-100 to V-128 (at 590 ms). Reflections are poorly defined west of spread V-126 and lateral continuity is maintained by bedrock observed in the logs of well holes A10 and A12.

Roberts et al., (1992) previously described the general seismic stratigraphy of this profile in the Armstrong area. Four seismic units were identified as (from bottom to top): lithified bedrock, diamicton, alluvial fan sediments, and lacustrine silt. The interpretations were based solely on seismic reflection characteristics and lithologic control provided by one well hole (identified in this study as well hole A10).

4.3.2 GSC Line 300 (Plate 7)

GSC Line 300 is a 2.9 km north-south line, the south end of the profile approximately joins the east end of GSC Line 100 (Figure 3.12). The south end of Line 300 originates near bedrock that crops out at the surface. From this position the line extends for some 2.9 km to the north and provides a longitudinal profile of the basin fill. Detailed lithologic data are limited to the upper 135 m of the profile and will be discussed in conjunction with SFU Line 500 (Section 4.3.3); the log of well hole A13, located between spreads V-307 and V-308, provides generalized lithologic control for the lower zones of the profile.

The uppermost unit of Line 300, from 110 to about 320 ms, shows parallel, continuous to semi-continuous, moderate amplitude reflections. The horizontal reflections are better defined between 110 to 175 ms. Below about 115 to 320 ms the parallel reflections are less continuous and have lower amplitudes. Between spreads V-379 to V-375 the reflections onlap lower seismic units. Onlap reflection terminations are observed below spreads OV-377 at 160 ms and OV-375 at 175 ms. North of spread V-342 the continuity of the profile is not as well defined. Pullan et al., (1992) suggests that this results from an influx of coarser-grained material that attenuates energy and obscures the lower units of the section. The assumption is supported by the presence of gravel observed in the lower portion of well log A13. Comparison of this unit with the zone of irregular point-source reflections observed on the west end of GSC Line 100 (from 320 to 455 ms) supports the association with coarse-grained sediments.

The lowermost seismic unit observed on the profile is characterized by continuous, high amplitude reflections that dip northward at about 9.5^{o} from 155 ms (50 m) below spread V-379 to 350 ms (275 m) below spread V-342. East of spread V-344 the unit is obscured by overlying coarse grained sediments, this results in limited reflection continuity and point-source reflections. This unit was interpreted as the bedrock contact (Pullan et al., 1992). Well log A13 shows a bedrock depth of 400 m below spread V-308 but, the log does not correlate with seismic data. A small wedge-shaped feature overlies the lowermost series of reflections (between spreads V-361 to V-371); this will be described in association with SFU Line 500 (Section 4.3.3).

4.3.3 SFU Line 500 (Plate 8)

SFU Line 500, a 915 m north-south profile, parallels GSC Line 300 and the south end of the line roughly ties into the east end of GSC Line 100 (Figure 3.12). The North Okanagan Valley strikes to the NNE -SSW in this area and Line 500 provides an approximate depositional strike section. The line provides a detailed profile of the upper basin fill in the Armstrong region. Lithologic control is provided by SFU drill hole A5 and by well holes A1 to A4, A6 and A7.

The upper part of the line, from 55 to 115 ms, shows a set of 2-4 parallel, continuous, high amplitude reflections that are concordant with the underlying seismic topography. The unit correlates with fine-grained, horizontally-bedded silt and clay observed in well logs. The profile deteriorates towards the south end of the section (between spreads OV-521 to OV-525) because the shallow bedrock depth observed at the south end of the profile obscures the signal.

Underlying the flat-lying reflections are 3-4 parallel, less continuous reflections with moderate to high amplitudes that occur from roughly 115 to 210 ms (below spread OV-501). Portions of this unit are almost reflection free (see spreads OV-508 and OV-515 from 88 to 116 ms), probably due to the homogeneity of the deposits and a consequent lack of density contrasts. The unit pinches out to the south and reflections onlap underlying seismic units. Onlap reflection boundaries are observed at approximately 125 ms between spreads OV-521 and OV-524. The unit correlates with a general increase in grain size characterized by isolated sand and gravel layers. The log of SFU drill hole A5 shows a 1 m thick gravel lens at 72 m depth, that correlates with a series of continuous, high amplitude reflections at 125 ms extending between spreads OV-522 and OV-507 and onlaps underlying seismic units at 125 ms (below spread OV-522).

Characterizing the lowermost reflections of the profile are a series of high amplitude, continuous reflections that dip at about 4.5^{o} from 59 m depth (below spread OV-526) at the south end of the section to 135 m at the north (below spread OV-501). The reflections correlate with bedrock depths of 59 m and 92 m observed in well logs A1 and A2 (see Plate 8).

Overlying these dipping reflections are a series of continuous, moderate to high amplitude reflections that occasionally obscure those below. The unit ranges from 4 to 7 m thick at the south end of the profile (below spread OV-526 at 155 ms) and correlates with cobble sized gravel observed in SFU drill log A5 and well log A6. Between spreads OV-517 (at 163 ms) to OV-505 (at 206 ms) the unit attains a maximum thickness of about 20 m. Discontinuous, low amplitude reflections observed in this unit are concordant with underlying seismic units. The thicker portion of this wedge-shaped feature, below spread OV-512 from 155 to 200 ms, correlates with alternating fine to medium-grained sand layers and pea to cobble sized gravel observed in SFU drill log V5 from 100 to 123 m depth.

4.3.4 GSC Line 700 (Plate 9)

GSC Line 700, a 2.0 km line, follows a NNE-SSW transect that roughly parallels the depositional strike of the North Okanagan Valley fill (Figure 3.12). The line is located east of GSC Line 300 and SFU Line 500, and north of GSC Line 100. Line 700 is aligned with the eastern margin of a paleo-meltwater channel that extends from Enderby to the north shore of Okanagan Lake (Figure 2.7). The paleo-channel floor is incised 20 m below the valley floor. GSC Lines 100 and 300, and SFU Line 500 are located on the valley floor above the paleo-channel floor and the location of GSC Line 700. Lithologic control for Line 700 is provided by well logs A9 and A14 that were collected as part of a 1964 petroleum exploration survey in the North Okanagan Valley.

The upper unit of the profile is composed of a series of parallel, continuous, moderate to high amplitude reflections. From the surface, at 120 to 160 ms, the reflections are continuous and extend from north to south across the profile between spreads V-754 to V-701. The unit correlates with horizontally-bedded, fine-grained sediments observed in well log A15 to 70 m depth. Below 160 ms, to a maximum of 350 ms, the parallel reflections are less continuous. This zone of low continuity reflections ranges from 160 to 350 ms below spread V-754 at the south end of the profile. To the north, below spread OV-701, the zone ranges from 160 to 275 ms. At some locations the parallel reflections onlap underlying seismic units. This is particularly evident at about 275 ms (below spread V-736) and 240 ms (below spread V-729).

Underlying this unit are a series of reflections that dip to the south end of the profile between spreads V-717 at 245 ms and spread V-754 at 350 ms. The upper boundary of the unit exhibits a series of high amplitude, continuous reflections that correlate with a gravel to coarse sand horizon observed in well logs A9 and A14. Internal reflections within this zone are erratic and indistinct; possibly due to the coarse sediments and subsequent attenuation of seismic energy. Below this unit lies a series of semi-continuous reflections. The reflections dip to the south at approximately 9.2^{o} between spreads V-733 at 375 ms to spread V-752 at 445 ms. The reflections rise to within 225 m (at 330 ms) of the surface below spread V-725 and drop to 206 m (at 280 ms) below spread V-701. Based on the correlation with well logs A9 and A14 the unit is interpreted as bedrock. North of spread V-724 the reflections are poorly defined, again due to the attenuation of energy in the coarse-grained sediments and to reduced bedrock depth.

4.4 Enderby Site

4.4.1 SFU Line 100 (Plate 10)

SFU Line 100, a 1.9 km east-west profile, provides a limited view of the basin fill north of Enderby. In this region the valley narrows to about 2.1 km and the valley floor is drained by the Shuswap River (see Figure 2.9). Deep lithologic information is limited to well log E3 collected from well hole E3 located immediately south of Enderby (Figure 3.13).

The upper unit of the profile, from 52 to 90 ms, shows parallel, semi-continuous, moderate to high amplitude reflections between spreads OV-100 to OV-154. The unit is best defined between spreads OV-113 to OV-100; the surface sediments along this section were saturated and provided optimum seismic conditions. West of spread OV-114 extremely dry surface conditions and high signal to noise levels caused by local farm machinery were encountered. This 38 ms zone of horizontal reflections correlates with horizontally-bedded, fine-grained sediments observed in the upper portion of well log E3.

Two lens shaped units are observed in the upper 30 ms of the profile between spreads OV-133 to OV-136 and OV-138 to OV-140. The units exhibit concave lower boundaries and range in width from 72 to 108 m and 8 to 10 m in thickness. Reflection boundaries of the lens-shaped units truncate surrounding reflections and lower reflection boundaries are better defined than upper boundaries.

Underlying the unit of horizontal reflections is a reflection free zone that attains a maximum thickness of 272 m at the west end of the profile (from 90 to about 270 ms) below spread OV-154. The unit correlates with medium coarse sand and gravel observed in well log E3. The lack of internal reflections and erratic seismic signature is attributed to coarse-grained sediments, lack of density contrasts, and background noise during the period of shooting. Although limited in lateral continuity, a series of reflections appears near the surface below spread OV-100 that dip basinward at about 7.9°, near spread OV-154 these reflections are observed at 330 ms. The reflections are tentatively correlated with bedrock observed in well log E3 at about 330 ms (272 m depth). At various locations on the profile, a unit characterized by poorly defined, low amplitude, erratic reflections overlie the bedrock reflections. These units are observed below spreads OV-133 (at 225 ms) to OV-138 (at 275 ms) and OV-113 (at 100 ms) to OV-126 (at 163 ms).

The information observed on the profile east of spread OV-118 will be discussed in conjunction with the description of SFU Line 900 (Section 4.4.2).

4.4.2 SFU Line 900 (Plate 11)

SFU Line 900 is a 648 m east-west profile that details the upper 110 ms of SFU Line 100 (Figure 3.13). The uppermost unit of the profile exhibits a set of 4-5 parallel, moderate to high amplitude reflections best defined between 50 to 85 ms. The reflections onlap the underlying seismic unit on the east end of the section at 85 ms below spread OV-900 (Figure 4.2). The unit is correlated with horizontally-bedded, fine-grained sediments observed in the upper portion of well E3 on SFU Line 100 (Plate 10). Underlying reflections have high amplitudes and dip steeply away from the east valley side at about 22.5°. The reflections are interpreted to represent bedrock that crops out along the valley margin immediately east of spread OV-901. These reflections are clearly defined east of spread OV-909, west of the spread bedrock reflections are obscured by a large 'umbrella-shaped' point-source diffraction. The diffraction pattern likely results from a shallow depth to bedrock and an abrupt rise in the bedrock floor; this circumstance can create an 'edge' or 'echo' effect resulting in signal-generated interference.

4.4.3 SFU Line 200 (Plate 12)

Line 200 illustrates the effects of a thick sequence of coarse sediments (?) and lack of internal density contrasts which can lead to a nearly reflection free profile, or one dominated by numerous point-source, irregular reflections. The coarse sediments attenuate energy and prevent the progression of energy into the deeper subsurface. Overall, this short (216 m) north-south profile (Figure 3.13), provides limited information of the basin fill in the Enderby area. The upper 55 ms of the section, from 65 to 120 ms, is characterized by parallel, high amplitude reflections that correlate with horizontally-bedded, fine-grained sediments observed in well log E3. At approximately 338 ms a series of high amplitude, parallel reflections correlate with bedrock observed at 272 m depth on well log E3. The effects of the homogeneous sediment fill is evident in the time zone extending from 120 to 320 ms. The lack of sediment density contrasts from which seismic waves are reflected, have resulted in the poorly defined unit.

4.4.4 SFU Line 1000 (Plate 13)

SFU Line 1000, a 288 m east-west profile, was shot starting 5 m from the bedrock that crops out along the west valley margin (Figure 3.13). This line provides information about the relationship between the basin fill and the bedrock wall of the valley. Lithologic information is established by well hole E4, located between spreads OV-1007 and OV-1008, that reveals a 36.6 m section of the basin fill. Deep borehole information was not available for this site.

The upper unit of the profile exhibits a series of parallel, high amplitude, continuous reflections that occur from 50 to 100 ms below spread OV-100. The unit pinches out towards the west end of the profile. The log of well E4 shows the correlation of this unit with horizontally-bedded, fine-grained sediments containing sand lenses. Below this unit the reflections are less coherent and are characterized by chaotic, point-source reflections. The zone of chaotic reflections diverges to the east, from 69 to 88 ms below spread OV-1007, to between 100 and 200 ms below spread OV-1001.

The lowermost portion of the profile shows a series of moderate amplitude, semi-continuous reflections that dip basinward at about 28°. The unit originates at approximately 69 ms on the west end of the profile below spread OV-1008 and continues to 169 ms below spread OV-1004. Continuity of the reflections diminishes east of spread OV-1004. The reflections are tentatively interpreted as representing the bedrock floor of the valley.

Towards the east end of the profile, between spreads OV-1004 to OV-1001, the bedrock reflections are overlain by a unit composed of a series of discontinuous, moderate amplitude reflections that dip basinward. The zone extends up profile to the base of the horizontal reflections (at 100 ms) and is correlated with coarse-grained sediments (similar to the zones of irregular, point source reflections observed on SFU Line 500, and GSC Lines 100 and 500, Appendix C).

4.4.5 SFU Line 700-800 (Plate 14)

SFU Line 700-800, a 1.8 km profile, is a composite section that provides an excellent seismic cross-section of the basin fill north of Enderby (Figure 3.12 and 5.12). Line 800 is located east of the Shuswap River and is aligned roughly east-west. Line 700 was shot on the west side of the river also following an east-west transect. The higher resolution of Line 700 is attributed to a variation in surface conditions between the two sites: all shot holes for Line 700 were located in saturated surficial sediments in a water filled ditch while shot holes for Line 800 were augured in dry compact sediments. Lithologic control is provided by well E3 located 6 km south of the east end of Line 700. SFU drill holes E1 and E2 were located along Line 700. The lack of detailed lithologic information obtained from the SFU drilling program is an outcome of the hazardous drilling conditions found north of Enderby where artesian flows are encountered. Groundwater well logs are rare because the Shuswap River serves as the primary freshwater source for the region.

The upper unit of Line 700-800 shows a series of 4-5 parallel, continuous to semi-continuous, high amplitude reflections (on Line 800 the zone is less distinct). The unit extends from the surface at 49 ms to about 95 ms. Reflections onlap the underlying seismic stratigraphy (below spread OV-801 at 105 ms) and tend to lose their parallelism along the western portion of the profile between spreads OV-701 to OV-715. The unit correlates with horizontally-bedded, fine-grained sediments observed in the upper portion of well log E3. Sediments in the upper 15 m of the log are extremely fine-grained and laminated. Below about 95 ms is a zone characterized by reflections that exhibit an irregular pattern. The zone attains a maximum thickness of 155 m (below spread OV-701) and OV-809 at 220 ms, and is correlated with a homogeneous complex of fine sandy silt. The unit pinches out to the west and east below spread OV-715 (at 95 ms) to spread OV-801 (at 70 ms), respectively.

Contained within the upper unit of the profile are a series of reflection packages characterized by lens-shaped morphologies. These are observed between spreads OV-708 to OV-712 (from 49 to 90 ms), and spread OV-805 to OV-808 (from 75 to 85 ms). The lower boundaries of the units are concave and exhibit higher amplitudes than the upper boundaries. The units pinch-out laterally and reflection boundaries truncate surrounding reflections. Dimensions of the lens-shaped units range from 30 to 100 m in width and 8 to 10 m in thickness. Numerous internal reflections are visible on a large lens-shaped unit observed from 49 to 85 ms between spreads OV-701 to OV-705.

Underlying the upper package of horizontal reflections is a unit of basinward dipping, semi-continuous, moderate amplitude reflections. The reflections originate below spread OV-715 (at about 80 ms) to the west, and below spread OV-801 (at 75 ms) to the east. Maximum extent of the unit is observed below spreads OV-819 and OV-701 from 220 to 330 ms The upper contact of the unit is well defined and correlates with a silt to medium sand transition observed at 155 m depth in well log E3. Internal reflections within the first 20 ms are basinward dipping and semi-continuous; irregular and reflection-free patterns occur towards the base of the unit.

West of spread OV-701 the profile has a series of basal reflections that dip basinward at about 17°; the reflections correlate with bedrock observed at 272 m depth in well log E3. The reflections are strongest below spreads OV- 701 (at 325 ms) and continue westward to spread OV-712 (at 190 ms). The reflections generally become less distinct to the east but, are again visible between spreads OV-808 to OV-801.

From 195 to 255 ms, between spreads OV-712 to OV-705, a poorly defined unit appears to overlie the lowermost basal reflections. Truncated reflectors are observed in the unit below spread OV-708 at 237 ms. The unit is tentatively correlated with similar wedge-shaped reflection configurations observed elsewhere in the study area (see SFU Lines 500 and 1000, and GSC Lines 100 and 500; Plates 5, 13, 6, and 8; Appendix C). These zones are composed mainly of coarser-grained sediments and interfinger and overlie other seismic units.

CHAPTER FIVE

SEISMIC UNIT INTERPRETATIONS

5.1 Introduction

In this chapter the interpretations are made of the seismic lines described in Chapter Four. The interpretations are based on the analysis of approximately 16 line km of shallow reflection data. Six distinct seismic units are identified in the North Okanagan basin fill: Seismic Units I, II, IIIa and IIIb, IV and V. The criteria used for defining the units are based on the definition of a seismic unit as "a mapable seismic section composed of similar reflection patterns that differ from surrounding reflection patterns" (Vail et al., 1977; Sangree and Widmier, 1979). Each interpretation of a seismic unit begins with a brief synthesis of the seismic reflection characteristics of the unit followed by the interpretation. All interpreted lines and raw/uninterpreted seismic lines are presented in Appendix C (Plates 1 to 14).

5.2 Seismic Unit I

Description

Unit I is characterized by a series of continuous to semi-continuous, moderate amplitude reflections that dip towards the basin axial plane (Figures 5.1 and 5.2). The unit is well defined throughout the North Okanagan Valley and is found on Vernon-SFU Line 400 and GSC Line 500, Armstrong-SFU Line 500 and GSC Lines 100, 300, and 700; and Enderby-SFU Line 700-800 (Plates 2, 5, 8, 6, 7, 9, and 14). In several places the seismic continuity of the unit is

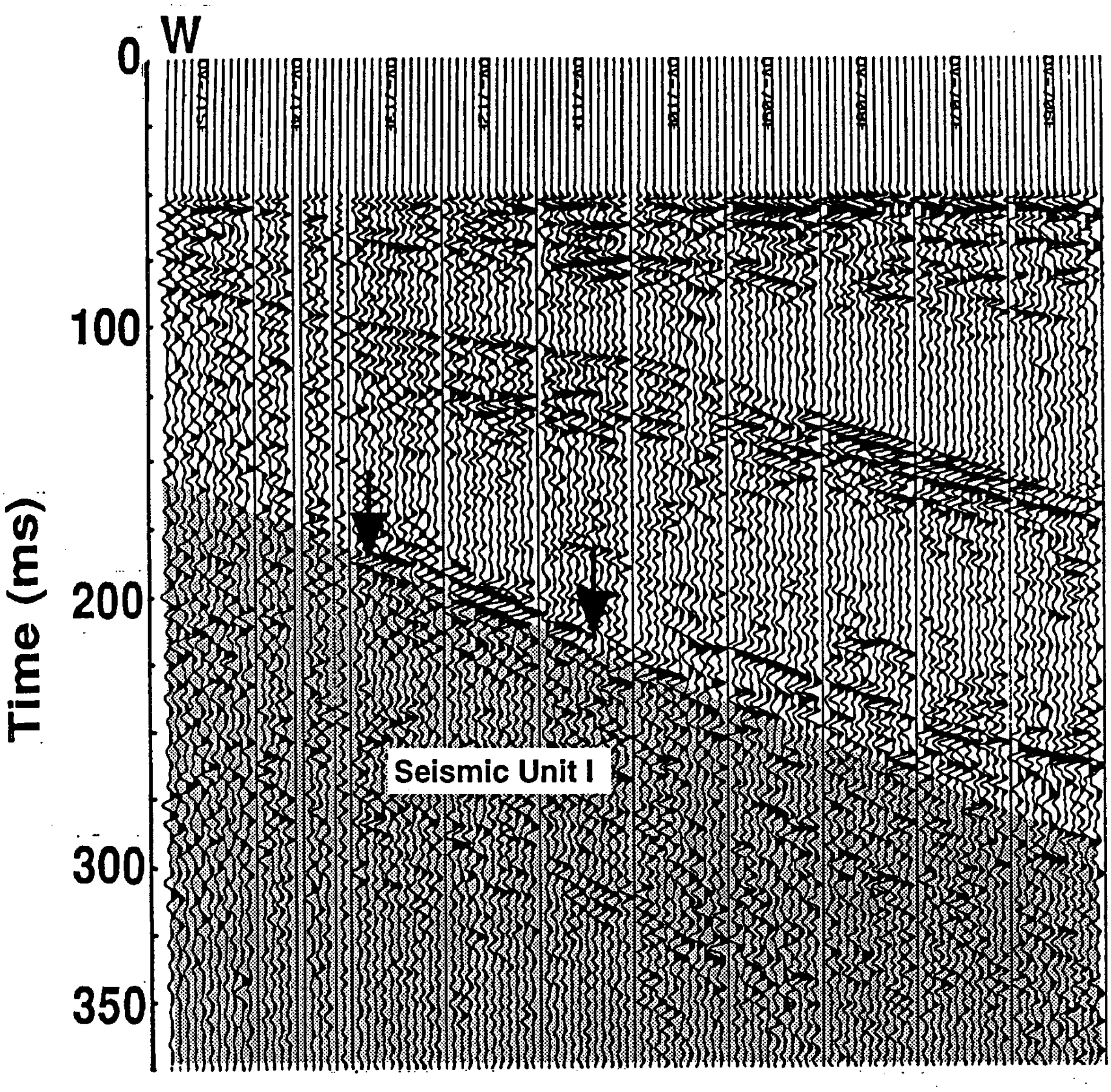
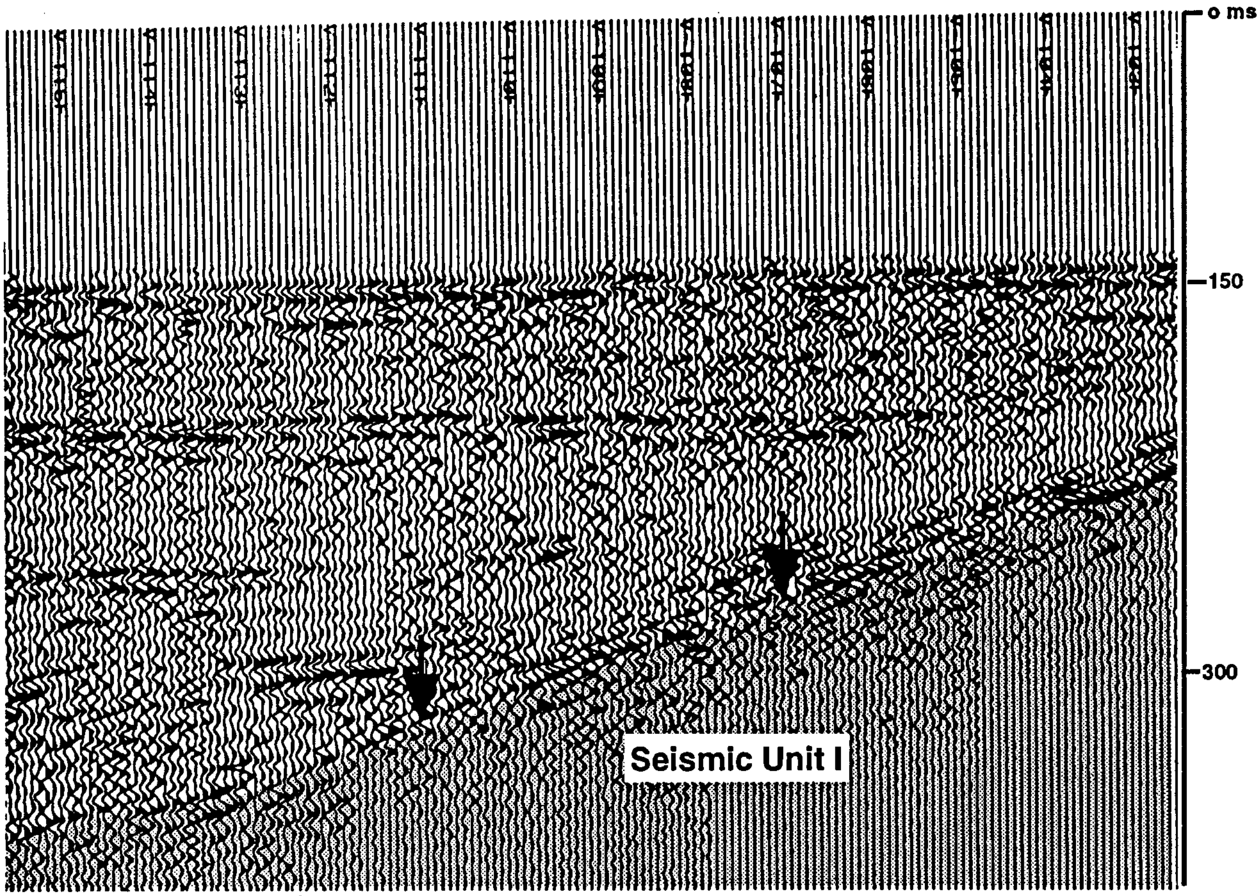


Figure 5.1 Series of basinward dipping reflections identified as Seismic Unit 1 on SFU Line 700 north of Enderby.



GSC LINE 100

Figure 5.2 Series of basinward dipping reflections identified as Seismic Unit I on the east end of GSC Line 100 northeast of Armstrong. Unit I occurs at about 250 msec below spread V-107.

limited due to the thickness of the overlying fill, coarse deposits, and dry, compact surficial sediments that all combine to attenuate energy.

Interpretation

Seismic Unit I represents the bedrock basement below the valley fill. The uppermost reflections of the unit are interpreted as representing a major chronologic and lithologic unconformity between the Tertiary (?) bedrock floor and the Quaternary valley fill. Depth to Unit I ranges from less than 25 m north of Vernon (SFU Line 300, Plate 1) to over 471 m northeast of Armstrong (GSC Line 100, Plate 6), and exceeds 600 m at the north end of Okanagan Lake (Vernon-GSC Line 500, Plate 5). At the Armstrong and Enderby sites bedrock slopes away from the valley margins at 16° to 23°. North of Vernon the bedrock slope is much less being between 4° to 7° towards the valley axis. Pullan et al., (1992), have interpreted similar basal reflections as a major bedrock unconformity that underlies the basin fill (Armstrong-GSC Lines 100 and 700, and Vernon-GSC Line 500, Plates 6, 9, and 5). Lithology of Unit I is discussed in more detail in Chapter Six (Section 6.2.1).

A longitudinal profile (SFU Lines 300 and 400, Plates 1 and 2) from the Vernon site shows Seismic Unit I rising to 45 m depth, and then back to the north and to the south bedrock sloping away at about 4° and 2°, respectively. Depth to bedrock values observed in well logs correlate with the bedrock unit observed on both seismic profiles. This bedrock high has not been previously documented. Early seismic refraction observations by MacAulay and Hobson (1972) indicated that depth to bedrock at this site exceeded 85 m depth. As discussed in Chapter Four (Section 4.2.1) bedrock depth in the region is variable and bedrock crops out northeast of SFU drill site V2 on the Toporchuk Ranch (Figure 3.8).

A similar bedrock high is observed on Armstrong-GSC Line 700. Along the northern portion of the line bedrock rises from 400 to 225 m depth (below spread V-725). The rise represents the southern extension of a large bedrock outlier located immediately north of GSC Line 700 (Figure 3.10). It appears that detached bedrock blocks, common throughout the North Okanagan Valley in mid-valley positions, play an important role in shaping the topography of the valley floor.

5.3 Seismic Unit II

Description

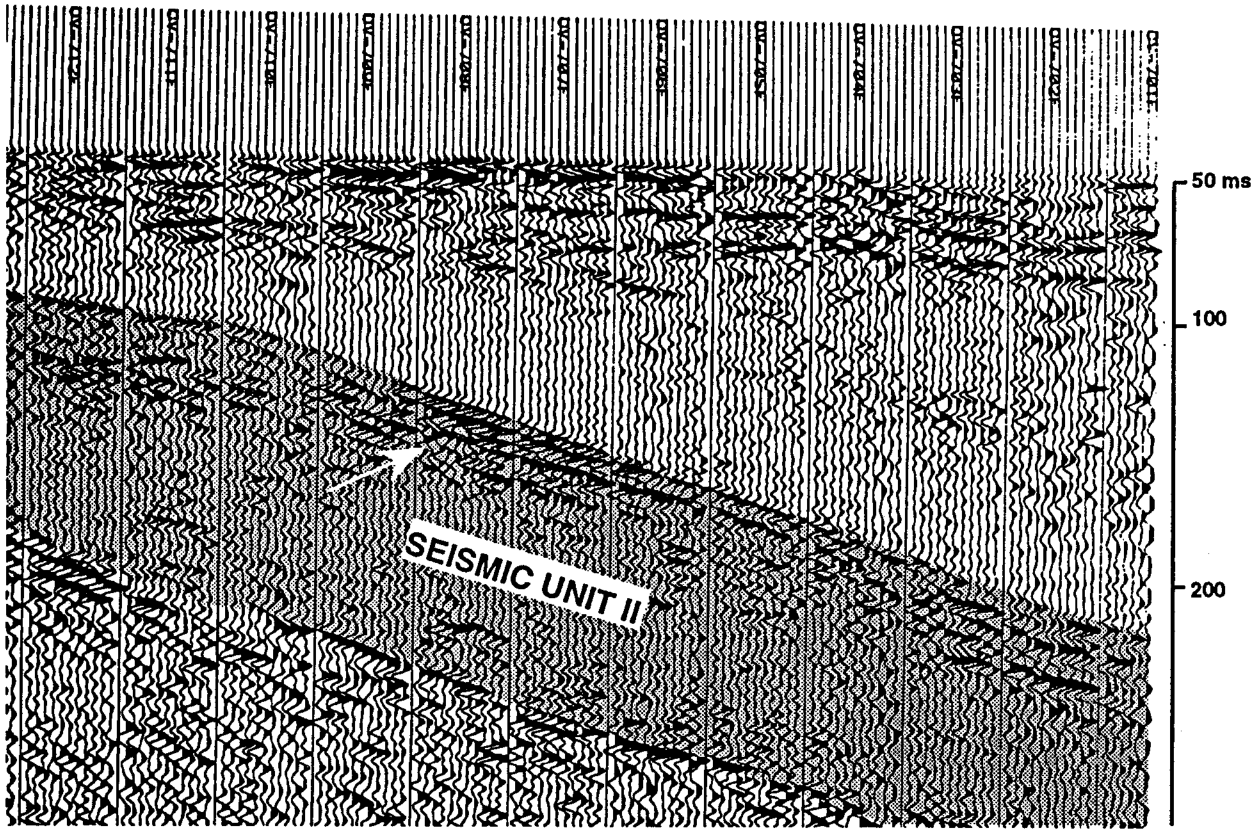
Seismic Unit II represents the second most important seismic component of the North Okanagan Basin fill. In the Armstrong area Unit II reaches a minimum thickness of 122 m on GSC Line 100 (Plate 6), north of Enderby the unit is at least 99 m thick (SFU Line 700-800, Plate 14). Unit II is thickest in mid-basin position and thins towards the basin margins, on Vernon-SFU Lines 1200 and 1300 (Plates 3 and 4) the unit is interpreted to be only 5 m thick. Near Enderby, on SFU Line 700-800 (Plate 14), the unit is best characterized by a series of up to 11 basinward dipping, continuous to semi-continuous, moderate to high amplitude reflections (Figure 5.3).

Unit II is typically concordant with the underlying bedrock topography while its upper contact is marked by high amplitude reflections (Enderby-SFU Line 700-800, Plate 14) (Figure 5.3). However, lower reflection boundaries of Unit II sometimes onlap the basal succession, this is observed at the east end of Armstrong-GSC Line 100 (Plate 6) (Figure 5.2). The internal composition of the unit is often reflection free or an irregular pattern with numerous point-source reflections (Figure 5.4). Generally, internal reflections are most prominent near the upper boundary of Unit II and diminish towards the base of the unit.

Interpretation

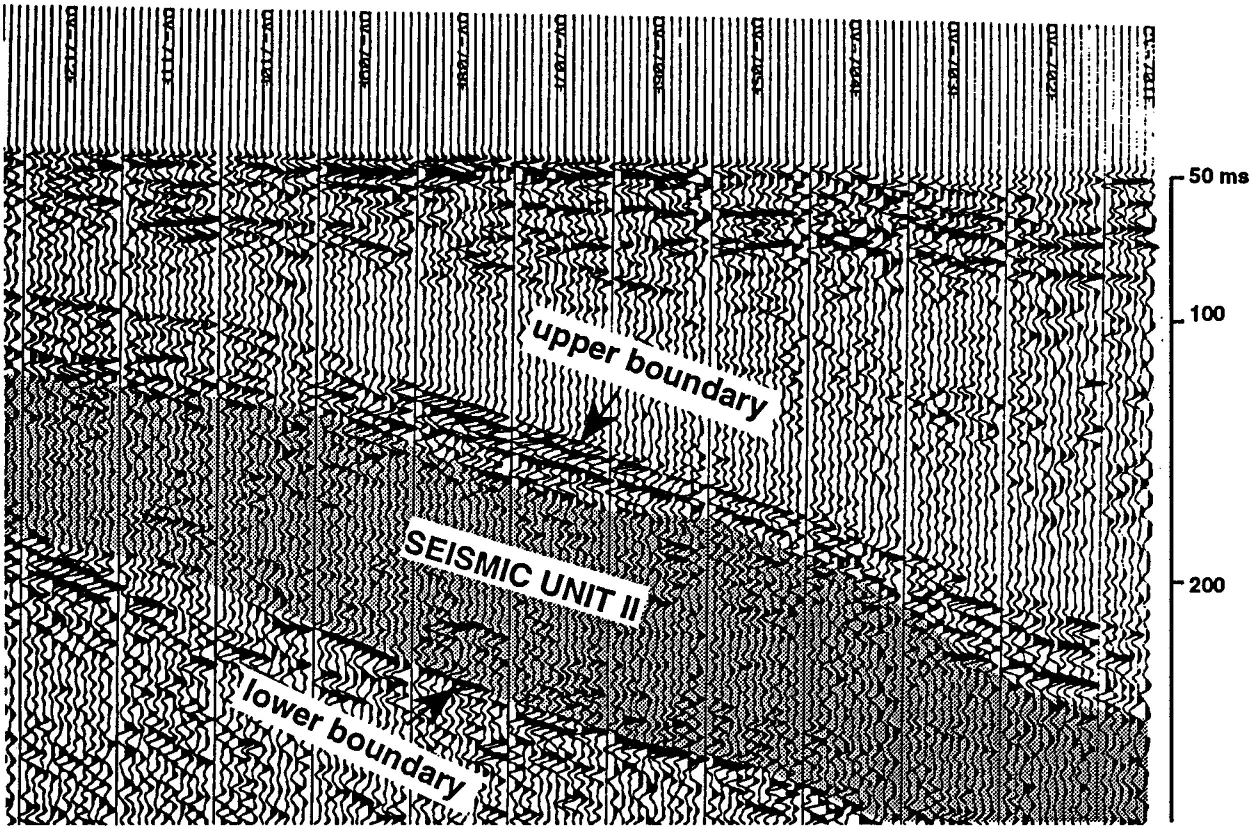
Well log information collected throughout North Okanagan Valley indicate that sediments correlated with Unit II are composed of alternating sequences of compact, medium to coarse silty sand, and pebble to cobble gravel with minor clay content. Individual gravel beds range from 5 m thick in the Vernon area (well V6, Plate 3) to over 24 m thick near Armstrong (well A10, Plate 6). Groundwater well A9 from the Armstrong area provides direct evidence that Seismic Unit II is composed of compact, crudely bedded cobble gravel and coarse sand. The driller's log of well A9 reads: " ... a till-like deposit composed of extremely compact, coarse-grained sand and gravel, this lower unit is up to 24 m thick and overlies bedrock." Sangree and Widmier (1979) indicate that seismic facies consisting of semi-continuous to irregular or reflection free configurations are indicative of deposition in a high energy environment and yield coarse-grained sediments in drill core. The sometimes irregular and incoherent seismic reflection configurations support the interpretation of Unit II as coarse grained sediments.

The upper portion of Seismic Unit II is better defined than the irregular or reflection-free zones found lower in the unit (Figure 5.4). This pattern is interpreted as revealing coarser sediments near the base and finer sediments towards the upper boundaries of the unit. Previous research in the North Okanagan region provides additional evidence supporting this interpretation of coarse-grained sediments. Fulton and Smith (1978) describe the Kamloops Lake Drift as a 38 m succession of compact silty sand and gravel overlying bedrock. A portion of this succession is interpreted as glacial outwash



SFU LINE 700-800

Figure 5.3 Seismic Unit II observed on SFU Line 700-800 north of Enderby. Notice high amplitude, basinward dipping reflections in the upper portion of the unit. Reflections become weaker and more irregular towards base of the unit.



SFU LINE 700-800

Figure 5.4 Zone of irregular and point source reflections observed in Seismic Unit II on SFU Line 700-800 north of Enderby. Notice well defined upper and lower boundaries of the unit.

deposited during glacial ice advance. Although the depositional environments of coarse-grained mixtures of silt, sand, pebble and cobble gravel is not easily interpreted (Brodzikowski and Van Loon, 1991), the change in reflection configuration of the lower portion of Unit II combined with well log data supports the interpretation of a subtle fining upward trend in the coarse-grained sequence.

Recent work (Eyles et al., 1991) in the Okanagan and Kalamalka Lake basins south of Vernon found a zone of incoherent point-source diffractions overlying bedrock. The zone was interpreted as coarse-grained deposits consisting of diamict or outwash sediments that were subsequently overridden and pressurized by advancing glacial ice. Seismic Unit II is probably correlative with the deposits identified south of Vernon. In the Lumby region east of Vernon (see Figure 2.6) Smith (1969) described the Lumby Till as a 12 m thick mixture of compact, unsorted pebbles and boulders in a silty sand matrix that overlies bedrock. Shaw (1975, 1979) observed similar compact silt, sand, gravel, and boulders in the Penticton area and interpreted them as basal, and possibly lodgement, till. These deposits are overlain by outwash silt, sand, and gravel. A 12 to 30 m thick acoustic unit overlying bedrock observed in an early sub-aqueous profile of Okanagan Lake basin was also interpreted as till (?) (Okanagan Basin Committee, 1974).

To summarize, Seismic Unit II is taken to represent a coarse-grained sedimentary assemblage that exhibits a subtle fining upward trend. The lower component of Unit II correlates with compact, bouldery diamict and pressurized outwash. This is overlain by less compact silt, sand and gravel with minor amounts of clay interpreted as less compact glacial outwash.

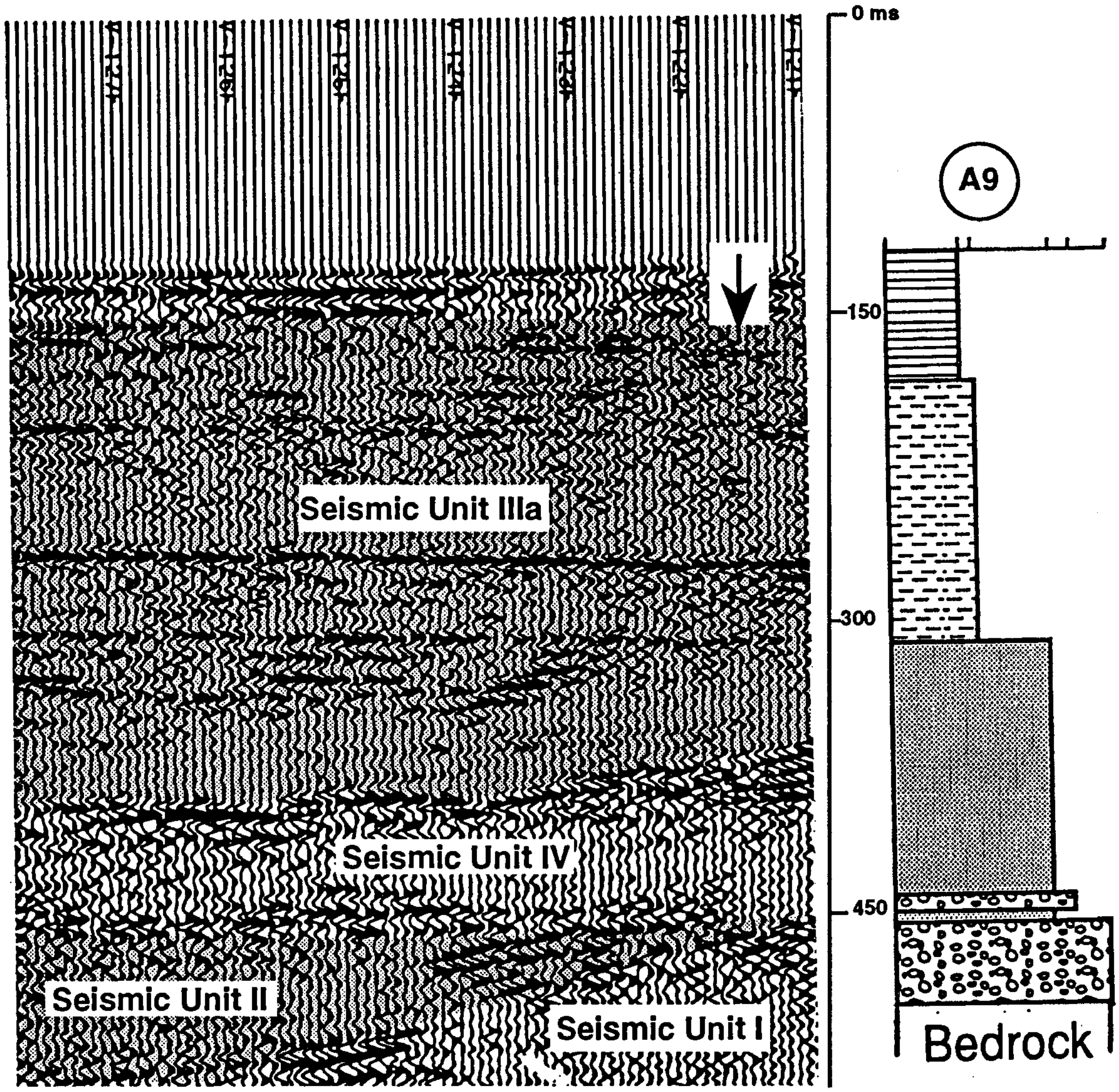
5.4 Seismic Unit III

Seismic Unit III is divided into two sub-units: a lower Unit identified as IIIa and an upper Unit identified as IIIb. Seismic Unit IIIa exhibits less continuous, lower amplitude, sub-horizontal reflections that occur below 50 ms of the surface, and logs show that the unit is composed of laminated fine sand and sandy silt. Seismic Unit IIIa is typically observed in the uppermost zones of all seismic profiles collected in the study area. The reflections exhibit higher amplitudes, continuous horizontal reflections, and are correlated with finely laminated clay on drill and well logs.

5.4.1 Seismic Unit IIIa

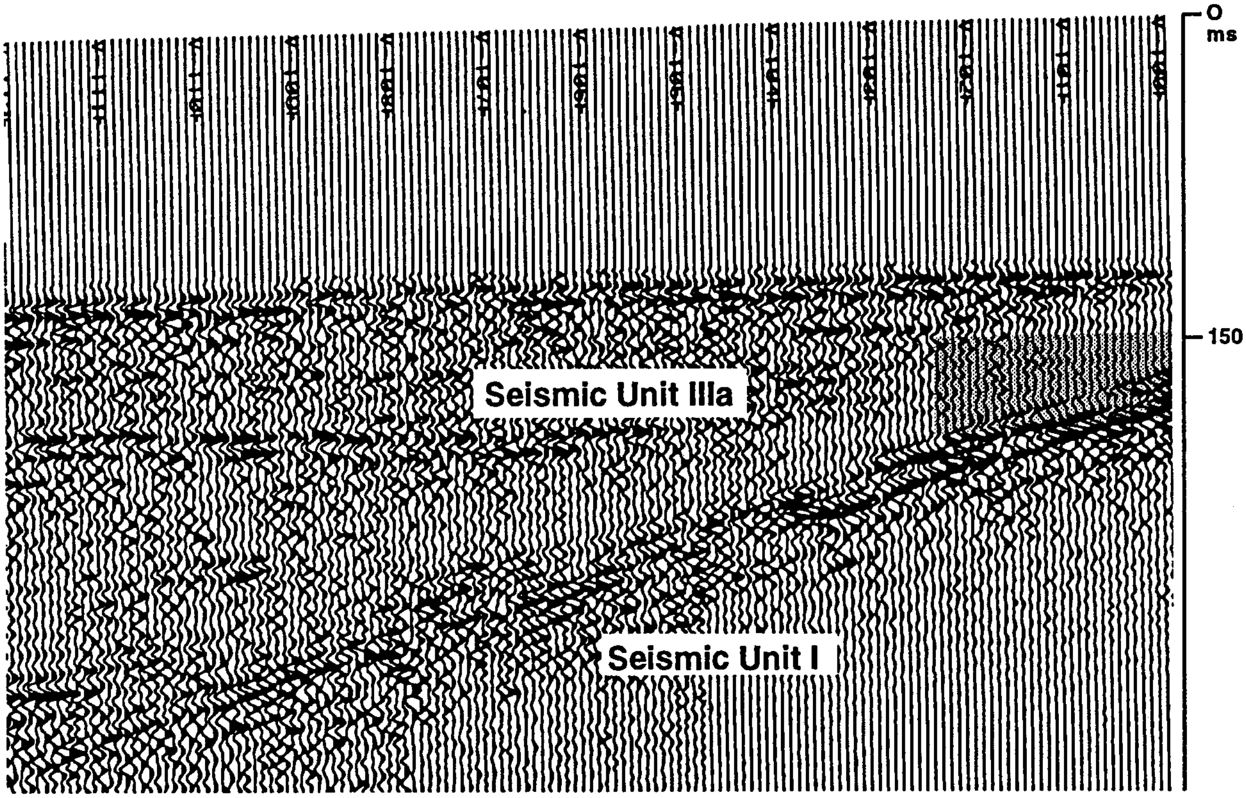
Description

Seismic Unit IIIa represents the most extensive seismic unit in the North Okanagan Basin. The unit varies in thickness from more than 330 m near Armstrong (GSC Line 100, Plate 6) and 345 m north of Okanagan Lake (Vernon-GSC Line 500, Plate 5) to 150 m thick north of Enderby (SFU Line 700-800, Plate 14) and 70 m north of Vernon (SFU Line 400, Plate 2). Characterizing the unit are a series of up to 24 parallel, continuous to semi-continuous, moderate to high amplitude reflections that are generally concordant with underlying seismic units (Figure 5.5). Unit IIIa reflection boundaries may onlap lower seismic units, this is observed on Armstrong-SFU Line 500 and GSC Line 100, and Enderby SFU Lines 700-800 and 900 (Plates 8, 6, 14, and 11) (Figure 5.6). On Enderby-SFU Line 900 the reflection boundaries clearly onlap the underlying basal succession (see Figure 4.2). North of Vernon portions of Unit IIIa are poorly defined and occasionally reflection free, this is especially evident on SFU Line 1200 (Plate 3). An explanation for this is the combination of a deep 500 ms sweep and shallow



GSC LINE 100

Figure 5.5 Seismic Unit IIIa is characterized by a set of parallel, high amplitude reflections. The top of Unit IIIa occurs at about 150 ms below spread V-121 on GSC Line 100, northeast of Armstrong.



GSC LINE 100

Figure 5.6 Parallel, continuous reflections that characterize Seismic Unit IIIa onlap bedrock at the east end of GSC Line 100 (northeast of Armstrong). The shaded area indicates zone of onlapping reflections.

depth to bedrock that combine to reduce signal return and favour the appearance of deeper bedrock reflections in the upper portions of the profile.

Interpretation

Regular and repetitive reflections and reflection patterns are often indicative of a rhythmic mode of deposition. Sangree and Widmier (1979) suggest that continuous reflections with reasonably uniform trace to trace amplitudes indicate uniformity in the mechanism of sediment deposition. Rhythmic reflections are also representative of sedimentation in a relatively stable depositional environment, such as a glacial lake . Considering the regularity and repetitive nature of seismic reflections observed in Seismic Unit IIIa, the unit is interpreted to represent lacustrine sediments. Parallel, repetitive, laterally continuous reflections were also observed in a 450 m thick sequence below Okanagan Lake (Eyles et al., 1991).

The interpretation of Unit IIIa as lacustrine deposits is supported by well log and core analysis (see Chapter Six, Section 6.2.3). Lithologic data reveals that Unit IIIa consists of lacustrine silt that exhibits alternating dark grey, silty-clay laminae of varying thicknesses. Lighter colored laminae range from 1 cm to less than 0.5 mm thick and have a higher silt content. In places these silty-clay sediments contain contorted and deformed sedimentary structures consisting of convoluted beds with wavy and micro-flame structures. The load structures result from rapid sedimentation and subsequent sediment instability. Ashley (1975) shows that coarse sand and silt layers having deformation structures often occur in sediments deposited proximal to an ice front or sediment source. Deformation structures were observed at 36 m and 51 m depth in core collected from SFU drill hole A5 and at 37 m depth in core from SFU drill hole V4 north of Vernon.

Coarse-grained sand and gravel units up to 1 m thick were observed in core extracted from the sediments identified as Seismic Unit IIIa (SFU drill log A5 at 72.5 m to 73.5 m depth, Plate 8). The gravel correlates with a series of parallel, high amplitude reflections visible on Armstrong-SFU Line 500 (Plate 8) at about 125 ms. The occasional occurrence of isolated coarse-grained layers interbedded with lacustrine sediments is not uncommon in glaciolacustrine sediments in the Okanagan and Thompson Valleys. Roberts and Cunningham (1992), Shaw and Archer (1978), Fulton (1965, 1969) have all described gravels overlying fine-grained lake sediments and interpreted the deposits as the result of localized mass movement processes. Gravels overlying lacustrine sediments have also been observed elsewhere in the Western Cordillera: near the margins of Hector Lake, Alberta, Smith (1978) identified gravel interbedded with lacustrine silt that originated from rockfalls along the lake perimeter and/or were deposited from ice-rafted debris.

The observed thicknesses of Unit IIIa are not unexpected given the thick glaciolacustrine sections exposed at the surface in many parts of the Okanagan and Thompson Valleys. These sections typically show alternating, rhythmic, silt, sand and clay. Gravel lenses interbedded with the lacustrine silt are interpreted as the result of valley side mass movement processes (Fulton and Smith, 1978). The glaciolacustrine sediments are varved and frequently contain load structures where a silt or sand unit overlies a clay layer (Shaw, 1977; Fulton, 1965; Banerjee, 1973). In consideration of the reflection patterns that characterize Unit IIIa, and available core data, the unit is interpreted as a thick sequence of (up to 345 m) glaciolacustrine sediments deposited in an ice proximal depositional environment.

5.4.2 Seismic Unit IIIb

Description

Unit IIIb represents one of the uppermost seismic components of the North Okanagan Basin fill. The unit ranges from a minimum thickness of 25 m at the Enderby site (SFU Line 700-800, Plate 14) and 36 m northeast of Armstrong (SFU Line 500 and GSC Line 100, Plates 6 and 8) to over 125 m north of Okanagan Lake (Vernon-GSC Line 500, Plate 5). Unit IIIb is characterized by parallel, continuous, high amplitude reflections that are usually found within 50 ms of the profile datum. The reflections frequently onlap the basin margins (see east end of Armstrong-GSC Line 100, Plate 6).

Interpretation

Sediments correlated with Unit IIIb typically have thin clay laminae from 1 mm to less than 0.3 mm thick in drill core. A 20 cm section of core collected at 13.8 m depth from SFU drill hole V4 has a minimum of 106 laminae; some silt laminae were up to 2 mm thick. Sedimentary structures observed in core from sediments in Unit IIIb include deformed bedding, micro-faults, and trace fossils (these sedimentary features are discussed in Chapter Six, Section 6.2.4). Overall, the sediments of Unit IIIb are finer-grained than sediments of Unit IIIa. The log of well A9, located on Armstrong-GSC Line 100 (Plate 6), has a 70 m thick sequence of horizontally-bedded, fine-grained sediments, this drill hole was completed as part of a 1965 oil and gas exploration program in North Okanagan Valley and the descriptions of the drill cuttings are extremely vague. It is ascertained here that this 70 m thickness is inconsistent with more reliable core data extracted at SFU drill site A5. At this site cuttings were monitored continuously and core samples were extracted at various depths. Close attention was paid to lithologic variations in the cuttings and the presence of sedimentary structures in core samples.

From their work in the Okanagan and Thompson Valleys, Shaw (1977, 1979), Shaw and Archer (1978), Fulton and Smith (1978) show that varve thickness and mean grain size decreases upsection in the glaciolacustrine sequences. During glacial retreat the ice front becomes more distant from previous locations, this results in reduced sedimentation rates in distal locations. Lacustrine sediments deposited in these more distal locations consist of thinly laminated, clay rich sediments. In Hector Lake, Alberta, thick varves were interpreted to result from proximal sediment deposition, more distal deposits were faintly laminated, massive, and finer-grained (Smith, 1978). Ashley (1975) describes proximal varves that exhibit coarser grain sizes relative to varved sediments deposited in more ice distal positions. As previously discussed, sediments located upsection in Unit IIIb are finer-grained and exhibit thin (1.0 to 0.3 mm) varves.

The relationships between Seismic Unit IIIb reflection configurations and well log data show the unit as a fine-grained glaciolacustrine deposit. These sediments were likely deposited in more distal locations, than those of Unit IIIa, during deglaciation in the North Okanagan Valley. Therefore, the finer-grained sediments correlated with Seismic Unit IIIb are indicative of sedimentation in an ice distal environment.

Eyles et al., (1991) described a similar 60 m thick seismic unit exhibiting parallel, continuous reflections as laminated silt deposited since deglaciation. Their interpretation is based entirely on acoustic data with no lithologic verification. The interpretation of the 60 m unit as post-glacial silt may be misleading in light of other studies that provide sedimentation rates and address post-glacial deposition in the Okanagan Valley. Sedimentation rates for Okanagan Lake, determined from pollen analysis, were estimated at approximately 2.9 mm/a for the last 100 years (Okanagan Basin Committee, 1974). Assuming the region was ice free by about 10,000 BP (Fulton, 1975), and a 2.9 mm/a sedimentation rate, this would account for only 29 m of deposition. Also, few tributary valleys flow into the main Okanagan Valley and post-glacial sediment input from adjoining basins may be less than predicted.

5.5 Seismic Unit IV

Description

Seismic Unit IV is found close to, or abutting, the basin margins of the North Okanagan Valley and has important implications for describing the architecture of the basin fill. The unit has basinward dipping, semi-continuous to divergent, moderate amplitude reflections lying unconformably over lower seismic units. The unit is best observed on Armstrong-SFU Line 500 and GSC Line 100 (Plates 8 and 6) and Vernon-GSC Line 500 (Plate 5). On Armstrong-GSC Line 100 (Plate 6) the unit is up to 120 m thick (66m average thickness) and internal reflections tend to flatten and lose their continuity to the west. A series of truncations are apparent along the upper contact of the unit in addition to a convex, mounded series of reflections that overlie lower reflections (Figure 5.7). Generally, Unit IV has wedge or lens-shaped morphologies that pinch out laterally. The upper contacts are sharp and well defined and lower contacts lie unconformably over, and downlap onto, Seismic Unit II and the basal succession (Unit I). On Armstrong-SFU Line 500 (Plate 8), a strike section of the basin fill, Unit IV attains a maximum thickness of about 22 m and exhibits a lens-shaped morphology that pinches out to the north and south (Figure 5.8). Internal reflections are well defined and minor truncations of the reflections are

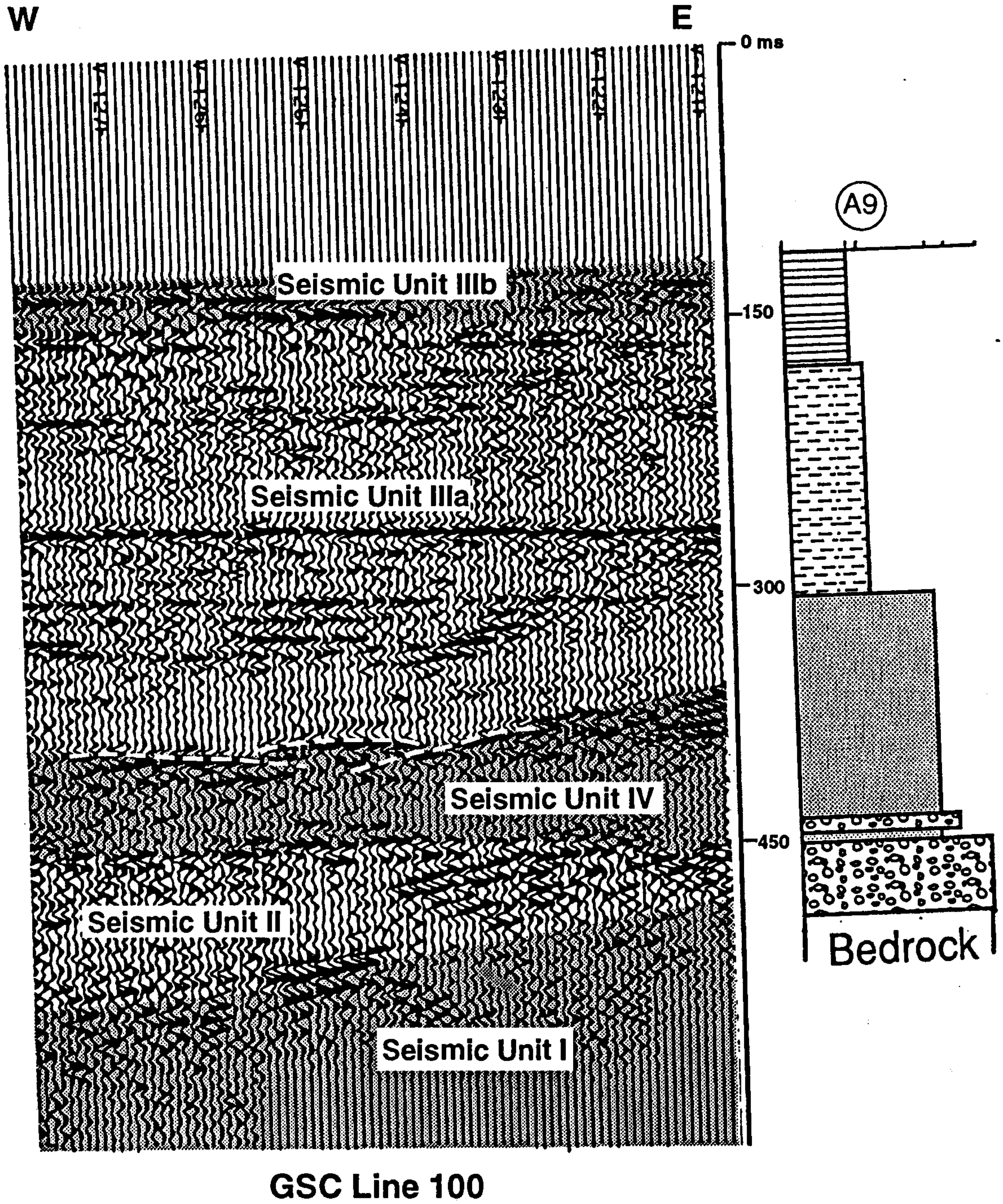
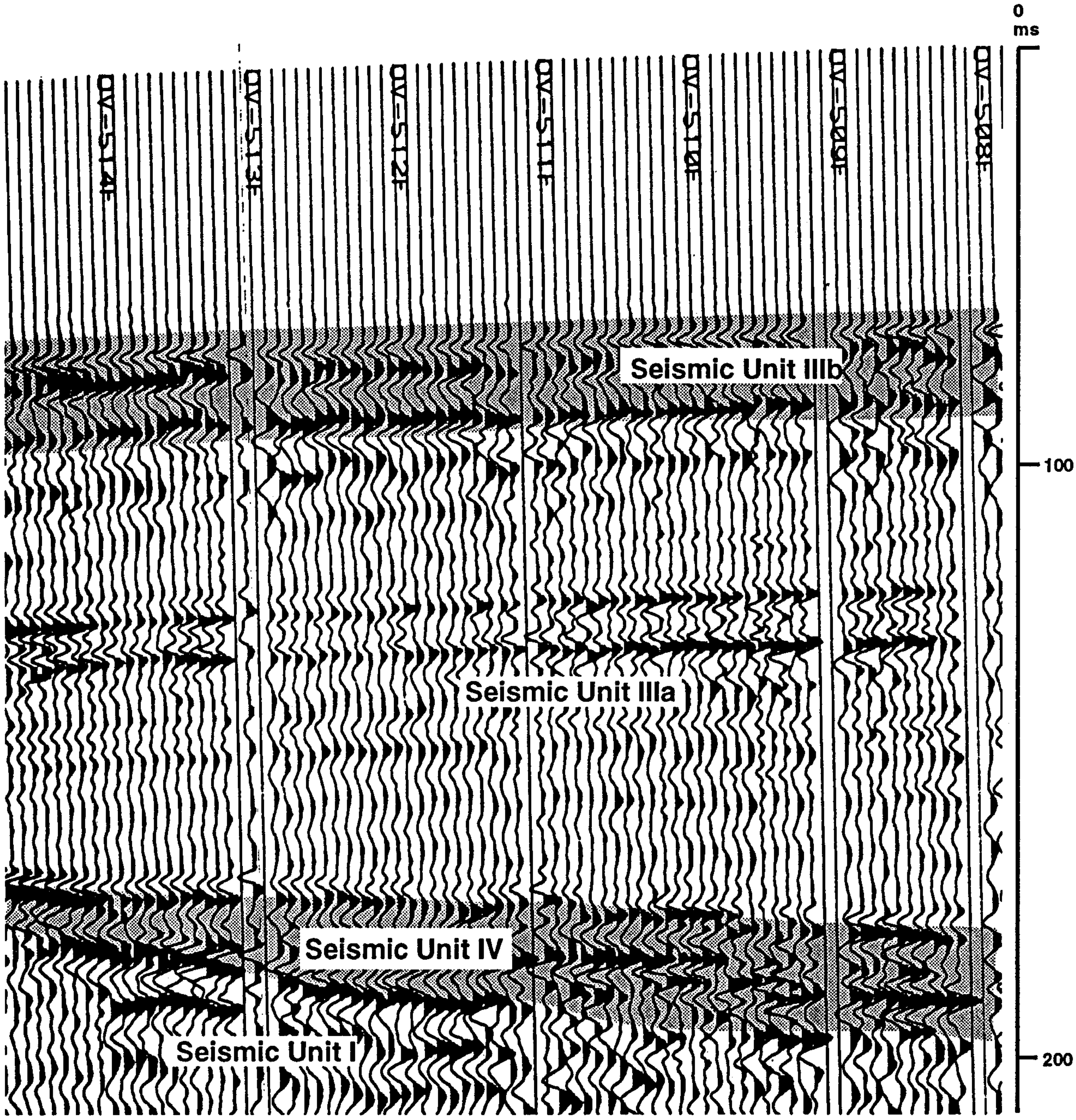


Figure 5.7 Convex and truncated reflections observed at the upper boundary of Seismic Unit IV on GSC Line 100 (north of Armstrong). The dashed lines highlight the reflection patterns



SFU LINE 500

Figure 5.8 A part of SFU LIne 500, northeast of Armstrong, showing the nature of Seismic Unit IV. The upper and lower boundaries of the unit are well defined and show moderate amplitude, continuous reflections.

observed near the north end of the unit.

A 120 m section of log A10 located on Armstrong-GSC Line 100 (Plate 6) is correlated with Unit IV and is characterized by alternating compact sand and pebble to cobble sized gravel. Individual gravel beds range from 10 to 12 m thick, the lower contact of Unit IV on GSC Line 100 correlates with a pebble to cobble gravel transition in well log A9 (Figure 5.7). In the Vernon area log V6 shows 32 m of interbedded compact sand and gravel with individual gravel beds up to 9.2 m thick. Upslope, on the east valley side, the log of well V7 has silt and gravel beds up to 9 m thick overlying bedrock These may represent lateral continuity between the surface gravels of the valley side with subsurface, wedge-shaped seismic units. Occasionally Seismic Unit IV occurs as 1 m thick sandy-gravel beds that appear as a series of continuous, parallel, high amplitude reflections. This is observed on Armstrong-SFU Line 500 (Plate 8) at approximately 72.5 m depth (125 ms).

Interpretation

The reflection configurations that characterize Seismic Unit IV, coupled with available lithologic data, supports the interpretation of the unit as alluvial fan or, more generally, mass movement deposits. This interpretation is supported by the wedge or lens-shaped morphology of the units, their position relative to the basin margins, and the occurrence of contemporary alluvial fan complexes located sub-aerially throughout the North Okanagan Valley (Figure 5.9). Similar coarse-grained deposits were observed in the South Thompson Valley by Roberts and Cunningham (1992) and Fulton (1965). They attributed the origins of gravels interfingered with lacustrine silt to coarse-grained sediment slumping into Kamloops Lake from the valley sides during lacustrine deposition. Along lake margins in Lillooet Lake similar sediment assemblages

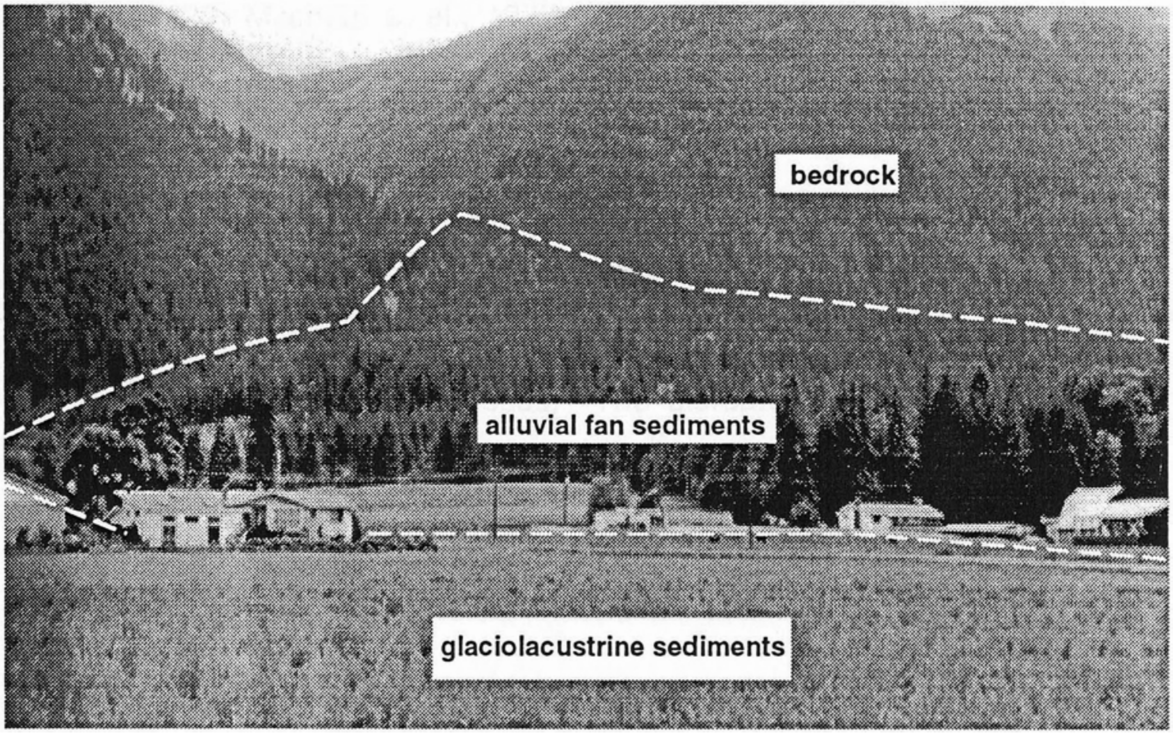


Figure 5.9 Basin margin alluvial fan overlying glaciolacustrine sediments at the Armstrong site. Photograph was taken looking southeast from Back Enderby Road north of Armstrong.

were observed by Gilbert (1975). Desloges and Gilbert (1991) identified a coarser, more opaque seismic layer bounded by acoustically stratified sediment in the basin of Harrison Lake, British Columbia. The coarse sediments were interpreted to originate from slow, basinward inflow of sediments from the lake margins that resulted in 1 to 7 m thick units confined to the basin margins.

Alluvial fan complexes, or mass movement facies, that are characterized by complex simple or complex compound external and internal reflection configurations are often indicative of high energy deposits (Sangree and Widmier, 1979; Mitchum et al., 1977) (Figure 5.10). Alluvial fan complexes typically exhibit lens-shaped external boundaries with limited internal reflection continuity. Internal reflection configurations may exhibit parallel, divergent, and possibly chaotic patterns that onlap underlying seismic units. To reiterate, Seismic Unit IV is interpreted as wedge to lens-shaped bodies of coarse-grained sediments located near the basin margins that are deposited as alluvial fans by mass movement processes. The disrupted, sub-parallel reflection configurations and wedge-shaped reflection geometries of Seismic Unit IV are consistent with those found in mass movement facies identified in the Fraser River delta, British Columbia (Jol and Roberts, 1988).

5.6 Seismic Unit V

Description

The lens-shaped features identified as Seismic Unit V are grouped together as one unit rather than interpreted as sub-units of a larger seismic package because they have sufficiently distinctive properties to be classified as a separate unit. Seismic Unit V is observed only in the upper 90 ms of Enderby-SFU Lines 100 and 700-800 (Plates 10 and 14) (Figure 5.11). The unit has

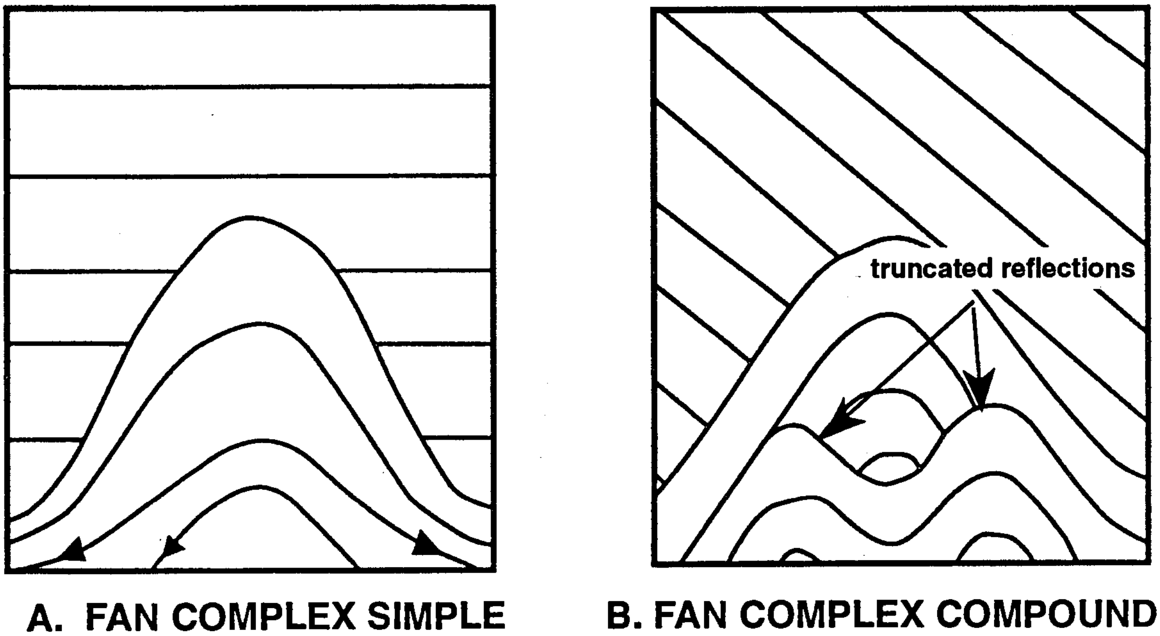


Figure 5.10 Examples of mounded reflections patterns (after Mitchum et al., 1977). **A** shows a simple mounded pattern with reflections that pinch-out laterally. **B** shows a complex set of reflections that pinch-out laterally and truncated reflections at the base of a mounded unit.

asymmetrical lens-shaped morphologies with concave lower boundaries. Each unit ranges from 30 to 100 m width (60 m average width) and from 8 to 10 m thick. The reflections have low continuity and variable amplitudes with boundaries that truncate surrounding seismic reflections. Often the lower boundary of the unit shows a stronger series of reflections than the upper boundary. Internal reflections within Seismic Unit V are apparent on a 35 m thick feature observed on SFU Line 700-800 (Plate 14) (Figure 5.12).

Interpretation

The lens-shaped features identified as Seismic Unit V represent channel deposits. Seismic reflection configurations representative of sediments deposited by fluvial processes exhibit low continuity and variable amplitude reflections that result from deposition in high and variable energy environments. The reflection characteristics of channel sequences are also characterized by transitional upper surfaces and sharp bases resulting from erosional truncations (Mitchum et al., 1977; Sangree and Widmier, 1979). Such reflection patterns are not unexpected given the architectural variations found in sandstone channel environments (Miall, 1984; Cant, 1982).

Lithologic information correlated with Seismic Unit V is limited due to the location of SFU Lines 100 and 700-800 (Plates 10 and 14) in the Enderby region. Attempts were made to complete exploration wells at the Enderby site during the drilling field season of 1990, however, artesian flows in excess of 374 litres/minute were encountered at only 12.7 m depth (SFU well site E1, Figure 3.13). After consultation with local water well drillers it became apparent that unless mud weighting compounds and blow-out preventions were used the safety and cost effectiveness of the drilling program was an issue. Drilling, therefore, was greatly curtailed in the Enderby area and the only detailed log

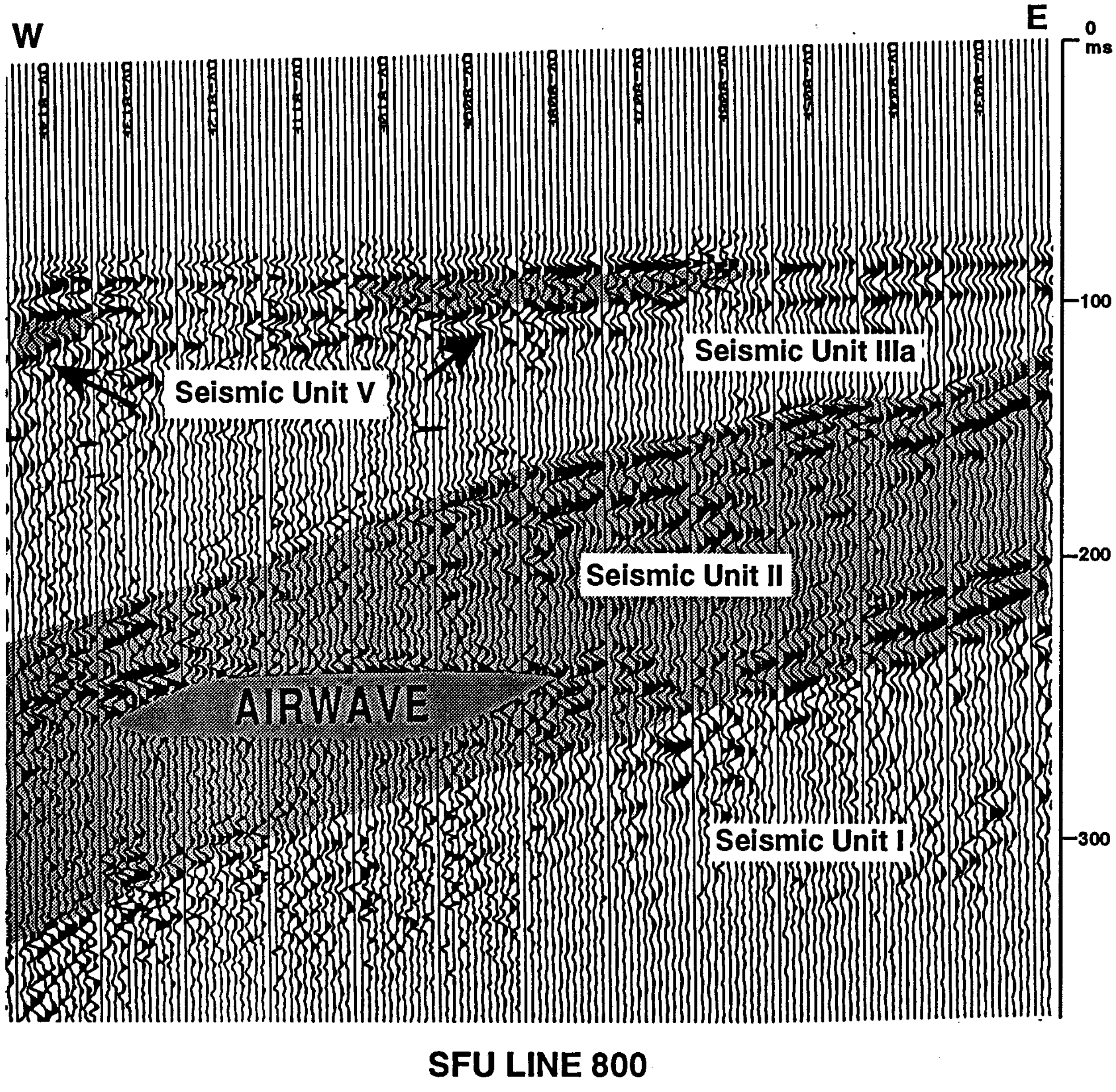


Figure 5.11 The seismic signature of fluvial channels, Seismic Unit V, observed on SFU Line 800 (north of Enderby). The eastern end of another channel is visible at the west end of the line (at about 100 ms).

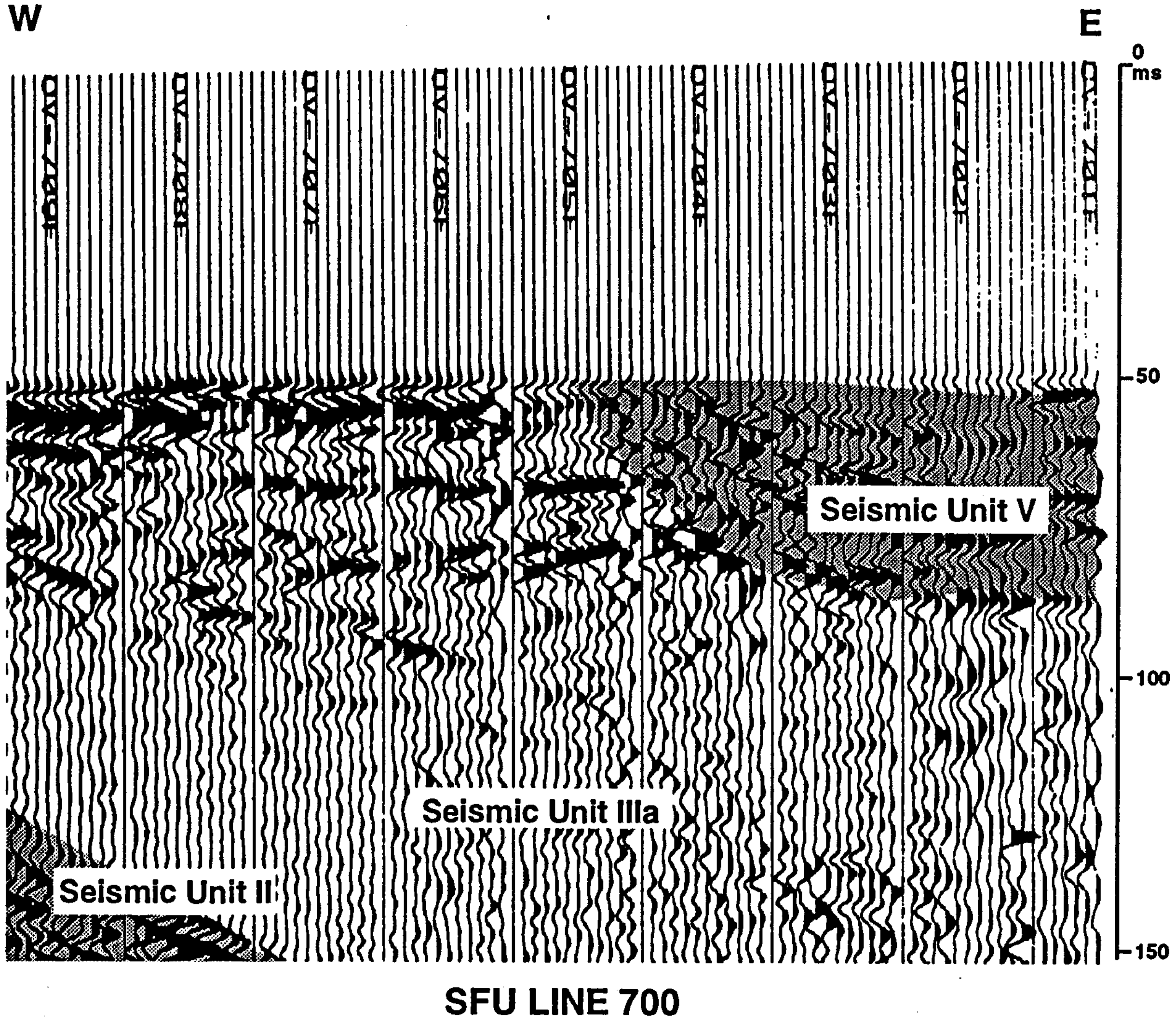


Figure 5.12 A large channel, Seismic Unit V, found at the east end of SFU Line 700 (north of Enderby). The unit extends from 50 to 85 ms.

information available is that collected at SFU drill holes E1 and E2.

At the Enderby site Seismic Unit V is interpreted as paleo-channels of the meandering Shuswap River. From the confluence of the Shuswap River with North Okanagan Valley, the river flows northward for about 30 km to Mara Lake along a narrow floodplain. SFU drill sites E1 and E2 were located at the base of a 3.5 m embankment that defined the eastern limit of a large paleo-channel on the floodplain (Figure 5.13). The stratigraphy observed in the logs of SFU drill holes E1 and E2 showed fining upward sequences composed of fine to medium sand underlain by a coarse sand channel lag.

It follows from the correlation of reflection properties with core data and surficial geomorphology that the interpretation of Seismic Unit V as channel deposits is warranted. Near Vernon, laterally continuous, fine to medium-grained sand range in thickness from 5 m to 12 m (see SFU well log V2 on Plate 1). The sand horizons are likely representative of channel fills. This channel feature was not observed on seismic profiles collected at the Vernon site.

Figure 5.13 Paleo-channel identified on the floodplain of the Shuswap River north of Enderby. SFU Seismic Line 700 and drill holes E1 and E2 are located immediately to the north of the paleo-channel.

CHAPTER SIX

LITHOFACIES ANALYSIS

6.1 Introduction

This chapter contains the description and interpretation of lithologic data collected in the North Okanagan Basin. SFU drill logs and groundwater well logs were used to construct 7 lithologic profiles (Figures 6.1 to 6.8). Locations of the lithologic profiles are provided in Figure 6.1. The facies were identified on the basis of sedimentological characteristics obtained from core, cutting samples, drill and well logs, driller's comments, seismic profiles (when necessary), and geophysical logs. From the data eight facies were identified in the North Okanagan Basin fill, these are:

1) Facies A - bedrock
2) Facies B_1 - poorly stratified cobble gravel and sand
3) Facies B_2 - stratified sand and gravel
4) Facies C - laminated sandy silt
5) Facies D - laminated silty clay
6) Facies E - interbedded gravel and sand
7) Facies F_1 - medium to coarse sand
8) Facies F_2 - upward fining sand.

Following the description of each of these lithofacies and an interpretation of the depositional environment, processes of deposition, and relative chronology of each facies is made. Finally, the volume of the basin fill is calculated

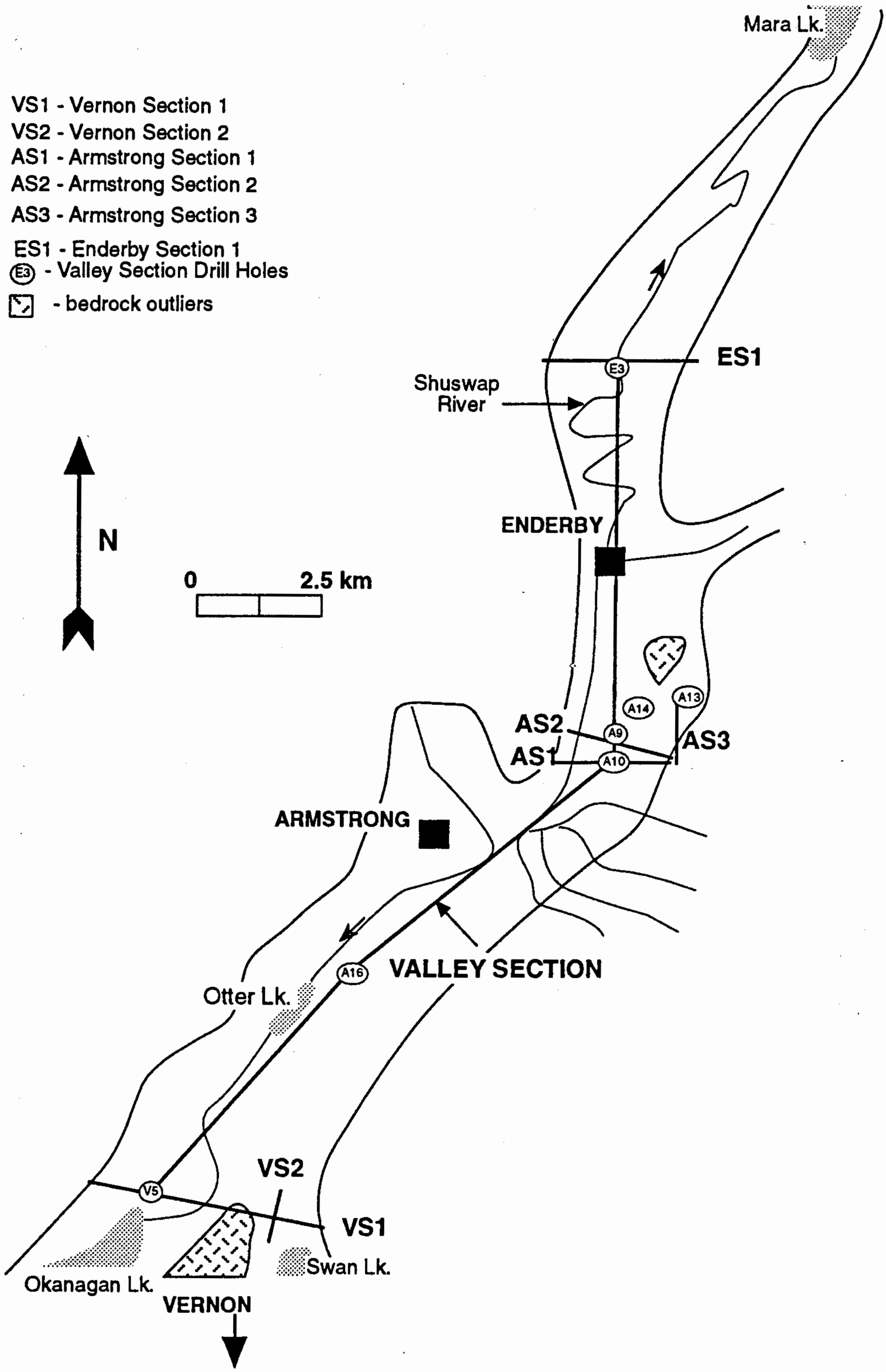


Figure 6.1 Location of lithologic cross-sections, North Okanagan Valley.

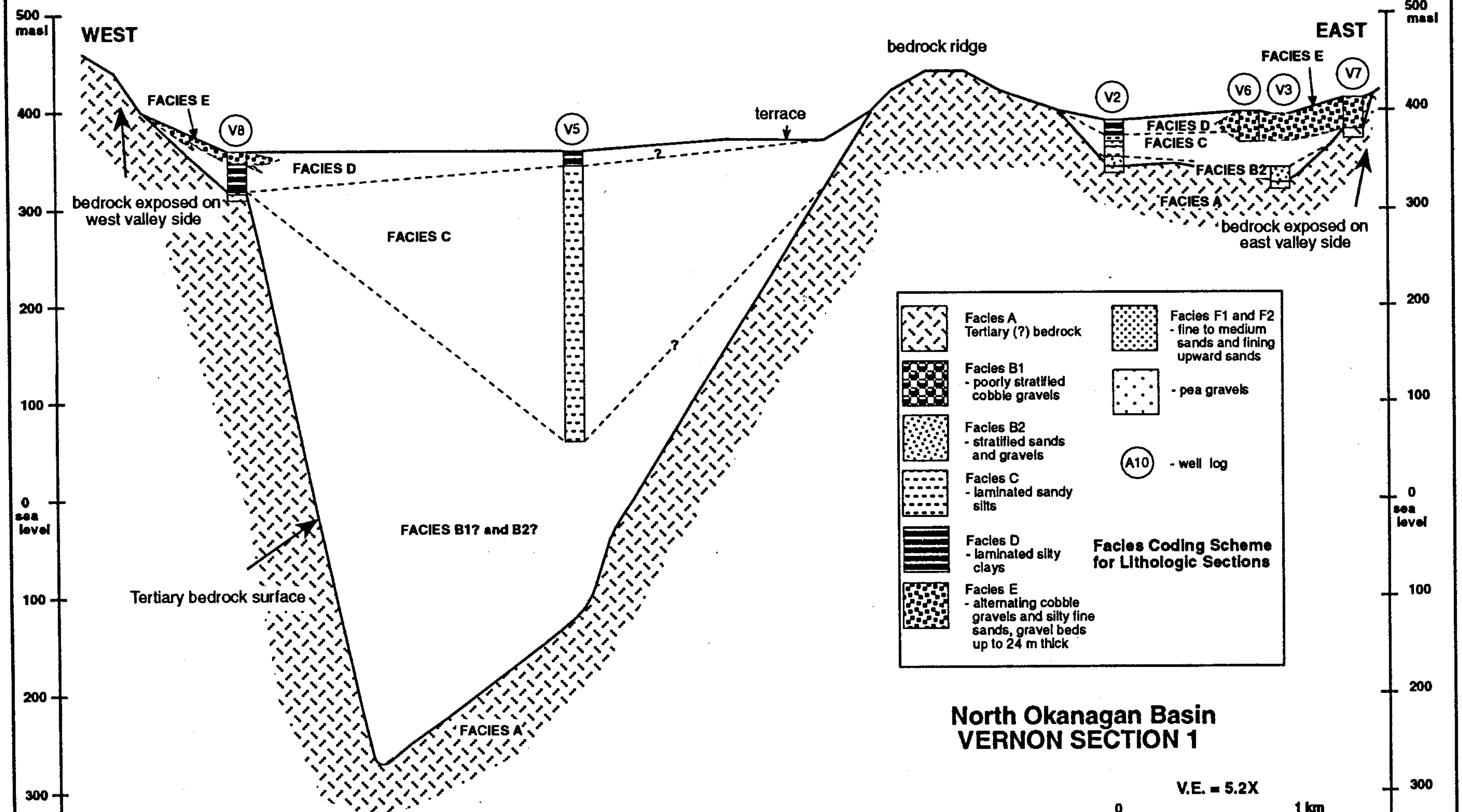


Figure 6.2 Vernon Section 1, Lithologic Cross-Section.

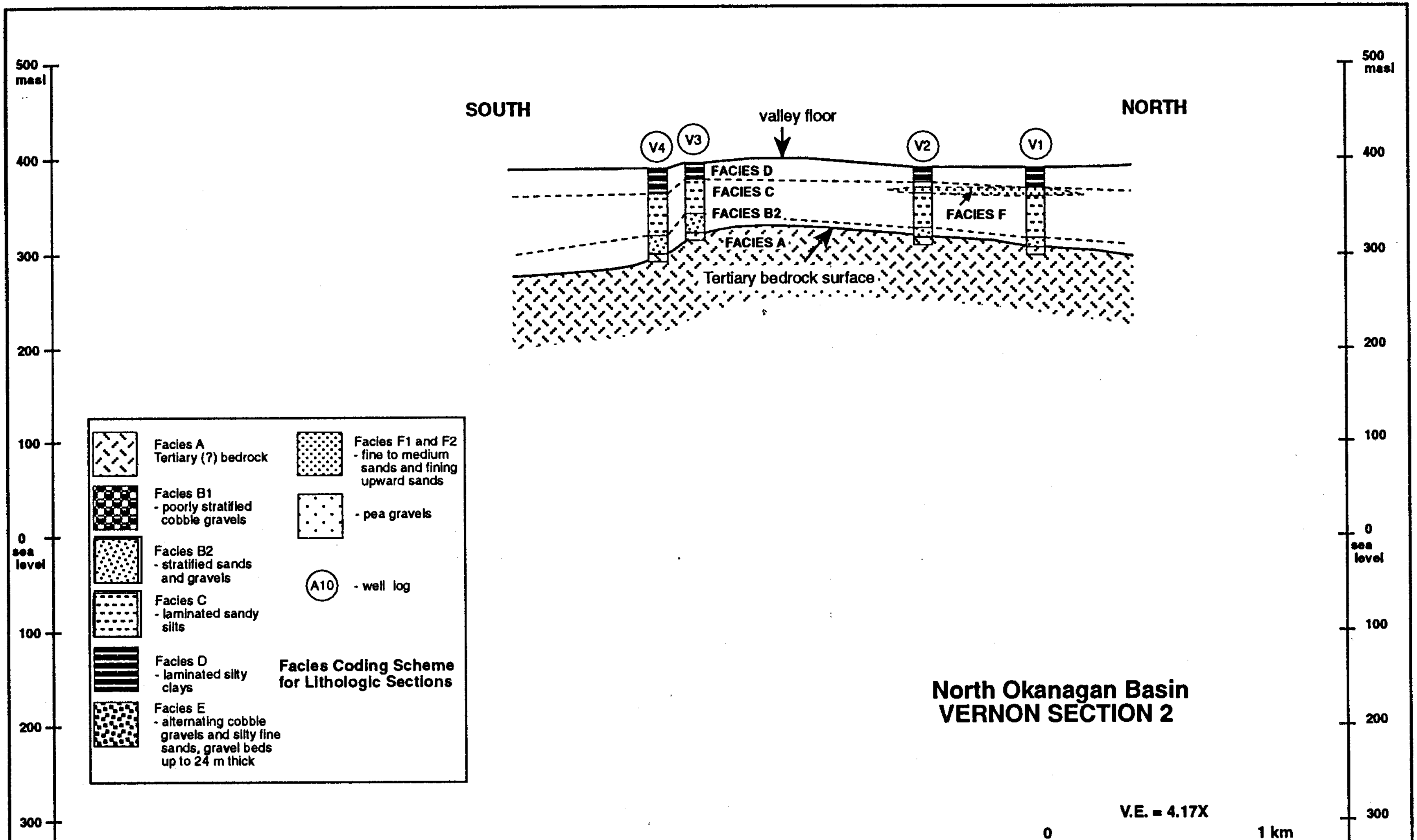


Figure 6.3 Vernon Section 2, Lithologic Longitudinal Profile

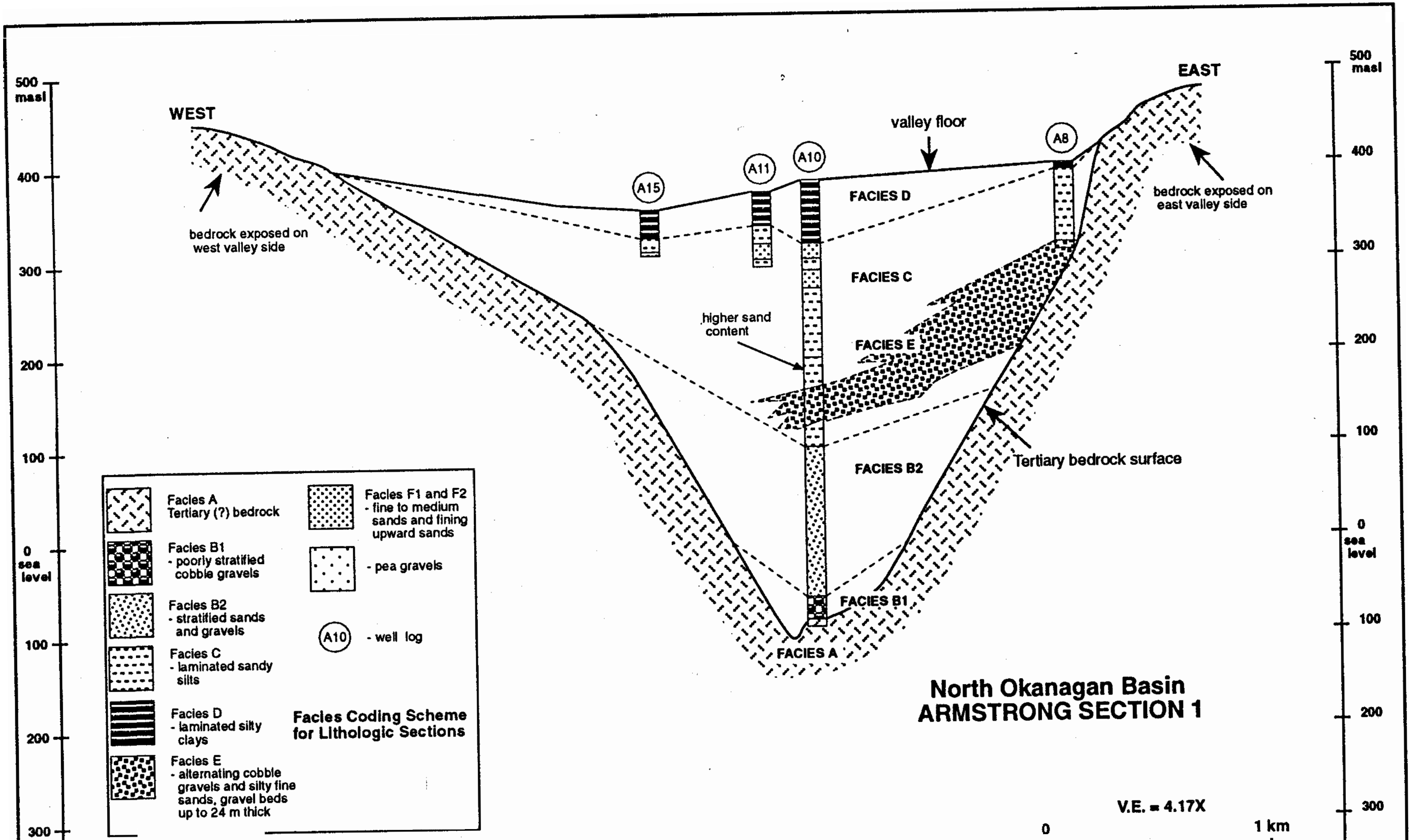


Figure 6.4 Armstrong Section 1, Lithologic Cross-Section.

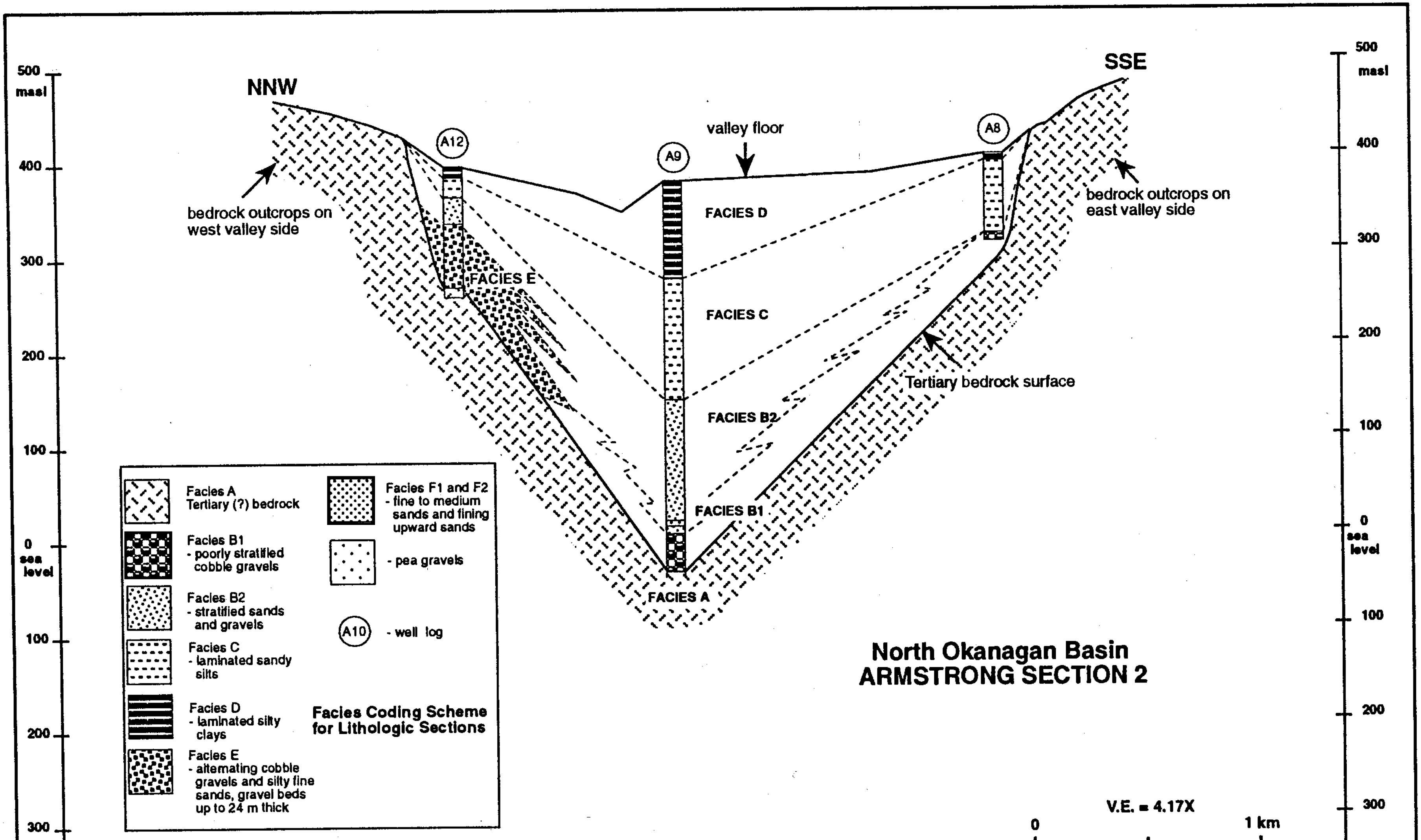


Figure 6.5 Armstrong Section 2, Lithologic Cross-Section.

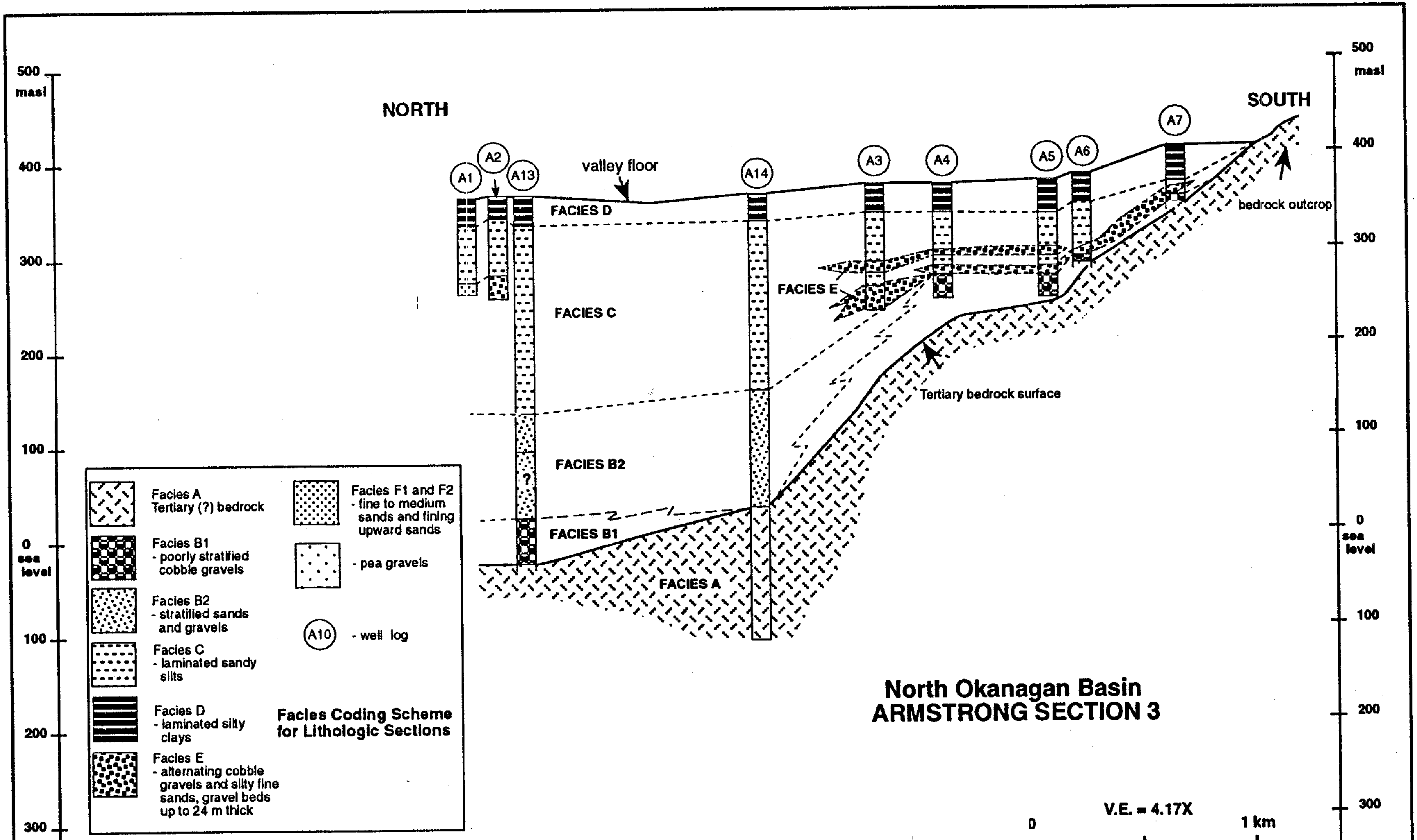


Figure 6.6 Armstrong Section 3, Lithologic Cross-Section.

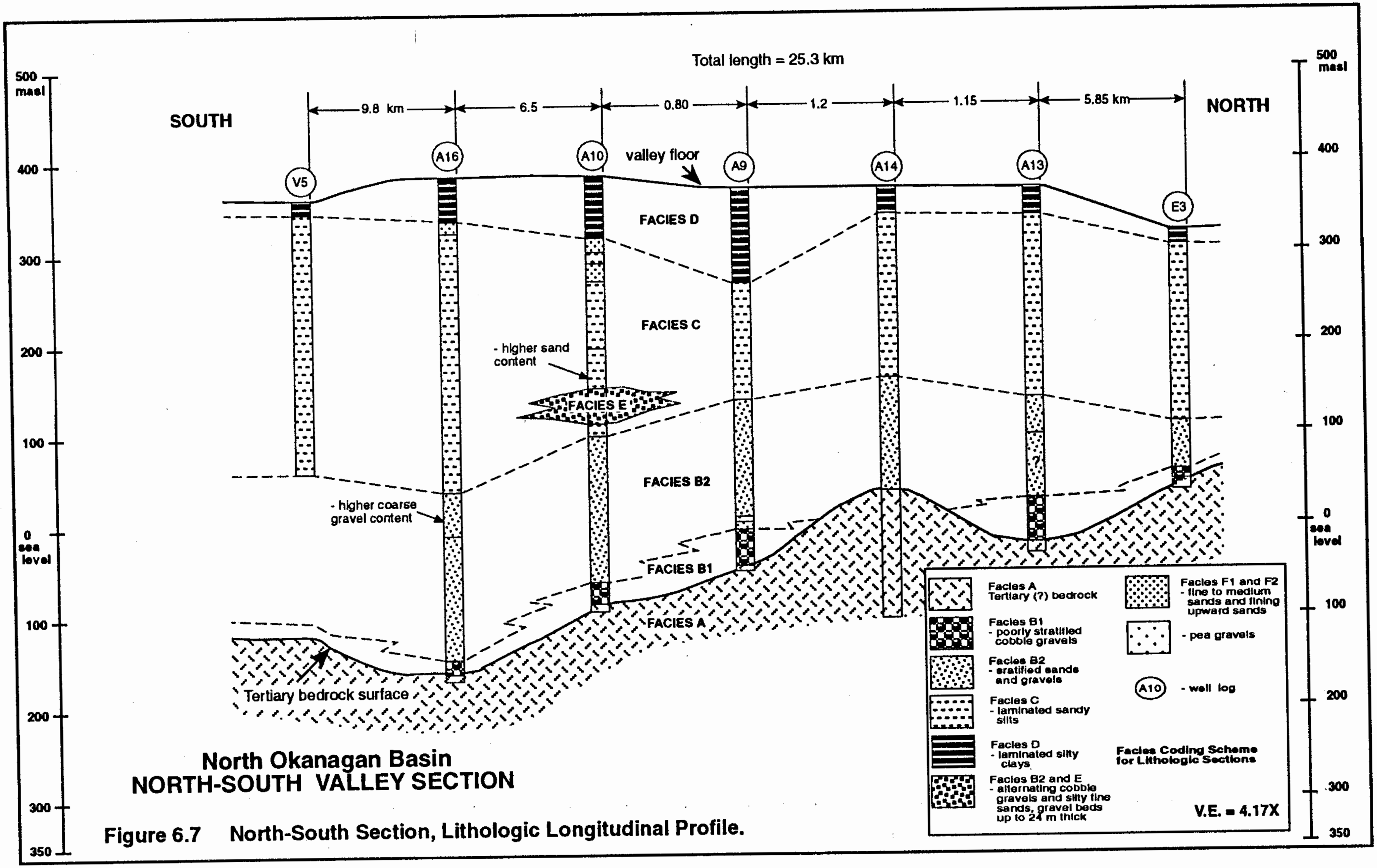


Figure 6.7 North-South Section, Lithologic Longitudinal Profile.

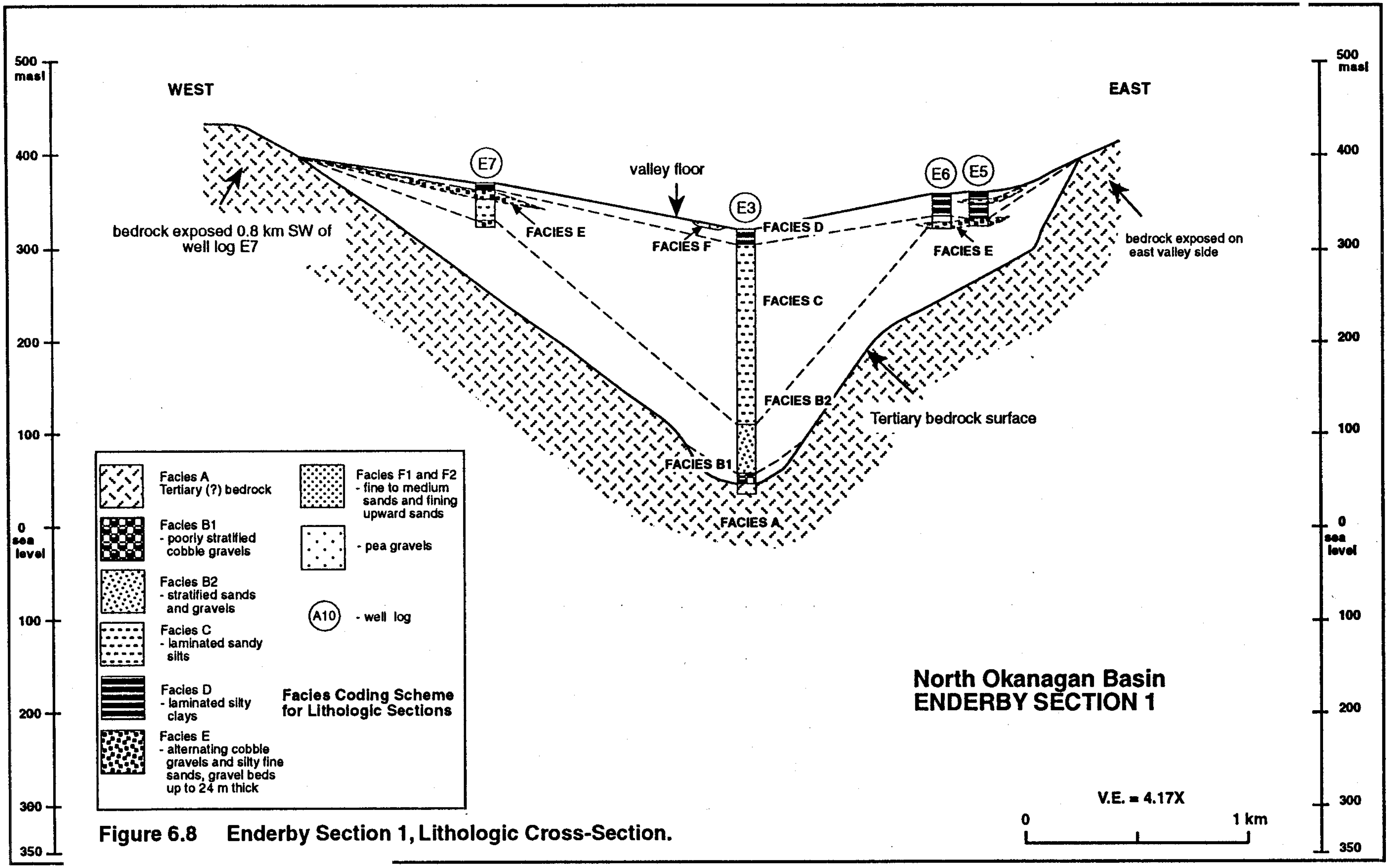


Figure 6.8 Enderby Section 1, Lithologic Cross-Section.

using data obtained from valley cross-sections between Vernon and the south shore of Mara Lake.

6.2 Lithofacies: Description and Interpretation

6.2.1 Facies A: Bedrock

Facies A was found at the Vernon, Armstrong, and Enderby sites in the North Okanagan Valley. In the Vernon area bedrock was sampled at 45 m depth in SFU drill hole V2 (Figure 6.2) and at a depth of 90.2 m some 1.1 km to the south in SFU drill hole V4 (Figure 6.3). North of Okanagan Lake, at well site V5 on seismic profile Vernon-GSC Line 500 (Plate 5), bedrock was interpreted at about 280 mbsl (metres below sea level) . In the Armstrong region depth to bedrock values range from 87 masl in log A10 to a depth of 189 mbsl in log A16 located south of Armstrong (Figures 6.4 to 6.7). North of Enderby bedrock was recorded at about 53 masl in the log of well E3 (Figure 6.8).

The geology of Facies A is a component of the complex arrangement of bedrock situated on either side of the Okanagan Valley fault in the Okanagan Complex (Okulitch, 1984) (Figure 2.5). Middle Tertiary extension of the region resulted in approximately 90 km of offset between two plates that were essentially 'pulled apart" (Tempelman-Kluit and Parkinson, 1986). This led ultimately to the formation of the south-trending Okanagan Valley fault. West of the fault, and southeast of Vernon, bedrock consists of Mesozoic, Paleozoic, pre-Cretaceous, and pre-late Ordovician metamorphic rocks and some rocks of the Shuswap Metamorphic Complex (Okulitch, 1979). East of the fault the bedrock geology is not as well understood and consists predominantly of Shuswap Metamorphic Core Complex rocks (Figure 2.5). Eocene volcanic and sedimentary rocks occur west of the fault and in the southeast portion of the map area; middle Triassic granitic rocks also crop out west of the fault (Figure 2.5).

Generally, as observed on the longitudinal profile between Enderby and the north shore of Okanagan Lake, bedrock exhibits a southward deepening trend (Figure 6.7). North of Enderby in log E3 bedrock occurs at 53 masl. Approximately 15.5 km to the south in log A16 bedrock is observed at 183 mbsl. Between these locations the basin floor exhibits a regional slope to the south of about 0.9°. Continuing the profile from log A16 to the position of log A5 (GSC Line 500, Plate 5; Figure 6.2) the slope of the basin floor is approximately 0.8°.

Interpretation

Facies A represents the Tertiary (?) uplifted and eroded bedrock surface that forms the 'basement' of the unconsolidated basin fill. The facies is identified from bedrock cuttings collected at SFU drill sites V2 and V4 and from groundwater well logs. The facies exhibits a southward regional dip of 0.8° to 0.9° and bedrock slopes basinward from the valley sides at 12.5° to 24.3°. In some areas a bedrock 'ledge' is observed on the outer margins of the basin. This is evident on the east end of Enderby Section 1 below logs E5 and E6 (Figure 6.8) and on Armstrong Section 1 (Figure 6.4) between log A15 and the west valley margin.

Vernon Section 1 provides a profile of a shallow sub-basin on the east side of the ridge that separates Okanagan Lake from Swan Lake (Figure 6.2). In this region of the North Okanagan Valley, Swan, Kalamalka and Woods Lake are all contained within in a shallower sub-basin that parallels the main Okanagan Valley.

6.2.2 Facies B: Stratified sand and gravel

Facies B is divided into two sub-components: Facies B_1 is poorly stratified cobble gravel and sand and B_2 is stratified sand and gravel. Descriptions and interpretations of the facies are based on cutting samples and comments from drill logs. Facies B is observed throughout the North Okanagan Valley in deeper, mid-valley positions (Figures 6.4 to 6.8). Near Armstrong, Facies B_1 and B_2 combined, attain a maximum thickness of about 226 m (log A16 in Figure 6.7). At Enderby, a minimum thickness of about 5 m is observed in the log of well E3 (Figure 6.8). Sediments described as Facies B represent the lowermost facies of the basin fill and are the second-most abundant sedimentary unit in the North Okanagan Basin.

6.2.2.1 Facies B_1: Poorly stratified cobble gravel and sand

Description

The lower component of Facies B is B_1 which is characterized by compacted bouldery gravel interbedded with coarse sand and silty fine sand containing some pebbles. The unit is up to 47 m thick (log A13 in Figure 6.7) while individual gravel beds can be up to 24 m in thickness. Samples collected from drill cuttings showed clasts that were moderately rounded. The upper boundary of the facies with the overlying sediments of Facies B_2 is transitional. Driller's comments indicate that drilling penetration into Facies B_1 was slow because the formation was extremely compact and poorly stratified. The deposits were often referred to incorrectly as 'till' on the logs of groundwater wells.

Interpretation

Facies B_1 is interpreted as an outwash deposit consisting of ice contact and possibly compacted, sub-glacially deposited sediments. The crude stratification observed in the facies suggests a fluvial environment of deposition. Although the coarse, compact nature of Facies B_1 may also be indicative of a till deposit, glacial tills typically show little or no sorting by fluvial activity and are characterized by poorly sorted, unstratified, matrix supported clasts (Dremanis, 1991).

Fulton and Smith (1978) describe the lower and middle units of the Kamloops Lake Drift as a 58 m thick sequence consisting of rhythmically bedded silt and clay with fine pebbly sand, bouldery gravel, and unstratified silty sand and gravel. These units were interpreted as outwash sediments and possibly lodgment or ablation till deposited by an advancing glacier. Furthermore, Smith (1985) describes the dominant facies in an ice proximal zone of a gravely sandur as massive, matrix supported, crudely bedded or stratified gravel. From this information it is suggested that Facies B_1 was initially deposited as ice proximal outwash that was subsequently overridden by glacial ice. This would account for the high cobble gravel content, crude stratification, and compact nature of the facies. Eyles et al., (1991) interpreted a similar depositional origin for their lowermost seismic facies identified in Okanagan Lake basin, however, no direct lithologic control was provided to support their interpretation.

6.2.2.2 Facies B_2: Stratified sand and gravel

Description

Facies B_2 is observed on all lithologic profiles constructed for the North Okanagan Basin (Figures 6.2 to 6.8). Thickness of the facies ranges from 210 m in log A16, to 103 m in log A10, and 52 m in log E3 (Figure 6.7). The elevation of the contact between Facies B_1 and B_2 occurs at 110 masl in log E3 and 37 masl in log A16. Facies B_2 is thickest in mid-basin positions and thins towards the basin margins. Drill logs indicate that the sediments are less compact than Facies B_1 sediments, show stratification, and consist of medium to coarse-grained sand and gravel. Sand layers often contain mica chips and organic fragments.

Details of Facies B_2 is provided by SFU drill holes V2 and V4, and groundwater well V3; all at the Vernon site. The log of SFU drill hole V4 shows a complex assemblage of cobble sized gravel interbedded with coarse to medium sand (Figure 6.9). A 20 m section through Facies B_2 obtained from SFU drill hole V4 exhibits a vertical profile of cobble sized gravel interbedded with fine to medium sand, silt, and clay overlying bedrock. From 70 to 72 m depth a 1 m thick gravel layer overlies a 1 m thick coarse sand layer. A 4 m thick cobble gravel layer, extending from 72 to 76 m, underlies the coarse sand. This unit is underlain by 4 m of horizontally bedded fine to medium sand. Laminated silty clay extends from the base of the sand unit at 80 to 86 m depth. The silty clay unit is interrupted by a 0.80 m thick coarse gravel unit at about 83.5 m. Coarse sand extends from 86 m to the base of the silty clay at 90 m depth and overlies the bedrock surface. Overall, a complex assemblage of horizontally-stratified, coarse-grained clastic material punctuated by finer-grained, laminated sediments is exhibited by Facies B_2.

Interpretation

The upper component, Facies B_2, is interpreted as a finer-grained assemblage (relative to Facies B_1) of proglacial or ice contact glaciofluvial sediments. The sediments are interpreted to have been deposited during ice retreat in the North Okanagan Valley. Adjacent to a receding glacier the

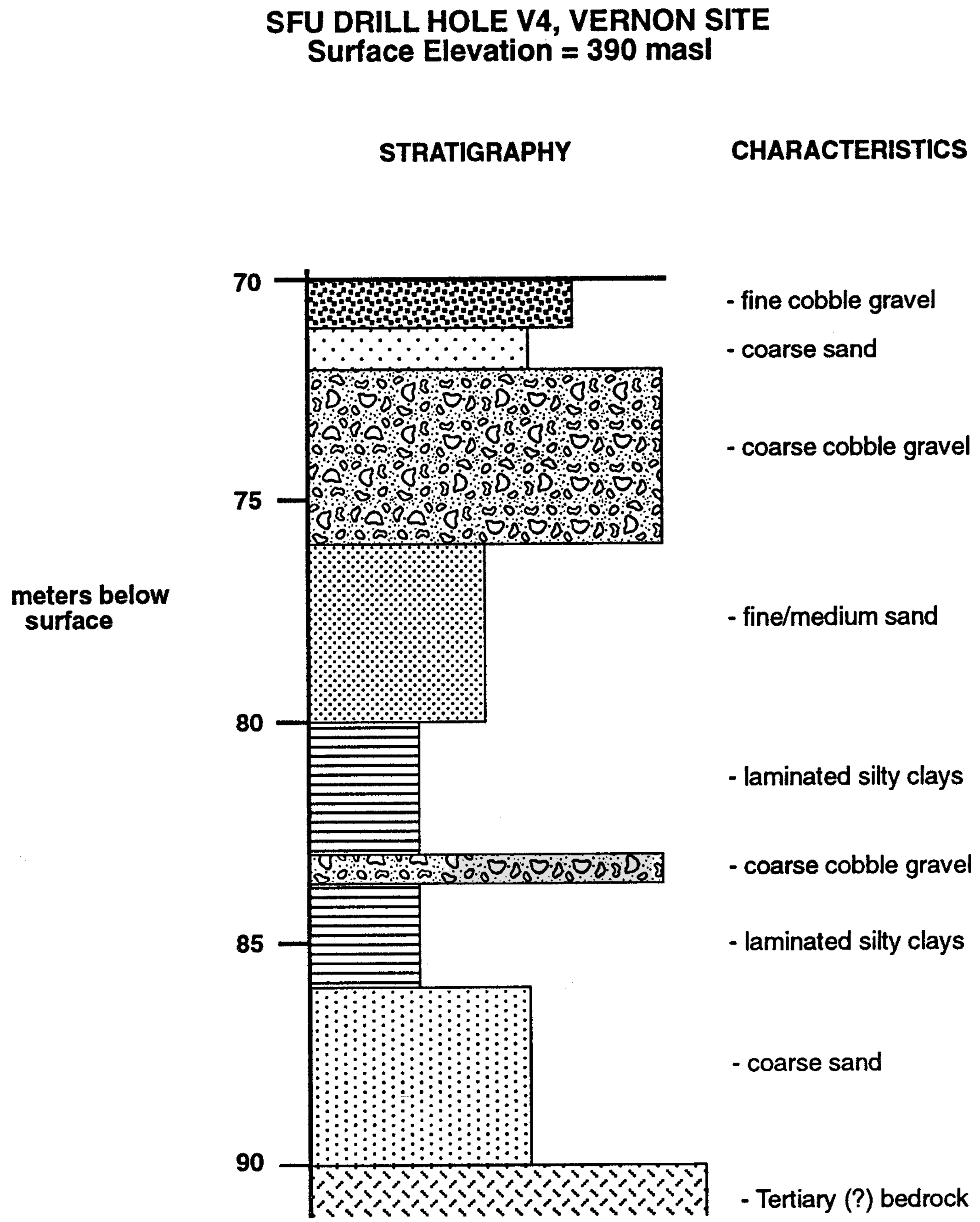


Figure 6.9 Expanded portion of core collected from Facies B2 in SFU drillhole V4 from 70 to 90 m depth.

depositional environment is characterized by stratified sand and gravel deposits. Within this proximal zone coarse material is abundant and glaciofluvial processes tend to dominate (Flint, 1971). Smith (1985) found that sand dominated sandur deposits often have medium to very coarse-grained, stratified sand that contains gravel. Facies B_2 was likely deposited in a more distal position on the sandur relative to Facies B_1 since sandur deposits commonly show a proximal-distal textural zonation (Smith, 1985). Deposits in the proximal zone are generally coarser grained, show some stratification, and do not exhibit fine-grained low energy deposits. Distal reaches of the sandur are progressively finer-grained and thin sequences of overbank sediments and shallow lake/pool deposits are possible. Essentially, most of the coarse clastic material is deposited in the proximal reaches of the sandur and the distal reaches exhibit finer-grained sediments resulting from lower energy depositional processes.

Smith (1985) suggests that fine grained facies composed of sand, silt or clay interbedded with coarse gravel facies result from overbank deposition, waning flood deposits, or deposition in shallow pools on a sandur plain. Since direct lithologic information pertaining to Facies B2 is limited to subsurface data; Figure 6.10 provides a possible analogy for the facies. The section crops out south of Vernon and is interpreted as ice contact deposits (Fulton and Smith, 1978).

An alternative interpretation for Facies B, and portions of Facies E (Section 6.2.5), is that these sediments represent Tertiary, not Quaternary, rocks. The evidence supporting this hypothesis includes: a laterally extensive angular unconformity between Facies B and C and Facies E and C (Seismic Units II, IV and III; GSC Line 500, Plate 6, Appendix C), textural maturity of organic samples collected from drillcore, colour variations between the facies, and compaction of the sediments.

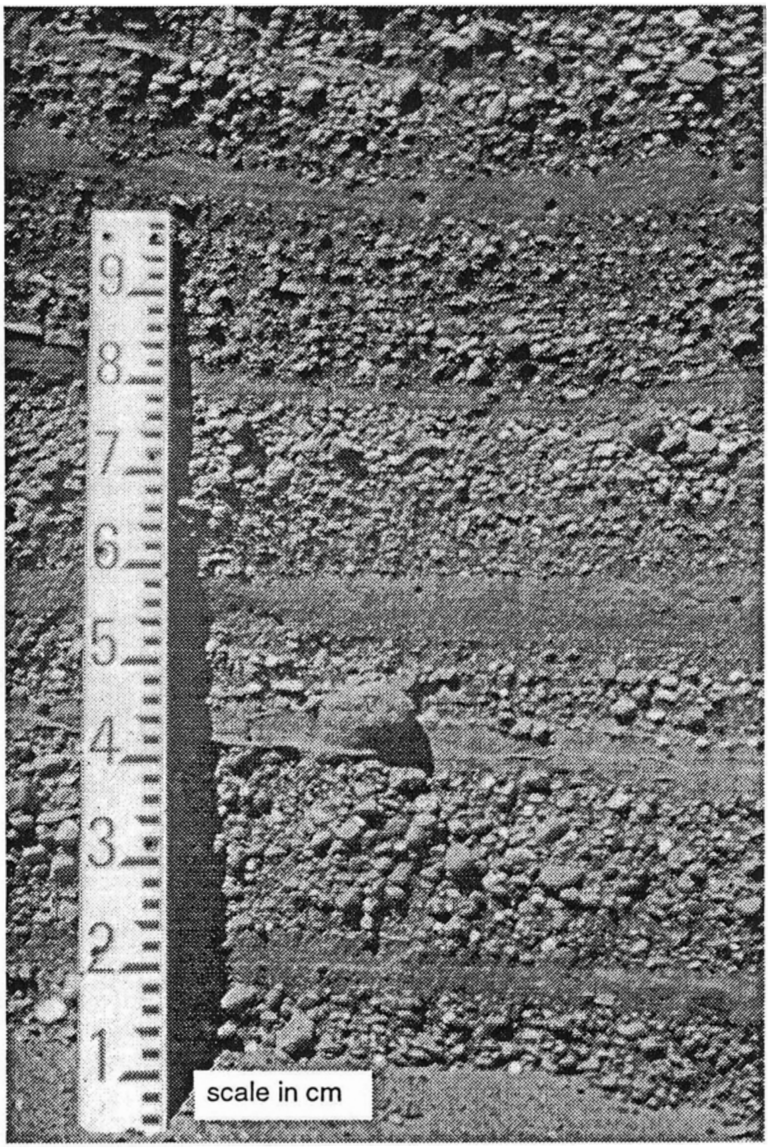


Figure 6.10 Section of alternating sand and gravel beds observed in outcrop south of Vernon. The deposits are ice contact sediments (Fulton and Smith, 1978) and are analagous to deposits identified as Facies B2.

The contact between Seismic Unit II and IV with Seismic Unit III reveals an angular unconformity shown by the downlappping and top lapping reflectors that occur right across the seismic profile. Organic samples collected from Facies B_2 (Seismic Unit II) and Facies E (Seismic Unit IV) in well A10 are lignitic and show a greater degree of maturation than organic samples collected from Facies C (Seismic Unit IIIa) in SFU drillhole A5. The colour of the sediments also varied with depth in the basin fill at the Armstrong site: dark grey sediments were recorded in core samples from Facies C while reddish-orange sediments were identified in core collected from Facies B and E. Furthermore, driller's comments indicate that sediments identified as Facies B_2, and B_1 in particular, are extremely compact.

This information alludes to the possibility that the boundary between Facies B and E with Facies C may represent a major chronologic unconformity between Tertiary and Quaternary sediments preserved in the basin fill. The lines of evidence presented above are inconclusive and restricted mainly to the Armstrong site. Therefore, confirmation of this alternate hypothesis can only be attained by more detailed drilling and coring elsewhere in the study area.

6.2.3 Facies C, laminated sandy silt

Facies C was identified throughout the study area, the unit is thickest in mid-basin positions and pinches out towards the east and west valley sides. The facies reaches a maximum thickness of about 297 m in log A16 (Figure 6.7) and a minimum thickness of 21 m on SFU drill log V2 (Figures 6.2 and 6.3). Subsurface elevations of the upper boundary of the facies range from 304 masl in log E3 to 267 masl in log A9 (Figures 6.8 and 6.5). The unit occurs in all drillholes and logs throughout the North Okanagan Basin (Figure 6.7) and accounts for up to 51% (on average) of the basin fill.

Description

Lithologic control for Facies C is extremely good. The facies was directly sampled in cores recovered at SFU drill sites V2, V4 and A5 (Figures 6.2, 6.3, and 6.6); in total, 5 cores were collected and analyzed. At SFU drill site A5 (Figures 3.12 and 6.6) cores were retrieved from 36.7 to 37.2 m, 51.8 to 52.5 m, and 79.86 to 80.6 m depth. At SFU drill site V2 a 90 cm core was collected at 37.6 m depth.

The core collected at SFU drill hole A5, from 36.7 to 37.2 m depth, revealed laminated fine sandy silt with mica flakes. Individual laminations range from 30 mm to less than 0.50 mm thick. The laminae were frequently wavy and soft sediment deformation structures were observed in most core samples (Figures 6.11 to 6.13). Soft sediment deformation structures included distorted beds, zones of 'micro-flames', and convolute bedding. Layers of massive, darker coloured silty clay with no deformation structures were also found. Some clay rich zones displayed significantly thinner laminae ranging from 0.20 to 0.50 mm. At 37.10 m depth in the core a wavey contact is observed with clay rich water escape structures. Deeper (below 37 m) the clays are massive with few visible laminae.

Interpretation

Sediments identified as Facies C are the result of glaciolacustrine deposition of laminated fine sand and silt in an ice proximal to intermediate position. Silt laminae in this environment exhibit sharp contacts and numerous deformation structures that are characteristic of rapid deposition in a lake close to the melting ice (Ashley, 1985). Sediment is delivered to the glacial lake by ice floes and meltwater streams originating from the retreating or stagnant ice. The lack of coarse material such as boulders and gravels in Facies C strongly

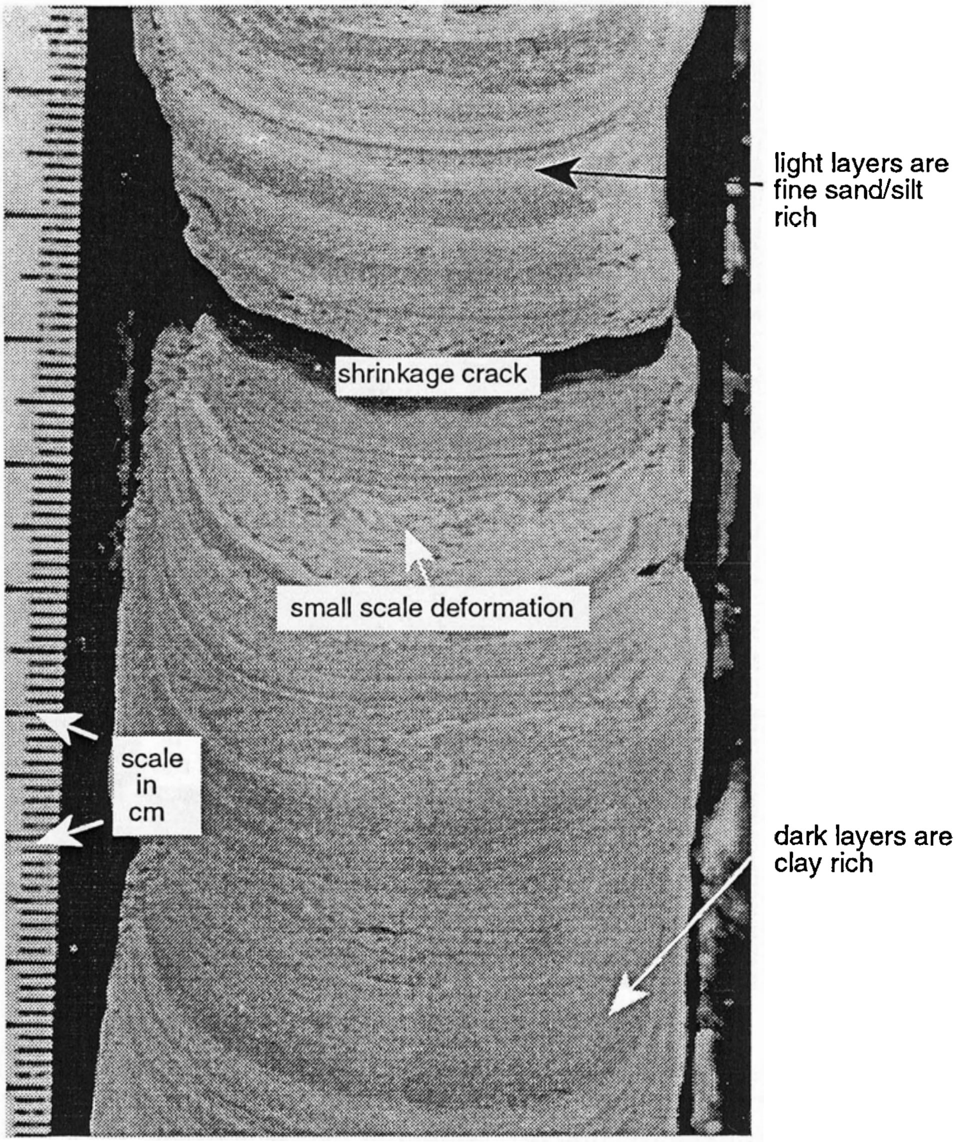


Figure 6.11 A 9 cm section of core collected from SFU drill hole A5 at the Armstrong site. The core, from 36.7 to 36.8 m, exhibits small scale sediment deformation features and thin, fine sand and silt laminations. Sampler induced deformation is evident on the outer margins of the core.

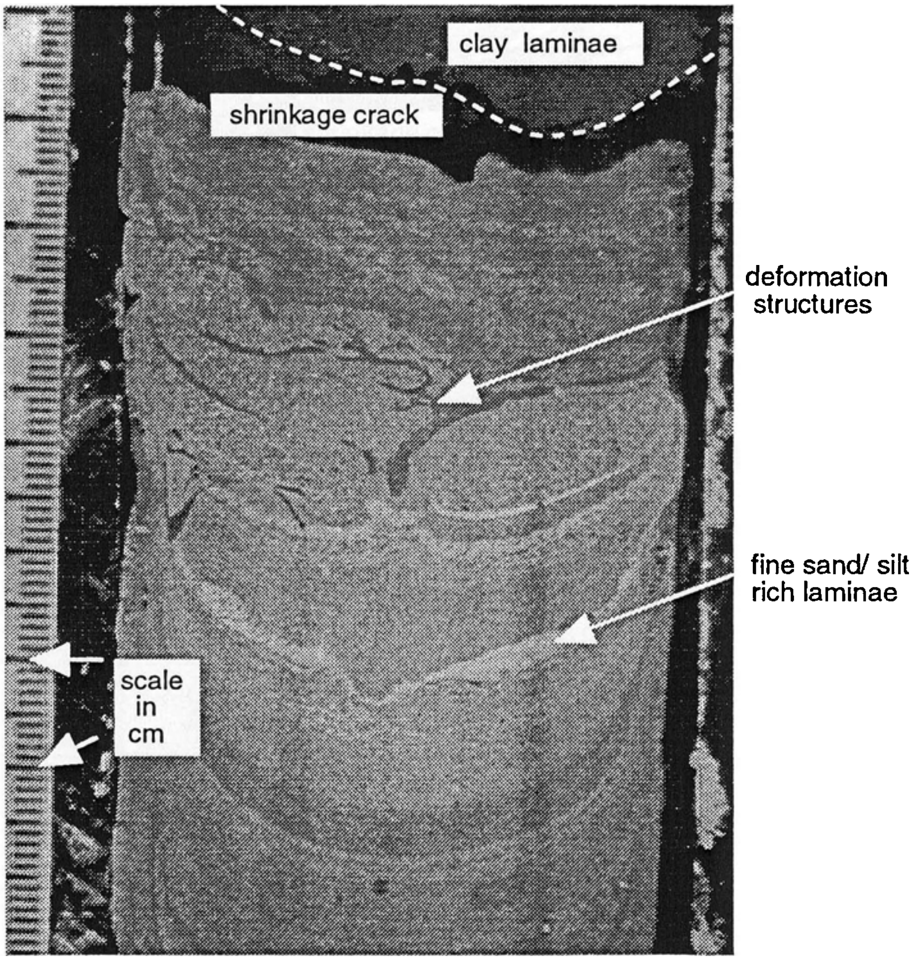


Figure 6.12 Section of core exhibiting deformation structures observed in Facies C. Notice the water escape structures and relative absence of clay rich laminae. The core was collected at SFU drill hole A5 from 36.7 to 37.2 m. Distortion of laminae at the outer margins of the core is attributed to the split-tube sampler.

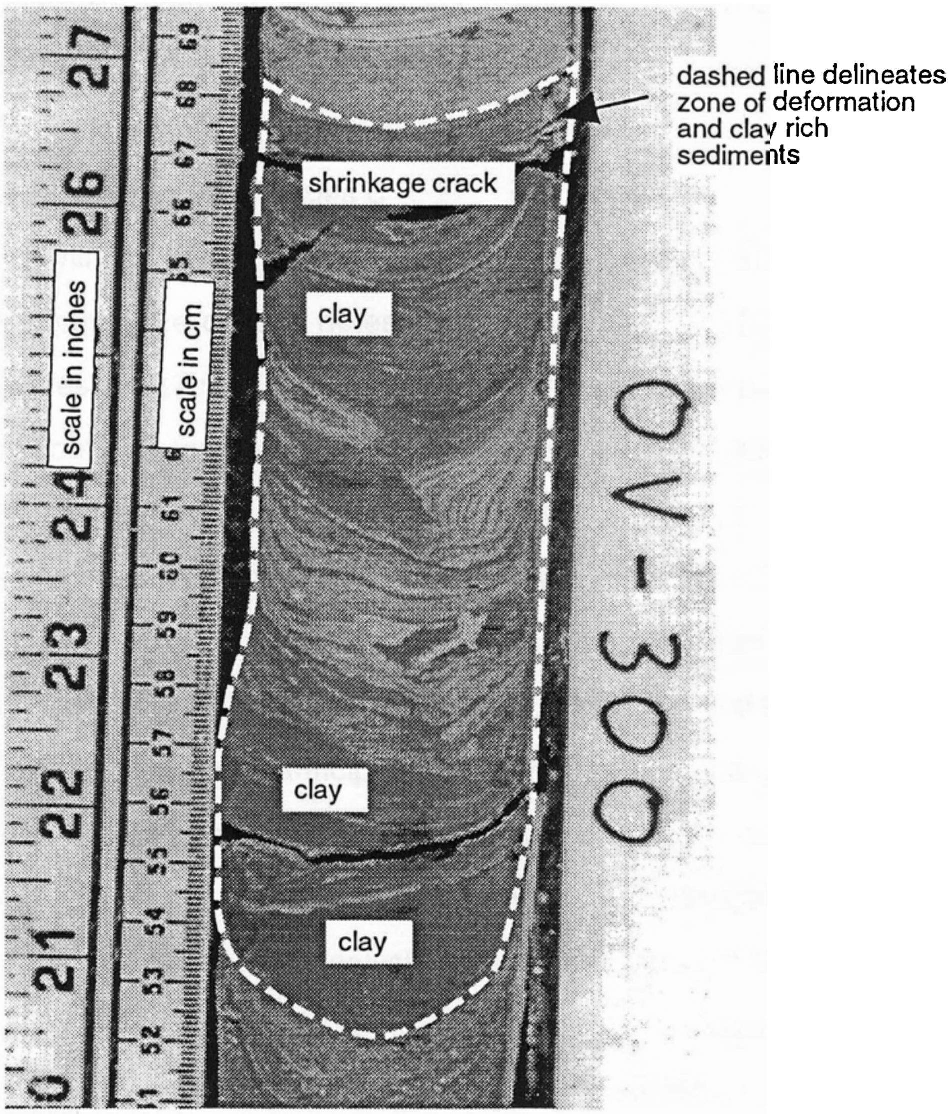


Figure 6.13 Section of core from SFU drill hole V2 at the Vernon site (on Toporchuk Ranch). The sediments exhibit deformed laminae of varying thicknesses that characterize Facies C. Note that deformation is most intense in association with clay rich sediments. The sample was collected from 38.15 to 38.33 m.

suggests that the sediments were not deposited in direct contact with glacial ice. There was also a general absence of large clasts and drop stones in the unit. The sediments described as Facies C are likely the product of interflow and underflow sediment transport and deposition processes.

6.2.3.1 Evaporite Deposits in Facies C

In SFU drill log V4 five, distinct hard layers were detected between 49.0 m and 57.9 m depth. The driller's notes indicate "vibrations or jumps in the drill stem perhaps resulting from more compact/dense units in the surrounding fine-grained formation". Recovered from the drill cuttings were 5 gypsum samples, 1-2 cm thick, at depths of 49.0 m, 51.8 m, 53.0 m, 54.9 m, and 57.9 m. The recovered samples were immediately stored to prevent contamination. At the end of the drilling field season a sample was submitted to the Department of Geology and Geophysics, University of Calgary, for sulfur and oxygen isotope analysis (Table 6.1). It was anticipated that the isotope analysis of the drill samples might provide some information pertaining to climatic conditions during the period of glaciolacustrine sedimentation in the North Okanagan Valley.

The results of the isotope analysis reveal a S^{34} value of 1.65 and an O^{18} value of 3.07 (Table 6.1). The S^{34} composition is consistent with the weathering of a sulfide mineral (e.g. pyrite) to produce a sulfate in solution, however, the O^{18} level is extremely enriched relative to standard ocean water (Dr. Ian Hutcheon, University of Calgary, pers. comm.). This suggests that the water in which the gypsum was precipitated was evaporated to some degree. Common meteoric water in the Okanagan Valley would typically exhibit isotope values of -10 to -15 relative to standard ocean water.

Table 6.1 **Isotopic data from gypsum samples collected from SFU drill hole V4, Vernon site.**

Sample I.D.	Isotope Sampled	Composition	Isotope Lab
SFU δV4-1	$\delta\ ^{34}S$	1.65 (1)	Univ. of Calgary Dept. of Geology
SFU δV4-1	$\delta^{18}O$	3.07 (2)	"

1 ⇒ relative to CDT (Canyon Diablo Triolite).

2 ⇒ relative to SMOW (Standard Mean Ocean Water).

Although the isotopic data is limited in scope it does provide an additional insight into the depositional environment of the lake. According to Warren (1989) the most important factor influencing evaporite formation and distribution is climate . Evaporation must exceed all other moisture inputs to the basin in order for evaporites to form, therefore, evaporite deposits are frequently associated with drying intervals during glacial retreat (Eugster and Hardie, 1978; Smith, 1979).

Considering the semi-arid climate of the North Okanagan Valley, location in a rain shadow belt, and deglacial history of the region, the gypsum may have been deposited during dryer conditions or warm hiatuses during glacial retreat. The evaporite deposits were collected from SFU drill hole V4 which was located on the eastern flank of the valley at the Vernon site (Figure D-1, Appendix D). The evaporite samples may therefore be representative of reduced winter run-off into Glacial Lake Penticton and drier summers resulting in lower lake levels and the formation of evaporite deposits along exposed shorelines.

6.2.4 Facies D: Laminated silty clay

The occurrence of Facies D is widespread throughout the North Okanagan Basin and represents one of the uppermost components of the basin fill. The facies accounts for about 12% of the valley fill and is thickest in mid-basin positions and pinches out towards the basin margins. Thickness of the unit ranges from about 103 m on log A9 near Armstrong (Figure 6.5) to 4 m and 6 m thick in logs E7 and A8 at the Enderby and Armstrong sites (Figures 6.8 and 6.5). Direct observation of the sediments was facilitated through split-tube samples collected from SFU drill holes at the Vernon and Armstrong sites.

Description

Facies D is characterized by alternating laminated clay and silty to fine sandy silt laminae (Figures 6.14 and 6.15); silt content increases with depth. The laminae are light olive gray above the water table to dark gray below the water table. Clay laminations range in thickness from 0.10 to 7.0 mm. At least 106 laminae were counted in a 20 cm core extracted from SFU drill hole A5 between 13.8 to 14.0 m depth. Lighter coloured, coarser-grained silt laminae that range from 0.30 mm to 5.0 cm thick, are also observed in Facies D. Highly contorted beds and micro-faulting are also observed in the sediments (Figure 6.16). The frequency of deformation structures increases with depth in the facies. Although outcrop is limited in the study region, a 4 m section of glaciolacustrine sediments is exposed at the west end of Larkin Road (Figure 3.4). The exposure reveals a vertical sequence of clay-rich laminations similar to those observed in drill core (Figure 6.17).

Other sedimentary structures observed in Facies D include trace fossils or 'lebbensspuren'. The fossils were observed at 5.06 m depth in core extracted from SFU drill hole V4 and consist of small, 1.0 -1.5 cm, tubular casts aligned

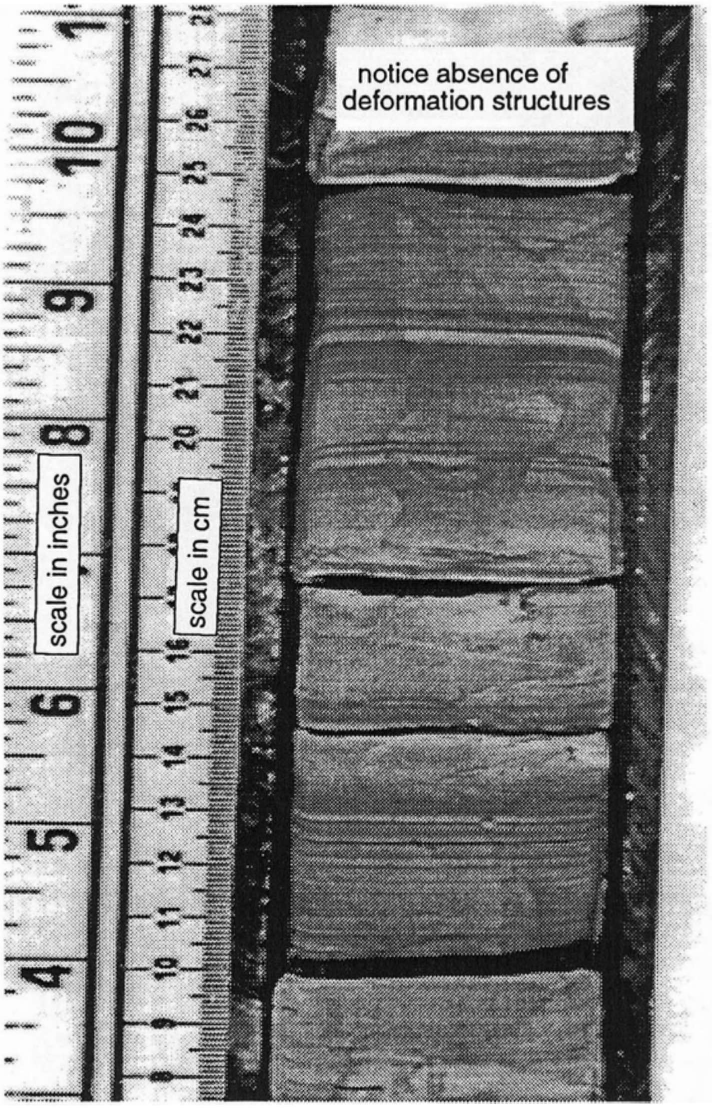


Figure 6.14 A 21 cm (8 in) section of core extracted from Facies D. The alternating clay and silty/fine sand laminae are clearly shown. The sample was collected from SFU drill hole V4 (north of Vernon) at 4.32 to 4.53 m depth.

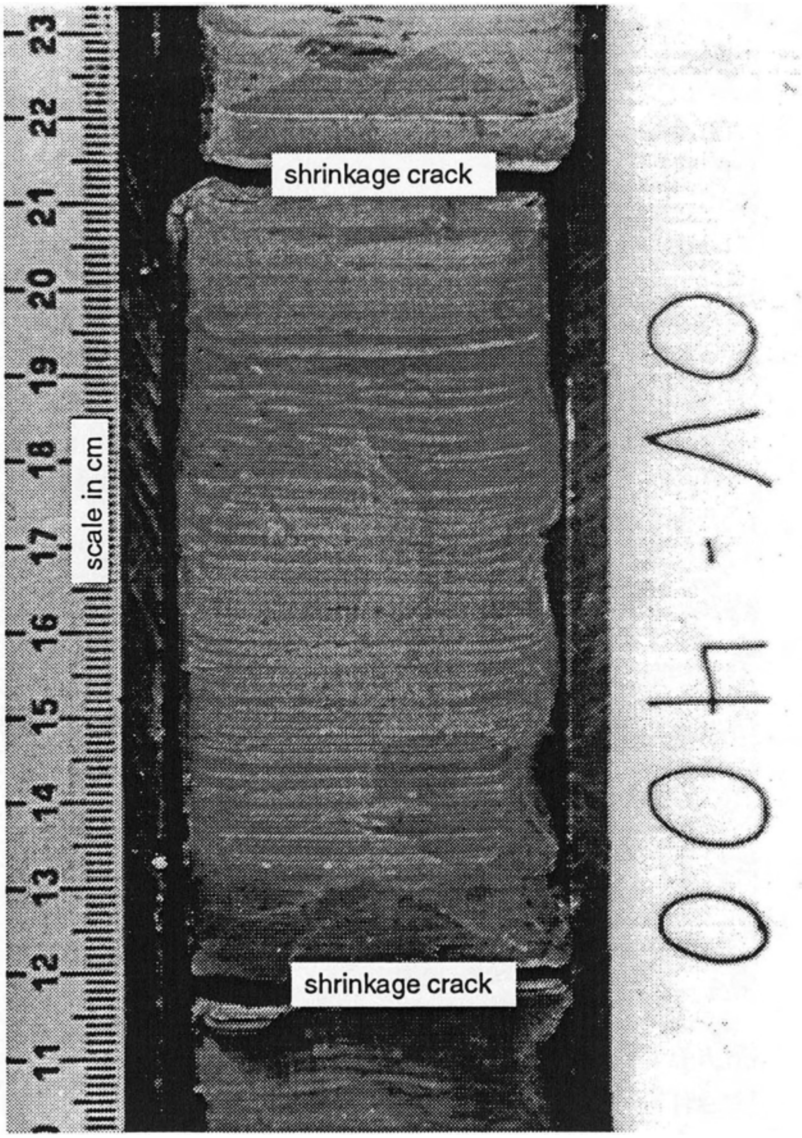


Figure 6.15 Expanded view of Facies D identified in Figure 6.14. Notice the cylcicity of the laminations and lack of deformation structures relative to Facies C. Darker laminae contain a higher clay content.

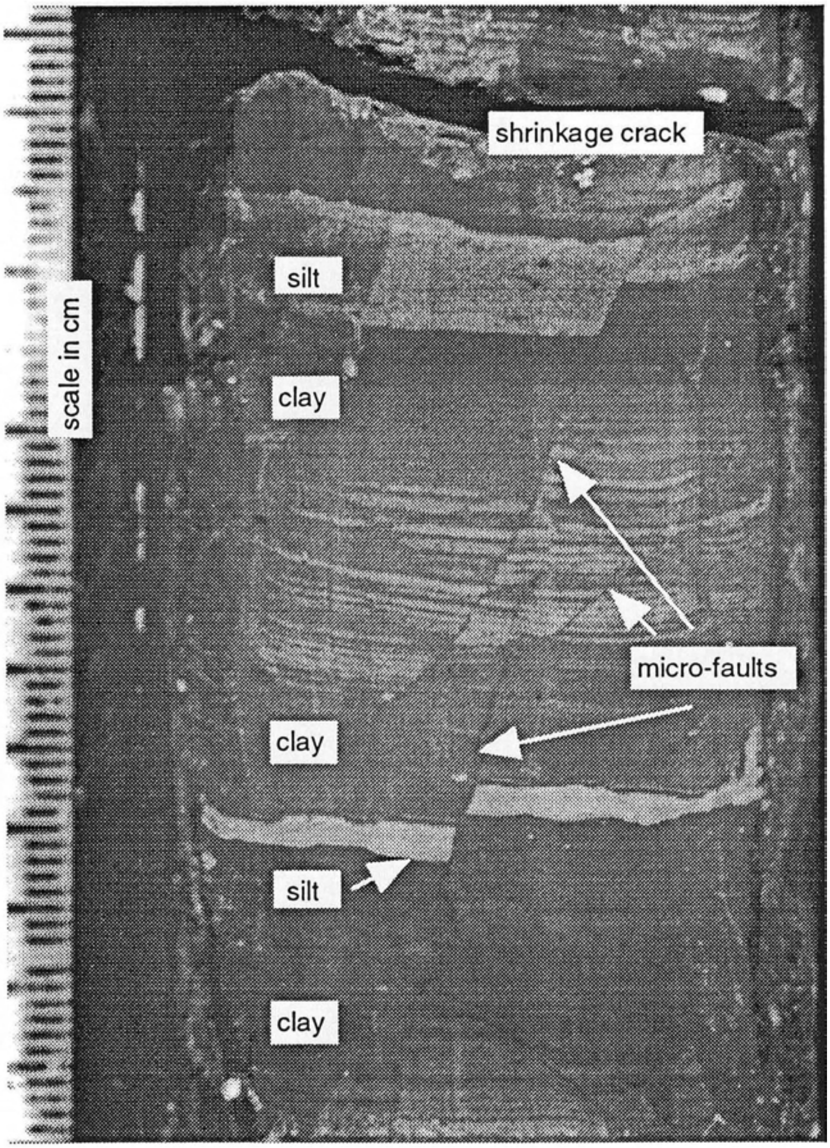


Figure 6.16 Faulted structures in Facies D: core sample was collected from SFU drill hole V4 at the Vernon site (on Toporchuk Ranch).

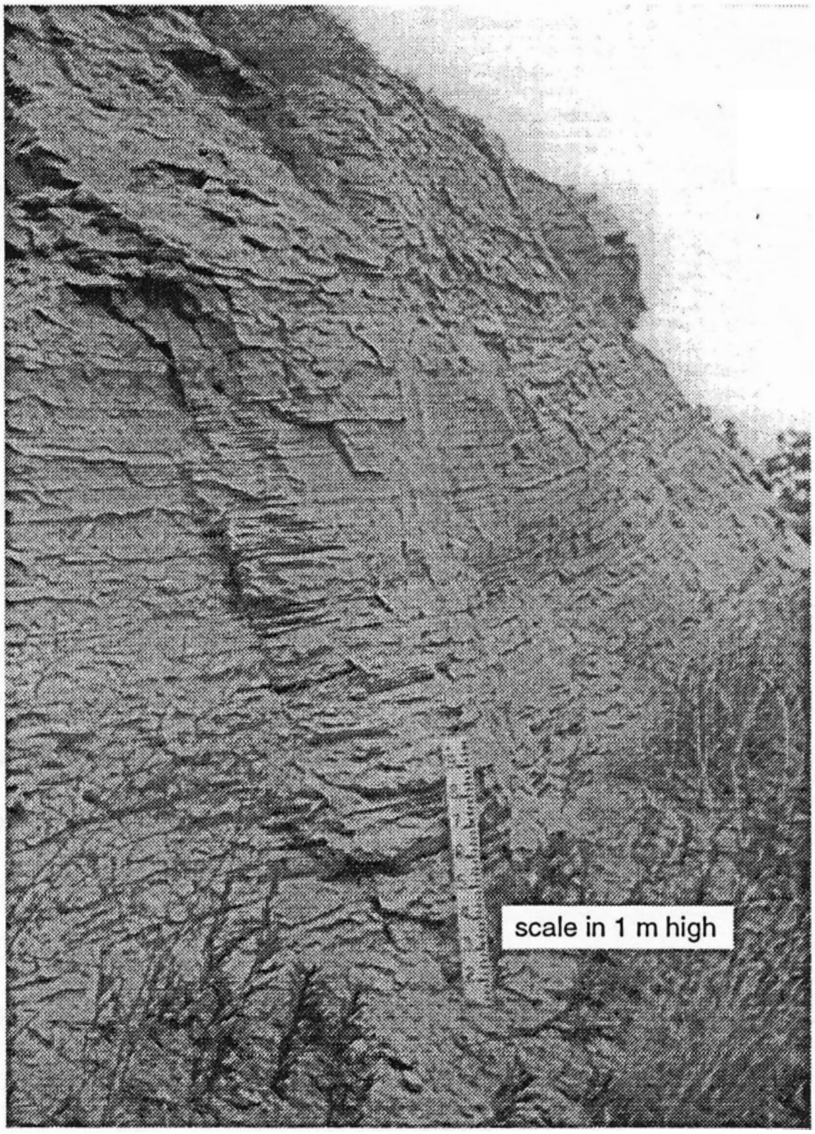


Figure 6.17 Four metre section of Facies D exposed at east end of Larkin Road north of the Vernon site. Notice the cyclicity and regular thicknesses of the clay rich laminations. The outcrop represents one of the few exposures of glaciolacustrine sediments (Facies D in this study) in the North Okanagan region.

parallel and perpendicular to the laminae (Figure 6.18). Both Ashley (1975) and Banerjee (1973) have observed trace fossil casts in the form of burrow impressions in Glacial Lake Hitchcock and Pleistocene lake sediments in Massachusetts and Ontario, respectively. Biogenic structures such as lebbensspuren are commonly found in distal glaciolacustrine environments where sedimentation rates are reduced relative to ice proximal depositional environments.

Interpretation

The fine-grained, horizontally laminated silty clay identified as Facies D are interpreted as glaciolacustrine sediments. The sediments were likely deposited from suspension following transport by interflow and overflow processes in an ice distal environment. Sediments described as Facies D are fine-grained and contain biogenic structures, both features characteristic of ice distal deposition. Glaciolacustrine clay deposited in an ice distal zone of a glacial lake exhibit lebbensspuren, silt laminae of variable thicknesses, and similar thicknesses of clay rich laminae (Ashley, 1985); all these features were observed in Facies D.

Desloges and Gilbert (1991) described laminated silt and clay in the basin of Harrison Lake, British Columbia. They interpreted the deposits to result from the slow settling of fine-grained material. Although post-glacial in age, the distal lacustrine sediments exhibited properties similar to those observed in Facies D. These properties included: parallel laminations, lighter colored laminae with a higher silt content, and few massive clay units.

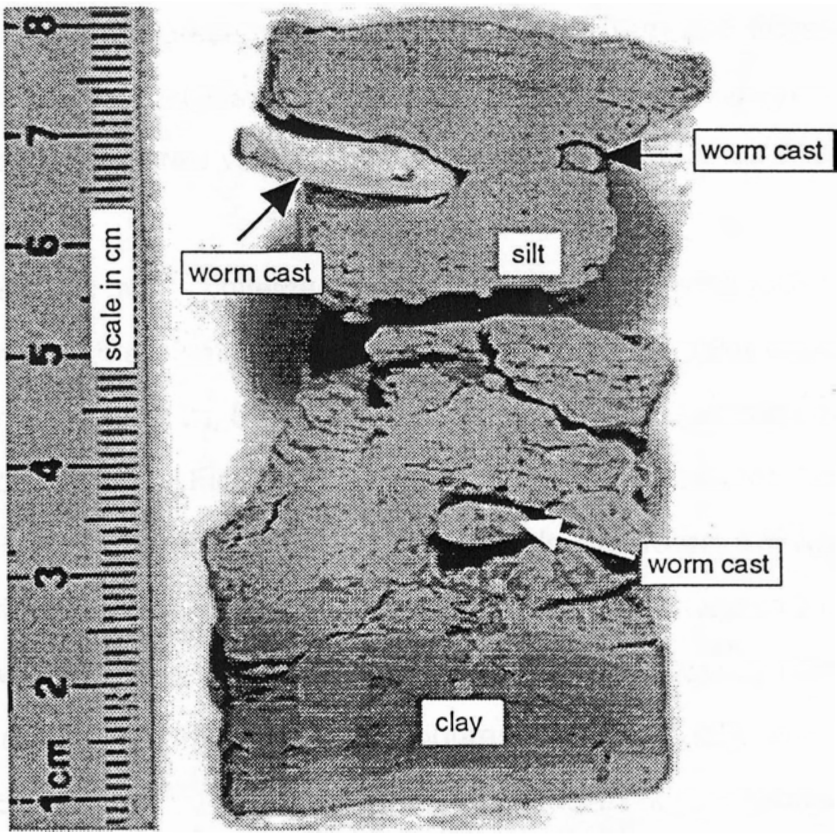


Figure 6.18 Trace fossils in Facies D at the Vernon site: the tubular casts are 1.0 to 2.0 cm long and aligned parallel and perpendicular to the laminae. The sample was collected from SFU drill hole V4 at 5.06 m depth.

6.2.4.1 XRD Analysis of laminae of Facies D

X-ray diffraction analysis (XRD) of a light and dark colored laminae collected from core in the North Okanagan Basin was conducted to determine variations in mineral and clay mineral composition of the laminae. Researchers have indicated that light colored laminae may represent summer deposition and dark colored laminae represent winter deposition (Ostrem and Olsen, 1987). They argue that XRD analysis should indicate a higher quartz and lower mica content in the light colored varve, a result of deposition in a more energetic environment.

The samples were collected at 5.12 m depth in SFU drill hole V4. Following sieving with a 62 micron sieve and grinding, the samples were x-rayed in the Department of Physics, Simon Fraser University. XRD spectrum of the two samples are presented in Figures 6.19 and 6.20. Interpretation of the spectra was facilitated through identification tables of clay mineral and associated minerals provided by Moore and Reynolds (1989). On both spectra dominant quartz peaks were observed at about 26.6° (2Ø). Secondary quartz and feldspar peaks are also identified on the spectra (Figures 6.19 and 6.20). Interestingly, peaks at 12.5° (2Ø) and 15.9° (2Ø) were identified as kaolinite/chlorite and montmorillinite, respectively, on both spectra.

The results of the XRD analysis indicate no obvious variations in mineralogy and clay mineral content between the light and dark laminae. A minor suppression of the light varve spectra is the main difference between the two plots. Fulton's (1965) XRD analysis of the Thompson Silts also indicated that quartz is the most abundant constituent of the Thompson Silts, with mica and feldspar as other dominant minerals. He determined minimal variation in mineral composition between light and dark varves.

Additional sampling and XRD analysis would be required to more

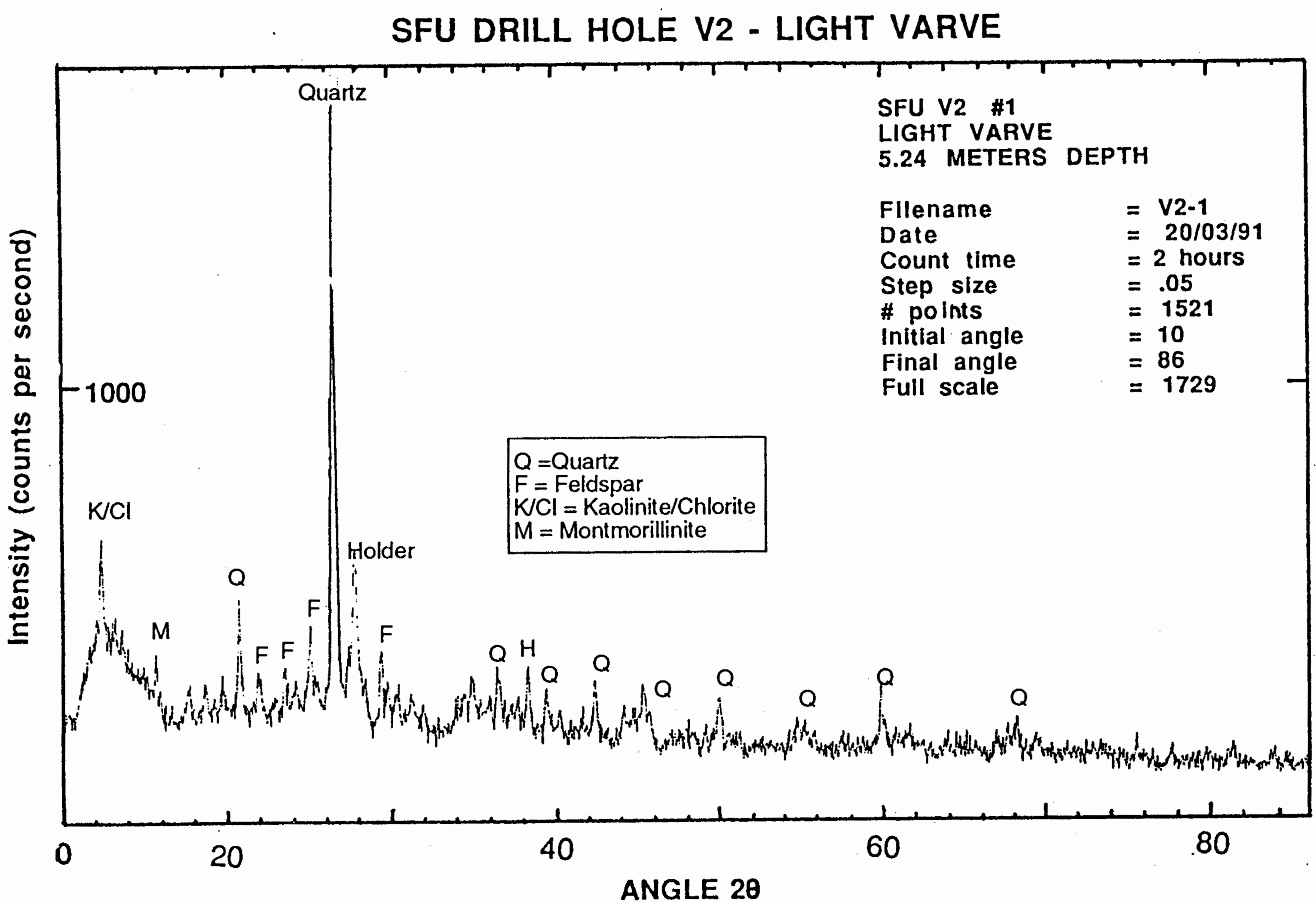


Figure 6.19 XRD spectrum of SFU V2, light varve, sample 1. Note frequency of quartz and feldspar peaks.

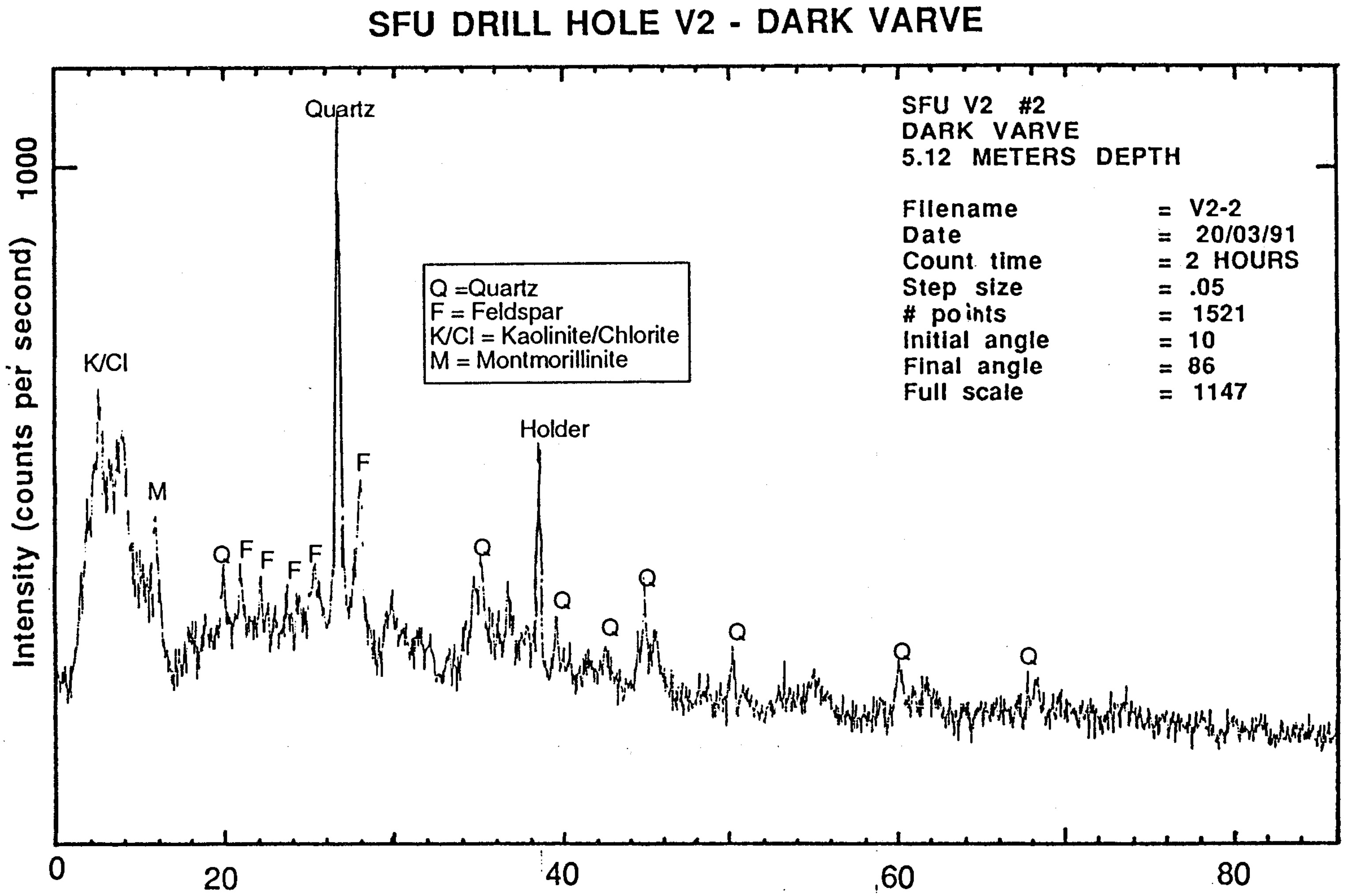


Figure 6.20 XRD spectrum of SFU V2, dark varve, sample 2. Note frequency of quartz and feldspar peaks that were also observed on the light varve spectrum (Figure 6.19).

accurately determine the seasonality of the varves and the mineralogy of the glaciolacustrine sediments.

6.2.5 Facies E: Interbedded gravel and sand

Facies E is observed in many sections in the North Okanagan Valley (Figures 6.2, 6.4 to 6.8), however, delineation of the lateral continuity and geometry of the facies was facilitated through the correlation of lithologic and seismic data (Seismic Unit IV, Plates 6,7,8, and 14, Appendix C). The facies shows an average thickness of about 66 m on Armstrong Section 2, well log A12 (Figure 6.5). Upper and lower boundaries of the facies is established from the correlation between seismic and lithologic boundaries (see Armstrong-GSC Line 100, Plate 6, Appendix C). On the east valley side at the Armstrong site the facies reaches a thickness of about 46 m (Figure 6.5).

In strike view Facies E thins towards the basin axial plane and thickens towards the basin margins. This is observed on Armstrong Section 3 where Facies E attains a thickness of about 12 m and extends laterally for over 1 km (Figure 6.6). Similar lens shaped morphologies are observed on the east valley side on Enderby Section 1 (Figure 6.8) and Vernon Section 1 (Figure 6.2).

Description

Lithologic analysis of Facies E is based on cuttings, a core extracted at SFU drill site A5, and groundwater well logs. Characterizing the facies are alternating, horizontally stratified sand and gravel beds. A 72 m section of groundwater well log A10 shows individual gravel units up to 24 m thick, the gravel is cobble sized and contains disseminated plant debris with fine to medium-grained compact sand (Figure 6.21). The thick cobble gravel beds are interrupted by stratified, coarse sand layers containing disseminated plant debris.

FACIES E, COMPOSITE SECTION

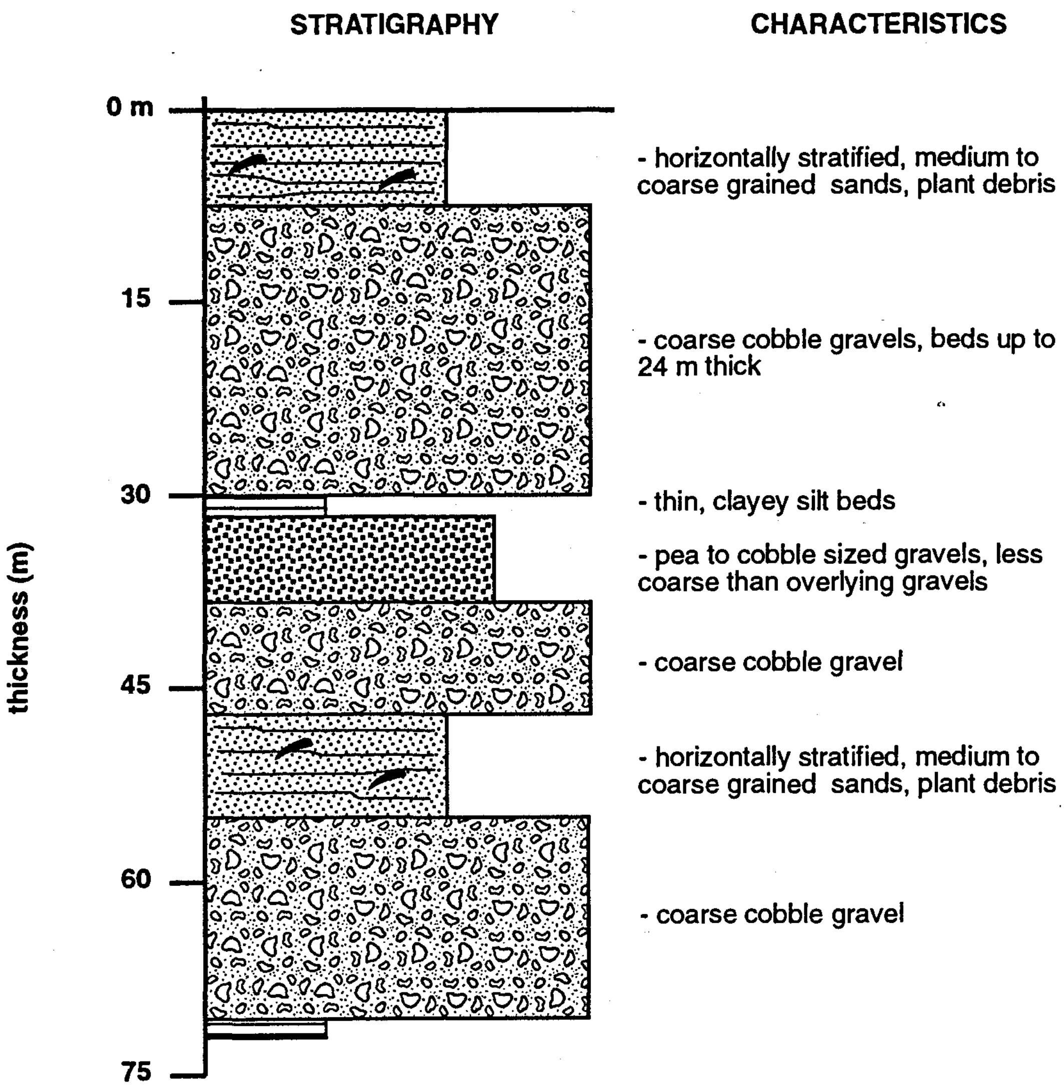


Figure 6.21 Composite stratigraphic profile showing the nature of Facies E at the Armstrong site. Notice coarse gravel layers that are interbedded with sand and silt layers.

Thin (up to 1.5 m) clayey silt layers are also observed in the section from 30 to 31.5 m and 70 to 71 m depth.

Analysis of SFU drill log A5 produced a detailed description of a 23 m sequence of Facies E from 100 to 123 m depth. Characterizing the sequence are alternating pea to cobble sized gravel and fine sand. Individual gravel beds are up to 7.5 m thick, a 0.5 m silt bed interrupted the gravel sequence. A 20 cm core sample collected from 100.46 to 100.66 m depth showed moderately-well sorted fine sand with minor silt content. This was underlain by a 1.5 cm clayey silt stringer and fine sand to the base of the core. Sedimentary structures were not observed in core and organic fragments were scarce.

Interpretation

Facies E is interpreted as coarse-grained sediments deposited by debris flow and fluvial processes in an alluvial fan geomorphic setting. The unit ranges in texture from poorly sorted to horizontally-bedded silt and cobble gravel. Nilson (1982) asserts that coarse-grained alluvial fan deposits are characterized by poorly sorted sediments ranging in grain size from clay to boulders. Although a proximal to distal reduction in clast size is typically observed in fans composed of debris flow deposits (Selley, 1988) this trend was not observed in Facies E.

The morphology of Facies E is wedge to lens-shaped, thickest at the basin margins and pinching out towards the basin axis. These morphologies are a common characteristic of alluvial fan and other mass movement deposits (Eyles and Miall, 1984). Facies E interfingers with other lithofacies identified in the North Okanagan Basin fill and is interpreted to be contemporaneous with other facies that the sediments transgress. Roberts and Cunningham (1992) and Fulton and Smith (1978) have found similar coarse-grained deposits interbedded with fine-grained glaciolacustrine sediments in the Okanagan and Thompson valleys and interpreted the sediments as mass movement deposits.

6.2.6 Facies F: Medium to coarse sand and upward fining sand

Facies F is divided into sub-facies F_1 and F_2 based on lithologic variations observed in drill logs, well logs, and core samples. Facies F_1 has a limited areal extent in the North Okanagan Valley and is located near the valley axis within 40 m of the valley floor just north of Vernon. The facies is observed on SFU drill log V2 from 20.6 to 21.0 m (Figure 6.22) and groundwater log V1 between 20.7 and 26.2 m depth.

Drill logs obtained at SFU drill sites E1 and E2 near Enderby reveal that Facies F_2 extends to 12.8 m and 14.0 m depth, respectively (Figure 6.23). Both logs show a distinct 2 cm thick band at about 12.5 cm below the surface, this horizon was also observed extending along a ditch between the two drill sites. Initial microscopic examination suggests that this unit may be representative of a tephra layer, however, this interpretation is highly speculative.

Facies F_1 is composed of medium to coarse sand and silt layers with mica flakes. The unit was found only in SFU drill hole V2 collected at the Vernon site (Figures 6.3 and 6.22). Facies F_2 typically exhibits a fining upward sediment trend from a basal gravel to fine-grained silt and clay. The facies is observed on seismic profiles collected north of Enderby (SFU Lines 100 and 700-800, Plates 10 and 14, Appendix C) and the logs of SFU drill holes E1 and E2 (Figure 6.23).

SFU DRILL HOLE V2, CORE 2, VERNON SITE
Depth from 20.57 m to 20.97 m
Surface Elevation = 390 masl

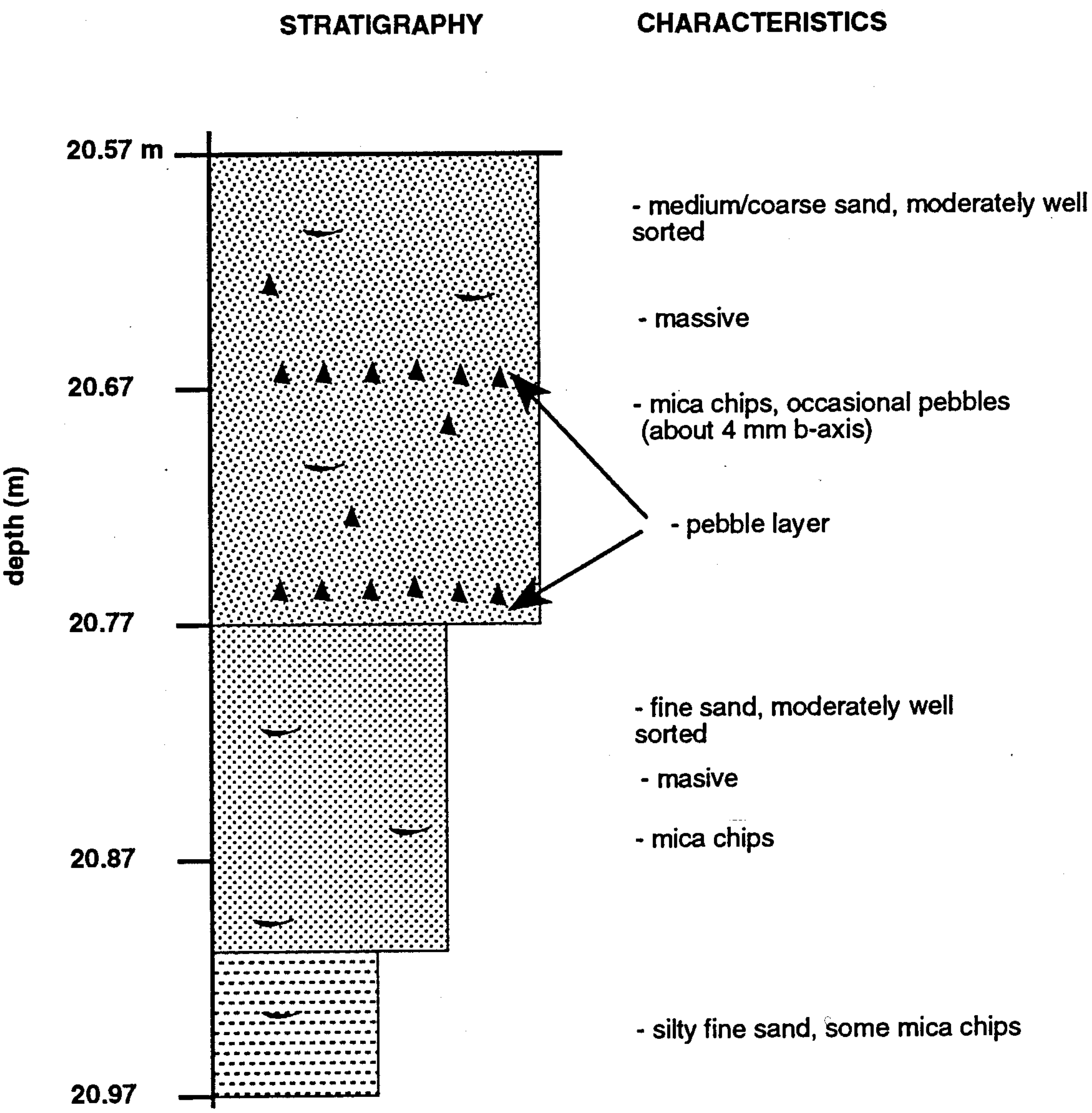


Figure 6.22 Expanded section of SFU drill hole V2, core 2, showing stratigraphy of Facies F1 (at theVernon site). Medium to coarse sands at top of section grade down-section into silty fine sands.

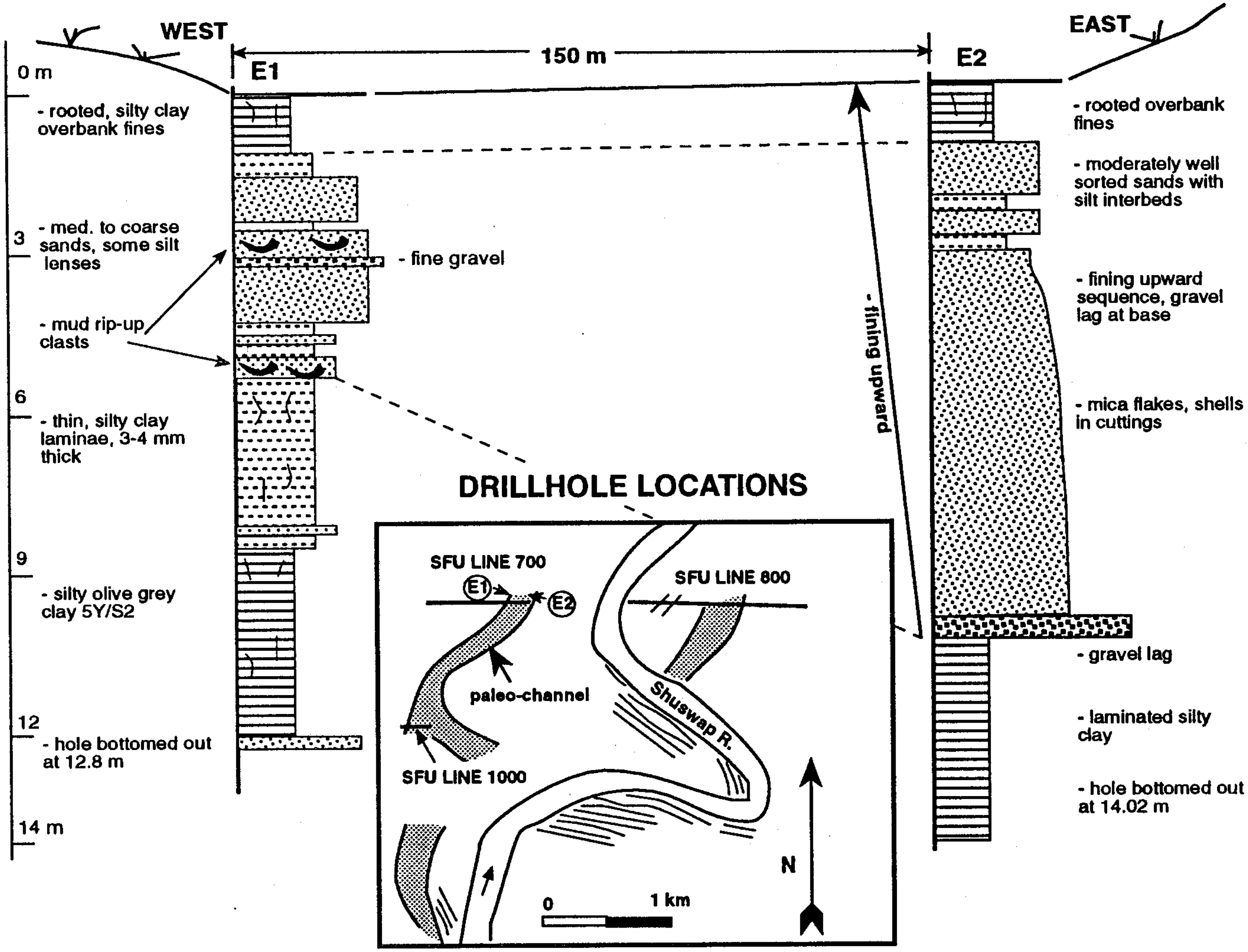


Figure 6.23 Cross-section of Facies F2 observed in SFU drill holes E1 and E2 (at the Enderby site). This is a section through a paleo-channel of the Shuswap River.

6.2.6.1 Facies F_1: Medium to coarse sand

Description

In the Vernon region Facies F_1 consists of fine to very coarse, quartz and feldspar rich, well sorted sand containing abundant mica flakes. Pebbles and 10 cm thick silt layers were identified in the coarse sand beds . In SFU drill log V2 the facies is well sorted and contains fine to medium upper sand, pebbles, mica flakes, and silty sand interbeds (Figure 6.22). A 3.9 m section of fine to medium-grained sand observed in log V2 can be correlated laterally with a 5.5 m thick section of similar lithology observed in log V1 some 475 m to the north (Figure 6.3).

Interpretation

Facies F_1 is interpreted as fluvial channel deposits found near the surface of the North Okanagan Valley. In the Vernon area the unit occurs as 4.0 to 5.0 m thick sands beds that can be correlated laterally for over 475 m (between logs V1 and V2, Figure 6.3). The coarse-grained texture and lateral continuity of the facies suggests a moderately high energy fluvial environment. Fitzsimmons (1992) interpreted similar 3 m thick sequences of moderately well sorted, medium sand and poorly sorted gravelly coarse sand in Linda Valley, western Australia. The units were interpreted as traction deposits of small channels.

6.2.6.2 Facies F_2: Upward fining sand

Description

In the Enderby region detailed observations of Facies F_2 are provided by SFU drill logs E1 and E2 (Figure 6.23). Log E1 was cored continuously to 8.4 m depth and a 40 cm core sample was extracted to the termination depth of 12.8 m. Cutting samples and a 0.72 m core sample obtained from log E2 provided lithologic control to the termination depth of 14.0 m. The two logs are correlated over a horizontal distance of approximately 150 m. The top of Log E1 was situated at 355.0 masl relative to log E2 at about 353 masl.

Vertical profiles in drill logs E1 and E2 show a distinct fining upward trend (Figure 6.23). Log E2 has a gravel (individual clasts up to 0.5 cm diameter) and very coarse sand channel lag at about 10.8 m depth. The sequence fines upwards through very coarse sand to well sorted, medium upper sand containing few pebbles. Laminated silt beds up to 10 cm thick are observed in the upper 3 m of the profile. The sand unit, from the basal gravel and coarse sand to 1.1 m depth, is overlain by horizontally laminated silt. A 0.5 m thick disturbed layer characterizes the upper component of the laminated silt, this layer is attributed to agricultural disturbance. Underlying the fining upward sequence, from 10.8 m to the bottom of the log, is a 2.0 m thick layer of silty, horizontally laminated clay. The upper contact between the laminated clay and the gravel lag is sharp and erosional.

Located about 150 m to the west, SFU drill log E1 revealed a facies succession that is correlated with drill log E2 (Figure 6.23). In log E1 Facies F_2 is characterized by a poorly defined upward fining trend from 5.4 m depth to the surface. From 5.4 to 1.4 m depth, fine to medium coarse, moderately well sorted sand containing mica flakes and occasional silt lenses with minor amounts of clay. Individual sand beds, up to 1.6 m thick, have contacts between sand and silt units that are abrupt and erosional. Equisetum roots in vertical position were observed in the silt layers and mud rip-up clasts were apparent in the sand beds. At 1.3 m depth a sharp contact exists between the upward fining sand and overlying laminated silt. Above this contact laminated silts grade into finer, clay rich silt. A 0.5 m thick disturbed layer is also observed immediately below the surface.

Below 5.4 m the profile exhibits thinly laminated (3 to 4 mm laminae) silty clay to a depth of 8.4 m. From 8.4 to 9.0 m fine sand is observed that is underlain by silty, olive gray clay with equisetum roots in growth position. An abrupt transition to well sorted coarse sand occurs at approximately 12.6 m depth. A core sample collected from 12.6 to 12.8 m depth revealed a lower 5 cm thick unit of heavily oxidized sand. Drilling and sampling was terminated at this site due to pressurized artesian flow encountered at this depth.

Interpretation

In the Enderby region sedimentary profiles identified as Facies F_2 are markedly different from Facies F_1 observed at the Vernon site. The sequences of Facies F_2 revealed by SFU drill logs E1 and E2 show distinct upward fining trends and are interpreted to represent meandering river deposits. Cant (1982) and Miall (1982) demonstrate that meandering river facies typically exhibit distinct upward fining sequences composed of medium-grained, moderately well sorted sand that grades into rooted floodplain mud. The channel base, or 'lag', is indicative of deposition during peak floods. In a meandering facies sequence, sand deposited as bedload typically overlie the channel lag (Walker and Cant, 1984).

The interpretation of Facies F_2 as meandering channel sediments is supported by the geomorphology of the Enderby site (Figure 2.9). SFU drill logs E1 and E2 were located in a paleo-channel of the meandering Shuswap River (Figure 5.12). This association, in addition to the vertical textural trends, supports the interpretation of Facies F_2 as meandering river deposits.

6.3 Lithofacies Chronology

Due to the paucity of organic material available for radiometric dating the chronology of the basin fill is deduced from the vertical assemblage of sediments and previous research. Only one organic sample, OV-500 D.3, was collected and dated by Accelerator Mass Spectrometry (Table 6.2). The detritus sample, collected at about 80 m depth in SFU drill hole A5 (Figure 6.6), yielded a radiocarbon date of 38,220±270 years BP. The sample was located near the base of a sand unit in Facies C.

The vertical assemblage of facies identified in the lithologic sections of the North Okanagan Valley suggest that at least one full glacial cycle is preserved in the North Okanagan Valley. This cycle, up to 572 m thick, is comprised of a simple stratigraphy composed of outwash gravel and sand (Facies B_1 and B_2) that is overlain by glaciolacustrine (Facies C and D) and fluvial sediments (Facies F). The entire sequence is punctuated by alluvial fan sediments that interfinger the fill (Facies E).

Table 6.2 Accelerator Mass Spectrometry dates of organic samples from the North Okanagan Basin fill.

Sample I.D.	SFU drill hole	Description	Weight used (mg)	Dating Lab	Lab number	Age (years BP)
OV-500 S.3	A5	-detrital organics	346	Isotrace, Toronto	TO-2359	38,220 ± 370
Location: SFU Drill Hole A5 - ~80 m depth - 50° 28' 47" North 119° 6' 15" West						

Although no absolute time frame can be placed on the fill sequence it is tentatively correlated with the late Wisconsinan Fraser Glaciation. Initiation of Fraser Glaciation conditions, determined from radiocarbon samples in the Kamloops Lake Drift (Fraser Glaciation lithologic unit), range in radiocarbon age from about 19,100 BP to 10,000 BP (Fulton and Smith, 1978). Two radiocarbon dates, from the North Okanagan and Thompson Valleys, indicate that the region was ice and glacial-lake free by about 8410±100 BP (GSC-1867) to 8900 BP (Fulton, 1969). With this in mind, it is postulated that in the North Okanagan Valley outwash sediments were deposited following the onset of glaciation at about 19,100 BP and that glaciolacustrine deposition had ceased by around 10,000 BP to 8400 BP. South of Vernon, Eyles et al., (1990,1991) and Mullins et al., (1990), suggest similar late Wisconsinan Glaciation time frames for the infilling of Okanagan and Kalamalka Lake basins.

No dateable material was recovered from the alluvial fan deposits and it was therefore difficult to ascertain the timing of alluvial fan deposition. Based on the presence of Mazama tephra observed in alluvial fan sediments Ryder (1971a, 1971b) indicates that the bulk of paraglacial alluvial fan deposition in south-central British Columbia occurred prior to 6800 BP. She also suggests that fan deposition rates have declined significantly since 6800 BP and deposition may have ceased to operate as recently as 1,000 to 500 years ago. In the North Okanagan Valley the uppermost fluvial units of the fill represent recent geomorphic processes; these processes may have also operated during the waning stages of Glacial Lake Penticton.

In consideration of the chronology proposed for the North Okanagan Valley fill the radiocarbon date of 38,220±270 years BP is interpreted to represent a date obtained from reworked and redeposited organic detritus. This suggestion is supported by the stratigraphic position of the sample at the base of a channel/debris flow unit (log A5 in Figure 6.6) that interfingers glaciolacustrine sediments. Also, organic material dated in the age range of sample OV-500 D3 have been documented in the Thompson, Okanagan, and Falkland Valleys (Fulton and Smith, 1978).

A consistent theme in much of the literature pertaining to the Okanagan region is the possibility of Tertiary and earlier Quaternary sediments preserved in the Okanagan Valley fill (Fulton, 1965, 1969, 1972, 1975; Nasmith, 1962). The potential for the preservation of Tertiary aged sediments in the North Okanagan Basin cannot be ruled out, however, existing seismic, lithologic, and stratigraphic evidence is inconclusive (Section 6.2.2.2).

6.4 Volume of the North Okanagan Basin Fill

A rough estimate of the sediment volume of the North Okanagan Basin was determined using available lithologic and seismic information. Data sources included: SFU seismic lines and drill logs, GSC seismic lines, groundwater logs, and early bedrock refraction seismic data (MacAulay and Hobson, 1972). In order to provide reasonably accurate measurements, the North Okanagan Valley was divided into 3 reaches based on the average cross-sectional width of the valley for each reach (Figure 6.24). In total, 7 cross-sections were used for the volume determination.

The procedure involved plotting the basin cross-sections at a proportional scale and determining the area for each reach using a compensating polar planimeter. Six planimeter readings were taken, the high and low values omitted, and the average of the remaining 4 readings for each reach were used in the area calculations. The areas derived for each cross-section were then averaged for each reach (when possible) and these averages were multiplied by the mid-basin length of each valley section (Table 6.3).

The volume of sediment fill in the North Okanagan Basin, based on the combination of sections A to C, was calculated to be approximately **48.99 km^3**. From this value the volume of the paleo-meltwater channel that extends south

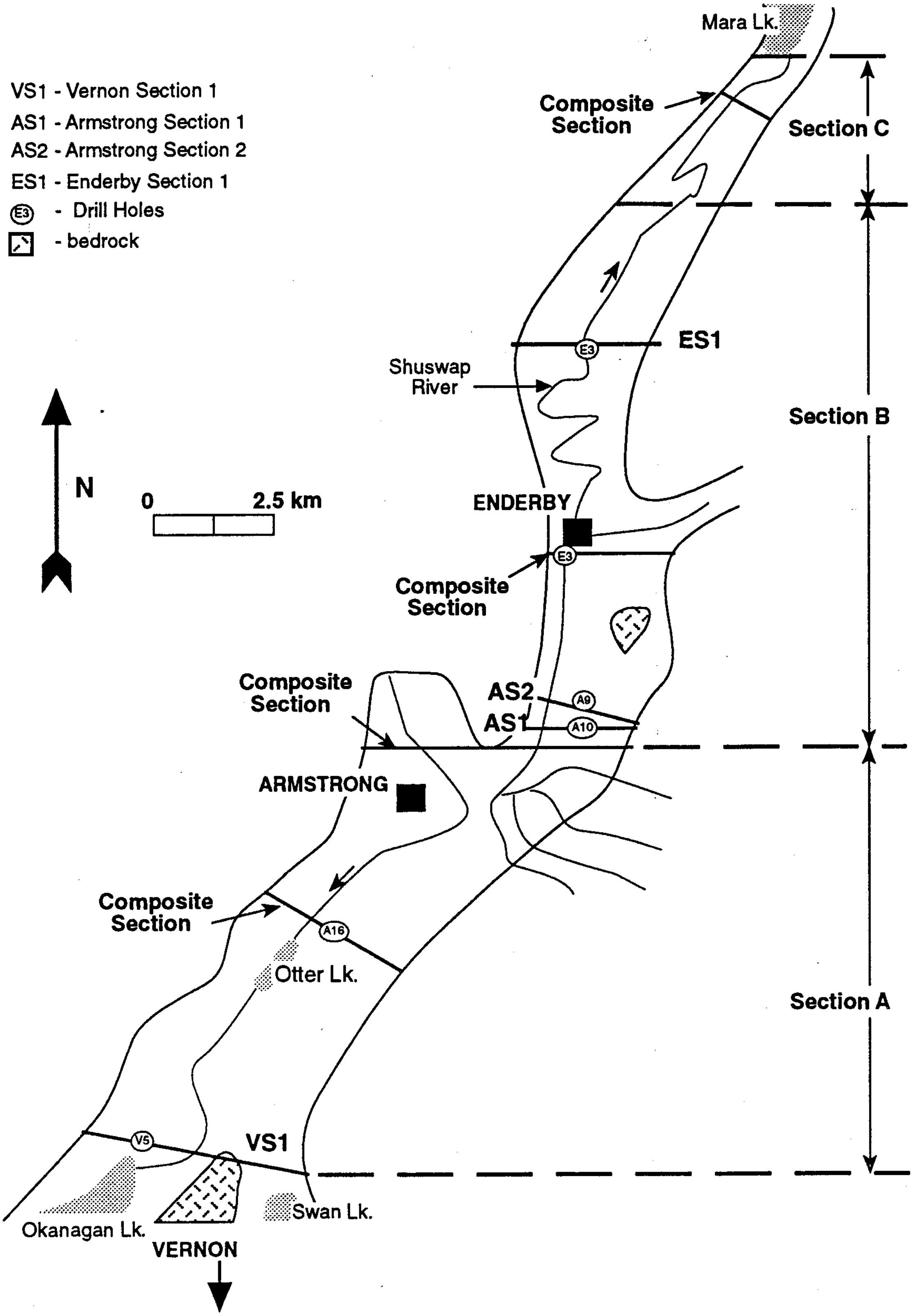


Figure 6.24 Basin profile locations that were used in the sediment volume calculation of the North Okanagan Valley.

from Enderby to the north shore of Okanagan Lake was subtracted. A maximum channel width of 700 m and depth of 27 m were used in the volume determination of the 25 km long paleo-meltwater channel. These values grossly over estimate the amount of material excavated by the channel, however, the impact on the total volume calculation is negligible (3%). The refined volume calculation is approximately **48.53 km^3**.

Elsewhere in the Okanagan Valley, Eyles et al., (1990) proposed a sediment volume of over 90 km^3 for the 120 km long Okanagan Lake basin. From the volume determinations for the North Okanagan and Okanagan Lake Basins it is apparent that a considerable amount of sediment is stored within these basins.

Table 6.3 Measurements used in determination of sediment volume, North Okanagan Basin, British Columbia.

Section	Area (km^2)	Average Area (km^2)	Section Length (km)	Volume (Km^3)
A P1	1.56	-	17.4	-
P2	1.83	-	-	-
P3	2.41	1.93	-	**33.58**
B P4	.66	-	20.4	-
P5	.77	-	-	-
P6	.61	0.68	-	**13.87**
C P7	.24	0.24	6.4	**1.54**
Meltwater Channel	.02	-	25	**0.46**
-	-	-	-	Total Volume (minus channel) **48.53 km^3**

CHAPTER SEVEN

BASIN ARCHITECTURE:

DEPOSITIONAL SYSTEMS AND COMPONENT FACIES

7.1 Introduction

In order to determine the relationships between the various depositional components of the North Okanagan Basin, and permit the amalgamation of the seismostratigraphic and lithologic information, an approach was required that would allow for a meaningful synthesis of the data. Therefore, the architecture of the North Okanagan Basin was constructed using a depositional systems approach similar to that implemented by Galloway et al., (1982) and discussed by Galloway and Hobday (1983) and Miall (1984). Numerous studies have demonstrated the value of the depositional systems approach to the analysis of petroleum reservoir architectures, particularly in the Gulf Coast hydrocarbon province of Texas (Galloway et al., 1982; Galloway and Cheung, 1985; Tyler and Ambrose, 1985). Yet, few studies in modern, or at least, Quaternary, environments have implemented this effective approach to the delineation of non-marine, intermontane, Quaternary basin fills (Eyles et al., 1985).

Most sedimentary basins are characterized by the deposition of clastic sediments through a series of depositional episodes and hiatuses (Galloway and Hobday, 1983). Hiatuses result in distinct stratigraphic surfaces that can be used to separate the depositional sequences. An outcome of these processes is a depositional arrangement or 'basin architecture' delineated by the bedding geometries and spatial relationships of the depositional systems (a depositional system is defined as a complete package of depositional environments and its sedimentary products; Miall, 1984).

Interpretation of a basin's architecture should follow a systematic approach that involves the description of each depositional system and its associated facies (Galloway and Hobday, 1983). The first step in this systematic approach is the determination of vertically and laterally extensive lithofacies. The lithofacies are then interpreted in terms of the environments in which they were deposited. The next step involves combining the genetically related lithofacies into depositional systems. Ultimately, analysis of the basin architecture should provide a sedimentary model that defines the structure, paleogeography, and depositional history of the basin (Sharpe et al., 1992).

In their study of basin fills Galloway et al., (1982) identified the Major Stratigraphic Unit (or MSU - composite of all depositional systems contained within the basin), which they subdivided into sub-components or 'systems' that comprise the basin fill. Each depositional system was defined by the overall geometry, internal bedding characteristics, textural trends, relationships to other depositional systems, and facies architecture. From this analysis a depositional model of the basin architecture was developed and compared to existing basin models. A similar approach is implemented in this study of the North Okanagan Basin.

In this chapter, the geomorphic setting of the North Okanagan Basin is addressed. This is followed by a discussion of the bedrock topography and the litho- and seismic facies used in the mapping of the various depositional systems of the basin architecture. Four depositional systems identified in the basin were used to reconstruct the paleogeomorphology and depositional history, provide a depositional model and generalized lithofacies profile, and compare the basin architecture to existing models of intermontane basins.

7.2 Geomorphic Setting

7.2.1 Initial Bedrock Topography

The North Okanagan Basin consists of a suite of clastic deposits that represent a succession of depositional environments. For purposes of defining the architecture and depositional systems, the North Okanagan Basin is considered to be the Major Stratigraphic Unit and will be referred to hereafter as the North Okanagan Basin Fill. To fully understand the architecture of the North Okanagan Basin Fill the initial geologic setting of the basin and subsequent geomorphic and depositional phases must be evaluated.

The North Okanagan Basin Fill was deposited in a structural trench created by mid-Tertiary extension along a 90 km shear zone (Tempelman-Kluit and Parkinson, 1986; Figure 2.4). The extensional structure of the basin is believed to be similar in style of formation to extensional basins in the Basin and Range Province of Western United States (Tempelman-Kluit and Parkinson, 1986; Okulitch, 1984). The North Okanagan basin is bounded by parallel, steeply dipping normal faults and the geology of the region is characterized by a complex assemblage of igneous, sedimentary and metamorphic rocks. Early Tertiary geomorphic processes played an important role in shaping the initial bedrock structure of the North Okanagan Basin. Late Pliocene uplift of the basin resulted in stream rejuvenation and downcutting of the valley floor (Jones, 1959). The combination of these geologic and geomorphic processes ultimately created a bedrock corridor that served as a natural conduit for glacial ice during subsequent Quaternary glaciations.

Depths to bedrock (Facies A and Seismic Unit 1) of the North Okanagan Basin range from 53 masl north of Enderby at SFU Line 700-800 (Plate 14; Figure 6.8) to at least 280 mbsl immediately north of Okanagan Lake (below well log V5 on GSC Line 500, Plate 5; Figure 6.2). The bedrock floor exhibits a regional north-south slope of 0.8° to 0.9°. Lithologic profiles that transect the north-south trending axial line show greater bedrock depths in mid-basin locations (Figures 6.2, 6.4 to 6.6, and 6.8).

Several reaches of the valley floor exhibit an asymmetrical bedrock profile where the valley changes orientation from a general north-south trend (Figure 7.1). North and south of the village of Armstrong bedrock profiles obtained from early seismic refractions studies (Okanagan Basin Committee, 1974) show deeper bedrock depths on the 'outside bends' of the valley at Profiles 1 and 2 (Figure 7.1). This characteristic is more pronounced on Profile 2. From this information it appears that the initial bedrock configuration of the North Okanagan Basin has controlled, to some degree, the erosion by valley glaciers. During the southward advance of Quaternary valley glaciers it appears that differential bedrock erosion has resulted in the asymmetrical geometry of the basin floor.

7.2.2 Basin Mapping

Over 16 line kilometres of shallow reflection seismic profiles were collected, interpreted and correlated with drill logs. Analysis of this led to the determination of six seismic units that were identified in the North Okanagan Basin Fill (Plates 1 to 14, Appendix C; Chapters Four and Five). In addition, a combination of 30 lithologic logs that included SFU drill holes, core samples, and groundwater well logs were used to identify eight lithofacies and construct over 37 kilometres of valley cross-sections and longitudinal profiles (Figures 6.1 to 6.8, Chapter 6). Comparison and correlation of the seismic units and lithologic facies (Table 7.1) allowed for the subdivision of the North Okanagan Basin Fill into various sub-components or 'depositional systems'. Analysis of the seismic and lithologic data revealed several important characteristics of the basin fill:

1) Major depositional episodes were defined by the analysis of lithologic transitions and well defined seismic reflection boundaries.

2) Seismic reflections are characterized by predominantly parallel, horizontal reflections that conform with underlying seismic units (especially in Units IIIa and IIIb).

3) The lithologic and seismic characteristics listed above reflect the aggradational structure of the basin fill.

4) Aggradational sequences are punctuated by progradational and lateral accretion sequences consisting of alluvial fans and channel deposits.

From this information is became possible to identify 4 distinct components of the North Okanagan Basin Fill that were used to determine its depositional systems.

7.3 Basin Architecture

7.3.1 Depositional Systems

Division of the North Okanagan Basin Fill into a number of distinct, spatially related, depositional systems was accomplished primarily on the basis of information provided by seismic reflection profiles, lithologic profiles, core data and geophysical logs. The Basin is subdivided into 4 distinct depositional systems identified as the:

1) Fluvio-Glacial System

2) Glaciolacustrine System

3) Alluvial Fan System

4) Fluvial System.

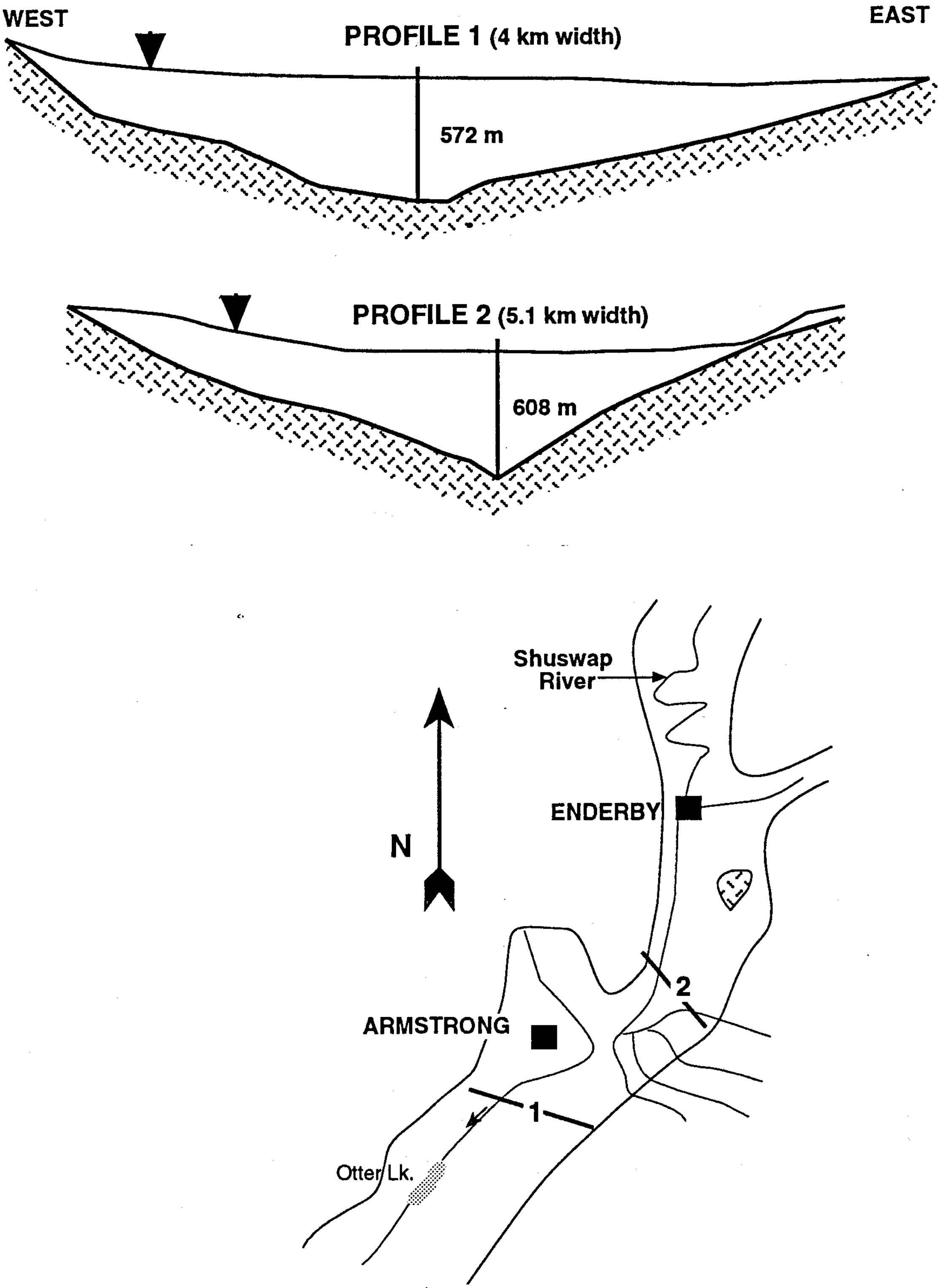


Figure 7.1 Asymmetrical bedrock profiles of the North Okanagan Basin near Armstrong (after Okanagan Basin Committee, 1974).

Table 7.1 Correlation of lithologic facies and seismic units, North Okanagan Basin Fill.

Facies	Characteristics	Seismic Unit	Characteristics
A	- bedrock/unconsolidated sediment fill contact - basinward dipping bedrock profiles	I	- continuous to semi-continuous, moderate amplitude reflections - basinward dipping - bedrock/unconsolidated sediment contact
B_1 and B_2	- compact, poorly stratified sand and gravel and stratified sand and gravel - thickest in mid-basin positions	II	- series of continuous to semi-continuous, moderate to high amplitude reflections - often reflection free or incoherent mass of chaotic reflections - thickest in mid-basin positions
C	- laminated sandy silt - thickest in mid-basin positions - thickest basin fill facies	IIIa	- series of up to 24 parallel, moderate to high amplitude reflections that are concordant with underlying seismic units - most extensive seismic unit
D	- laminated silty clay - thickest in mid-basin positions - overlies Facies C	IIIb	- series of parallel, continuous, high amplitude reflections that are concordant with underlying seismic units - most extensive uppermost seismic unit - thickest in mid-basin positions
E	- interbedded gravel and sand - extends from basin margin to basin axis - occurrence determined from seismic reflection geometries - interfingers other basin fill facies	IV	- basinward dipping, semi-continuous to divergent, moderate amplitude reflections - extend from basin margins to basin axis - lens shaped - overlies lower seismic units
F_1 and F_2	- medium to coarse sands and upward fining sand - exposed at surface and shallow subsurface - lens shaped geometries, laterally continuous	V	- low continuity and variable amplitude reflections - lower concave boundaries that truncate lower seismic reflections - observed in upper 30 ms of SFU Lines 100 and 700-800

The Fluvio-Glacial and Glaciolacustrine Systems represent major aggradational complexes of the North Okanagan Basin Fill (Figure 7.2). The Fluvio-Glacial System is characterized by thick, coarse-grained, glacial outwash and glacigenic diamict. This contrasts with the thick, horizontally-bedded, fine-grained sediments of the Glaciolacustrine System.

Situated intermittently within the two major aggradational sequences is the Alluvial Fan System. This depositional system represents the major progradational sequence of the North Okanagan Basin Fill. Alluvial fan deposits punctuate the Fluvio-Glacial and Glaciolacustrine Systems and vary in location from immediately overlying the Fluvio-Glacial deposits to interfingering and overlying finer-grained sediments of the Glaciolacustrine System. The Alluvial Fan System consists of numerous debris flow derived fans composed of mixed sediment load, basinward dipping coarse to fine gravel, sand, silt and minor amounts of clay. The delineation of Alluvial Fan Systems at depth in the North Okanagan Basin Fill is limited due to the reduction in resolution of the seismic profiles at depth and lack of cores.

Cutting across the uppermost portions of the Glaciolacustrine System, the Fluvial System represents the only extensive lateral accretion depositional sequence observed in the Okanagan Valley's basin architecture. The Fluvial System is located in the shallow sub-surface and consists of various channel deposits composed of mixed sands, silts and clays. Although accounting for only a relatively small part of the basin fill, the Fluvial System was observed on both seismic and lithologic data collected at the Vernon and Enderby sites. Channels sampled at the Vernon site are composed of mixed sand sized sediments (Figure 6.22). At the Enderby site channel deposits exhibited textural trends identified as meandering channel facies (Figure 6.23).

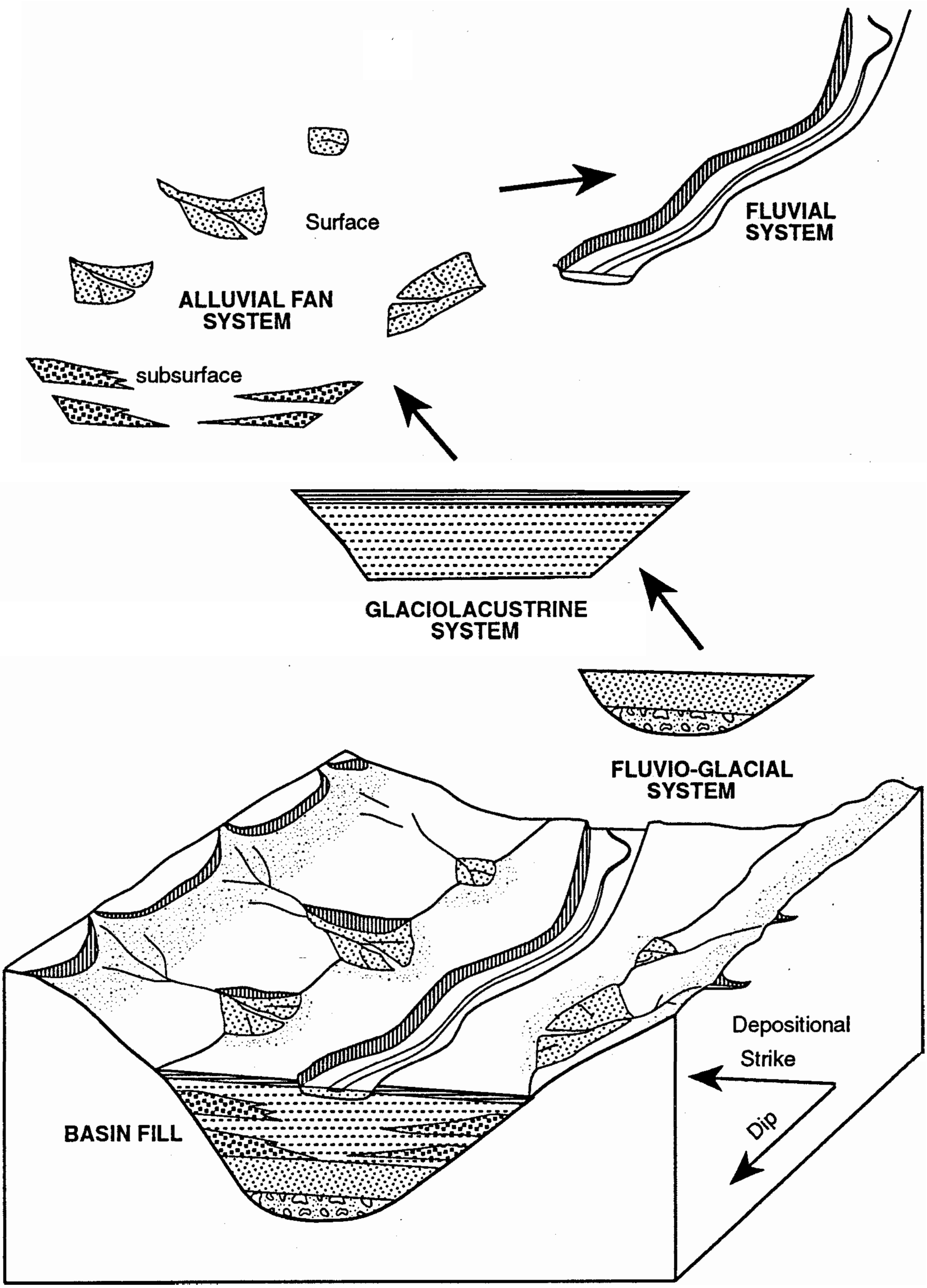


Figure 7.2 Depositional systems of the North Okanagan Basin Fill.

7.3.2 Fluvio-Glacial System

The Fluvio-Glacial System records the deposition of fluvial-glacial outwash in the North Okanagan Basin Fill (Figure 7.2). The system is characterized by compact, poorly stratified sand and gravel, stratified sand and gravel, and accounts for some 43% of the basin fill. On seismic profiles the system has continuous to semi-continuous reflections that accord with the underlying bedrock topography. Often the system is reflection free or appears as an irregular pattern of point-source reflections - a result of complex internal structure and coarse texture. The system occurs throughout the North Okanagan Basin. Mapped thicknesses of the system ranges from 57 m north of Enderby (log E3 in Figure 6.8), to 226 m south of Armstrong (log A16 in Figure 6.7), to an estimated thickness of about 338 m north of Okanagan Lake (below log V5 in Figure 6.2). Underlying the Fluvio-Glacial System is Tertiary (?) bedrock while the system is overlain by the Glaciolacustrine, Alluvial Fan, and Fluvial Systems.

Component Facies

The facies of the Fluvio-Glacial System, representing an aggradational episode, includes a lower facies B_1 and an upper facies B_2, that are correlated with Seismic Unit II (Table 7.1). The compact, poorly stratified, coarse-grained nature of Facies B_1 is interpreted as pressurized and compacted outwash and sub-glacial diamict that was laid down in front of, and subsequently overridden by, advancing glacial ice. Similar massive, coarse-grained, stratified diamict has been identified at the base of lithofacies sequences in late Pleistocene glacial lakes in the Lake Ontario Basin (Eyles and Miall, 1984). Mullins et al., (1989) interpreted pressurized sub-glacial meltwater and mixed sediments as the lowermost facies of valley fills in the Finger Lakes of New York. In areas of the

North Okanagan Basin Fill, where gravels thin to 5 m, the facies are also interpreted as a veneer of weathered bedrock.

Facies B_2 occurs as interbedded, coarse to medium-grained stratified sand and cobble gravel which were deposited adjacent to the retreating ice front into Glacial Lake Penticton. The lake was maintained at its maximum stage by a sediment and ice 'plug' situated at Okanagan Falls immediately south of Penticton (Nasmith, 1962; Figure 2.6).

Facies B_1 underlies Facies B_2 and accounts for up to 47 m of the Fluvio-Glacial system; Facies B_2 is up to 210 m thick. Contacts between the two component facies are poorly defined, though both lithologic and seismic sections indicate an abrupt contact with underlying bedrock (Facies A and Seismic Unit 1). Upper boundaries with the Glaciolacustrine and Alluvial Fan Systems are well defined. Relationships between the component facies indicate a transitional sedimentary environment between glacial advance and retreat. As glacial ice advanced southward through the North Okanagan Valley, fluvio-glacial outwash and basal diamict deposited in front of the advancing ice were overridden and compacted (Facies B_1). During northward ice retreat less compact outwash sediments (Facies B_2) were deposited on the sandur adjacent to the retreating ice front. A subtle fining upward textural trend is observed from Facies B_1 to B_2 that is a result of these depositional processes.

7.3.3 Glaciolacustrine System

The Glaciolacustrine System records the major period of aggradational infilling of the North Okanagan Basin (Figure 7.2). The system consists of a vertically extensive suite of predominantly fine-grained glaciolacustrine sediments that record deposition in Glacial Lake Penticton. Characterizing the sediments is a laminated sandy silt component that is overlain by a sequence of laminated silty clay. A distinct fining upward textural trend is observed within the Glaciolacustrine System. The laminated silt ranges up to 297 m thick (log A16 in Figure 6.7) and are draped by the laminated clay up to 103 m thick (log A9 in Figure 6.5).

The system is observed throughout the North Okanagan Basin, combined the deposits account for about 46% of the basin fill. The system is underlain by the Fluvio-Glacial System and extends to the valley surface. Alluvial Fan Systems interfinger the fine-grained sediments at various depths and channel fills of the Fluvial System are incised into the upper portion of the Glaciolacustrine System. Seismic profiles and drill hole logs show that the Glaciolacustrine System is a composite of fine to coarse-grained sandy silt and clay that exhibit a fining upwards trend. The system is thickest in mid-valley positions and thins rapidly towards the basin margins (see Armstrong Section 2, Figure 6.5). Component facies assemblages of the system include Facies C and D.

Component Facies

Facies C, correlated with Seismic Unit IIIa, is characterized by parallel, semi-continuous seismic reflection patterns that are composed of laminated sandy silt (Table 7.1). The irregularly laminated fine sandy silt contains numerous small scale load structures and overlies coarse-grained outwash deposits. Facies C sediments were formed during rapid glaciolacustrine deposition during northward ice retreat. Laminated silt accumulated in an intermediate or ice proximal position in Glacial Lake Penticton. Fulton (1969) has shown that during deglaciation the retreating ice front was in contact with the northern shore of Glacial Lake Penticton (Figure 2.8). Sediment deposition in this ice proximal setting is typically characterized by interflow and underflow processes and rapid sedimentation rates (Ashley, 1985). The presence of load structures in Facies C, including distorted bedding, load casts, and micro-faults, supports the notion of rapid sedimentation rates. Furthermore, the sediments showed no visible signs of biologic activity. According to Ashley (1975,1985) organic activity is not anticipated in such a dynamic depositional environment (i.e. rapid sedimentation rates).

Based on ice positions during the early stages of Glacial Lake Penticton (Figure 2.8), it is postulated that deposition of Facies C occurred early during glacial lake formation. During Long Lake and Grandview Flats Stages lake water would have been in direct contact, or proximal to, the northward retreating glacial ice. During these stages sedimentation rates would have been rapid and coarse-grained sediments would be abundant relative to more ice distal locations.

In Fulton's (1969) description of the initial lake stages no evidence is provided that suggests the presence of stagnant ice complexes in the North Okanagan Valley during deglaciation. Other researchers including Nasmith (1962); Fulton, (1969); Eyles et al., (1991); Shaw, (1975, 1979); Shaw and Archer (1979); adhere to the notion that deglaciation in the southern Okanagan Valley was characterized by rapid ice retreat and the *in situ* downwasting of sediment covered ice blocks. In the North Okanagan Basin Fill the limited number of soft sediment deformation structures found in drill core and lack of chaotic reflection patterns on seismic profiles suggests that deposition of supraglacial sediment onto stagnant ice was not an important process during deglaciation of the North Okanagan Valley.

In summary, Facies C and Seismic Unit IIIa are representative of ice proximal glaciolacustrine deposition in a setting relatively free of stagnant ice complexes.

Facies D is correlated with Seismic Unit IIIb (Table 7.1) and is interpreted to represent glaciolacustrine sedimentation in an ice distal environment. The laminated silt and clay were deposited at a time when glacial ice in North Okanagan Valley was situated well to the north of the depositional environment. This would account for finer-grained sediments and the presence of biogenic structures observed in Facies D. In lower energy glaciolacustrine environments organisms burrow into the deposits and are not rapidly covered by sediments. According to Ashley (1975,1985,1988) glaciolacustrine facies of a distal environment exhibit laminations of fine-grained sediments, contain lebbensspuren (biogenic structures), show silt layers of variable thicknesses, and rarely contain ice-rafted debris. All these characteristics were observed in Facies D.

Fulton's (1969) discussion of the various stages of Glacial Lake Penticton provides further insight into the depositional environment of Facies D (Seismic Unit IIIb). During Grandview Flats and B.X. Stages (Figure 2.8) glacial ice had retreated to the present region of the Shuswap Basin and Glacial Lake Penticton extended to Okanagan Falls south of Penticton This supports the supposition that ice was located a considerable distance to the north and that deposition was occurring in an ice distal environment.

The essential difference between Facies C and Facies D is that Facies D was deposited in an ice distal environment relative to Facies C. The distinction is evidenced by the vertical textural transition to finer-grained sediments that occurs between the two component facies. As glacial ice retreated northward in North Okanagan Valley Facies C was deposited proximal to the ice front. Proximity to the ice front and rapid sedimentation rates resulted in coarser-grained sediments that contained numerous deformation structures. Continued northward retreat of glacial ice led to reduced sedimentation rates in more ice distal locations. This accounts for finer-grained sediments, limited deformation structures, and biogenic structures observed in Facies D.

7.3.4 Alluvial Fan System

The Alluvial Fan System makes up the major progradational component of the North Okanagan Basin Fill and records the interfingering of alluvial fan sediments with the Fluvio-Glacial and Glaciolacustrine Systems (Figure 7.2). Lithologically the system is characterized by cobble gravel sequences up to 24 m thick mixed with plant debris, sand, silt, and some clay. Up to 8% of the basin fill is comprised of the Alluvial Fan System which has an average thickness of 66 m (well log A12 in Figure 6.5). Seismic profiles portray the system as an assemblage of basinward dipping, semi-continuous to divergent, moderate amplitude reflections bounded by the Fluvio-Glacial and Glaciolacustrine Systems.

Along Armstrong-GSC Line 100 (Plate 6, Seismic Unit IV; Appendix C) the Alluvial Fan System exhibits a wedge-shaped, basinward thinning geometry that extends laterally for some 963 m. The alluvial fan pinches out from a proximal (east basin margin) thickness of 102 m to a distal thickness of less than 20 m. Although not as laterally extensive, a lens-shaped Alluvial Fan System overlying bedrock observed on SFU Line 700 -800 (Plate 14, Seismic Unit IV; Appendix C) extends laterally for at least 300 m with a maximum thickness of 25 m. Alluvial Fan Systems observed on seismic profiles (see Armstrong GSC Line 100 and SFU Line 500 and Enderby SFU Line 700-800, Seismic Unit IV, Plates 6, 8, and 14; Appendix C) may show distinct wedge or lens-shaped morphologies, near horizontal lower boundaries, and less distinct upper boundaries that are lobate and convex in cross-sectional profile.

Convex, lobate bounding surfaces are indicative of multiple or 'stacked' alluvial fans (Mitchum et al., 1977). According to Galloway and Hobday (1983) arid alluvial fans in intermontane basins are limited in size, exhibit non-erosive (horizontal) bases, and are deposited by debris flows and associated fluvial processes. These characteristics were also observed in the Alluvial Fan Systems of the North Okanagan Basin Fill. Along depositional strike the Alluvial Fan Systems are lens-shaped and pinch-out laterally: this was found on Armstrong-SFU Line 500 where an alluvial fan extends laterally for 500 m and thins from 25 m to less than 5 m (Plate 8, Seismic Unit IV, Appendix C; Figure 6.6). Deposits of the Alluvial Fan System are composed of interbedded gravel and sand identified as Facies E and correlated with Seismic Unit IV (Table 7.1).

Component Facies

Detection of alluvial fan deposits in the subsurface requires the correlation of drill and groundwater logs with seismic reflection patterns. Alluvial fan sediments are characterized by interbedded gravels and sands with individual gravel beds up to 24 m thick indicative of high energy depositional environments. Relative to other sedimentary units observed in the North Okanagan Basin Fill, the sediments are distributed throughout the basin at various depths. Fulton (1975) mapped the location of surface alluvial fans throughout the North Okanagan Valley (Figure 2.7) and showed that alluvial fans characterize the valley side/valley floor transitional zone. At the Armstrong site an alluvial fan overlies glaciolacustrine sediments near the southeast corner of Back Enderby Road (Figure 5.10). At this site boulder sized cobbles and gravel directly overlie glaciolacustrine silt and clay.

During deglaciation, prior to the establishment of permanent vegetation, a great volume of sediment existed on glacially oversteepened, unstable slopes. This condition may provide some clues to the possible timing of the deposition of the Alluvial Fan Systems. The paraglacial period, following and during deglaciation in the Cordillera, was often characterized by the presence of unstable 'drift' (Church and Ryder, 1972). The drift was ultimately transported by fluvial and mass movement processes as long as material remained available for transport. Ryder (1971a, 1971b) described the formation of paraglacial alluvial fans in south-central British Columbia where the fans were the result of mud or debris flow sedimentation attributed to the reworking of glacial 'drift' soon after deglaciation. Ryder (1971a) also suggests that most fan building processes (debris flows and stream action) no longer operate at present as evidenced by the presence of aeolian sand, well developed soil horizons, and permanent vegetation that indicate surface stability. It is suggested that surficial alluvial fans in the North Okanagan Valley have not been altered significantly in the recent past and that alluvial fan deposition occurred during or soon after deglaciation. Where the alluvial fan sediments interfinger other depositional systems, the sediments are interpreted to be contemporaneous with the enclosing deposits.

7.3.4.1 Implications of the Alluvial Fan System on Basin Architecture

The Alluvial Fan System, although limited in volume, plays a critical role in the stratigraphy of the basin architecture and provides information regarding basin fill processes. Typically, alluvial fans in the North Okanagan Basin Fill occur as non-cyclic, stacked sets of basinward thinning progradational wedges (Figure 7.2). The fans interfinger other depositional systems and are also observed overlying surficial sediments on the valley floor (Figure 2.7). Formation of Alluvial Fan Systems are attributed to the onset of deglacial conditions and climatic amelioration. During deglaciation in the North Okanagan Basin, loose, unstable, glacigenic material was transported into the basin by debris flow and fluvial processes. Unlike fan deposition controlled by tectonic activity, alluvial fans in the North Okanagan Basin Fill reflect transitional climatic conditions between glaciation and deglaciation. As valley sides became ice free, and vegetation had not yet established, loose clastic material situated on oversteepened slopes was redistributed into the basin by mass movement processes. This resulted in the deposition of alluvial fans, and fan-deltas if deposition occurred directly into Glacial Lake Penticton. In light of this, the Alluvial Fan Systems that interfinger finer-grained deposits in the North Okanagan Basin Fill reflect geomorphic processes controlled by climatic conditions.

In arid, fault-controlled basins alluvial fans typically extend basinward from mountain fronts or fault generated escarpments and indicate deposition during tectonically active periods, and sometimes following rapid climatic change or changing base levels (Galloway and Hobday, 1983). They (Galloway and Hobday, 1983) also suggest that basin fills in extensional, intermontane, non-marine basins are characterized by stacked alluvial fan systems. Unfortunately, limited consideration is given to basin and basin fill modifying geomorphic processes. Miall (1981) described sedimentation in alluvial basins formed by tectonic processes; the paper did not attempt to describe stratigraphic and basin architecture variations caused by climatically driven geomorphic processes.

The non-cyclic nature of the Alluvial Fan System in the North Okanagan Basin Fill, relative to other intermontane basin models (Figure 1.5), is interpreted to be a function of the limited thickness of the North Okanagan Basin Fill (up to 680 m north of Vernon) and the episodic scouring and removal of sediments by glacial processes. As previously indicated, the Okanagan Valley has experienced at least two glaciations during the Quaternary Period (Fulton, 1984), and at least one cycle of glacial and deglacial sediments are postulated to be preserved in the North Okanagan Basin Fill (Chapter Six, Section 6.3). Nevertheless, erosion of the fan systems by glacial processes would severely limit the preservation potential of the deposits. Furthermore, few tributary valleys and streams flow into the North Okanagan Valley; this is another control on the frequency of progradational units in the basin architecture. In summary, the Alluvial Fan Systems in the North Okanagan Basin architecture are non-cyclic and limited in areal extent. Most importantly, the arrangement of alluvial fans illustrates the role of geomorphic processes in contributing to the overall geometry of the basin architecture.

7.3.5 Fluvial System

The Fluvial System records the deposition of fluvial sediments in the North Okanagan Basin (at the Vernon and Enderby sites) and represents only a small percentage (up to 3%) of the basin fill (Figure 7.2). The system is characterized by extensive channel fills dominated by medium to coarse-grained sand and fining upward sequences of sediments.

Stratigraphy of the system is defined by medium to coarse, horizontally-bedded sand and upward fining sand. On seismic sections Fluvial Systems exhibit asymmetrical lens-shaped morphologies with concave lower boundaries that truncate underlying seismic units. Dimensions on seismic profiles range from up to 60.1 m (mean width) and 8 to 10 m thick. The system is identified throughout the North Okanagan Basin Fill. At Vernon a 5.5 m thick fluvial sequence can be traced laterally for 475 m (Figure 6.3). Similarly, on Enderby-SFU Line 700-800 (Plate 14, Appendix C; Figure 6.23) fining upward channel sediments are correlated for 150 m between SFU drill holes E1 and E2. Relative to other depositional systems the Fluvial System is incised into the Glaciolacustrine System and exposed on the valley floor. The system was not observed in the Alluvial Fan or Fluvio-Glacial depositional systems, however, this does not exclude their preservation at depth in the North Okanagan Basin Fill. Component facies of the Fluvial System include Facies F_1 and F_2 that are correlated with Seismic Unit V (Table 7.1).

Component Facies

Facies F_1 is interpreted as coarse-grained, well sorted, horizontally-bedded sand that record moderately high energy fluvial processes. At the Vernon site fluvial deposits identified in drill core are possibly paleo-channel deposits. This interpretation is supported by a large paleo-channel that extends from Enderby to the north shore of Okanagan Lake (Figure 2.7). Fulton (1969) documented the development of the channel during the waning stages of Glacial Lake Penticton - Lake Shuswap Stage, when glacial ice had retreated northward into the Shuswap Basin. Another possible interpretation is that the Vernon area fluvial deposits represent paleo-channel fills of streams that emanated from the valley sides and flowed into Glacial Lake Penticton. This would account for the channel sands 'sandwiched' between glaciolacustrine silt.

On lithologic profiles from the Enderby site Facies F_2 shows a basal gravel lag that fines upward into overbank silt and clay. The sequence is interpreted to represent meandering channel deposits.

Boundaries between component Facies F_1 and F_2 and other depositional systems are well defined. Deposits of the Fluvial System, although limited in volume, represent alterations and ongoing fluvial reworking of the basin fill and surficial deposits. This is particularly evident at the Enderby site where the Shuswap River currently flows northward into the Shuswap Basin (Figure 7.3). Alteration of the valley floor is evident in numerous, abandoned channels.

7.4 Paleogeomorphology and Depositional Systems

7.4.1 Depositional Model

The particular architecture of the North Okanagan Basin Fill developed in response to glacial, deglacial, mass movements, and glaciolacustrine processes.

These processes, most importantly deglaciation and glaciolacustrine deposition, account for the Fluvio-Glacial and Glaciolacustrine Systems that comprise the bulk of the 680 m thick basin fill. In vertical succession, the Fluvio-Glacial System is overlain by the Glaciolacustrine System, and both are interrupted by the Alluvial Fan System that overlies the Fluvio-Glacial System and interfingers the Glaciolacustrine System. Incised into the Glaciolacustrine System, the Fluvial System records fluvial reworking of the fill in recent geologic time.

From the analysis of the depositional systems, and component seismic and lithofacies, two stages are proposed for the evolution of the basin architecture (Figures 7.4 A and B). The first model (Figure 7.4A) illustrates depositional environments during late glacial time (ca. 11,000 to 10,000 BP). The model shows a lowermost unit (B_1) consisting of pressurized outwash and glacigenic diamict that formed from the overriding of outwash and glacigenic diamict by southward advancing glacial ice. Overlying this unit are less compact, stratified outwash sediments deposited during ice retreat (B_2). A significant portion of this material may have been laid down during the existence of Glacial Lake Penticton. As deglaciation continued and Glacial Lake Penticton increased in areal extent, deposition proximal to the retreating ice was characterized by glaciolacustrine sedimentation (C). Ice stagnation and the subsequent melt-out of buried ice masses was not considered an important depositional mechanism in the North Okanagan Valley during deglaciation.

The second model (Figure 7.4B) shows a succession of basin fill sediments with distal glaciolacustrine sediments (D) shown as the uppermost facies. The sequence is punctuated by alluvial fan sediments (E) at various depths and positions in the basin fill. The valley floor is currently characterized by a large paleo-meltwater channel and contemporary deposits of the Shuswap River (F). This model closely approximates the current geomorphology and

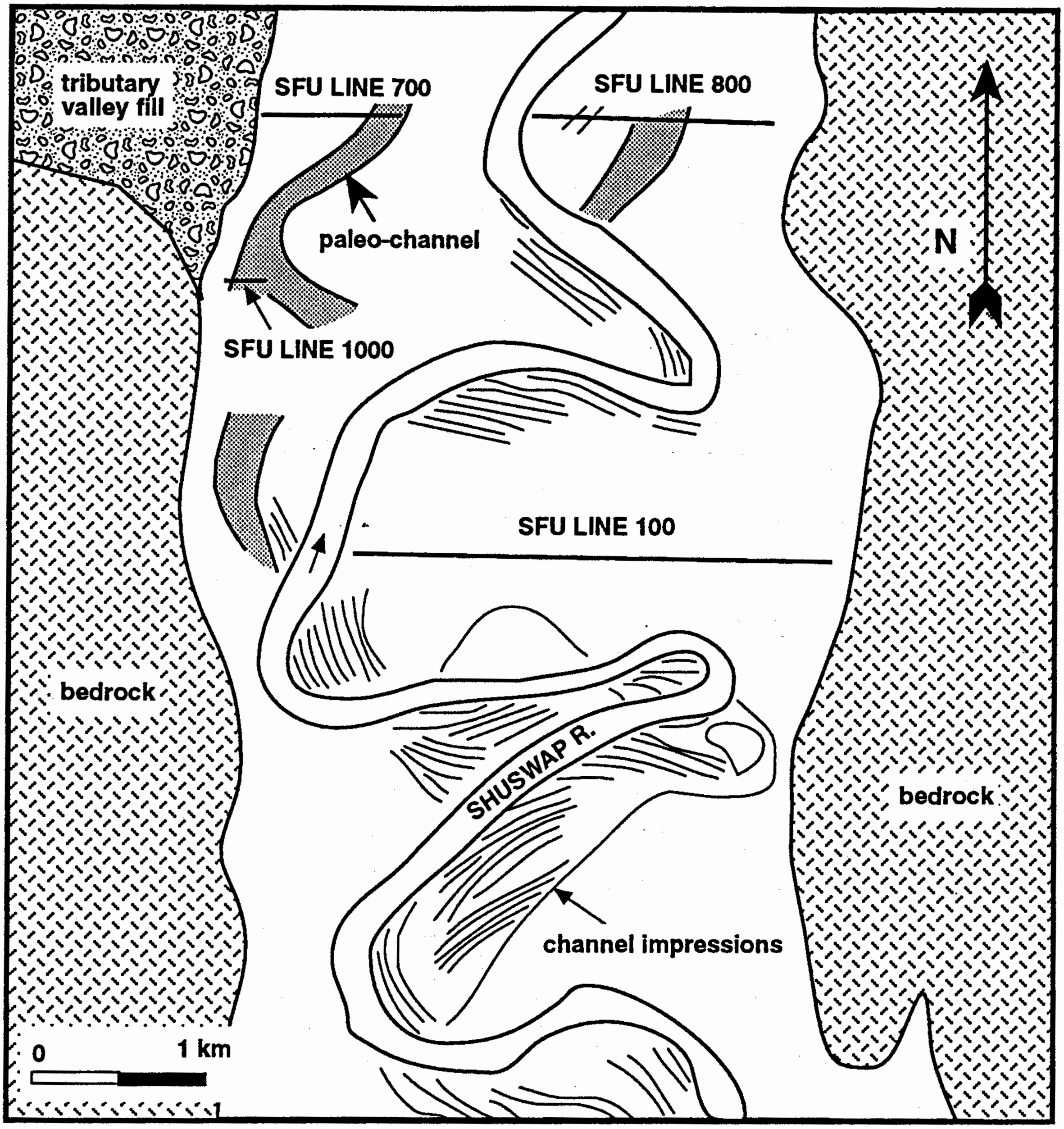


Figure 7.3 Lineations and paleo-channels of the Fluvial System that characterize the North Okanagan valley floor (at the Enderby site).

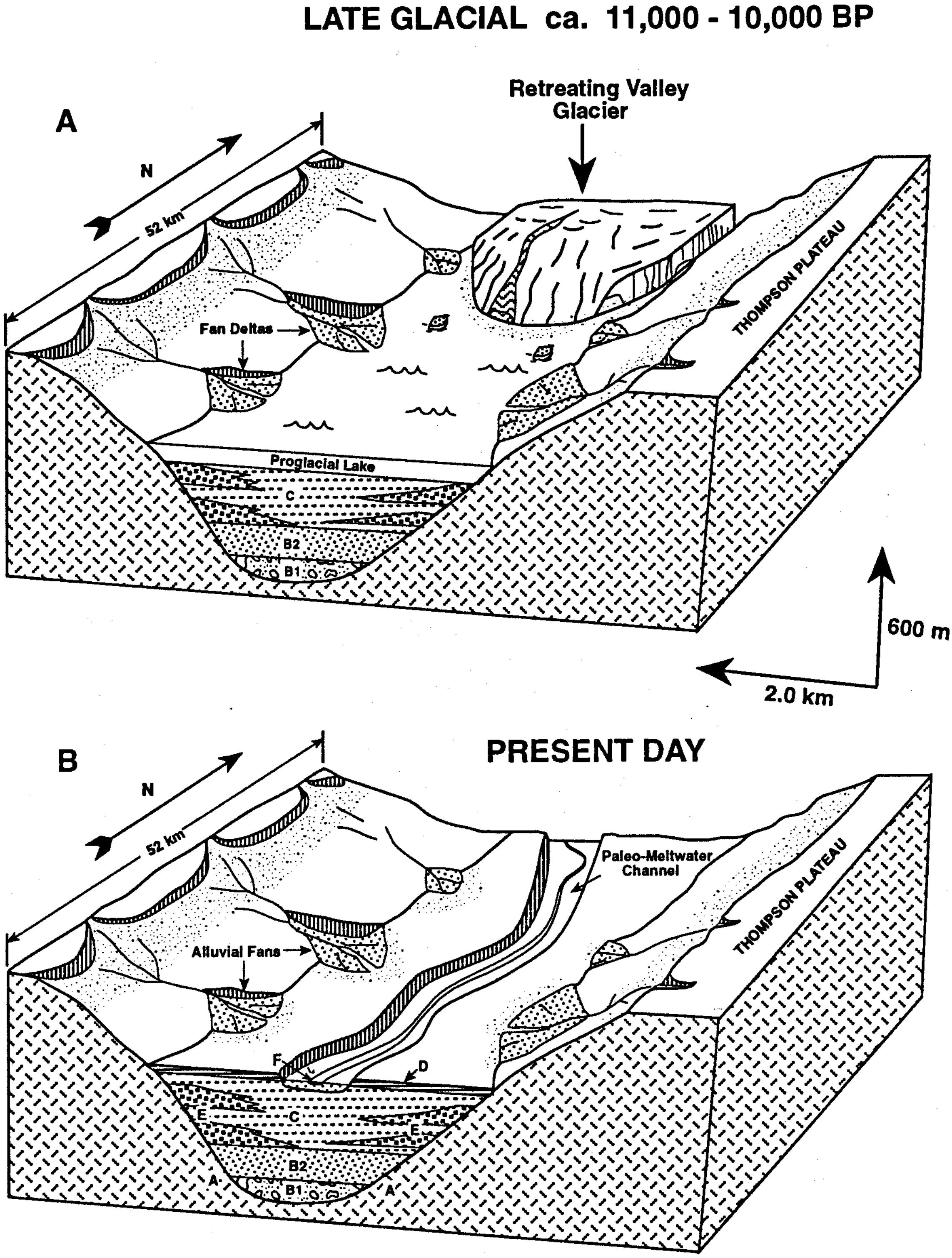


Figure 7.4 Models of the basin architecture of the North Okanagan Basin Fill. Model **A** shows the architecture during deglaciation and glacial lake formation. Model **B** shows the nature of the present day basin architecture and surficial geomorphology.

architecture of the North Okanagan Basin Fill.

7.4.2 Generalized Schematic of the Basin Fill

Relationships between depositional systems and component facies were used to delineate an idealized vertical profile of the North Okanagan Basin Fill (Figure 7.5). From the Tertiary (?) basement to the valley surface a large scale fining upward cycle is superimposed over two fining upward cycles of lesser magnitude. The larger cycle is defined by coarse grained deposits of the Fluvio-Glacial System that fine upward into glaciolacustrine silt and clay of the Glaciolacustrine System.

Secondary fining upward cycles are also identified in the vertical profile of the basin fill. The lowermost component of the Fluvio-Glacial System (Facies B_1 and Seismic Unit II) fines upward from compact, poorly stratified bouldery outwash and diamict into less compact, stratified outwash gravel and sand (Facies B_2 and Seismic Unit II). Laminated glaciolacustrine sandy silt (Facies C and Seismic Unit IIIa) distinguish the lower component of the Glaciolacustrine System. The sediments fine upward into glaciolacustrine deposits composed of laminated silty clay (Facies D and Seismic Unit IIIb). These fining upward trends in the Fluvio-Glacial and Glaciolacustrine Systems define the secondary aggradational sequences.

Superimposed over the Glaciolacustrine System are coarse-grained alluvial fan and sandy fluvial deposits. Alluvial fan sediments are observed at various elevations in the profile from overlying the Fluvio-Glacial System to interfingering the Glaciolacustrine System. Fluvial sediments are typically incised into the Glaciolacustrine System on the valley surface or within 30 m depth.

IDEALIZED VERTICAL LITHOFACIES PROFILE OF THE NORTH OKANAGAN BASIN FILL

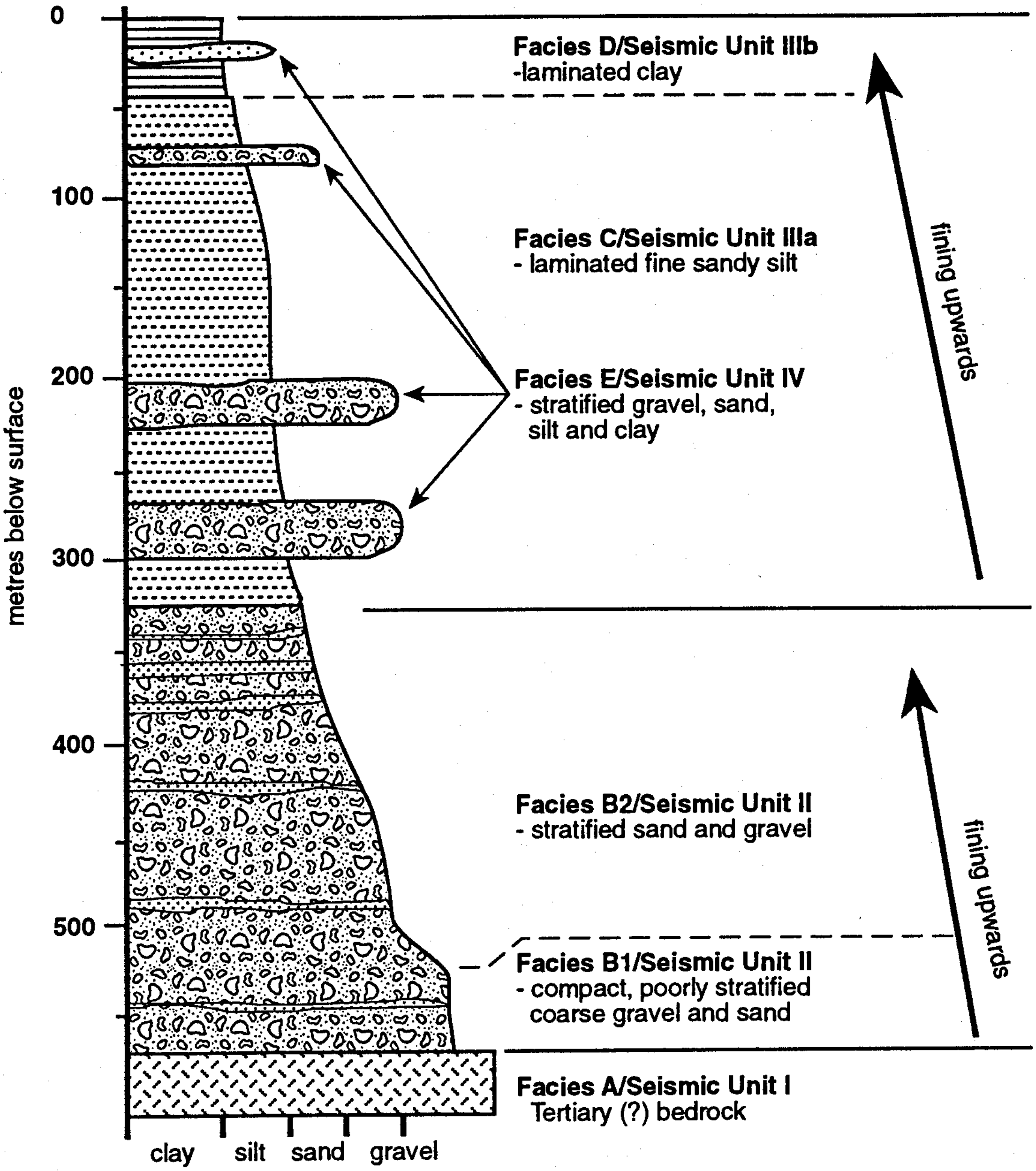


Figure 7.5 Idealized profile of the North Okanagan Basin Fill determined from lithologic and seismic data. Profile extends from the valley floor to bedrock.

7.4.3 Depositional History

The vertical assemblage of depositional systems identified in the North Okanagan Basin Fill reflects the previously described interpretations of the late Wisconsinan (Fraser Glaciation) sedimentary sequence. During Fraser Glaciation time multiple ice lobes coalesced in south-central British Columbia and flowed roughly north to south through Okanagan Valley into Washington State (Nasmith, 1962). Following climatic amelioration ice retreated rapidly to the north. During the stages of ice advance and retreat thick sequences of outwash sediments and diamict accumulated in the Okanagan Valley (Eyles et al., 1991; Fulton and Smith, 1978). South of Vernon deposition occurred in an ice stagnation environment characterized by the melt-out of buried ice masses (Nasmith, 1962; Fulton, 1969, 1975; Fulton and Smith, 1978; Shaw, 1975, 1977; Shaw and Archer, 1978, 1979; Eyles et al., 1991).

As northward ice retreat continued a large glacial lake, Glacial Lake Penticton (Fulton, 1969), formed and at its maximum extent spanned from north of Vernon to Okanagan Falls (Figure 2.8). Deposition in, and adjacent to, Glacial Lake Penticton accounts for the thick accumulations of glaciolacustrine deposits in the North Okanagan Basin Fill. By the time glacial ice had retreated to the Vernon region it is assumed that climatic amelioration was extremely advanced. Lithologic and seismic evidence indicate that ice stagnation and the detachment of large ice blocks did not significantly affect depositional processes. This assumption is supported by the lack of irregular seismic reflection patterns and associated soft sediment deformation structures in the basin fill. In essence, the North Okanagan Basin Fill is characterized by the Fluvio-Glacial and Glaciolacustrine Systems which record the deposition of glacial outwash and glaciolacustrine sedimentation.

A depositional dip profile (north-south) of the basin architecture reveals a deepening of the basin floor and thickening of the Fluvio-Glacial and Glaciolacustrine Systems to the south (down depositional dip). This is not unexpected considering the north-south direction of glacier advance and retreat, and coalescence of ice lobes south of Vernon. South of Vernon depth to bedrock below the basin of Okanagan Lake exceeds 1 kilometre (Eyles et al., 1991).

7.4.4 Depositional Processes

The main depositional processes contributing to formation of the basin architecture were the accumulation of ice contact deposits during glacial advance and retreat, and the settling from suspension of clouds of fine-grained glaciolacustrine sediments. Secondary depositional processes include the mass movement of valley side material by debris flows and fluvial processes, and the reworking of valley floor sediments by fluvial activity. Debris flow and fluvial processes account for the downslope redistribution of coarse-grained, unstable sediment that were deposited as alluvial fans and interfinger with other depositional systems.

During glacial advance and retreat deposition was controlled by rapidly changing hydrodynamic conditions at an unstable ice front. As previously discussed, the Fluvio-Glacial System is characterized by compact to poorly stratified sediments ranging from cobble gravel to fine-grained intercalations of silt and silty clay. Initially, glacial outwash deposited during ice advance was overridden by ice and compacted. During northward ice retreat fluctuating flow regimes resulted in a vertically extensive cover of ice contact sediments characterized by braided stream deposits. Extent of the ice contact environment from the ice front can range from 1 to 100's of km (Brodzikowski and Van Loon, 1991). Deposition of the Fluvio-Glacial System likely occurred very rapidly and was characterized by fluctuating flow conditions. Sudden, high energy conditions resulted in the deposition of coarse-grained sediments. Fine-grained sediments, often destroyed by successive high energy flows, were deposited during waning flow, lower energy conditions, and increasing distance from the retreating ice front.

Deposition of the Glaciolacustrine System was a direct result of the settling from suspension of fine-grained sediments. Characterizing this system are bottomset laminae composed of sandy silt and silty clay. Interflow , overflow, and turbidity flow processes in Glacial Lake Penticton account for these thick sequences of glaciolacustrine deposits observed in the North Okanagan Basin Fill. Turbidity currents that deposit coarser sediments lakeward of the ice margin were identified as a primary depositional mechanism in the Penticton region (Shaw, 1975, 1977; Shaw and Archer, 1978, 1979).

Although representing a small volume of the North Okanagan Basin Fill, secondary depositional processes associated with the Alluvial Fan and Fluvial Systems, including mass movements and fluvial reworking, were important depositional mechanisms. Following the waning stages of glaciolacustrine deposition and the onset of post-glacial conditions, debris flows redistributed coarse clastic material throughout the basin. Debris flows are the most common landform in semi-arid regions or in basins with abundant glacigenic surficial material (Galloway and Hobday, 1983). Valley side accumulations of coarse clastic material was quickly transported basinward during high precipitation events resulting in poorly sorted, stratified, coarse-grained sediment accumulations ranging from basinward thinning cobble gravel to silt and clay. Fluvial processes are also an integral component of debris flows and are not excluded as a depositional mechanism. The combination of debris flow and fluvial processes are ultimately responsible for thick (up to 66 m) and laterally extensive (up to 1 km) Alluvial Fan Systems observed in the basin architecture.

Fluvial erosion and depositional processes represent recent and ongoing adjustments to the surficial geomorphology of the valley floor. This is particularly evident at the Enderby site where the Shuswap River exhibits a meandering planform confined by steep valley sides (Figure 7.3). Scouring and re-deposition of alluvial sediments by fluvial processes have led to the accumulation of coarse to medium-grained sands with silt and clay deposits that characterize the Fluvial System. In particular, fining upward sequences shown in SFU drill logs E1 and E2 (Figure 6.23), are composed of lag gravel and coarse sand that grades into overbank silt and sand. These deposits represent sedimentation in a meandering channel system.

In summary, the architecture of the North Okanagan Basin Fill is made up of four distinct depositional systems: Fluvio-Glacial, Glaciolacustrine, Alluvial Fan, and Fluvial Systems. The Fluvio-Glacial and Glaciolacustrine Systems account for up to 89% of the basin architecture. Both systems increase in thickness to the south, from north of Enderby to the Vernon site, and exhibit a general fining upwards textural trend. Although limited in volume, the Alluvial Fan System exerts an important control on the framework of the basin architecture. Numerous coarse-grained, progradational wedges have limited cyclicity, a random distribution in the basin fill, and interfinger or overlie other basin fill systems. Fluvial reworking of surficial sediments by fluvial processes associated with the Fluvial System account for recent geomorphic alterations to the basin architecture.

7.5 Comparison of the North Okanagan Basin Architecture to Other Basin Fill Models

Distributions of reconstructed North Okanagan Basin Fill depositional systems differ in several ways from existing models of intermontane, non-marine basin fills (Figure 1.5). A consistent theme in the descriptions of basin fill architectures is that sedimentation is controlled by tectonic activity (Frostick and Ried, 1987; Blair and Bilodeau, 1988; Heller et al., 1988; Galloway and Hobday, 1983; Miall, 1981). This typically results in asymmetrical basin fill geometries caused by the dominance of faulting along one basin margin. Along the faulted margin alluvial fans extend into finer-grained sediments that are located more central to the basin axis. Therefore, the architecture is characterized by: wedge-shaped, basinward thinning, cyclical, thick accumulations of alluvial fan deposits. The main depositional mechanisms for alluvial fan formation are attributed to debris flows and fluvial transport of clastic material during periods of tectonic activity.

The architecture of the North Okanagan Basin Fill is characterized by 2 clastic depositional systems: the Fluvio-Glacial and Glaciolacustrine Systems. These glacigenic systems are interfingered by non-cyclic, stacked Alluvial Fan Systems that are wedge or lens-shaped, thin distally, and represent only a small percentage (8%) of the basin fill. Deposition of the Alluvial Fan Systems was controlled by debris flows and fluvial processes that reworked and redistributed coarse-grained, glacially derived valley side material.

In light of this information, the architecture of the North Okanagan Basin Fill contrasts with existing models for several reasons. Sedimentation in unglaciated, extensional, intermontane basins is controlled by faulting and basin fills exhibit mega-cycles of alluvial fans mixed with fine-grained sediments (Miall, 1981). In the North Okanagan Basin Fill coarse-grained deposits are not limited to an active fault margin, occupy the lower axial positions of the basin, and are deposited by climatically driven geomorphic processes. Furthermore, alluvial fan deposition was not triggered by tectonic activity, but rather, by the availability of unstable, valley side, glacigenic material exposed during deglaciation. This clastic material was ultimately redistributed into the basin by debris flows and fluvial processes.

The arrangement of depositional systems in the North Okanagan Basin Fill somewhat resembles the Graben-type basin architecture proposed by Galloway and Hobday (1983) (Figure 7.6). However, unlike the North Okanagan Basin Fill, their model shows a thick, vertically continuous and laterally extensive sequence of alluvial fan deposits along a fault controlled basin margin. In addition, thick accumulations of coarse-grained deposits are not observed in lower, mid-basin positions.

In summary, the architecture of the North Okanagan Basin Fill is the result of a variety of geomorphic processes in glacial, deglacial, and contemporary depositional environments. The geomorphic processes have been controlled to a large degree by prevailing climatic conditions. Tectonic activity is identified only as a key factor during Tertiary formation of the basin. Geomorphic processes influenced by broader scale climatic conditions have generally controlled the processes of sedimentation, basin infilling, and subsequent basin architecture. This has led to an asymmetrical basin architecture defined by fining upward glacigenic sediments that are interfingered by debris flow derived alluvial fans and fluvial deposits. The Alluvial Fan Systems are non-cyclic, wedge or lens-shaped, vertically limited (tens of meters in thickness), and occur in various basin locations. Alluvial Fans Systems are progradational complexes deposited by debris flow and fluvial processes triggered by the availability of unstable clastic material that was transported during intense precipitation events.

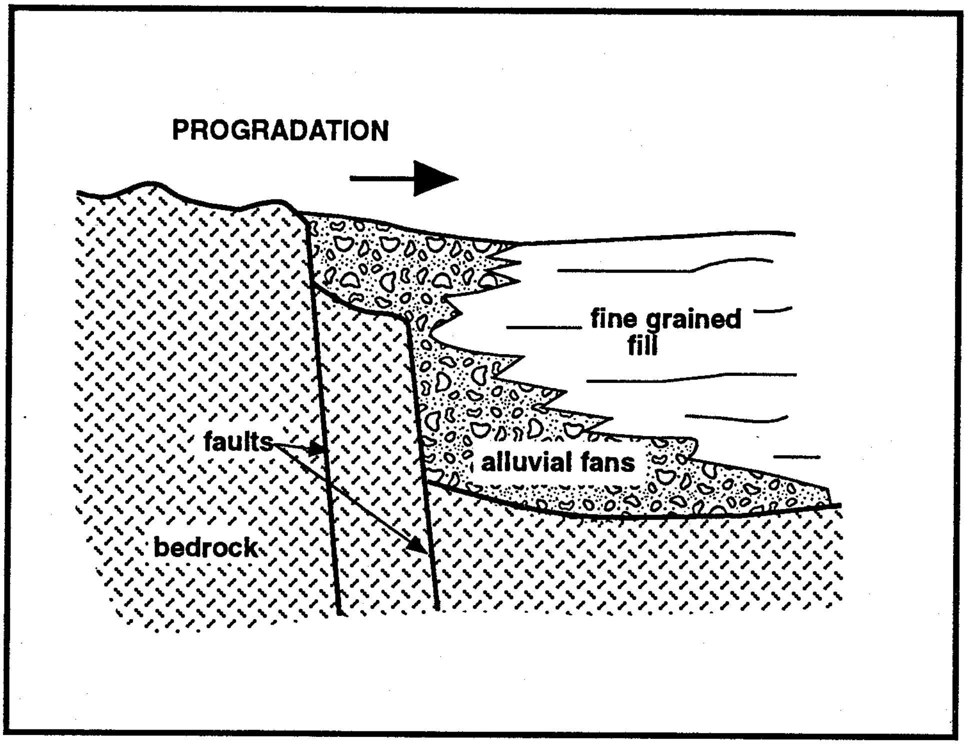


Figure 7.6 Interpretation of a stacked alluvial fan sequence in a basin characterized by limited faulting (after Galloway and Hobday, 1983).

CHAPTER EIGHT

DISCUSSION AND CONCLUSIONS

8.1 Introduction

The analysis of the three-dimensional architecture of the North Okanagan Basin Fill can be approached in the context of the depositional systems that characterize the basin fill. The discussion illustrates that the arrangement of the depositional systems in the basin serve as an interpretive framework for Cordilleran valley fills.

Determination of the depositional systems has permitted the construction of a North Okanagan Basin Fill model, comparisons to be made with other basin fill models as outlined in Chapter One, and an examination of the chronology and volume of the basin fill.

The major findings of this study are summarized in point form at the conclusion of the chapter.

8.2 Discussion of the Study Findings

Collection of over 16 line km of seismic profiles and 30 lithologic logs (including 5 detailed SFU drill holes), construction of over 37 km of lithologic sections, and application of a depositional systems analysis has provided the first detailed three-dimensional description of the North Okanagan Basin architecture. Previous investigations of basin fills in Okanagan Valley are based largely on limited surface lithologic and generalized seismic information (Eyles et al., 1990, 1991; Mullins et al., 1990; Fulton, 1972). Furthermore, previous analyses and modeling of intermontane Cenozoic basin fills (discussed in Chapter One) have focused on deep (1,000's of metres), unglaciated, extensional basins (Frostick and Ried, 1987; Blair and Bilodeau, 1988; Heller et al., 1988).

The three-dimensional architecture of the North Okanagan Basin Fill is characterized by a distinct sequence of depositional systems that are observed throughout the basin fill. Sediments that define the depositional systems exhibit a fining upward profile from the bedrock floor to the valley surface. The lowermost depositional unit, the Fluvio-Glacial System, overlies bedrock and is composed of outwash sediments. A thick sequence of glaciolacustrine deposits, identified as the Glaciolacustrine System, overlies the outwash deposits. The sediments of the system show a sandy silt to silty clay transition that indicate a shift from proximal to distal glaciolacustrine sedimentation. The Glaciolacustrine System makes up the bulk of the North Okanagan Basin Fill and the fining upward trend has not been previously identified in subsurface examinations of the Okanagan Basin. The Fluvio-Glacial and Glaciolacustrine Systems are interfingered by the Alluvial Fan System and cut by the Fluvial System (within 30 m of the valley floor). Overall, the architecture of the North Okanagan Basin is characterized by a relatively straightforward assemblage of depositional systems.

The model developed for the North Okanagan Basin Fill provides a framework of depositional episodes in intermontane valley fills which can be applicable to other Cordilleran valleys. During glacial advance and retreat coarse-grained outwash sediments and diamictons are deposited in lower basin positions. As in the Okanagan Valley, drainage of other elongate Cordilleran valleys was often blocked during deglaciation, favouring the formation of glacial lakes and the deposition of thick accumulations of glaciolacustrine silt. For example, at least 400 m of glaciolacustrine silt is stored in the North Okanagan Basin. Following ice retreat, and soon after the establishment of non-glacial (ice free) conditions; unstable, glacially derived valley side material is reworked and redeposited into the basins as alluvial fans. In the Okanagan Valley the alluvial fan deposits show an average thickness in the order of 70 m and interfinger the basin fill. Fluvial channel deposits are often preserved near the surface and represent recent geomorphic processes.

The North Okanagan Basin depositional model can also be utilized for comparisons of glaciated Quaternary basin fills to models of unglaciated, intermontane basins. The bulk of the North Okanagan Basin Fill is the direct result of glacial and deglacial depositional processes, as expressed in the Fluvio-Glacial and Glaciolacustrine Systems. Alluvial fans interfinger the main depositional systems and have distinctive morphologies. Subsurface alluvial fans are thickest towards the axial plane of the basin and pinch-out laterally to the valley margins. The occurrence of alluvial fan sediments is controlled, to some degree, by the erosion of the basin fill by earlier glaciations that rework and redistribute the fill. Alluvial fan deposition is also partially controlled by the availability of unstable, coarse-grained glacigenic material on the valley margins during, or soon after, deglaciation. In contrast, non-glaciated, intermontane alluvial basins similar to the Okanagan Valley, exhibit architectures characterized by thick sequences (1,000's of metres) of stacked alluvial fans that interfinger finer-grained sediments deposited during periods of tectonic quiescence. In these basins the thick alluvial fan sequences are intact and alluvial fan sedimentation is triggered by tectonic activity (Frostick and Ried, 1987; Blair and Bilodeau, 1988; Heller et al., 1988).

Analysis of the seismic profiles and lithologic sections has also allowed for the calculation of the sediment volume stored in the North Okanagan Basin. It is estimated that about 49 km^3 of unconsolidated sediments are stored in the basin. Eyles et al., (1990) determined the sediment volume stored in Okanagan Lake basin south of Vernon to be about 90 km^3. This, in combination with the volume obtained for the North Okanagan Basin, illustrates the significant volumes of sediment stored in Cordilleran valleys and the importance of these sites as depo-centres or 'traps'.

Chronology of the depositional systems is determined from the relative positions of the depositional systems and lithology. The basin fill sequence is interpreted to represent Fraser Glaciation deposits (mainly outwash and glaciolacustrine sediments) and is indicative of only one glacial cycle. The possibility of glacial tills, older Quaternary glacial and interglacial deposits, and Tertiary sediments preserved in the basin fill can not be discounted. Nevertheless, the three-dimensional architecture and stratigraphy of the North Okanagan Basin supports the interpretation of a late Wisconsinan sedimentary succession. The chronology can only be verified by the collection and radiometric dating of additional organic samples.

8.3 Conclusions

The results of this study support the following conclusions:

1) The three-dimensional architecture of the North Okanagan Basin Fill is characterized by four depositional systems. These systems are identified as the: a) Fluvio-Glacial, b) Glaciolacustrine, c) Alluvial Fan, and d) Fluvial Systems.

   a) The Fluvio-Glacial System, up to 226 m thick, overlies bedrock and shows a fining upward sequence of outwash sediments. The system represents sedimentation in ice proximal depositional environments during glacier advance and retreat.

   b) The Glaciolacustrine System is up to 400 m thick and the sediments also exhibit a fining upwards profile. The system is representative of proximal to distal glaciolacustrine sedimentation in Glacial Lake Penticton.

c) Deposits identified as the Alluvial Fan System (66 m average thickness) are important components of the North Okanagan Basin architecture. The deposits exhibit distinct morphologies and are interpreted to have been deposited during, or soon after, deglaciation.

d) The Fluvial System cuts into the upper portion of the Glaciolacustrine System near the valley surface. The system defines recent geomorphic alterations to the basin fill. At the Vernon site the system occurs as channel fills within 30 m of the surface.

2) Underlying the sequence of depositional systems is Seismic Unit 1/Facies A that represents the contact between the basin fill and Tertiary bedrock(?). The bedrock floor of the North Okanagan Valley has a regional dip to the south of about 1° and rises sharply to the basin margins from 13° to 24°. Below the site of well V5 bedrock occurs at about 280 metres below sea level.

3) The study findings illustrate the contrasts in basin fill architecture between glaciated Cordilleran valleys and tectonically controlled sedimentation in intermontane alluvial basins.

4) The model developed for the North Okanagan Basin is offered as an interpretative guide for future investigations of Cordilleran valley fills.

5) The stagnation and subsequent meltout of buried ice masses is not considered to have been an important depositional process during deglaciation of the North Okanagan Valley.

6) Approximately 50 km^3 of sediment is stored in the North Okanagan Basin.

7) The vertical arrangement of the depositional systems strongly suggests that the sequence is representative of one glacial cycle that was deposited during Fraser (late Wisconsin) glaciation.

8) This dissertation has demonstrated the utility of an integrated research methodology for geomorphic investigations. The study employed high resolution seismic profiling, well drilling for detailed lithologic analysis, geophysical logging, surficial mapping, and a depositional systems approach for the analysis of the basin fill.

8.4 Recommendations for Future Research

Future research in the North Okanagan Valley could expand upon the findings of this study and might include some of the following:

1) Additional seismic reflection surveying at the Vernon site should be carried out using a shorter recording time scale, perhaps in the 100 to 200 msec range, and shorter source-geophone offsets. This would allow for better definition of the seismic fill at shallow depth.

2) A detailed drilling and core sampling program at the Armstrong site would allow for more concise interpretations of the fill chronology and further definition of alluvial fan geometries. Close attention should be paid to the presence of datable organic material, sediment provenance, and palynology.

3) The use of a high resolution technique such as Ground Penetrating Radar (GPR) to characterize the coarser channel facies and surficial alluvial fans.

4) A more comprehensive drilling and logging program at the Enderby site along Emeny Road (near SFU Lines 700 and 800). Future drill programs would require the use of mud weighting compounds in the drilling fluid and additional blowout prevention measures.

APPENDIX A

SFU SEISMIC LINE PROCESSING AND PLOTTING PARAMETERS

This appendix provides the processing and plotting parameters used for all SFU seismic lines. All processing and plotting procedures implemented Geological Survey of Canada, Shallow Reflection Seismic Software, available in GSC Open File 1277 (Norminton and Pullan, 1986). Data processing and plotting parameters for GSC lines used in this study of the North Okanagan Valley are available in GSC Open File 2545 (Pullan et al., 1992).

To reproduce the SFU seismic lines on a flatbed Tecktronics 4663 plotter, the plotting parameters are required and are listed in tabular format in this appendix. Also, for each profile, and often sections of each profile, different gain tapers were required; these values are listed for all seismic lines. For the spreads indicated, the end time zones (ms) and appropriate gain tapers, are given.

Example: Tap-1:1/100

is

Zone 1: gain = 1/end time of zone = 100 ms

A detailed discussion of linear gain tapers is provided in the Engineering Seismic Reflection Software Manual provided in GSC Open File 1277.

Table A.1 Processing Parameters - SFU Line 100

Plotting Parameters

POLARITY	NORMAL
3 POINT SMOOTHING	Yes
AGC CONSTANT	10
INITIAL GAIN	.35
MUTE	55
DIRECTION	FORWARD

Linear Gain Tapers

SPREAD NUMBER	GAIN TAPERS
100 - 159	Zone 1: 1.7/215
	Zone 2: 0.2/348
	Zone 3: 0.1/500

Table A.2 Processing Parameters - SFU Line 200

Plotting Parameters

POLARITY	REVERSE
3 POINT SMOOTHING	Yes
AGC CONSTANT	10
INITIAL GAIN	.35
MUTE	67
DIRECTION	FORWARD

Linear Gain Tapers

SPREAD NUMBER	GAIN TAPERS
201 - 208	Zone 1: 1.3/430
	Zone 2: 0.5/440
	Zone 3: 0.1/500

Table A.3 Processing Parameters - SFU Line 300

Plotting Parameters

POLARITY	NORMAL
3 POINT SMOOTHING	Yes
AGC CONSTANT	10
INITIAL GAIN	.35
MUTE	301 - 307 @ 58, 308 - 324 @ 55
DIRECTION	FORWARD

Linear Gain Tapers

SPREAD NUMBER	GAIN TAPERS
301 - 324	Zone 1: 1.5/220
	Zone 2: 0.5/350
	Zone 3: 0.1/500

Table A.4 Processing Parameters - SFU Line 400

Plotting Parameters

POLARITY	NORMAL
3 POINT SMOOTHING	Yes
AGC CONSTANT	10
INITIAL GAIN	.35
MUTE	401-409 @ 60, 410-413 @55, 413-418 @ 50
DIRECTION	FORWARD

Linear Gain Tapers

SPREAD NUMBER	GAIN TAPERS
401 - 418	Zone 1: 1.5/220
	Zone 2: 0.5/375
	Zone 3: 0.1/500

Table A.5 Processing Parameters - SFU Line 500

Plotting Parameters

POLARITY	REVERSE
3 POINT SMOOTHING	Yes
AGC CONSTANT	10
INITIAL GAIN	.35
MUTE	55
DIRECTION	REVERSE

Linear Gain Tapers

SPREAD NUMBER	GAIN TAPERS
501 - 526	Zone 1: 1.3/240
	Zone 2: 0.5/241
	Zone 3: 0.1/500

Table A.6 Processing Parameters - SFU Line 700

Plotting Parameters

POLARITY	NORMAL
3 POINT SMOOTHING	Yes
AGC CONSTANT	10
INITIAL GAIN	.35
MUTE	46
DIRECTION	FORWARD

Linear Gain Tapers

SPREAD NUMBER	GAIN TAPERS
701 - 715	Zone 1: 1.5/375
	Zone 2: 0.5/380
	Zone 3: 0.1/500

Table A.7 Processing Parameters - SFU Line 800

Plotting Parameters

POLARITY	NORMAL
3 POINT SMOOTHING	Yes
AGC CONSTANT	10
INITIAL GAIN	.35
MUTE	67
DIRECTION	FORWARD

Linear Gain Tapers

SPREAD NUMBER	GAIN TAPERS
201 - 208	Zone 1: 1.5/375
	Zone 2: 0.5/380
	Zone 3: 0.1/500

Table A.8 Processing Parameters - SFU Line 900

Plotting Parameters

POLARITY	REVERSE
3 POINT SMOOTHING	Yes
AGC CONSTANT	10
INITIAL GAIN	.33
MUTE	901-902 @ 47, 903-906 @ 51, 907-911 @ 53, 912-919 @ 58
DIRECTION	FORWARD

Linear Gain Tapers

SPREAD NUMBER	GAIN TAPERS
901 - 918	Zone 1: 1.5/140
	Zone 2: 0.5/160
	Zone 3: 0.1/200

Table A.9 Processing Parameters - SFU Line 1000

Plotting Parameters

POLARITY	NORMAL
3 POINT SMOOTHING	Yes
AGC CONSTANT	10
INITIAL GAIN	.35
MUTE	51
DIRECTION	FORWARD

Linear Gain Tapers

SPREAD NUMBER	GAIN TAPERS
1001 - 1008	Zone 1: 1.5/210
	Zone 2: 0.5/215
	Zone 3: 0.1/500

Table A.10 Processing Parameters - SFU Line 1200

Plotting Parameters

POLARITY	REVERSE
3 POINT SMOOTHING	Yes
AGC CONSTANT	10
INITIAL GAIN	.35
MUTE	48
DIRECTION	FORWARD

Linear Gain Tapers

SPREAD NUMBER	GAIN TAPERS
1201 - 1240	Zone 1: 1.5/210
	Zone 2: 0.5/211
	Zone 3: 0.1/500

Table A.11 Processing Parameters - SFU Line 1300

Plotting Parameters

POLARITY	NORMAL
3 POINT SMOOTHING	Yes
AGC CONSTANT	10
INITIAL GAIN	.35
MUTE	1301-1306 @ 95, 1307-1308 @ 90, 1309-1311 @ 93, 1312@87, 1313@83, 1314@79, 1315@77, 1316@65
DIRECTION	FORWARD

Linear Gain Tapers

SPREAD NUMBER	GAIN TAPERS
1301 - 1316	Zone 1: 1.5/200
	Zone 2: 0.5/375
	Zone 3: 0.1/500

APPENDIX B

SEISMIC SURVEY FIELD NOTES AND SITE CONDITIONS

Each site in the North Okanagan Valley was subject to different site conditions and in order to address these changing conditions, this appendix lists the field notes and site conditions for each SFU seismic line in tabular format.

All SFU seismic lines were collected using a Bison 8012A engineering seismograph. The common field set up for the seismograph included:

1) Sweep Length - 500 ms (except SFU Line 900 @ 200 ms)
2) Low Pass Filter - 825 Hz ChebyShev
3) High Pass Filter - 75 Hz Bessel
4) Notch Filter - On, 60 Hz (overhead electrical power lines)
5) Gains - ranger on seismograph from 66 - 90 dB, varied from spread to spread.

Table B.1 Summary of field notes and site conditions - SFU Line 100

SPREAD NUMBER	DESCRIPTION
100	- east end, 77 m from N-S road along east valley side
114	- 3 m gap, road
116	- 12 m gap, windy
117	- 12 m gap, windy
118	- 9 m gap, driveway
120	- 12 m gap, trees and driveway
121	- 9 m gap, trees and tractor noise
122	- 15 m gap, tractor noise
124	- 9 m gap, driveway
125	- 3 m gap, driveway
126	- 12 m gap, road

127	- 6 m gap, driveway and tractor noise
128	- 12 m gap, driveway
129	- 12 m gap, road
148	- 3 m gap, driveway
151	- 6 m gap, road
153	- 12 m gap, road
157	- 3 m gap, driveway
158	- 6 m gap, driveway, west end of line- Shuswap River

GENERAL COMMENTS

- sediments were extremely dry along Anderson Road, windy conditions, tractor noise throughout survey, all shot holes were augured and water tamped, geophones covered with top soil to reduce noise, high gain settings.

Table B.2 Summary of field notes and site conditions - SFU Line 200

SPREAD NUMBER	DESCRIPTION
201	- north end of line, Lonestar Road
208	- 12 m gap, end of line, ties into SFU Line 100

GENERAL COMMENTS

- sediments were extremely dry along Lonestar Road, windy conditions, frequent tractor noise, all shot holes were augured and water tamped, geophones covered with top soil to reduce noise, high gain settings.

Table B.3 Summary of field notes and site conditions - SFU Line 300

SPREAD NUMBER	DESCRIPTION
301	- line starts 72 m from south end of middle pond
310	- 21 m gap, bee houses
311	- omit, bee houses and pond
312	- omit, pond and bee houses
322	- 18 m gap, road
323	- south end of line, 18 m gap, road

GENERAL COMMENTS

- shots and geophones planted in moist ditch in Toporchuk Ranch pasture, no standing water except for first three shot holes, spreads 310-312 were omitted due to bee houses (field crew suffered numerous bee stings), most shot holes were augured, often windy.

Table B.4 Summary of field notes and site conditions - SFU Line 400

SPREAD NUMBER	DESCRIPTION
401	- north end of line
409	- powerline towers nearby
418	- south end of line

GENERAL COMMENTS

- no wind, line originates on south end of L and A Cross Road, dry surficial sediments, intense cricket noise, all shot holes were augured, line is west of train tracks and alongside of the model airplane landing strip, powerline towers from spread 409 onwards.

Table B.5 Summary of field notes and site conditions - SFU Line 500

SPREAD NUMBER	DESCRIPTION
501	- north end of line, 3 m gap, creek
503	- SFU drill site A5 is located about 120 m west of spread on Bonger's dairy farm
506	- 6 m gap, driveway
508	- 6 m gap, driveway
508	- 6 m gap, driveway
511	- 3 m gap, driveway
515	- 3 m gap, driveway
517	- 3 m gap, driveway
519	- 6 m gap, driveway
523	- 6 m gap, road
524	- 3 m gap, farm noise
525	- 3 m gap, road, phones 6-12 off, end of road, south end of line ties into east end of GSC Line 100

GENERAL COMMENTS

- clear sunny day, minimal wind, wet ditch along Back Enderby Road, no auguring and tamping of geophones was required, saturated and fine grained surficial sediments, some farm equipment noise at end of line.

Table B.6 Summary of field notes and site conditions - SFU Line 700

SPREAD NUMBER	DESCRIPTION
701	- east end of line, phone # 7 off on all spreads due to damaged cable
713	- 3 m gap, driveway
714	- 6 m gap, driveway
715	- phones 6-12 of, west end of line

GENERAL COMMENTS

- west end of line connects with Highway #97 on west valley side, first shot point is 9 m west of driveway on Emeny Road due west of the railway tracks, wet ditch, no auguring and tamping of geophones were required, slight breeze, generally extremely quiet shooting conditions.

Table B.7 Summary of field notes and site conditions - SFU Line 800

SPREAD NUMBER	DESCRIPTION
801	- east end of line, phone # 7 off on all spreads due to damaged cable
819	- west end of line

GENERAL COMMENTS

- first geophone is 72 m west of 97A Road to Grindrod, line is located along north side of access road to Honeyman farm, moist topsoil, light breeze blowing, shot holes were augured and geophones tamped, powerlines on south side of road, wind picked up from spread OV-808 onwards.

Table B.8 Summary of field notes and site conditions - SFU Line 900

SPREAD NUMBER	DESCRIPTION
901	- east end of line, geophone off on all spreads due to damaged cable
918	- west end of line

GENERAL COMMENTS

- line shot from east to west along Anderson Road, first geophone is 66 m west of Highway 97A to Grindrod, line shot on north side of road, powerlines on southside, clear calm day, all shot holes and geophones were in ditch alongside road, surficial sediments were moist, shot holes were augured and geophones tamped below surface.

Table B.9 Summary of field notes and site conditions - SFU Line 1000

SPREAD NUMBER	DESCRIPTION
1001	- east end of line, geophone #7 off on all spreads due to damaged cable
1005	- 3 m gap, culvert
1008	- west end of line

GENERAL COMMENTS

- line originates slightly west of Cliffview Farms sign on Salts Road, line shot in ditch on south side of road, powerlines overhead, shot holes augured for first two spreads, remaining holes in water filled ditch, slight breeze, west end of line connects with Highway 97 North.

Table B.10 Summary of field notes and site conditions - SFU Line 1200

SPREAD NUMBER	DESCRIPTION
1201	- east end of line, 3 gap, phone line
1204	- 3 m gap, well
1205	- 12 m gap, train tracks
1206 - 1207	- 87 m gap, too dry
1208	- 6 m gap, driveway
1210	- 9 m gap, road
1212	- 6 m gap, driveway
1215 - 1225	- 459 m gap, too dry
1226	- 3 m gap, too dry
1232 - 1239	- 256 m gap, too dry
1240	- west end of line, phones 11-12 off

GENERAL COMMENTS

- line shot on north side of L and A Cross Road on Toporchuk Ranch, no overhead powerlines, highway traffic noise at east and west ends of line, surficial sediments were extremely compact, fine grained and dry, in some instances auguring into the sediments was impossible with power auger, this accounts for large gaps in the profile.

Table B.11 Summary of field notes and site conditions - SFU Line 1200

SPREAD NUMBER	DESCRIPTION
1301	- east end of line, bee houses nearby
1302	- 12 m gap, bee houses

1307 - 9 m gap, driveway

1316 - west end of line, phones 6-12 off

<u>GENERAL COMMENTS</u>

- line located in field north of trees by first drainage pond on Toporchuk Ranch, line ties into north end of SFU Line 300, no power lines overhead, moist sediments in ditch, shot holes were augured and geophones were tamped, noise at west end of line due to traffic noise from Highway 97, slight breeze, gap in spread 1302 due to field crew sustaining numerous bee stings.

APPENDIX C

SEISMIC PROFILES OF THE NORTH OKANAGAN BASIN

All seismic profiles and seismic facies interpretations are presented in this appendix. The seismic data are displayed as variable area plots, all processing parameters and locations of the seismic lines are provided in Chapter Three and Appendices A and B. The plotted sections and interpretations were reduced photographically and black line prints were made of each profile. The seismic profiles are identified as Plates 1 - 14 and include:

Plate 1	SFU Seismic Line 300: Profile and Interpretation.
Plate 2	SFU Seismic Line 400: Profile and Interpretation.
Plate 3	SFU Seismic Line 1200: Profile and Interpretation.
Plate 4	SFU Seismic Line 1300: Profile and Interpretation.
Plate 5	GSC-SFU Seismic Line 500: Profile and Interpretation.
Plate 6	GSC-SFU Seismic Line 100: Profile and Interpretation.
Plate 7	GSC-SFU Seismic Line 300: Profile and Interpretation.
Plate 8	SFU Seismic Line 500: Profile and Interpretation.
Plate 9	GSC-SFU Seismic Line 700: Profile and Interpretation.
Plate 10	SFU Seismic Line 100: Profile and Interpretation.
Plate 11	SFU Seismic Line 900: Profile and Interpretation.
Plate 12	SFU Seismic Line 200: Profile and Interpretation.
Plate 13	SFU Seismic Line 1000: Profile and Interpretation.
Plate 14	SFU Seismic Line 700-800: Profile and Interpretation.

Figure C-1 provides the identification key for the lithologic logs and display parameters used for the presentation of the seismic information.

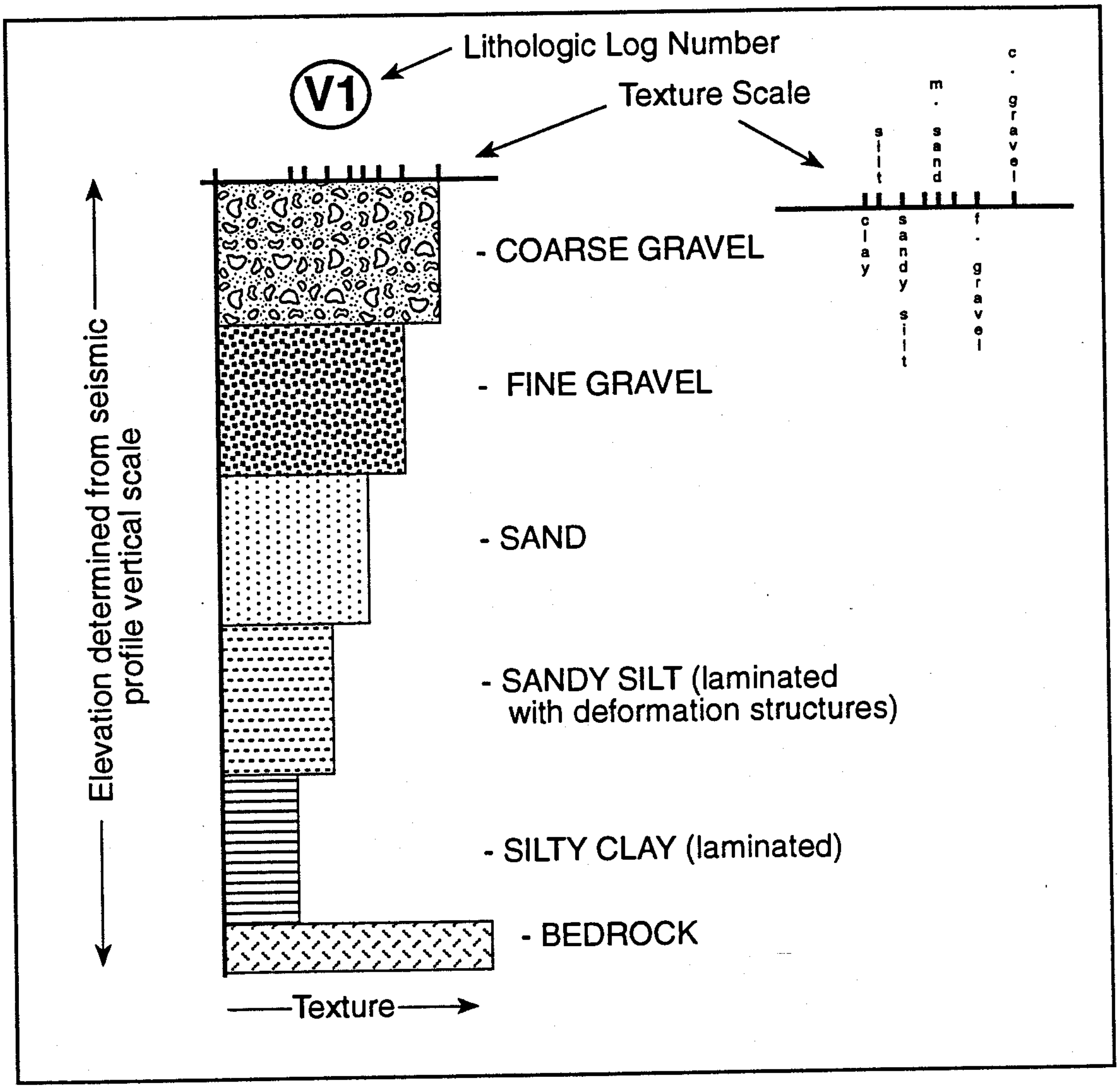


Figure C-1 Coding scheme used for seismic units and lithologic logs displayed on the seismic profiles.

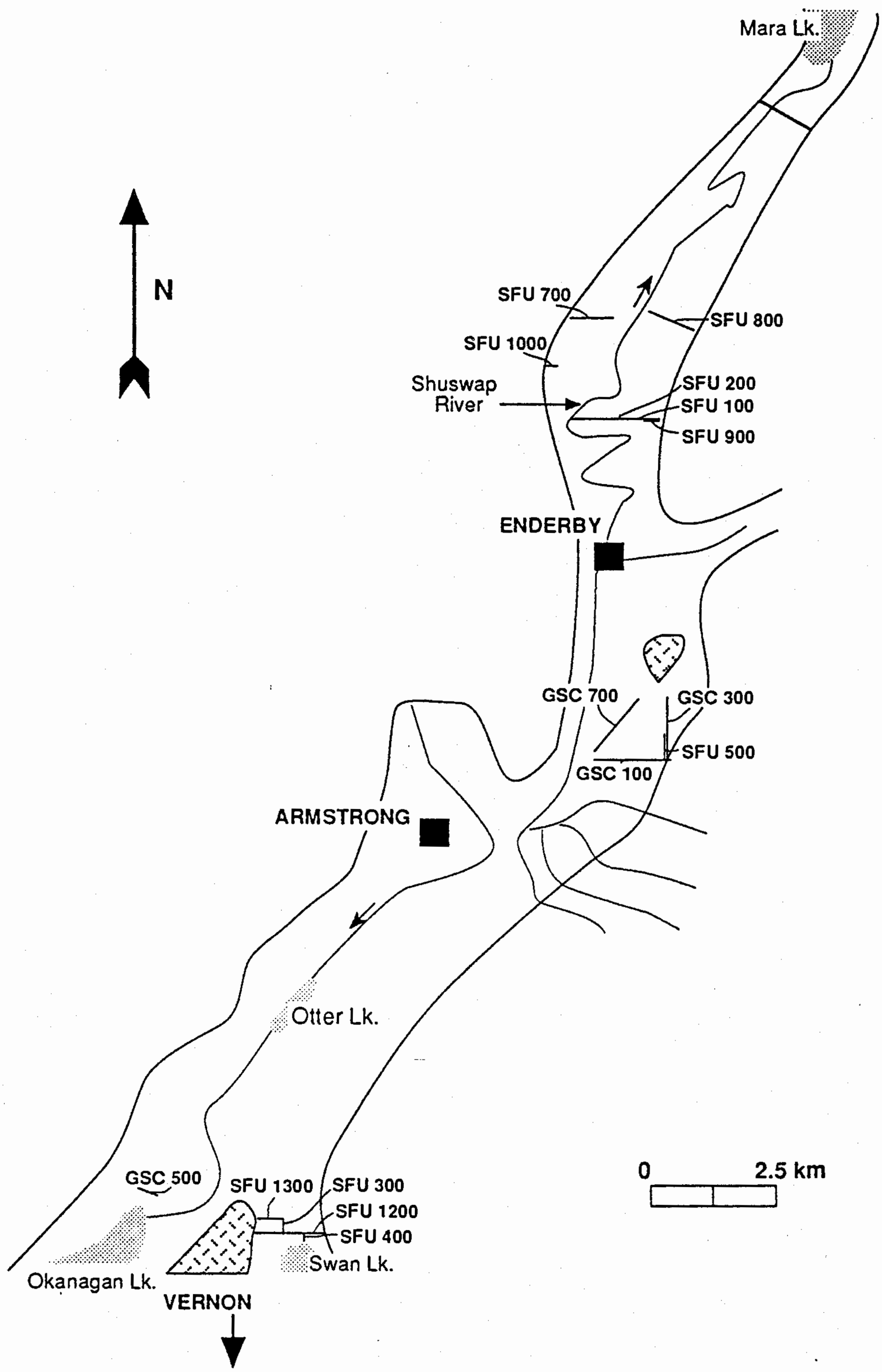


Figure C-2 General locations of the seismic lines in North Okanagan Valley, see Chapter Three for precise locations. GSC = Geological Survey of Canada and SFU = Simon Fraser University.

APPENDIX D

SFU DRILL HOLES AND GROUNDWATER WELL LOGS

Appendix D provides original designations for all SFU drill logs and B.C. Ministry of Environment groundwater well logs used in the study. This information is presented in tabular format in Tables D.1 to D.3. The precise locations of all drill and well holes are shown on Figures D.1 to D.3. Drill and well site locations were plotted on 35% enlargements of 1:50,000 scale Energy, Mines, and Resources topographic maps.

Table D.1 Vernon site drill hole and well log designations.

STUDY DESIGNATION	SFU DRILL SITE NUMBER	B.C. ENVIRONMENT GROUNDWATER DESIGNATION
V1	-	82L.034.4.1.2
V2	SFU D.5	-
V3	-	82L.034.2.4.3.8
V4	SFU D.4	-
V5	-	82L.034.3.2.2.b
V6	-	82L.034.4.1.2.6
V7	-	82L.034.2.4.3.1

Table D.2 Armstrong site drill hole and well log designations.

STUDY DESIGNATION	SFU DRILL SITE NUMBER	B.C. ENVIRONMENT GROUNDWATER DESIGNATION
A1	-	82L.045.3.4.4.11
A2	-	82L.045.3.4.4.10
A3	-	82L.045.3.4.2.5
A4	-	82L.045.3.4.2.4
A5	SFU D.3	-
A6	-	82L.045.3.4.2.2
A7	-	82L.045.3.2.4.1
A8	-	82L.045.3.2.4.1
A9	-	82L.045.3.4.1.1 (C43-TH3)
A10	-	82L.045.3.2.3 (C42-TH2)
A11	-	82L.045.3.2.3.4
A12	-	82L.045.3.4.1.6
A13	-	82L.045.3.4.4 (Enderby #2a)
A14	-	82L.045.3.4.4 (Enderby #2)
A15	-	82L.045.3.1.4.6
A16	-	82L.045. (C42-TH1)

Table D.3 Enderby site drill hole and well log designations.

STUDY DESIGNATION	SFU DRILL SITE NUMBER	B.C. ENVIRONMENT GROUNDWATER DESIGNATION
E1	SFU D.1	-
E2	SFU D.2	-
E3	-	82L.065 (C43-TH5)
E4	-	82L.055.3.3.4.3
E5	-	82L.065.1.2.2
E6	-	82L.055.3.4.4.4
E7	-	82L.065.1.2.1.16

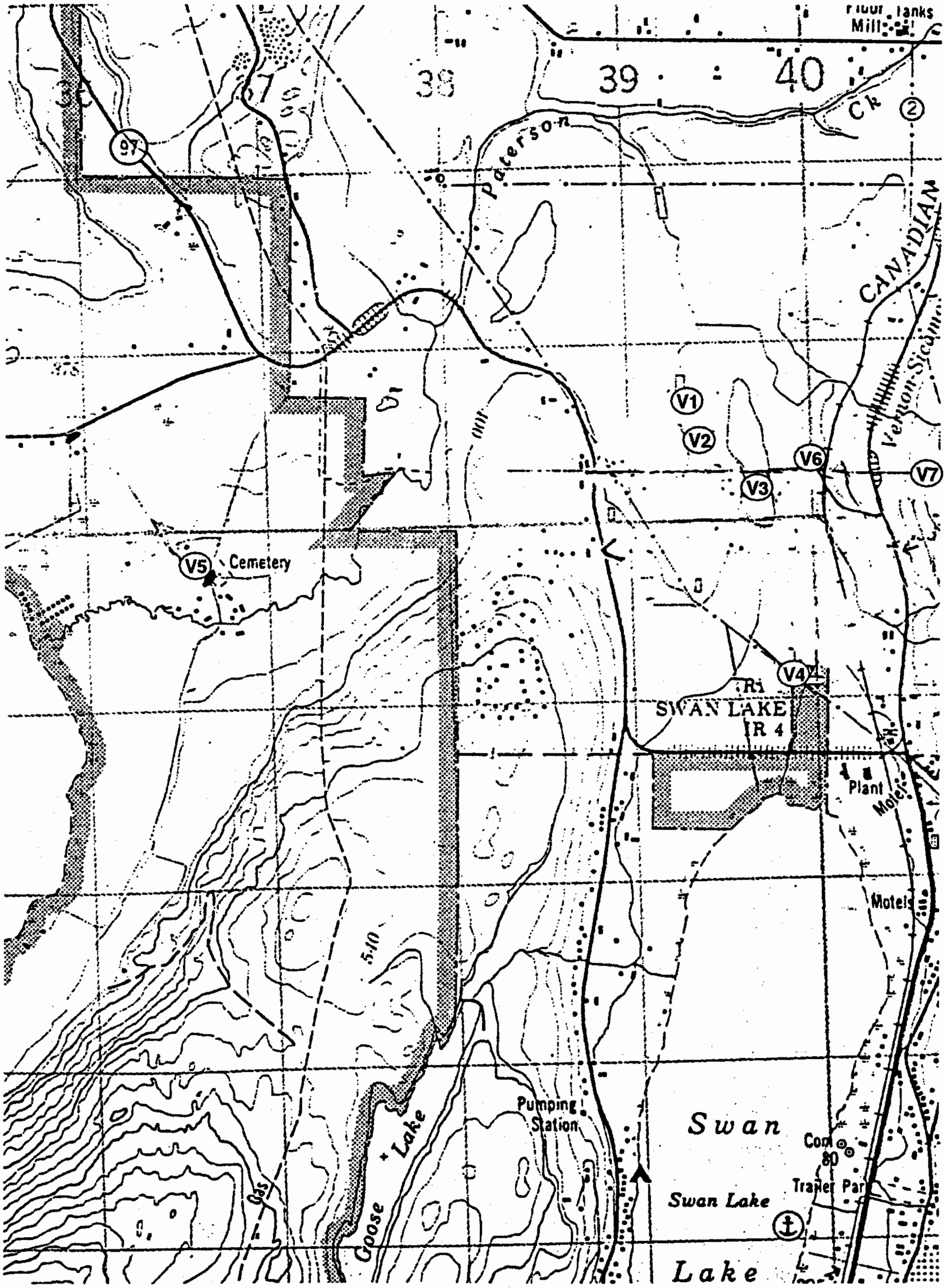


Figure D-1 Location of SFU drill holes and groundwater wells at the Vernon site. Base map is a 35% enlargement of Energy, Mines, and Resources Vernon Map 82 L/11, 1:50,000 scale.

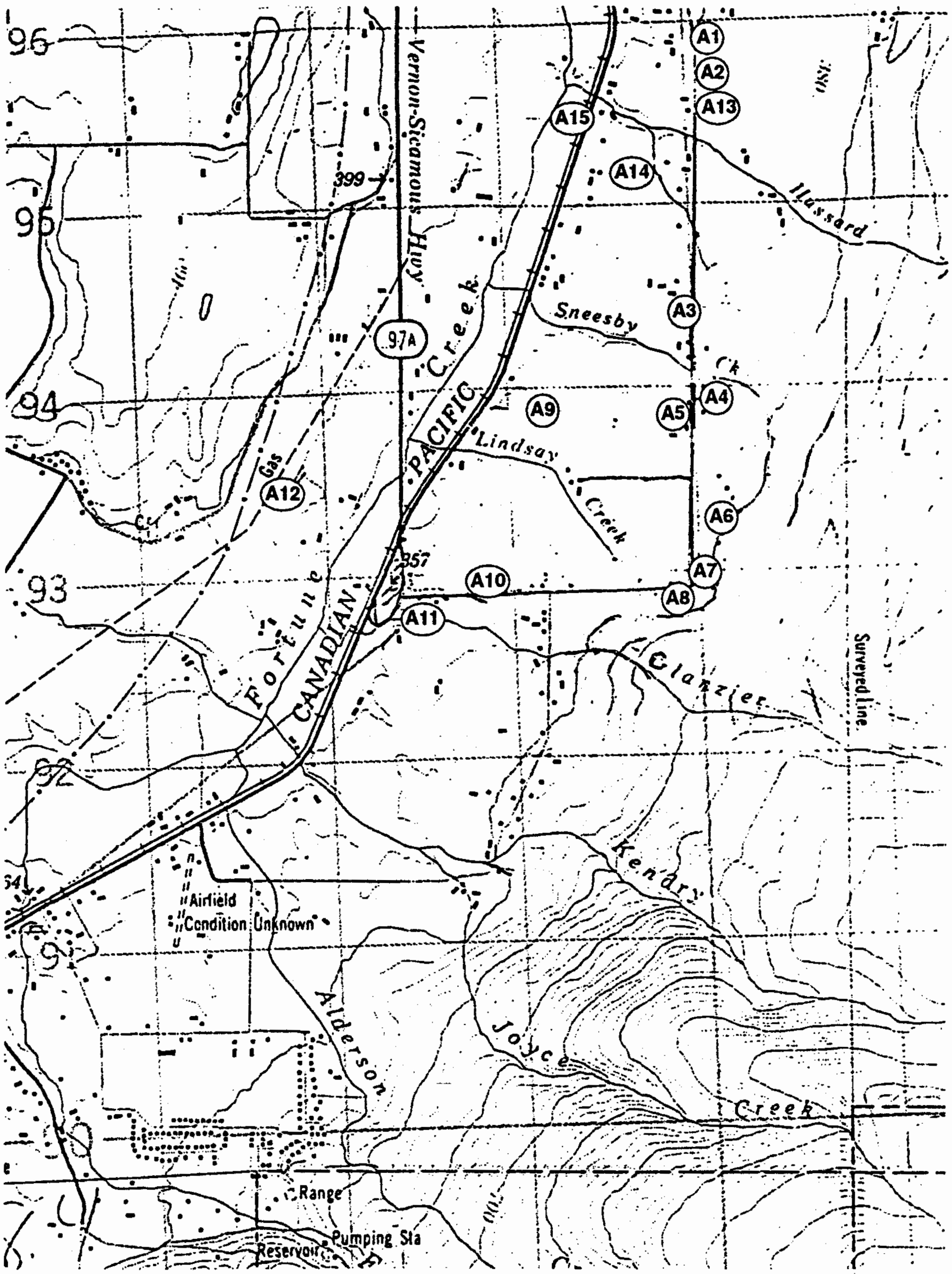


Figure D-2 Location of SFU drill holes and groundwater wells at the Armstrong site. Base map is a 35% enlargement of Energy, Mines,and Resources Vernon Map 82 L/11, 1:50,000 scale.

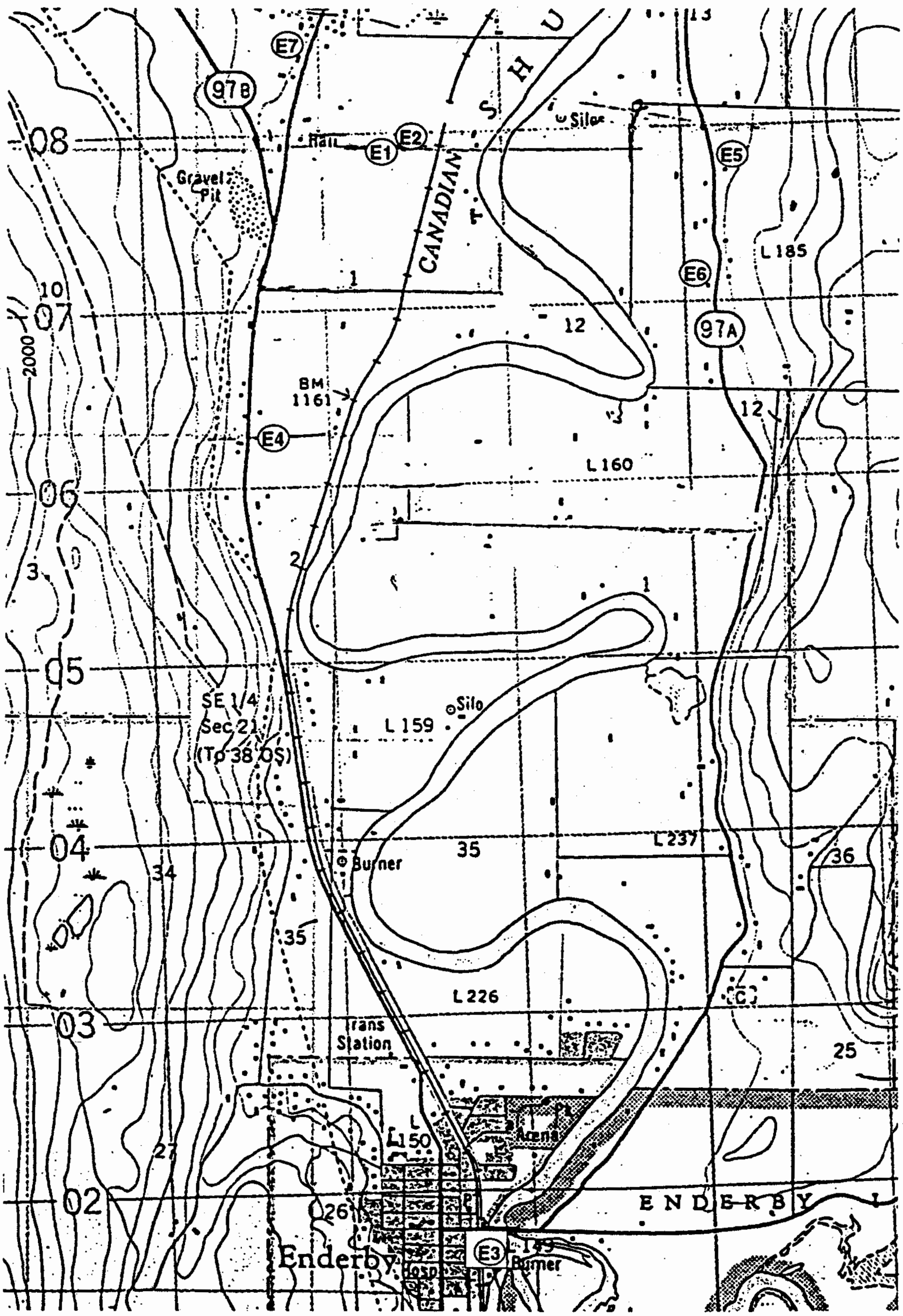


Figure D-3 Location of SFU drill holes and groundwater wells at the Enderby site. Base map is a 35% enlargement of Energy, Mines, and Resources Salmon Arm Map 82L/6, 1:50,000 scale.

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