

Quaternary Stratigraphy and Geomorphology of the Central Okanagan Valley, British Columbia

by

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ABSTRACT

Theories on the origin of the valley-fill architecture and age of the Okanagan basin sediments remain divided between those favouring a pre-Fraser Glaciation and those favouring a post-Fraser Glaciation genesis. Regionally, landforms related to large meltwater discharges are continually being recognized, but sediment packages demonstrating those processes were previously unknown.

Glacial sediments and landforms on the University of British Columbia campus near Kelowna BC were studied using surficial mapping, shallow seismic, and lithologic logs. Analysis revealed basin architecture consisting of fluvial valley fills, tributary fans, and subglacial flood deposits. The lowest valley sequence includes coarse fluvial sediments >65,000 yrs BP. Above are fine-grained sand and layers of organics (woody debris) radiocarbon dated at 35,000 - 23,000 yrs BP. Dates indicate continual deposition leading up to and during glaciation. The upper 10 - 20 m of sediments contains high energy bedforms that include dunes, antidunes, hummocky cross-stratification, and hummocky unconformities. Stacked bedforms are commonly conformably draped by laminated silt and clay couplets, indicating repeated discharge events filling a subglacial reservoir. Esker networks intrude into subglacial bedforms and represent high energy subglacial meltwater conduit erosion and deposition near the ice margins. Waning flow gravel deposits were initially parallel to esker direction, but locally reoriented into clastic dykes. Clastic dyke formation likely resulted from pressure created by regional ice recoupling after drainage of a subglacial lake phase.

The following sequence is proposed:

- 1) The Okanagan Valley operated as a pre-glacial river valley 65,000 - 23,000 yrs BP and filled with clastic sediments and woody debris during glacial onset.
- 2) During the Fraser Glaciation, several high energy subglacial floods from the north and northwest filled a subglacial lake that repeatedly drained.
- 3) Esker conduit sedimentation and erosion indicates last stages of rapid flow from the west of the campus.
- 4) Clastic dykes within the esker indicate massive pressure heads ensued, and were likely caused by regional ice sheet recoupling.
- 5) Absence of tills in the central part of the valley and truncation of the esker distally indicates a late-stage water flow scoured out glacial sediments, except in the lee of bedrock obstacles.

TABLE OF CONTENTS

ABSTRACT	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	v
LIST OF FIGURES	vi
ACKNOWLEDGEMENTS	ix
1.0 CHAPTER ONE.....	1
1.1 Introduction.....	1
1.2 Research Rationale.....	5
1.3 Research Objectives.....	5
1.4 Significance of Research.....	6
1.5 Thesis Structure	7
2.0 CHAPTER TWO – LITERATURE REVIEW.....	8
2.1 Review of Glacial and Subglacial Processes and Landforms.....	8
2.1.1 Buried Quaternary Valley Systems.....	8
2.1.2 Glacial Lake Systems.....	9
2.1.3 Subglacial Landforms	10
2.1.4 Subglacial Lakes	15
2.1.5 Eskers.....	17
2.2 Regional Setting.....	18
2.2.1 Bedrock Geology	18
2.2.2 Surficial Geology.....	20
2.3 Regional Glacial History of the Area.....	22
2.4 Models of Valley-fill Genesis.....	26
2.5 Okanagan Stratigraphic History.....	30
2.6 Okanagan Depositional Models.....	31
2.7 Procedures of Seismic Stratigraphy	34
2.8 Biostratigraphy and Deglaciation	36
2.9 Palynological Evidence for Deglaciation.....	38
3.0 CHAPTER THREE – METHODS	40
3.1 Introduction.....	40
3.2 Terrain Assessment.....	40
3.3 Surface Mapping.....	41
3.4 Subsurface Mapping	42
3.5 Seismic Reflection Data Acquisition	45
3.6 Seismic Reflection Data Processing	51
4.0 CHAPTER FOUR – RESULTS	53
4.1 Radiocarbon Dating	53

4.2	Grain Size Analyses	54
4.3	Stratigraphic Sections	57
	4.3.1 Geologic Section A-A'	59
	4.3.2 Geologic Section B-B'	62
	4.3.3 Geologic Section C-C'	65
4.4	Other Well Records With Organics Present	67
4.5	Campus Geomorphology	68
	4.5.1 Campus Esker Morphology	69
	4.5.2 Campus Surface Exposures.....	74
4.6	Seismic Stratigraphy	96
	4.6.1 Seismic Line 00-01	96
	4.6.2 Seismic Line 00-02	98
	4.6.3 Seismic Line 00-03	100
	4.6.4 Seismic Line 00-04	102
	4.6.5 Seismic Line 00-05	105
	4.6.6 Discussion of Seismic Survey.....	107
5.0	DATA SYNTHESIS AND CHRONOLOGY	109
	5.1 Stratigraphy.....	109
	5.2 Geomorphology	113
6.0	DISCUSSION AND CONCLUSIONS	120
	REFERENCES	126
	APPENDICES	134
	Appendix A Well records	134
	Appendix B Grain size distributions.....	156

LIST OF TABLES

Table 2.1: Time stratigraphic sequence for the Okanagan Valley	23
Table 3.1: Grain size classification	44
Table 3.2: Processing flow chart for seismic reflection data	52
Table 4.1: Radiocarbon dates of organic samples.....	54

LIST OF FIGURES

Figure 1.1: Location map showing study area in relation to Kelowna, BC.....	2
Figure 2.1: Subglacial deformation structures forming on the lee side of a boulder.....	11
Figure 2.2: Model to describe the meltwater flow pattern in the formation of flutes.....	12
Figure 2.3: Model of the development of subglacial meltwater landforms.....	14
Figure 2.4: Bedrock geology map of the Central Okanagan Area.....	19
Figure 2.5: Surficial geology map of the Central Okanagan Region.....	21
Figure 2.6: Depositional model of North Okanagan basin fill.....	32
Figure 2.7: Late glacial depositional model of North Okanagan basin fill.....	33
Figure 2.8: Present day model of North Okanagan basin fill	34
Figure 3.1: Location plan for exposures, boreholes and geophysical lines	46
Figure 3.2: Determining the optimum window for seismic surveying using common offset	48
Figure 3.3: Geometry of a typical land based seismic surveying array	49
Figure 3.4: Seismic survey setup using a hammer as the energy source	50
Figure 3.5: Schematic depiction of the subsurface travel path of reflections.....	51
Figure 4.1: Photograph of organic detritus retrieved during drilling program	53
Figure 4.2: Particle size distribution for Well 4 grain size samples	55
Figure 4.3: Particle size distribution for Well 5 grain size samples	55
Figure 4.4: Particle size distribution for Well 6 grain size samples	56
Figure 4.5: Particle size distribution for Well 7 grain size samples	56
Figure 4.6: Location plan with water wells and geologic cross-sections	58
Figure 4.7: Geologic cross-section A to A'	61

Figure 4.8: Geologic cross-section B to B'	64
Figure 4.9: Geologic cross-section C to C'	66
Figure 4.10: Location plan of exposures on and adjacent to the UBCO campus	68
Figure 4.11: Location plan of exposures A1, A2 and A3	71
Figure 4.12: Esker location plan and exposure A1 cross-section	72
Figure 4.13: Esker cross-sections of exposures A2 and A3.....	73
Figure 4.14: Location plan of exposures B and C	76
Figure 4.15: Exposure at site B.....	77
Figure 4.16: Exposure at site C.....	78
Figure 4.17: Profiles of sedimentology at site C.....	79
Figure 4.18: Exposures at sites D and E	80
Figure 4.19: Sites D and E sedimentology.....	84
Figure 4.20: Location plan of site F exposure	85
Figure 4.21: Photograph of site F exposure	86
Figure 4.22: Second photograph of site F exposure	86
Figure 4.23: Location plan of site G exposure.....	88
Figure 4.24: Photograph and interpreted section at G1	92
Figure 4.25: Photograph and interpreted section at G2	93
Figure 4.26: Photograph and interpreted section at G3	94
Figure 4.27: Photograph and interpreted section at G4	95
Figure 4.28: Seismic line 00-01	97
Figure 4.29: Seismic line 00-02.....	99
Figure 4.30: Photo of undulating silts adjacent to seismic line 00-02.....	100

Figure 4.31: Seismic line 00-03	101
Figure 4.32: GSC seismic reflection survey along Bulman Road	103
Figure 4.33: Seismic line 00-04	104
Figure 4.34: Seismic line 00-05	106
Figure 4.35: Photograph of exposure adjacent to seismic line 00-05	107
Figure 5.1: Model of valley fill sequence in the Central Okanagan valley	112
Figure 5.2: Model of hummocky bedforms and esker genesis	119

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1.0 CHAPTER ONE

1.1 Introduction

This thesis focuses on the interpretation of Wisconsin age sediments and glacial landforms in the Okanagan Valley region of south-central British Columbia, Canada. Lake Okanagan dominates the north-south trending Okanagan Valley located in the southern Interior of British Columbia (BC) (Figure 1.1). The Okanagan Valley extends from Shuswap Lake in the north to the Columbia Valley in northern Washington State to the south. The valley floor reaches approximately 3 km in width and extends for about 145 km. Several tributary valleys join the main Okanagan trench. Study of the sedimentology and geomorphology of the area elucidates the glacial chronology and paleohydrology of the region.

Extensional tectonics and faulting largely control the bedrock topography of the Okanagan Valley. The bedrock basement extends as much as 180 to 650 m below sea level in some locations, resulting in an estimated 500 to 700 m of sedimentary fill (Eyles *et al.* 1990; Fulton 2006). The geomorphic character of the area has been shaped by a variety of subsequent glacial and meltwater processes.

The study area lies at the northeastern margin of Kelowna BC in an eastern tributary valley running parallel to the main Okanagan Trench (Figure 1.1). North of the study area, Kalamalka, Wood and Ellison Lakes drain northwards into Okanagan Lake.

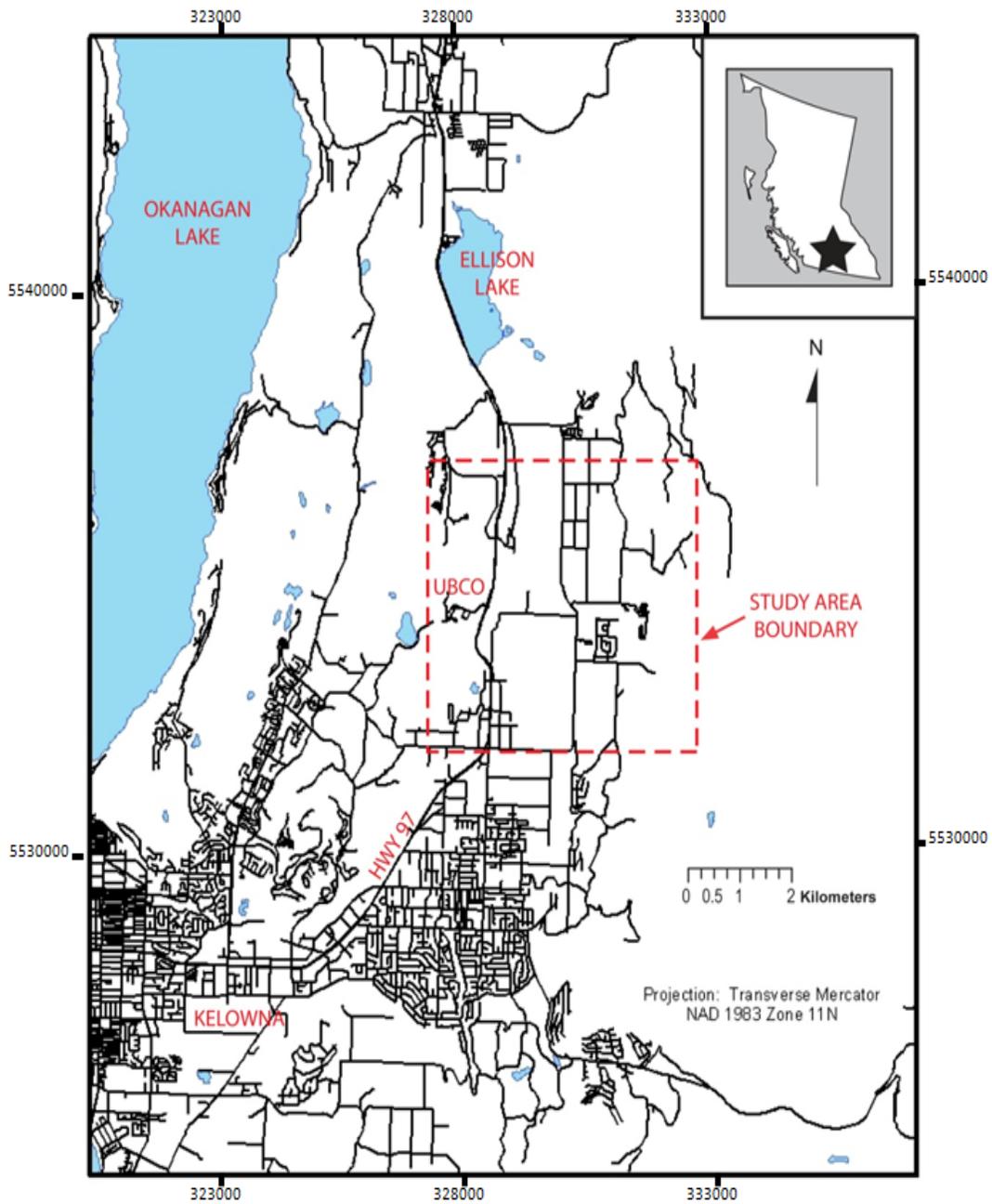


Figure 1.1: Location map showing study area in relation to Kelowna, BC.

Recent sediments were deposited during glacial retreat through meltwater channelling and deposition, creating glaciofluvial terraces and other meltwater derived deposits (Nasmith 1961; Fulton and Smith 1978; Clague 1985; Fulton 1991). Surficial mapping of the Central Okanagan region has been carried out by Nasmith (1961), Fulton (1975) and Paradis (2009). As glacial ice thinned in the late stages of deglaciation, proglacial and subglacial lakes may have developed as stagnant ice blocked local drainage systems (Lesemann and Brennand 2009). Subglacial lakes drained catastrophically through the valley, the outbursts sculpting and eroding landforms (Lesemann and Brennand 2009). Widespread glaciolacustrine deposits mark areas of the Okanagan Valley inundated during glacial retreat by an extensive deglacial lake, Glacial Lake Penticton. Following deglaciation of the area, more recent alluvial fan deposits have been laid down in association with drainage courses originating in the upland areas (Vanderburgh and Roberts 1996).

The deeper stratigraphic record of the Okanagan is comparatively less complete and previous studies have been based solely on a few subaerial geologic exposures and extremely limited geophysical data (Fulton and Smith 1978; Clague 1985). Lithologic records are compiled by the Ministry of Environment in the B.C. Water Well database, but at the start of this project, a comprehensive study of these logs had not been carried out for the Kelowna area.

Prior theories about the valley-fill architecture and age of the Okanagan basin sediments remain divided between those favouring Early and those favouring Late Wisconsin genesis. Some studies interpret the valley-bottom fill sequence as containing primarily post-Fraser Glaciation (Late Wisconsin age) sediments (Vanderburgh and Roberts 1996; Eyles *et al.* 1990; Eyles and Mullins 1997). These researchers concluded that Fraser Glaciation meltwaters completely scoured interglacial sediments from the valley floor, with subsequent deposition of glacial and post-glacial sediments (Vanderburgh and Roberts 1996; Eyles *et al.* 1990; Eyles and Mullins 1997).

In contrast, Fulton (1972) and Monahan (2006) have noted the presence of organics in the valley fill sediments and have described these sediments as interglacial and part of the Olympia-age Bessette sediment sequence. The presence of organic sediments within the stratigraphic sequence would suggest that only partial scouring of pre-existing sediments occurred during the last glaciations, leaving entire sedimentary packages relatively undisturbed.

The geomorphology of the region, related to late stages of the last glaciation, also remains contentious. Flint (1935), Nasmith (1961) and Fulton (1975) attribute the presence of unusual clean exposures of silts and clays in the South Okanagan to the regional proglacial lake system (Glacial Lake Penticton) that developed during late glacial periods. Glacial Lake Penticton is believed to have been a continuous body of

water that spanned the area now occupied by Okanagan, Kalamalka, Wood and Skaha Lakes.

Recently, a regional reconstruction of the paleohydrology of the southern edge of the Cordilleran Ice Sheet has yielded evidence that the Okanagan Valley may have been part of a larger subglacial drainage system (Lesemann and Brennand 2009). Drumlin swarms, tunnel valleys, and other subglacial landforms are cited as evidence to support the Okanagan Valley as part of a larger network of connected subglacial valley systems (Lesemann and Brennand 2009). Lesemann and Brennand (2009) postulate subglacial lakes in the Okanagan Valley developed when advancing glaciers coalesced over pre-existing sub-aerial lakes (catch lakes) or through the gradual storage and accumulation of basal meltwater under the ice sheet.

1.2 Research Rationale

Recent geothermal drilling activity has yielded new lithostratigraphic and chronostratigraphic evidence that permits re-evaluation of the valley-fill sequence in the Central Okanagan. In light of the new evidence, the sedimentology and geomorphology of the region is re-evaluated with the goal of providing a more complete reconstruction of Quaternary environments and events.

1.3 Research Objectives

This research better defines the valley-fill stratigraphy and late stage glacial landforms of the Central Okanagan region in a way that rationalizes previous

sedimentologic conclusions. Understanding the valley-fill sequence is essential for further geologic and hydrogeologic characterization of the region. Previously unrecognized processes discovered during this study may enhance knowledge on glacial processes and potentially refine process models necessary for aggregate exploration and environmental studies.

The two working hypotheses relating to the origin of the stratigraphy of the Central Okanagan valley are as follows:

- 1) The presence of sediments older than the Fraser Glaciation would confirm a multiple filling hypothesis within the study area. The preservation of glacial erosional features above non-glacial sediments would also support multiple episodes of valley fill.
- 2) Sub-glacial meltwater scouring of pre-existing sediments would create a suite of subglacial bedforms that would be distinct from those of a regional scale proglacial lake. If preserved in the stratigraphic sequence, this would support the occurrence of a subglacial drainage system within the study area.

These hypotheses will be addressed using surficial mapping, lithologic log analysis and seismic reflection studies.

1.4 Significance of Research

This research provides a sedimentologic framework to better understand the lithologies and structures of the sediments in the Kelowna area. This knowledge can be applied to improve understanding of the movement of groundwater and aids

identification of regional hydrostratigraphic units. This vital information holds fundamental importance for future aquifer delineation, groundwater flow modeling, land uses and hydrologic budget assessments.

1.5 Thesis Structure

This thesis is presented in six chapters. Chapter 1 provides an introduction and background to the thesis topic. Chapter 2 contains a review of the literature and a discussion of glacial processes. Chapter 3 describes the methodology used to study the sedimentology, geomorphology and stratigraphy of the landforms in the region. Chapter 4 examines the results of the stratigraphy, geomorphology and seismic stratigraphy studies to examine the lateral and spatial extent of structures. Chapter 5 provides a data synthesis and chronology of the landform assemblages seen in the area. Chapter 6 integrates the discussion and conclusions, and compares them to previous work, to determine the origin of the landscape features.

2.0 CHAPTER TWO – LITERATURE REVIEW

Chapter 1 identified a debate exists concerning recent glacial geomorphology and stratigraphy of the Central Okanagan. The study of recent glacial features is important to resolve this debate. Below, is a review of those glacial features that may be present in the Central Okanagan and may be important in understanding and discussing the Okanagan glacial sequence.

2.1 Review of Glacial and Subglacial Processes and Landforms

2.1.1 Buried Quaternary Valley Systems

Buried Quaternary valley systems are important sources of groundwater and may sometimes be identified using seismic reflection surveys (Jorgensen *et al.* 2003).

Irregular longitudinal bottom profiles seen in cross-sections may sometimes be interpreted to be the products of subglacial meltwater erosion, glacial scouring and deposition, and may be preserved in stratigraphic sequences (Jorgensen *et al.* 2003).

Jorgensen *et al.* (2003) show that Quaternary fill sediments consist mainly of glaciofluvial, glaciolacustrine, and glaciogenic (till) materials with localized intercalations of each. Their research showed that erosional surfaces, evident as high-amplitude coherent reflections, could be detected using seismic reflection techniques, strengthening the need for similar studies on the Central Okanagan valley-fill sequence.

2.1.2 Glacial Lake Systems

There are three main types of glacial lake systems: supraglacial, proglacial and subglacial. Supraglacial lake systems occur as ponding in depressions and crevasses on the glacial ice surface from seasonal melting of the ice surface or by the impoundment of waters from nearby highlands onto the ice surface. Proglacial lake systems form when glacial meltwater is dammed by sediment (e.g. debris fans) or by lobes of ice and allowed to accumulate in depressions. Proglacial lakes may be ice marginal and in direct contact with an ice front. Subglacial lakes form at the base of a glacier. Subglacial lakes are theorized to form from geothermal heating (e.g., Berthier *et al.* 2006), basal pressure melting (e.g., Siegert 2000), drainage and ponding from adjoining subglacial cavities (e.g., Munro-Stasiuk 2003), or through supraglacial sources draining to a subglacial position (e.g., Shaw 1996).

The advance and coalescence of lobes of glacial ice during the last glaciation disrupted the natural drainage of valleys causing temporary impoundments of water in the Interior of BC (Eyles and Clague 1991). Evidence for glacial lake systems appears in almost every major valley system in the interior, including the Okanagan Valley. These lakes are believed to have grown in size, possibly evolving from subaerial to subglacial as ice coalesced over the plateaus and formed the Cordilleran Ice Sheet (Eyles and Clague 1991). During deglaciation, extensive lake systems also developed from the

large volumes of meltwater displaced by decaying ice masses (Eyles and Clague 1991; Lesemann and Brennand 2009).

2.1.3 Subglacial Landforms

Section 1.3 hypothesises that the presence of meltwater landforms above an interglacial sequence may provide evidence of multiple glacial periods preserved in the stratigraphic sequence. By contrast, large-scale mega-flood features might support the idea of complete valley scouring. There are several unique features that distinguish meltwater landforms from other glacial features and these are described below.

Subglacial bedform assemblages have been described using two separate hypotheses:

- a) Direct glacial action or glaciotectonic deformation of the substrate through direct erosion and deposition by glacial deformation (Gravenor 1955; Boulton 1979; Benn 1994; Johnson *et al.* 1995; Eyles *et al.* 1999)
- b) Formation by meltwater through erosion and deposition related to subglacial meltwater discharges (Rains *et al.* 1993; Brennand and Shaw 1994; Munro-Stasiuk and Shaw 1997; Munro-Stasiuk 1999; Shaw 2002; Fisher *et al.* 2002)

These hypotheses describe very different processes for the formation of common subglacial features.

Evidence to support a glacial deformation origin for bedforms would be glaciotectonized sediments, groove-ploughed flutings, and ice-streaming flow paths (Shaw 1983; Benn 1994) (Figure 2.1).

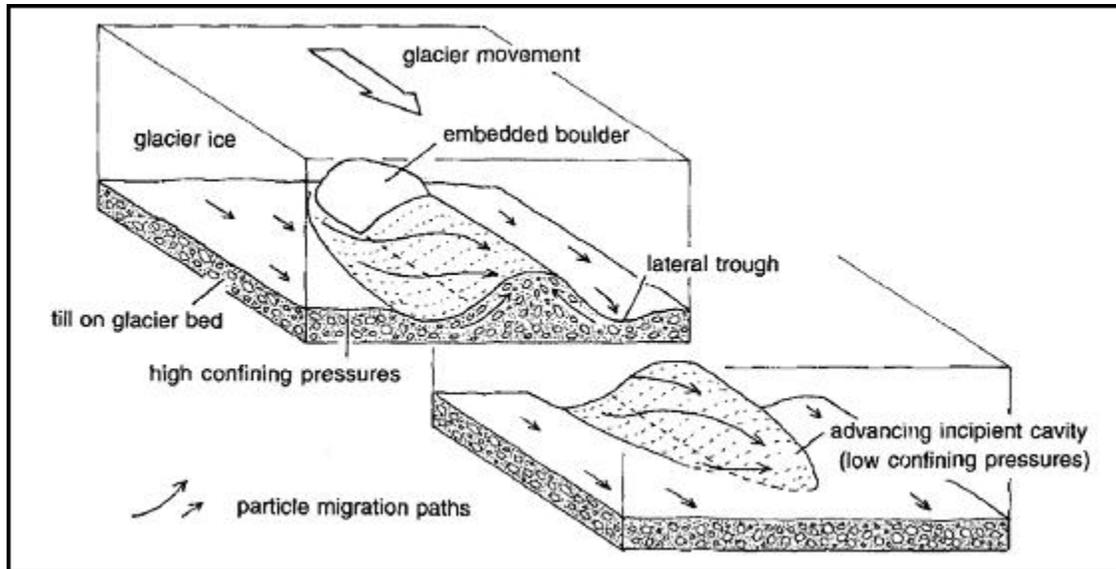


Figure 2.1: Subglacial deformation structures forming on the lee ward side of an embedded boulder (Modified from Benn 1994).

The subglacial meltwater hypothesis was first introduced by Shaw (1983). With additions, it explains glacial landforms such as drumlins, hummocky terrain, tunnel channels and scoured bedrock p-forms (see Shaw 2002). Since its inception, the subglacial meltwater hypothesis has been used to explain streamlined bedrock surfaces, erosional marks, as well as drumlins composed of varied internal sediments in various locations in North America (Fisher *et al.* 2002). In Alberta, large-scale coherent landform fields of drumlins and associated bedforms, eroded into bedrock, have led

researchers to suggest that erosion occurred as a result of “catastrophic” releases of meltwater sheetflow under the Laurentide Ice Sheet (Shaw 1983; Shaw and Kvill 1984; Rains *et al.* 1993; Shaw 1996).

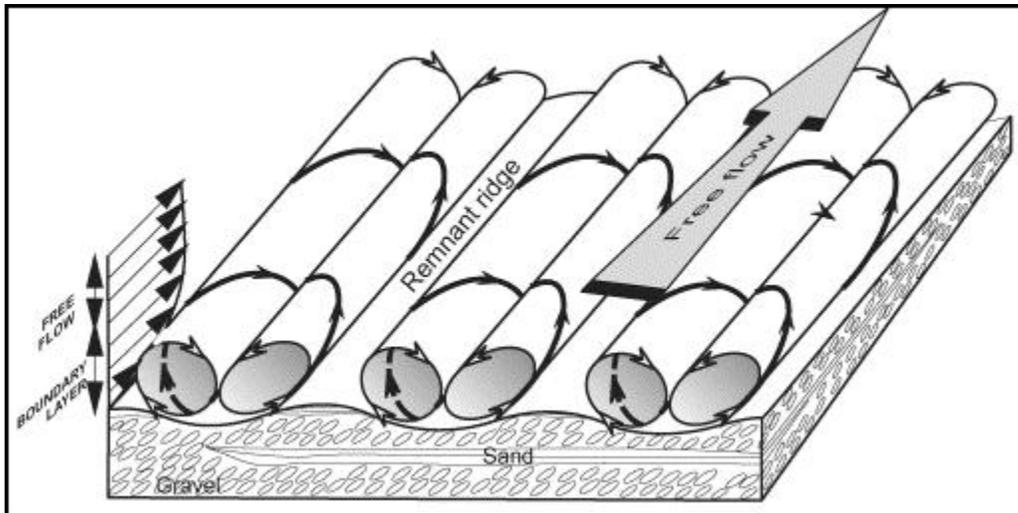


Figure 2.2: Model to describe the meltwater flow pattern in the formation of flutes (Modified from Munro-Stasiuk and Shaw 2002)

Evidence to support a meltwater-derived landscape would include the forms and patterns of drumlins, Rogen moraine, hummocky terrain, current ripples, dissection of sediments, tunnel channels and boulder and cobble lags (Figure 2.3) (Munro-Stasiuk and Shaw 2002, Sjogren *et al.* 2002; Shaw 2008). Subglacial meltwater flow can occur in channels (R or N channels), tunnel channels and valleys, linked cavity systems or braided networks of channels (Fisher *et al.* 2002). The relationship between cross-cutting channels and sediments, fluting, and transverse bedforms suggests that sheetflows concentrate into discrete channelized flows that culminate in the development of esker

networks (Beaney and Shaw 2000; Fisher *et al.* 2002; Sjogren *et al.* 2002), much as is found in the Channeled Scablands (Baker 1978).

Hummocky terrain may be erosional (e.g. eroded through existing bedrock or sediments) or depositional (Baker 1978; Munro and Shaw 1997; Beaney and Shaw 2000; Fisher *et al.* 2002; Sjogren *et al.* 2002; Shaw 2008). From a meltwater perspective, hummocky landscapes could form through a single or multiple violent events (e.g. megafloods), eroding pre-existing sediments and scouring them into sculpted hummocks and swales (Munro and Shaw 1997; Shaw 2008; Sjogren *et al.* 2002). As the rapid discharge of water abates, subglacial streams would continue to erode channels in the ice, creating ice-walled conduits and, if sediment supply was adequate, eventually depositing eskers on the underlying sediments (Shaw 2008). See Figure 2.3 for a model of the development of some subglacial meltwater bedforms.

Sub-glacial meltwater scouring is caused by the progressive channelization of sheet flow (Sjogren and Rains 1995). These meltwater channel networks can have varied sizes, shapes and orientations (Sjogren and Rains 1995; Shaw 2002).

These turbulent erosional and depositional processes create an array of geomorphic forms (Figure 2.3), in particular drumlins and hummocks (Shaw 1983; Shaw and Kvill 1984; Sjogren and Rains 1995; Beaney and Shaw 2000; Shaw 2002). Sjogren *et al.* (2002) described a series of incipient tunnel channels in Alberta that dissect hummocky terrain and include superimposed eskers. Rounded hummocks and swale

assemblages with similar morphology and internal structure are interpreted as supporting the argument for meltwater formed hummocky terrain (Munro and Shaw 1997; Shaw 2008).

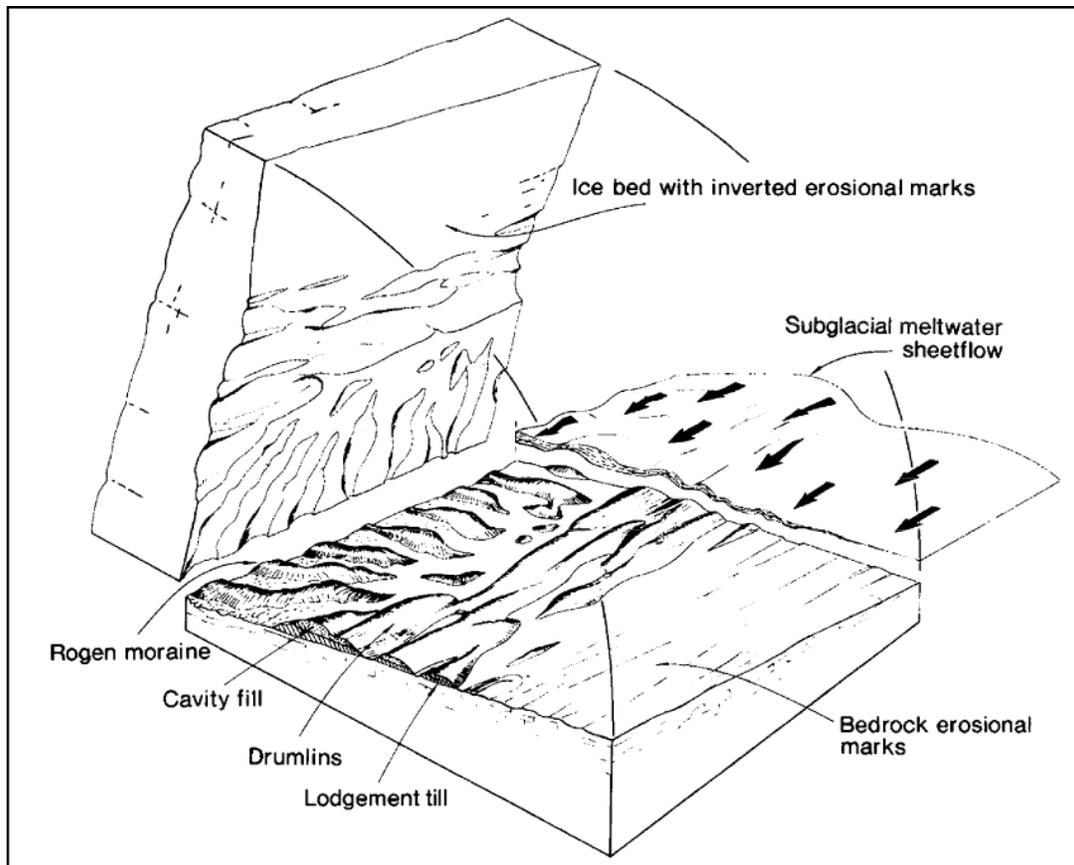


Figure 2.3: Model of the development of subglacial meltwater landforms (Modified from Shaw 2002).

Many of these glacial landforms have been buried by subsequent sedimentation and may be preserved in the sedimentary architecture of the Okanagan

Valley. Seismic reflection techniques could provide evidence of such features and thus be used to test the theory of meltwater channel incision.

2.1.4 Subglacial Lakes

Subglacial lakes exist today in many locations around the world. For a subglacial lake to form, there must be a local reversal in the hydraulic gradient to cause ponding (Wingham *et al.* 2006), a source of available water, and an energy source to melt glacier ice. Several suggested energy sources include geothermal heating, frictional heat generated from basal friction, advected heat from surface or groundwater, and frictional heat from viscous dissipation of flowing water (Paterson 1994, p. 213-219).

Rapid discharges of water have been observed from storage basins underneath ice sheets in Antarctica (Wingham *et al.* 2006), Greenland (Das *et al.* 2008) and Iceland (Fowler, 1999; Flowers *et al.* 2004). The relative frequency of these events has led many researchers to conclude that rapid discharges between subglacial lakes may commonly occur. Research by Wingham *et al.* (2006) shows that some subglacial lakes have very short residence times, with periodic subglacial drainage of the entire lakes. Fracture propagation through the cold ice of a thick glacier caused rapid drainage of a supraglacial lake to a subglacial lake in Greenland (Zwally *et al.* 2002; Das *et al.* 2008). This rapid drainage resulted in water driven fracture (moulin) propagation through the ice, increased seismic events, transient ice acceleration, ice-sheet uplift, and horizontal movement of the entire ice sheet (Das *et al.* 2008). The entire drainage of a lake

containing $0.044 \pm 0.01 \text{ km}^3$ of water took place catastrophically from a supraglacial position to a subglacial position in less than two hours (Das *et al.* 2008).

Rapid discharges of subglacial water are hypothesized to occur through conduits, linked cavity systems, and as sheetflow below the glacier (Wingham *et al.* 2006). The mechanism driving the movement of the basal waters is through temporary changes in the hydraulic gradient under the ice. A positive feedback mechanism causes flow to increase rapidly, drainage through meltwater conduits, terminating with the collapse of a tunnel during waning stages of flow as the reservoir pressure falls.

A potential source of geothermal heat in the Okanagan is the north-south trending fault system through the centre of the valley (see Figure 2.4). Thermal profiling of deep wells on the UBC Okanagan campus, as well as several provincial groundwater observation wells in the region (Woodbury, personal communication, 2009) shows groundwater table temperatures of around 12 to 14 °C near the surface. This elevated heat flow may be attributed to two sources of heat: 1) discrete thermal heating during the Eocene, and 2) steady-state supply of heat from the back-arc location of the asthenospheric subduction of plates off the west coast (Davis and Lewis 1984). Recent seismic, magnetic and electrical surveys show that the lithosphere may be as thin as 30-40 km in the region (Davis and Lewis 1984). This would certainly facilitate bottom heating to create basal ice melting and subsequent ponding of subglacial waters during late glacial stages.

2.1.5 Eskers

Eskers are casts of subglacial tunnels created at the base of warm-based glaciers (Gorrell and Shaw 1991; Brennand 2000). Eskers may locally extend up a slope, indicating pressurized flow in subglacial conduit. Meltwater conduits collect water and carry flow to subglacial positions (Brennand 2000). If eskers form at the base of a glacier they are easily preserved when the ice retreats.

Eskers vary in shape and size, with lengths up to 100 km (Gorrell and Shaw 1991). They are sinuous ridges that may be discontinuous, broad or flat topped. They tend to contain sand and gravel transported by subglacial fluvial discharges. They may transport large volumes of sand and gravel in ice-walled, pipe-like conduits. These deposits tend to be horizontally or cross-bedded sand and gravel, but vary locally depending on sediment supply or flow regimes (Brennand 2000). Sedimentation is discontinuous and dependent on the flow regime (Gorrell and Shaw 1991). Tunnel channels may become blocked causing temporary ponding of water and, therefore, a change in deposition from sand and gravel to finer grained materials, creating beaded esker networks (Gorrell and Shaw 1991).

Beaded eskers are discontinuous features with hillocks and depressions. They may be deposited in segments with each segment terminating in a bead where a delta entered a proglacial lake system or related to expansions along the lengths of conduits

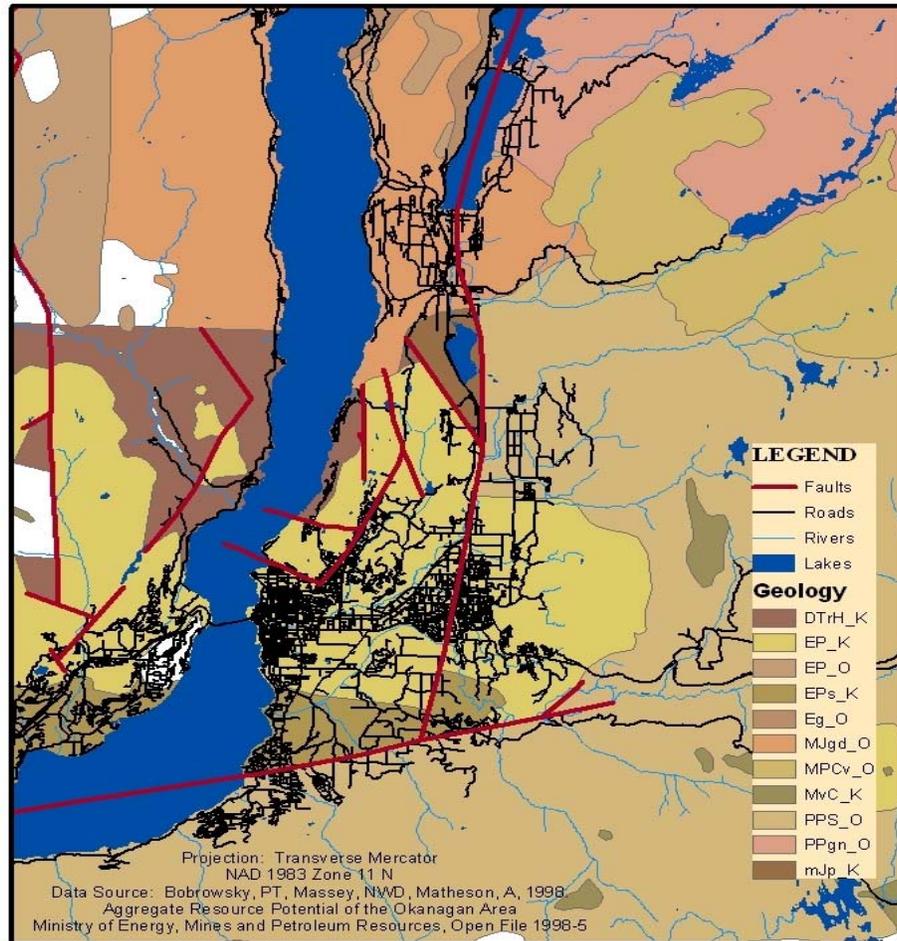
(Gorrell and Shaw 1991). Eskers are sometimes associated with sedimentary fans or delta complexes at the terminus of a glacier (Gorrell and Shaw 1991).

2.2 Regional Setting

2.2.1 Bedrock Geology

The Central Okanagan region contains bedrock belonging to the Eocene White Lake and Penticton Formation (Carbonaceous siltstone, sandstone, conglomerate, volcanic conglomerate), Marama Formation of the Penticton Group (intermediate volcanic flows), Precambrian Monashee Gneiss of the Shuswap Terrane (foliated, granitic gneiss), Middle Jurassic Nelson Plutonic rocks (foliated granite and granodiorite, intrusive rock) and Eocene Kitley Lake Formation (buff intermediate volcanic flows) (Bobrowsky *et al.* 1998; Church 1980 and 1981; Tempelman-Kluit 1989)(Figure 2.4).

Oblique extension in the early to middle Tertiary is believed to have caused two microplates to pull apart, producing a north-south striking system of normal faults collectively known as the Okanagan Valley Fault System (Little 1961; Templeman-Kluit and Harakal 1986; Vanderburgh and Roberts 1996). Geophysical studies show the Okanagan Fault zone to extend to depths of twenty kilometers (Templeman-Kluit and Harakal 1986). Other geophysical studies show that the bedrock basement of the Okanagan Valley extends to 180 to 650 m below sea level in some locations, with an estimated 500 to 700 m of sedimentary basin fill (Eyles *et al.* 1990; Vanderburgh and Roberts 1996; Fulton 2006).



Bedrock Units of the Okanagan Area

0 2 4 8 Kilometers



Figure 2.4: Bedrock geology map of the Central Okanagan area, modified from Bobrowsky *et al.* (1998). Fault lines are delineated as the thicker solid red lines.

2.2.2 Surficial Geology

The surficial geology of the region was recently summarized by Paradis (2009). According to Paradis *et al.* (2010), the Central Okanagan region contains surficial landforms related to alluvial fans (Af), lacustrine sediments (La, Lb, Lv), diamicton (Tb, Tv), exposed bedrock (R) and glaciofluvial sediments (Go, Gb, Gt). Lacustrine sediments are categorized according to relative thicknesses: Lv – 0.3 m to 1m thick, Lb – 1 m to 5 m thick, and La – 5 m to 8 m thick. Diamicton are similarly described according to the relative thickness scheme above (Da, Db, Dv). Glaciofluvial sediments are described as Go, Gb and Gt. Paradis (2009) identified Go deposits as subaerial proglacial outwash fan sediments (forming benches and fans with flat to undulating surfaces marked by sinuous shallow paleochannels), Gb as glaciofluvial blanket sediments usually over 2 m thick, and Gt as glaciofluvial sediments up to 6 m in thickness.

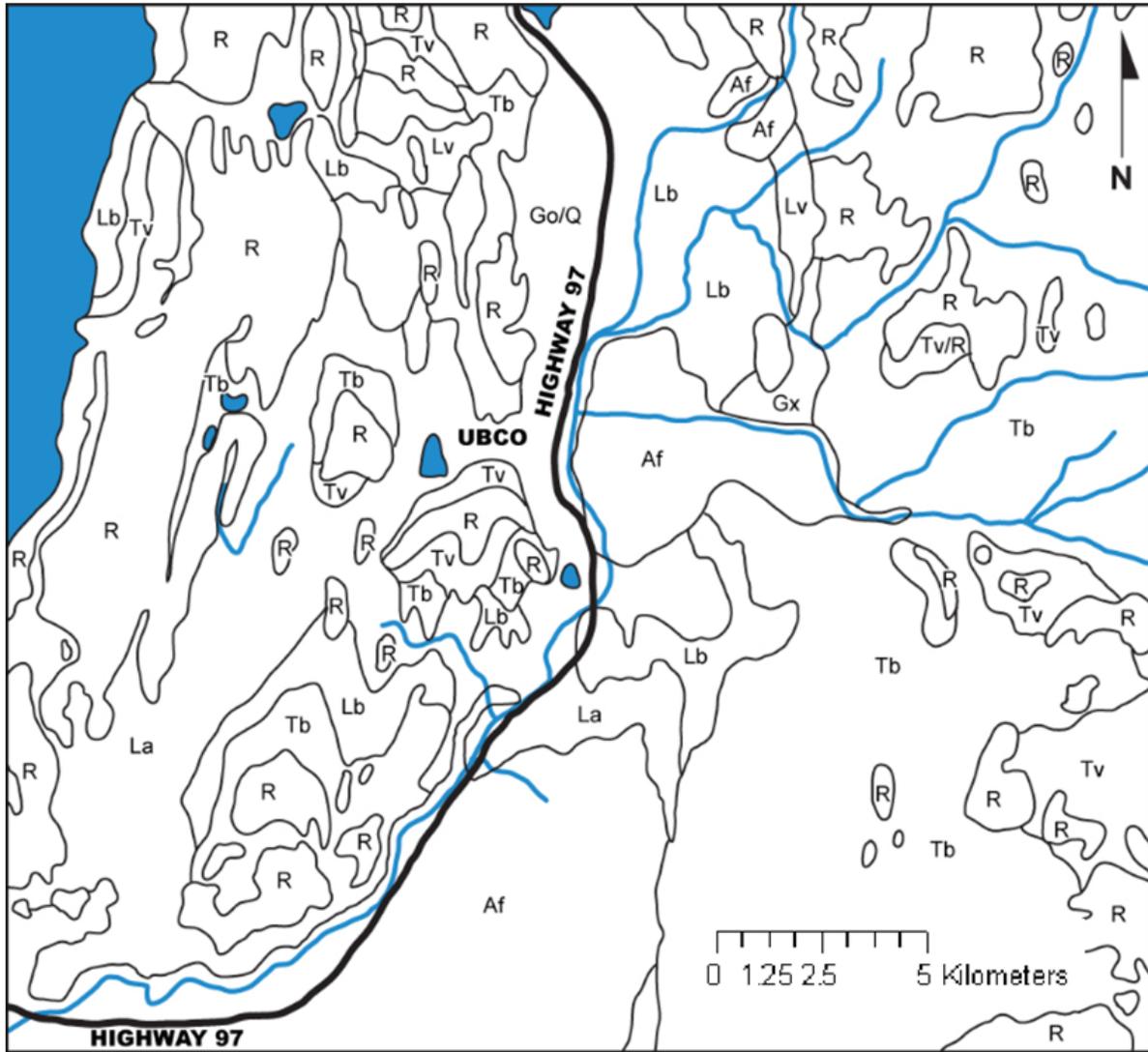


Figure 2.5: Surficial geology map of the Central Okanagan area northeast of Kelowna, BC, modified from Paradis (2009). The surficial geology of the study area are described as alluvial fans (Af), lacustrine sediments (La, Lb, Lv), diamicton (Tb, Tv), exposed bedrock (R) and glaciofluvial (Go, Gb, Gt).

2.3 Regional Glacial History of the Area

The Pleistocene epoch (2.6 million yrs BP to 10,000 years BP) was a period of recurring and extensive glaciations in the northern hemisphere. Variations in the solar insolation caused by Earth's orbital changes initiated North American ice-sheet growth at 19,000-23,000, 41,000 and 100,000 years BP (Ruddiman and Wright 1987).

Evidence for multiple Cordilleran glaciations can be seen in repeated sequences of glacial and non-glacial sediments in several locations throughout the province. Clague (2000) considered that repeated growth and decay of ice sheets across British Columbia included as many as eight cycles, each punctuated by abrupt climatic fluctuations.

The two most recent glaciations in the Interior are the Okanagan Centre and Fraser glaciations (Table 2.1).

The local record in many areas of BC remains contentious. Much of the interior of British Columbia is estimated to have been covered by more than 1000 to 2000 metres of ice during the Fraser Glaciation (Nasmith 1961; Fulton 1989; Clague 2000). This continuous body of ice formed a complex network of glacial lobes, collectively known as the Cordilleran Ice Sheet (Nasmith 1961; Fulton 1991). The Cordilleran Ice Sheet probably originated from cirque glaciers that filled valleys and eventually overtopped plateaus (Lesemann and Brennand 2003).

Table 2.1: Time stratigraphic sequence for the Okanagan Valley (from Fulton 1978; 2006)

Geological Time	Approximate Age (Cal. Yrs B.P.)	South Central BC Climate Unit	South Central BC Lithologic Unit	
Holocene	10,000 to present	Recent	Postglacial Sediments	
Late Wisconsin	10,000 to 23,000	Fraser Glaciation	Kamloops Lake Drift	Upper Stratified Unit
				Unstratified Unit
				Lower Stratified Unit
Middle Wisconsin	23,000 to 65,000	Olympia Non-glacial	Bessette Sediments	
Early Wisconsin	65,000 to 80,000	Okanagan Centre Glaciation (Regionally known as Penultimate Glaciation)	Okanagan Centre Glacial Units	Upper Stratified Unit
				Unstratified Unit
				Lower Stratified Unit

The most recent deposits in the interior are known as the Fraser Glaciation (Late Wisconsin equivalent) deposits, represented by Kamloops Lake Drift (Fulton and Smith 1978). Current debate rests around the presence of pre-Fraser glaciation sediments in the Central Okanagan region.

Geologists have recognized the stratigraphic record of the Okanagan to be incomplete since it is based solely on a few subaerial geologic exposures and extremely limited geophysical data (Clague 1985). Theories about the valley-fill architecture and

age of the Okanagan basin sediments remain divided between those favouring both pre- and post-Fraser Glaciation and those favouring only post-Fraser Glaciation genesis. A poor understanding of the stratigraphy of the glacial and post glacial sediments which infill the valley bottom hampers these debates.

The two theories of glacial fill depend on processes occurring during deglaciation and the presence or absence of valley-scour flooding. The surrounding mountains buttressed the most recent Cordilleran Ice Sheet to approximately 2000 m asl allowing it to be relatively stable, with only a few of the highest mountain peaks remaining unglaciated (Fulton 1989).

The Cordilleran Ice Sheet rapidly disappeared as climatic factors changed, resulting in complex deglacial downwasting and stagnation of ice in the valley bottoms (Clague 1985; Johnsen and Brennand 2004). Some researchers suggest topographic highs deglaciated first and ice thicknesses in the valleys far exceeded that on the plateaus (Fulton 1989 and 1991; Lesemann and Brennand 2009). The ice sheet geometry favoured the disappearance of plateau ice first, leaving impounded stagnant ice in the valley bottoms (Lesemann and Brennand 2009).

As a result, large ice masses which occupied the interior valleys eventually became covered with debris, altering meltwater drainage patterns, creating meltwater ponding and causing extensive valley bottom scouring and deposition of sediments (Fulton 1991). The impoundment and subsequent release of valley-side water bodies led

to the development of energetic meltwater flows and abundant sediment delivery from the upland areas (Lesemann and Brennand 2009) that may have contributed to ponding of meltwaters.

Mapping of lake-bottom sediments, deltas and subaqueous fans shows temporary water ponding of ice marginal lakes to about 900 m asl (Lesemann and Brennand 2009). Steeply dipping terraces suggest rapid and episodic lake drainages, with lakes being very short lived (years to 100's of years) (Lesemann and Brennand 2009).

Regional scale deglacial meltwater lakes are believed to have been common in tributary valleys throughout the interior (Ryder *et al.* 1991; Johnsen and Brennand 2004). Glaciolacustrine silts present on valley floors throughout the Cordillera are evidence for regionally extensive lakes which occupied the Okanagan Valley during late stages of the Fraser Glaciation (Eyles *et al.* 1990; Vanderburgh and Roberts 1996; Johnsen and Brennand 2004). Glacial Lake Penticton, which occupied the Okanagan Valley, developed late in the Wisconsin (Fraser) glaciation and may have extended as far south as the Columbia Valley in Washington State (Lesemann and Brennand 2009). A basin-wide understanding of the paleohydrology of Glacial Lake Penticton is incomplete as very few sedimentologic indicators remain to indicate its extent (Lesemann and Brennand 2009). Lesemann and Brennand (2009) inferred the maximum elevation of Glacial Lake Penticton to be approximately 520 m asl, based on localized water plane reconstructions.

Lesemann and Brennand (2009) propose that Glacial Lake Penticton drained as a series of jökulhlaups, routed through the Okanagan Valley and into northern Washington State. Rapid discharges of water are common in glaciated landscapes and meltwater tunnels commonly lie beneath present-day temperate glaciers (Wingham *et al.* 2006). However, no modern analogues exist for the large-scale subglacial meltwater floods (10-100 km wide) inferred to explain the suite of bedforms (drumlins, flutings, hummocks and lineations) seen in many formerly glaciated environments (Shaw *et al.* 1989; Fisher and Shaw 1992; Rains *et al.* 1993).

The collective presence of hummocky terrain, eskers, tills, glaciolacustrine sediments and tunnel valleys at the study site could provide evidence for a subglacial meltwater derived drainage system in the Okanagan Valley.

2.4 Models of Valley-fill Genesis

There are two main models to describe valley-fill genesis in the Okanagan Valley.

Model 1:

The first model puts forward the idea that all valley-fill sediments are pre-glacial, glacial, and post-glacial related to the latest Fraser Glaciation. This theory is partly based on valley-bottom seismic reflection surveys performed by Vanderburgh (1993) and Vanderburgh and Roberts (1996) in the North Okanagan valley near Vernon, Armstrong and Enderby. The profiles reveal a thick sequence (as much as 350 metres) of coarse to fine clastic sediment identified as subglacial fluvial, glaciolacustrine, alluvial fan and

channel deposits. They recognized two main sedimentary packages: 1) An upper, horizontally bedded package generally including fine deposits of silt, sand and clay; 2) A lower package including coarser sand and gravel with an unconformable upper boundary. The stratigraphic position, sediment type and density of these lower sediments suggest a subglacial fluvial origin. The upper sediment contacts onlap the lower package that tends to dip toward the valley centre. The subglacial fluvial sediments were compact, stratified to poorly stratified coarse clastics likely deposited under tremendous hydrostatic pressure. Evidence for high pressure comes from drill core analysis and seismic surveying (Vanderburgh and Roberts 1996).

A lack of abundant organic bearing non-glacial sediments found during the drilling allowed Vanderburgh and Roberts to propose that the older Pleistocene sediments had been completely eroded away and replaced with subglacial fluvial and glaciolacustrine sediments from the Fraser Glaciation.

Eyles and Mullins (1997) performed a seismic reflection survey at the northern extent of the Okanagan Valley near Salmon Arm, concentrated in the Shuswap Lake basin. Their profile showed chaotic seismic facies filling the lower 400 m of an 800 m basin fill sequence. They interpreted these lower seismic reflectors (400 m to 800 m) as subaqueously-deposited ice-contact silts, sands and gravels deposited in a deep ice-marginal lake formed during deglaciation. The upper 400 m of sediments were interpreted to be rhythmically and more distally-deposited glaciolacustrine silts and sand,

with a relatively thin (<70 m) capping of Holocene age lacustrine silts. However, differentiation of fine-grained materials from a seismic profile is not very effective. Eyles *et al.* (1990) conducted an air-gun seismic reflection investigation of Okanagan Lake. The survey showed almost 800 m of sediment fill above the v-shaped bedrock valley underlying Okanagan Lake (Eyles *et al.* 1990). The depth to bedrock in some locations within the Okanagan Lake basin involves a relief of 2000 m (650 m below sea level) relative to the elevation of the surrounding plateau, exceeding the total relief of the Grand Canyon (Eyles *et al.* 1990). Eyles *et al.* (1990) postulated the removal of enormous volumes of pre-Fraser Glaciation sediment from Okanagan Lake by glaciological processes associated with an ice stream, subglacial meltwater erosion and transport.

Several pieces of information are problematic in this hypothesis. First, the few boreholes penetrating through to the lower package encountered a dense till-like sequence, which would suggest accumulation of the lower sediment package in multiple glaciations (Fulton 2006).

Secondly, Vanderburgh (1993) obtained organics from the upper layers of a sediment unit near Enderby which he dated at $38,220 \pm 370$ radiocarbon years, placing its age within the non-glacial Bessette sediments. Vanderburgh (1993) attributed the lone sample to being redeposited organics, derived from older organic materials somewhere on the side of the valley. The presence of these organics suggests there may have been

minor to incomplete meltwater scouring of pre-existing valley sediments in some locations.

Thirdly, the interpretation of Eyles and Mullins (1997) were based on the interpretation of seismic facies interpretation only, and no drilling has been conducted to confirm the subsurface lithologies.

Model 2:

The second model holds that the sedimentary sequence represents multiple glacial episodes and that the valley fills include interglacial sediments. Proof for the second model of valley-fill genesis relies on the presence of organics within these valley-bottom sediments. Monahan (2006) used well records to reconstruct stratigraphy and provided evidence of multiple borehole locations where organics were present in the North Okanagan valley fill. Monahan (2006) and Fulton (1972) described these sediments as non-glacial and part of the Olympia-age Bessette sediment sequence. Monahan (2006) also points out that sediment several hundreds of metres below the surface contains abundant organic debris, which drillers have described as lignitic, very dense, and locally red and pink in colour. The reddish colour could be attributed to oxidized iron sediments which is an indication of subaerial conditions at the time of deposition.

Researchers working in other locales in the Cordillera have also reported the presence of non-glacial sediment. Stumpf *et al.* (2004) identified non-glacial sediments correlated to the Olympia Non-glacial Interval in north-central BC. These non-glacial

sediments are reportedly overlain by a succession of ice advance sediments, Fraser Glaciation tills (Late Wisconsin), and post-glacial sediments. As other locales in the Cordillera include organics preserved in sediments, then it is prudent to re-examine the valley fill in the Okanagan for organics to confirm or refute the existence of interglacial sediments.

2.5 Okanagan Stratigraphic History

During the Late Pleistocene, the glacial history of British Columbia has been a complex sequence of depositional and erosional events (Ryder and Clague 1989). The Okanagan Valley is no exception to these events. Thick sequences of Late Pleistocene glacial sediments have filled the interior valleys of BC with extensive, and in some places, well preserved sediments.

Two non-glacial and two glacial events are recorded in Okanagan Quaternary sediments (Fulton and Smith 1978). The Olympia non-glacial interval (65,000 - 23,000 yrs BP), as well as the Fraser Glaciation (23,000-10,000 yrs BP), has been extensively studied (Fulton and Smith 1978), however, geologists have recognized that the stratigraphic record of the Okanagan is poorly understood (Clague 1985). Each glacial unit records advances and recessional sediments of glaciofluvial and glaciolacustrine origin (Monahan 2006). The Olympia non-glacial sediments, characterized by locally abundant plant remains, record a non-glacial period similar to present climate conditions (Fulton and Smith 1978; Monahan 2006). Organic materials in these sediments have

provided calibrated radiocarbon dates ranging from $43,000 \pm 800$ years to $19,100 \pm 240$ years BP (Fulton and Smith 1978).

2.6 Okanagan Depositional Models

A three-dimensional model to describe the depositional environments of the North Okanagan was developed by Vanderburgh (1993). He described four main components of the valley fill cycle as a) subglacial fluvial system, b) glaciolacustrine system, c) alluvial fan system, and d) channel system.

Vanderburgh (1993) and Vanderburgh and Roberts (1996) late glacial model of the North Okanagan basin highlights the geomorphic environments that existed during final stages of deglaciation (Figure 2.7). The model illustrates that during retreat of the ice sheet, thick sequences of coarse grained stratified sediments were deposited (B1 and B2). Subsequent blockage of the Okanagan Valley and the development of an extensive lake, Glacial Lake Penticton, resulted in the thick accumulations of glaciolacustrine sediments seen in the valley (C) (Figure 2.8).

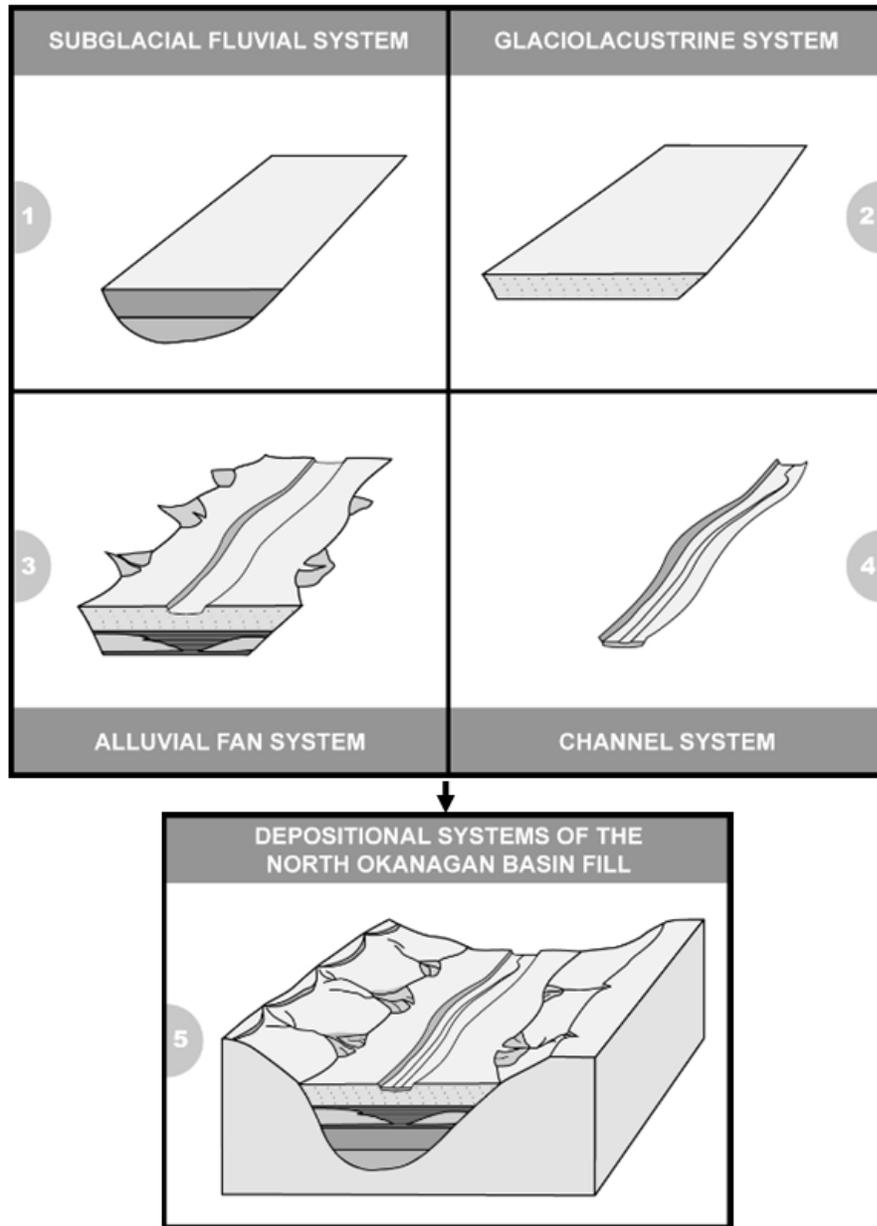


Figure 2.6: Depositional model of North Okanagan basin fill (from Vanderburgh and Roberts 1996).

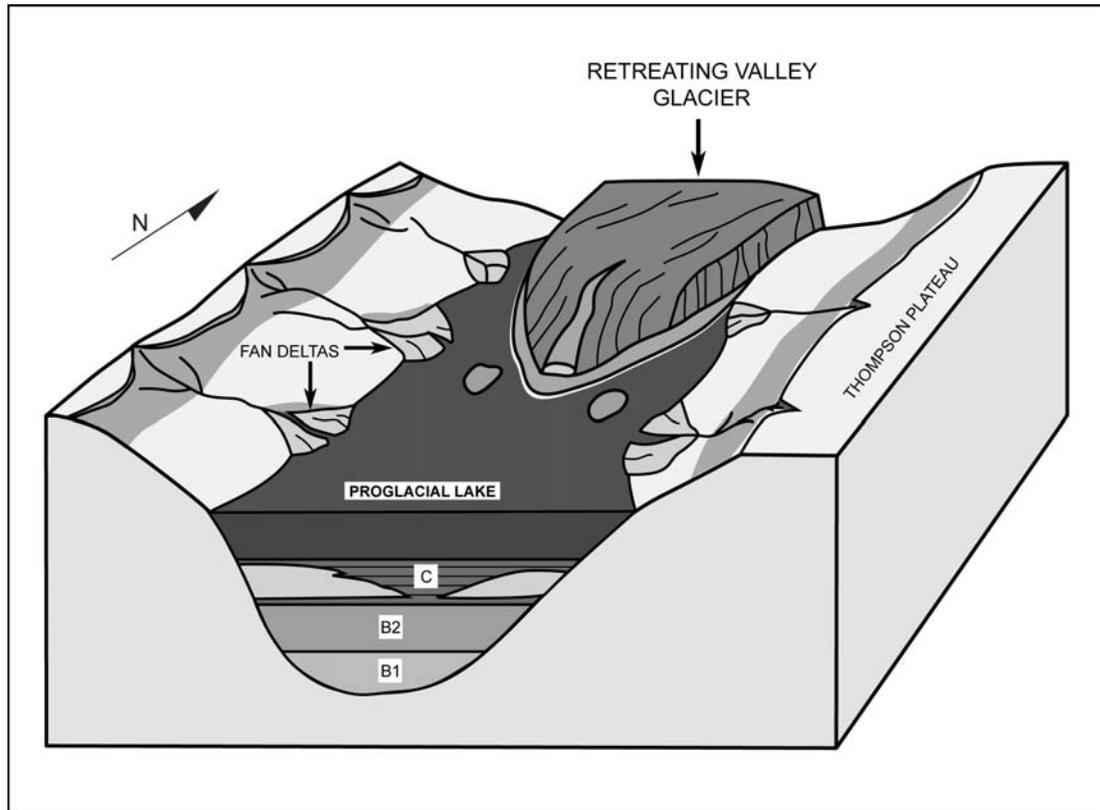


Figure 2.7: Late glacial depositional model of North Okanagan basin fill (from Vanderburgh and Roberts 1996).

Interfingering with the glaciolacustrine sediments are alluvial fans deposited into the valley bottom through mass movement processes and originating from unstable glacigenic deposits on the valley margins (E). Post-glacial lacustrine sediments (D), and present day fluvial channel incision (F) complete the depositional model for the Okanagan Valley, as described by Vanderburgh (1993) and Vanderburgh and Roberts (1996).

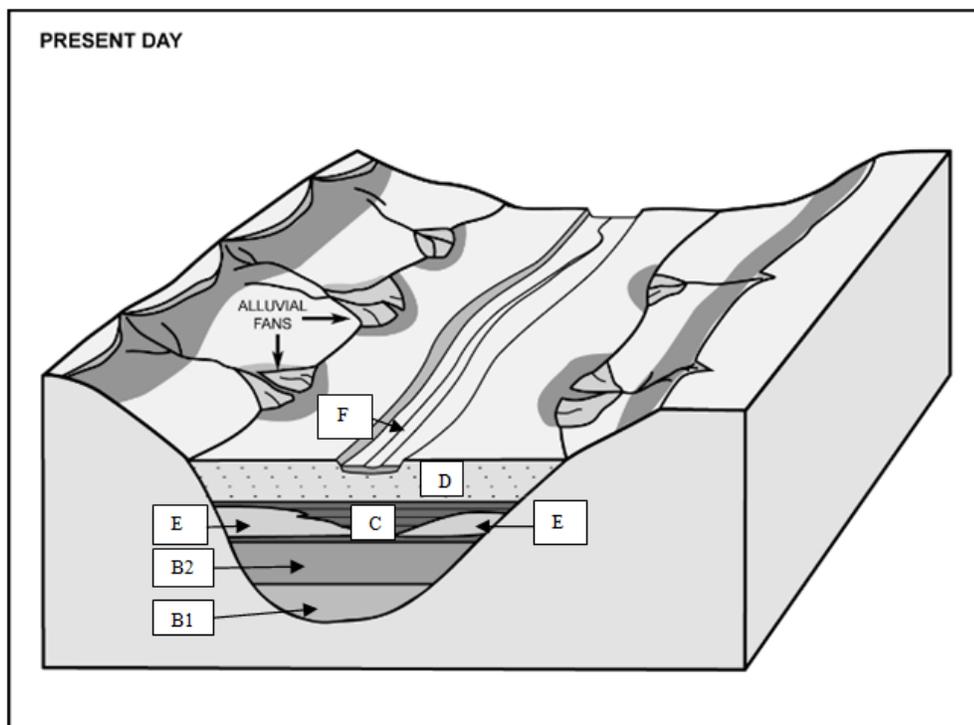


Figure 2.8: Present day model of North Okanagan basin fill (from Vanderburgh 1993 and Vanderburgh and Roberts 1996).

2.7 Procedures of Seismic Stratigraphy

Geophysical surveys provide an unobtrusive and easily performed method to further understand glacial valley fills, affording an opportunity to visualize architecture and variability of subsurface formations (Sharpe *et al.* 2003). Geophysical surveys may provide further information on the aerial extent and thickness of sequences, overburden depths, depth to water table, geologic contacts and correlation between critical geologic features (Lucius *et al.* 2006). Seismic reflection techniques provide good dimensional information that is essential for hydrogeologic interpretation (Sharpe *et al.* 2003).

Another key advantage of this method for Quaternary investigations is the ability to obtain low-cost and high-resolution subsurface information using affordable engineering seismographs, field computers, and safe energy sources (Vanderburgh 1993).

The continuity and facies distribution of sedimentary deposits directly influence the spatial extent of aquifers and aquitards (Sharpe *et al.* 2003). Models of the valley fill derived solely from lithologic boreholes may not adequately capture the stratigraphic framework, horizontal continuity, scale or architecture of sedimentary deposits (Sharpe *et al.* 2003). Glacial deposits are generally spatially heterogeneous, making interpretation of hydraulic properties problematic and necessitating the need for multi-disciplinary techniques (Sharpe *et al.* 2003).

Surveys are typically done to provide subsurface detail between known boreholes that are used for geologic control of the geophysical profile and subsequent corrections. Results of geophysical surveys show variations in geophysical properties (e.g. density and elastic modulus, and hence velocity of seismic waves), that may be translated into properties such as material thickness (Lucius *et al.* 2006). Therefore, geophysical surveys are considered a complement to traditional geologic exploration techniques rather than a direct replacement (Lucius *et al.* 2006). Exposures at the UBC Okanagan campus can be used to determine structures and verify the geophysical surveying. Shallow seismic reflection can be used to determine if these structures exist in locations where no exposures are visible or accessible. Given the large number of deep boreholes and recent

excavations at the UBCO campus, shallow reflection techniques can be calibrated using known geologic structures and grain sizes.

2.8 Biostratigraphy and Deglaciation

Terrestrial glacial deposits have been extensively studied and correlated with radiocarbon dates to enhance understanding of the stratigraphic sequences seen in British Columbia. Wood, peat, fossil pollen, paleosols and invertebrate and vertebrate faunal remains from glacial sediments provide radiocarbon dates and chronologic control for the growth and decay of the Cordilleran Ice Sheet (Clague *et al.* 1980; Clague 1989). Based on radiocarbon dates from many localities, Clague *et al.* (1980) postulated many valleys in southern BC remained ice-free until about 19,000 to 20,000 yrs BP. Clague *et al.* (1980) also indicated that at 18,000 yr. BP, the period commonly accepted to represent the Laurentide Ice Sheet climax, the Cordilleran Ice Sheet was well short of glacial maximum. However, Young *et al.* (1994, 1999) maintain that the array of deflected landforms oriented NW-SE, and high altitude glaciated features also oriented NW-SE, indicate that coalescence of the two ice sheets occurred during the late Wisconsin maximum. This could only have occurred if the Cordilleran and Laurentide maximums were synchronous. Rapid buildup of ice area and thickness is believed to have peaked in two to three millennia around 15,000 yr BP in the late Wisconsin, with an equally impressive rate of decay until around 12,900 yr BP (Clague *et al.* 1980). Climatic deterioration during the onset of glaciation caused poorly understood vegetation and

hydrologic changes (Clague 1985). It is believed that in the southern Cordillera, non-arboreal plant communities adapted to tundra-like conditions were the first to appear, followed by shrub vegetation and finally various tree species (Clague 1989). Organic samples obtained from a borehole drilled by Paradis et al. (2010) in the Mission Creek fan yielded radiocarbon dates for the upper sediments (within 23 m of the ground surface). The radiocarbon dates are interpreted to represent two major late stage sedimentation events: 1) ages between $3,650 \pm 20$ yrs BP and $7,260 \pm 25$ yrs BP represent a floodplain environment; and 2) ages between $9,235 \pm 25$ yrs BP and $10,060 \pm 25$ yrs BP represent a lacustrine environment (Paradis *et al.* 2010).

Organic material recovered during Vanderburgh's (1993) research program yielded a calibrated radiocarbon date of $38,220 \pm 370$ years BP, consistent with placing deeper sediments in the North Okanagan valley within the Bessette interglacial period and within the same geologic time period as sediment in the study area. Since only one sample was retrieved, Vanderburgh (1993) theorized that it may have been older organic matter transported as detritus by glacial meltwater action.

Other locations in the Cordilleran region for which radiocarbon dates are available include: at Babine Lake (northern BC) with dates ranging from $43,800 \pm 1830$ BP to $34,000 \pm 690$ BP (Stumpf *et al.* 2004), at Golden (Columbia River) ranging from $21,500 \pm 300$ BP to $25,300 \pm 310$ BP (GSC – 173, 1285 and 1802), at Salmon Arm (Shuswap Lake) ranging from $10,500 \pm 170$ BP to $21,630 \pm 870$ BP (GSC – 154, 477,

and 1524), near Castlegar (West Kootenay) ranging from $11,000 \pm 180$ BP to $33,000 \pm 280$ BP (GSC – 909 and 1008), near Invermere (East Kootenay) ranging from $10,270 \pm 190$ BP to $43,800 \pm 800$ BP (GSC – 719 and 740), near Lumby and Kelowna (Okanagan) ranging from $19,100 \pm 240$ BP to $30,700 \pm 1,090$ BP (GSC 563, 913 and 1005) (Fulton and Smith, 1978; Lowdon *et al.* 1967). These calibrated radiocarbon dates for other locales within the Cordillera are consistent with dates for the non-glacial interval.

2.9 Palynological Evidence for Deglaciation

Fossil pollen assemblages from peat cores in the Southern Interior were studied by Alley (1976). He suggested that the Okanagan Valley was free of ice and Glacial Lake Penticton had drained before 8,900 yr BP. Pine and spruce forests that had colonized the valley prior to lake drainage gave way to semi-arid grasslands around 8,400 yr BP (Alley 1976). Lake sediment cores collected from the south Okanagan highlands were also studied for climatic changes (Heinrichs *et al.* 2006). Tundra and cold-steppe species such as grasses, junipers and sages initially colonized deglaciated upland areas (Heinrichs *et al.* 2006). With the increased aridity in the area, aeolian processes became dominant and sand dunes migrated across the landscape (Alley 1976). At approximately 6,600 yr BP, the climate became moister and cooler with increased runoff from montane regions, giving way to mixed stands of deciduous trees (birch, alder and hazel) that stabilized dune landforms. Three subsequent moist and cool phases, identified in the

palynological reconstruction, correlated with the stades of Neoglaciation recognized in southern BC and the northern US (Alley 1976).

3.0 CHAPTER THREE – METHODS

3.1 Introduction

This study used the following approaches to investigate the stratigraphic history of the Kelowna area:

- Terrain mapping;
- Stratigraphic logging of surficial and subsurface deposits;
- Correlation of Quaternary sediments through detailed lithofacies profiles from surface mapping, borehole sampling and geophysical surveying;
- Radiometric dating of organic samples obtained from the subsurface to determine whether the valley-fill sequence is mid-Wisconsin (65,000 to 23,000 yrs BP) in age; and
- Together, data from this investigation are used to revise the previous process models to accommodate the results of this research. This involves testing hypotheses regarding sedimentary paleo-environments in the Okanagan, including the potential occurrence of paleo-outburst floods, and inferring how they may have altered the present Okanagan landscape.

3.2 Terrain Assessment

Analysis of aerial photographs complemented the later fieldwork. Air photos from the Integrated Land Management Bureau, Base Mapping and Geomatics Services, Province of BC provided an initial understanding of the geomorphology of the study area.

The air photos were analyzed according to the BC Terrain Classification System (Howes and Kenk 1997). Air photos used included 30BCC96036 Nos. 203, 204 and 206, as well as 15BCC04038 Nos. 125, 126 and 127. Landforms identified in the air photos were analyzed for shape, size (relative and absolute), patterns, topographic location, texture and landscape association. An initial geomorphic field map was created to facilitate the interpretation of landform shape, size, superposition, cross-cutting relationships and landform associations observed in the field.

3.3 Surface Mapping

The University of British Columbia Okanagan Campus at Kelowna BC was studied to qualitatively assess the landform assemblages, determine a chronology, and reconstruct sedimentary environments. An active quarry to the northeast of the campus provided excellent exposures from which to study the sediments. Excavations for new campus buildings afforded the opportunity to sample and analyze sedimentary structures that would not have been possible otherwise (Figure 3.1).

Exposures of Late Pleistocene sediments within the study area were examined during the 2007 and 2008 field seasons. The most significant sections are reported in Chapter 4. Some of these exposures have subsequently been covered by building construction.

Section locations were determined from contour maps and a handheld GPS unit with ± 5 m horizontal accuracy. Measurements using tape measures and staff rods gave

exposure thicknesses. Sedimentologic characteristics, lateral continuity, upper and lower contacts, and detailed examination of physical properties defined individual stratigraphic units identified in cleaned sections. The physical properties included texture, composition, degree of consolidation, colour, sedimentary structures, degree of weathering, and clast roundness.

Paleoflow directions were inferred from fabric analyses. Clast fabrics were obtained from cleaned exposures by measuring the trend and plunge of elongated clasts (a axis greater than 2 cm and a:b ratio greater than 1.5:1) (Evans and Benn 2004). Each analysis involved a minimum sample of 25 clasts. Steronet projections and rose diagrams provide reconstructed paleoflow directions. Bedding characteristics such as ripples, orientation of planar cross-beds, and clast imbrication also provided paleocurrent information.

3.4 Subsurface Mapping

A total of 12 boreholes were drilled on the UBCO Campus for the purpose of installing an open loop geothermal exchange system to heat/cool the campus buildings. These boreholes were drilled from 2004 to 2007 by JR Drilling Ltd and monitored by hydrogeologists with EBA Engineering Consultants Ltd. Borehole logs were obtained from EBA with permission from UBC Okanagan Facilities Management. Appendix A includes borehole lithologies, and Figure 3.1 provides a detailed location plan. Drilling involved air rotary methods and extended to depths ranging from 64 to 100 m, depending

on the depth of unfavourable hydrogeologic conditions. Subsurface conditions and aquifer properties were logged at each of the wells during the drilling phase by Oleg Ivanov of EBA Engineering, and by the author while working with EBA Engineering and subsequent to commencement of this graduate work. During drilling, samples were collected every 3 m to the bottom of each borehole or at any change in lithology. Drill cuttings moved through a sample hose from the drill rig to a cyclone. The cuttings travelled around the inside of the cyclone until they fell through an opening at the bottom into a sample bag. Samples were labeled and stored for future laboratory analysis.

Sixteen borehole samples were analyzed in the laboratory. Sieving gave particle size distributions of weighed samples, dried in a drying oven 24 hours at 105 °C to remove hygroscopic water. The slot openings in the sieve meshes were >16mm, 8 mm, 4 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125mm, 0.063 mm and <0.063 mm. The grain size classification system used in this study is presented in Table 3.1.

Individual sieve weights for each particle size fraction were summed to calculate the percent passing for each sediment class.

Organic samples were obtained from the drilling program (Figure 4.1). Samples were air dried to remove any water and stored in sealed containers to prevent the growth of moulds. Samples for radiocarbon analysis were shipped by overnight delivery to Beta Analytic Inc in Miami, Florida. The samples were analyzed using Accelerator Mass Spectrometry (AMS) radiometric techniques, with an acid/alkali/acid pretreatment to

isolate the carbon fractions in the samples. AMS radiometric techniques provide chronologic control and correlation between boreholes.

Table 3.1: Grain Size Classification

mm	ϕ	Wentworth Class
>16	-5 to -8	Cobble
16 to 4	-2 to -5	Pebble
4 to 2	-1 to -2	Granule
2 to 1	0 to -1	Very Coarse Sand
1 to 0.5	1 to 0	Coarse Sand
0.5 to 0.25	2 to 1	Medium Sand
0.25 to 0.125	3 to 2	Fine Sand
0.125 to 0.063	4 to 3	Very Fine Sand
< 0.063	> 4	Silt and Clay

The British Columbia Ministry of Environment (MOE) groundwater well database identifies boreholes and water wells within the study area. Sediments of the region are thick (500-700 m in some places) and few wells penetrate the entire sequence. As most water wells were terminated upon penetrating sufficient water reserves, a limited number of water wells were deep enough to be useful in constructing sedimentary cross-

sections of the valley. All borehole logs were analyzed to identify other organic horizons within the stratigraphic sequence.

3.5 Seismic Reflection Data Acquisition

Potential seismic reflection sites were identified based on accessibility, proximity to good lithologic control (i.e. boreholes), length of unobstructed straight line access, relatively flat sites, and locations adjacent to areas that needed further stratigraphic resolution (Figure 3.1).

An optimum common offset test was performed prior to full-scale subsurface testing. Early arrivals from a seismic reflection survey can be masked by signal generated disturbances (e.g. ground roll, air waves) (Figure 3.2). These were overcome using the “optimum window” method; a range of geophone separations that allows for reflected events to be received without significant signal generated disturbances (Hunter *et al.* 1984; Hunter *et al.* 1989). An offset of 20 m was determined to be effective given the limitations of the depth/energy penetration from the hammer source.

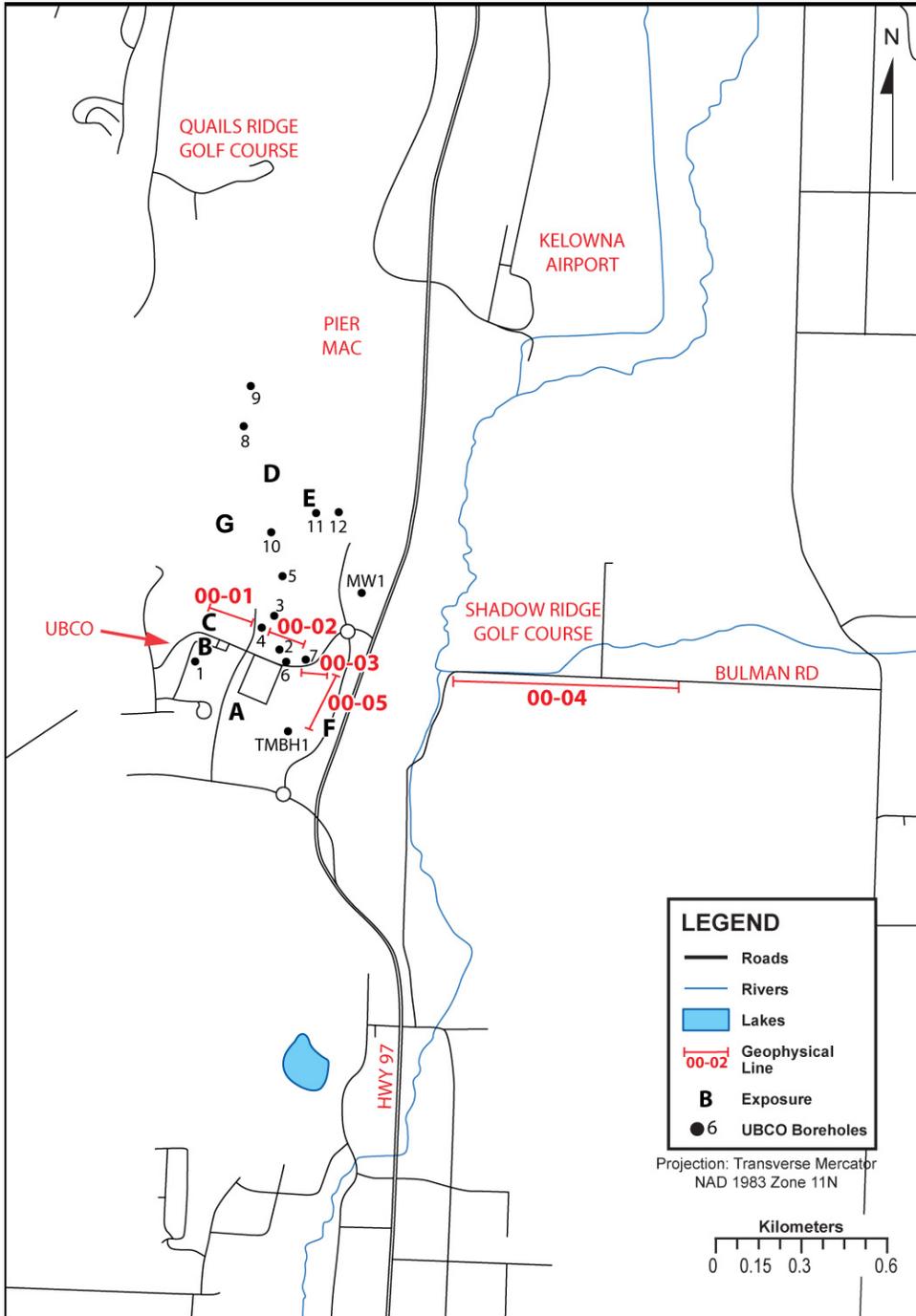


Figure 3.1: Location plan for exposures, boreholes and geophysical lines.

Four east-west seismic profiles sites were chosen, as well as one north-south seismic profile. Approximately 2 line km of high resolution seismic reflection profiles were recorded. The key objective of running the east-west transects was to collect a detailed snap shot of the valley-fill architecture. The cross-valley seismic lines were numbered from west to east.

The seismic reflection survey used a portable 24-channel SMART SEIS engineering seismograph, powered by a 12 V deep cycle battery source. A 15 lb sledge hammer and steel plate provided the energy. Source offset distance was 20 m. Geophones were Mark Products 30 Hz spaced on a 3 m interval.

A spread of 36 to 48 m was collected at each location (Figure 3.3). Geophones placed in the dampest areas along the drainage ditches maximized signal contact with the ground. Lines were collected with a 250 ms recording period. Notch filters were applied in areas with overhead powerlines or when other electrical interferences were noted. The sweep spectrum was 30-175 Hz. Six sweep repetitions were used to amplify the stacked signal. Geophone locations and shots were surveyed after completion to verify their location. Seismograph files were downloaded to a laptop computer in the field to verify consistency and to check for errors.

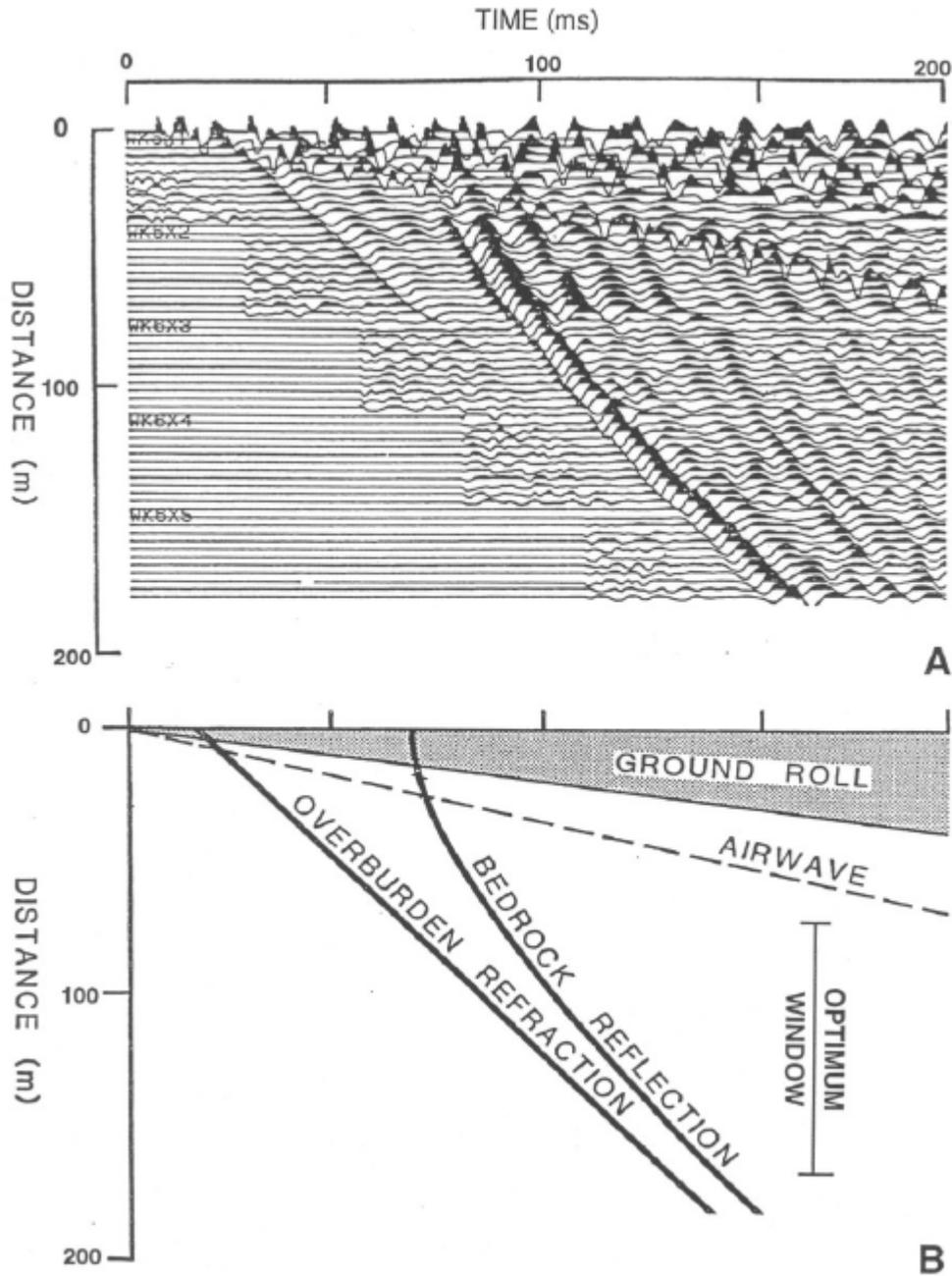


Figure 3.2: Determination of the optimum window for seismic surveying using a common offset technique (from Hunter et al. 1984). A – The uninterrupted record; B – Interpreted acoustic record and optimum window.

Seismic reflection surveys are typically performed by moving an energy source and an array of geophones a short distance along the ground (Figure 3.4). After firing a shot and collecting the data, the geophones must be repositioned linearly to accommodate increasingly overlapping sets of data. The use of a roll-along switch can greatly decrease this laborious task by efficiently selecting groups of geophones in an array, eliminating the need to move geophones after each shot. Connecting a 24 channel GEOSTUFF roll-along switch to the seismograph thus greatly improved data collection capabilities.

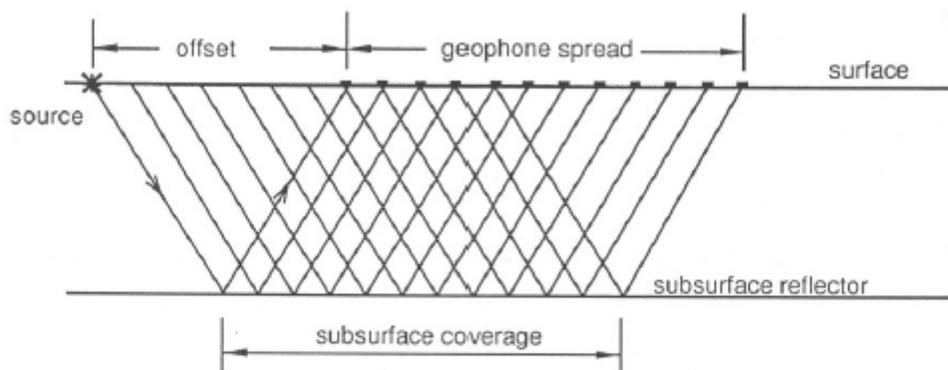


Figure 3.3: Geometry of a typical land based seismic surveying array, with an offset distance from the source to the first geophone (from Hunter *et al.* 1984).

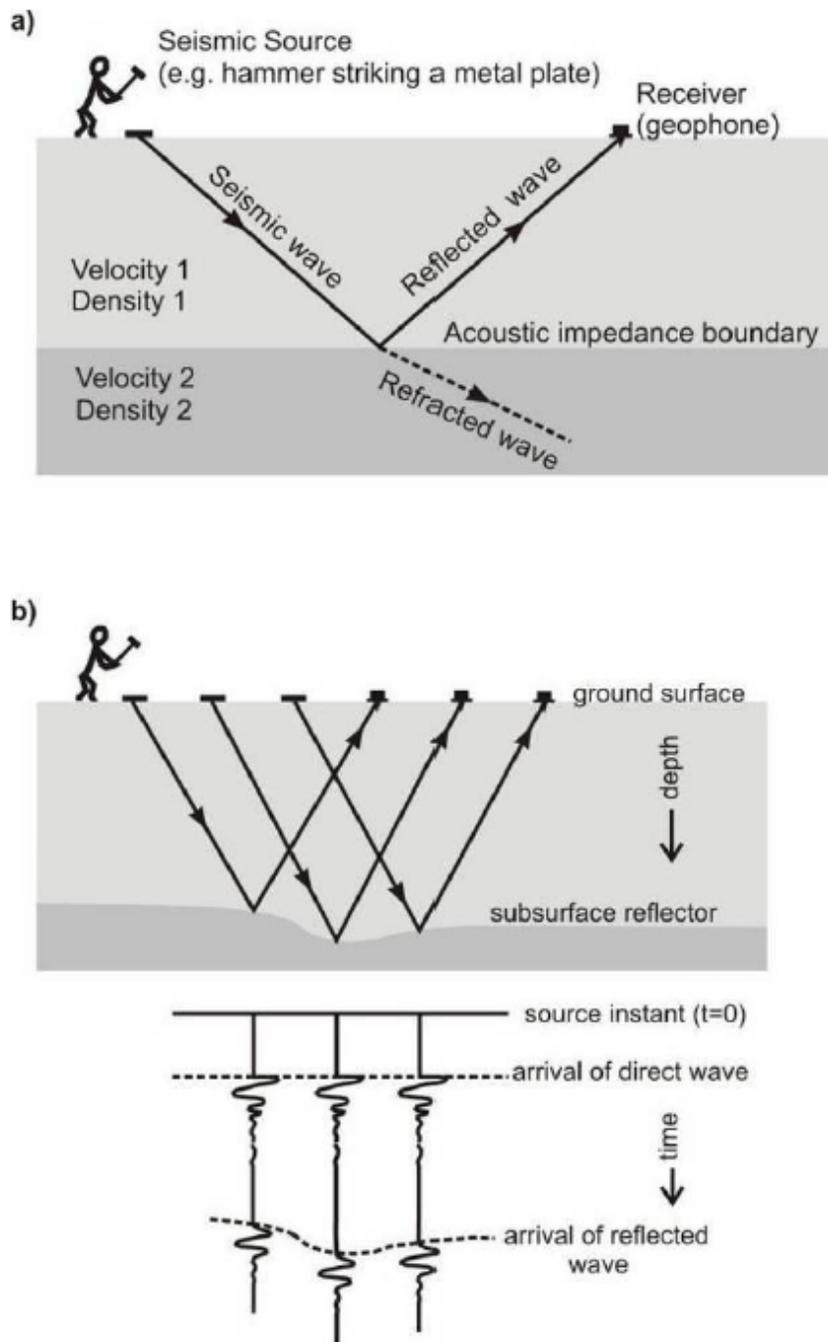


Figure 3.4: Seismic survey setup using a hammer as the energy source (from GSC 2008)

3.6 Seismic Reflection Data Processing

Variations in the overburden thickness, depth to ground water, and construction activities in the area greatly affected the high frequency seismic data collection. The simple common midpoint data gather (CMP) line geometry was chosen to produce the seismic sections (Figure 3.5). Traces from multiple shots are combined based upon their reflection from a common midpoint.

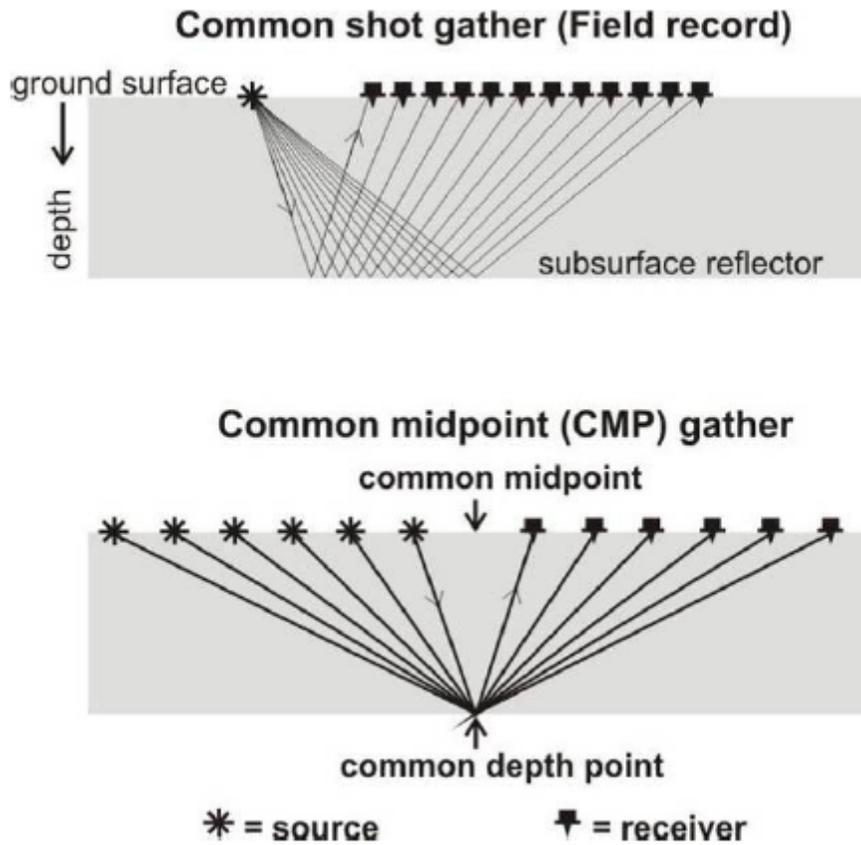


Figure 3.5: Schematic depiction of the subsurface travel paths of reflections in a field record and a common midpoint gather (modified from GSC 2008).

The normal moveout (NMO) method was applied to the data as well. Data were analyzed using REFLEX-W 4.2 software produced by Sandmeier Geologic. Processing steps included applying an automatic gain control, applying a two-dimensional filter, applying a one-dimensional bandpass filter to remove the air wave, FK Filtering, common midpoint analysis, velocity analysis, and NMO correction (Table 3.2).

Table 3.2: Processing flow chart for seismic reflection data

Format Conversion, SEG2 to SEGY
Geometry Editing
Automatic Gain Control
2 D Filtering
1 D Bandpass Filtering
FK Filtering
Static Corrections
Velocity Analysis
NMO Corrections
Stacking

4.0 CHAPTER FOUR – RESULTS

4.1 Radiocarbon Dating

Organic samples were collected at 4 different locations during the drilling of new boreholes on the UBCO campus. In total, 7 samples were retrieved and sent for AMS radio carbon analysis. The samples (Figure 4.1) are of wood, and are most likely fluviually transported based on the evidence of rounded edges.



Figure 4.1: Photograph of wood retrieved during drilling program.

Table 4.1 – Radiocarbon dates of organic samples

Sample ID	Lab ID	Location	Depth (meters asl)	Measured Radiocarbon Age (BP)	Calendar Years BP	¹³ C/ ¹² C Ratio (‰)
UBC-01	217969	Well 6	358 - 360	31,600 ± 350	36,976 ± 386	-25.0
UBC-02	220568	Well 9	380 - 385	24,430 ± 150	29,205 ± 209	-25.8
UBC-03	236556	TMBH 1	369 - 374	24,420 ± 110	29,203 ± 170	-28.8
UBC-04	236557	TMBH 1	355 - 360	28,110 ± 150	33,481 ± 222	-25.1
UBC-05	236558	TMBH 1	378 - 383	22,880 ± 100	27,460 ± 178	-24.2
UBC-06	241602	Well 11	360 - 365	30,690 ± 260	36,057 ± 283	-23.8
UBC-07	241603	Well 11	370 - 372	24,420 ± 130	29,204 ± 191	-25.1

Note: Radiocarbon age to calendar age conversion was done using the method outlined by Fairbanks *et al.* (2005).

4.2 Grain Size Analyses

Samples indicate that the borehole sediments range from a fine to coarse-grained sand with minor amounts of silt and coarse gravel (Figures 4.2 to 4.5). Individual samples are presented in Appendix B. Samples taken at 56 m depth in well 4 were considerably coarser grained as compared to the other well sites. Samples were remarkably similar for the other wells and depths, ranging from fine to coarse sands with minor silts and gravel.

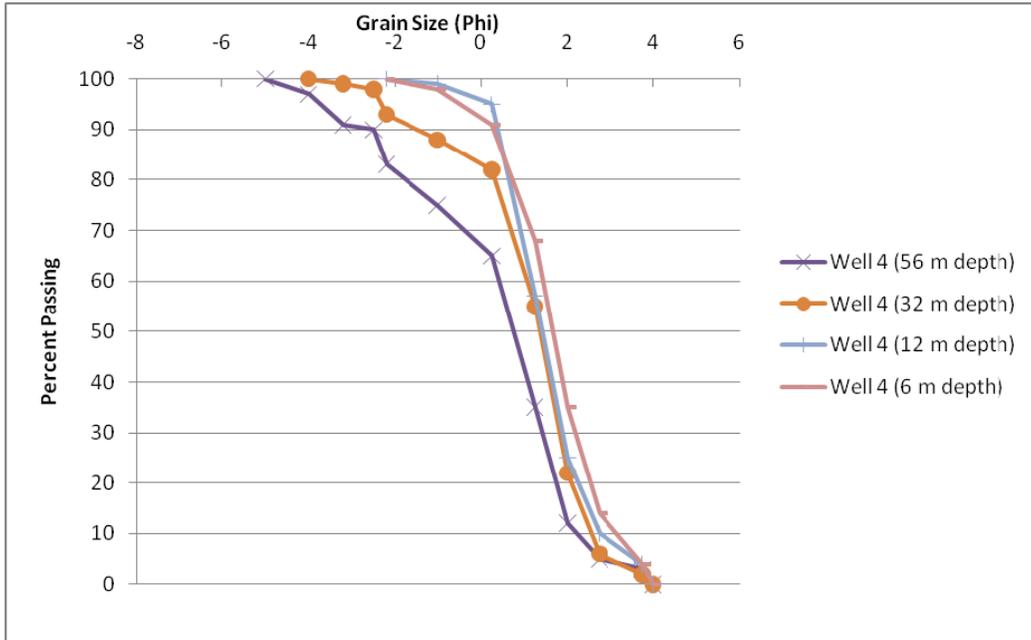


Figure 4.2: Particle size distribution for Well 4 grain size samples.

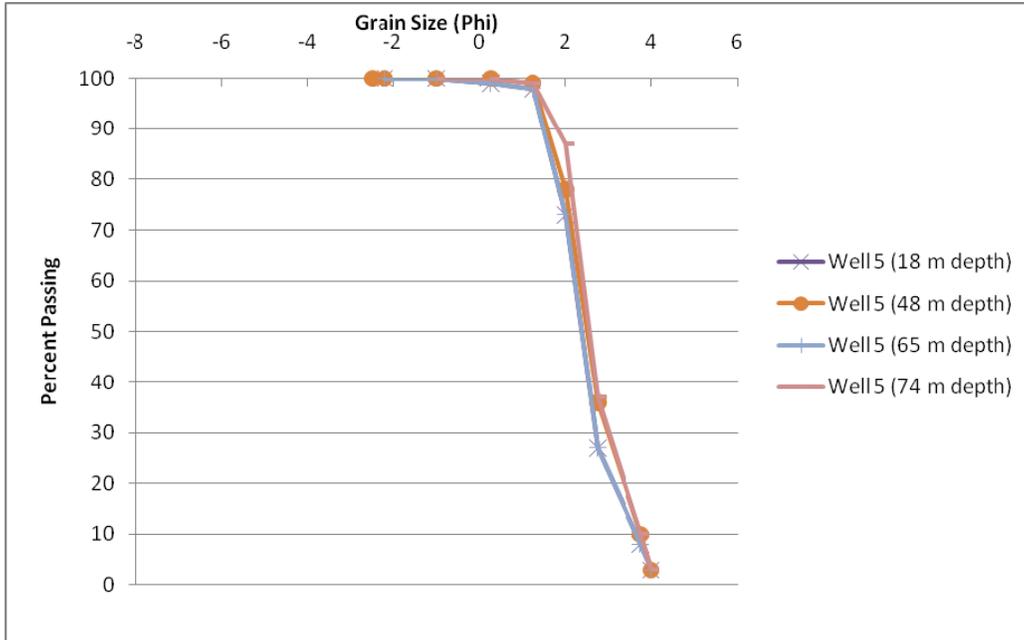


Figure 4.3: Particle size distribution for Well 5 grain size samples.

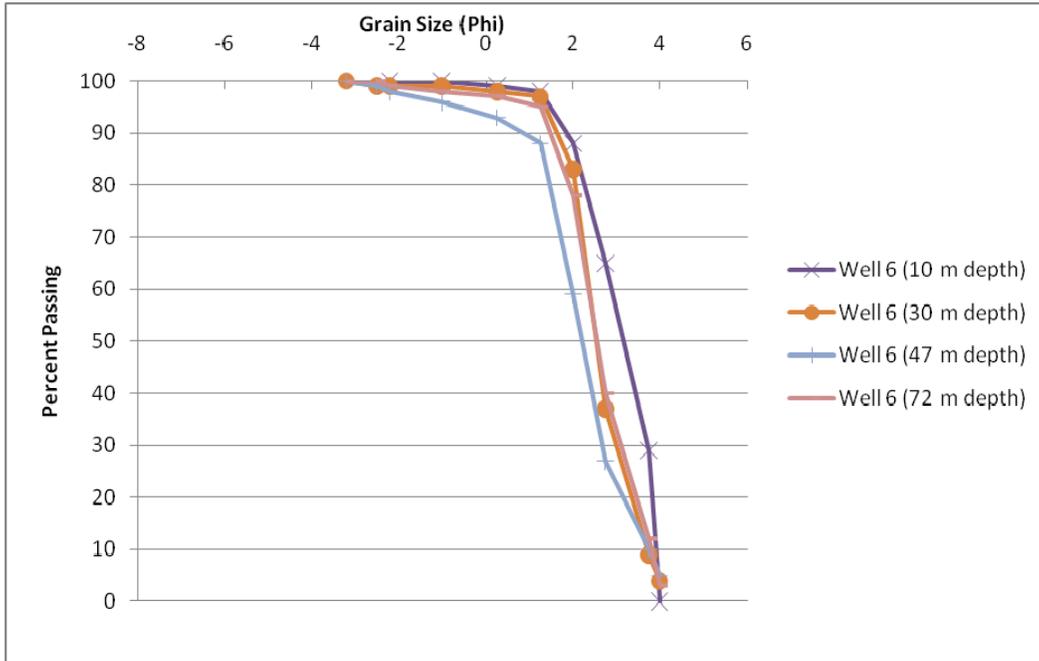


Figure 4.4: Particle size distribution for Well 6 grain size samples.

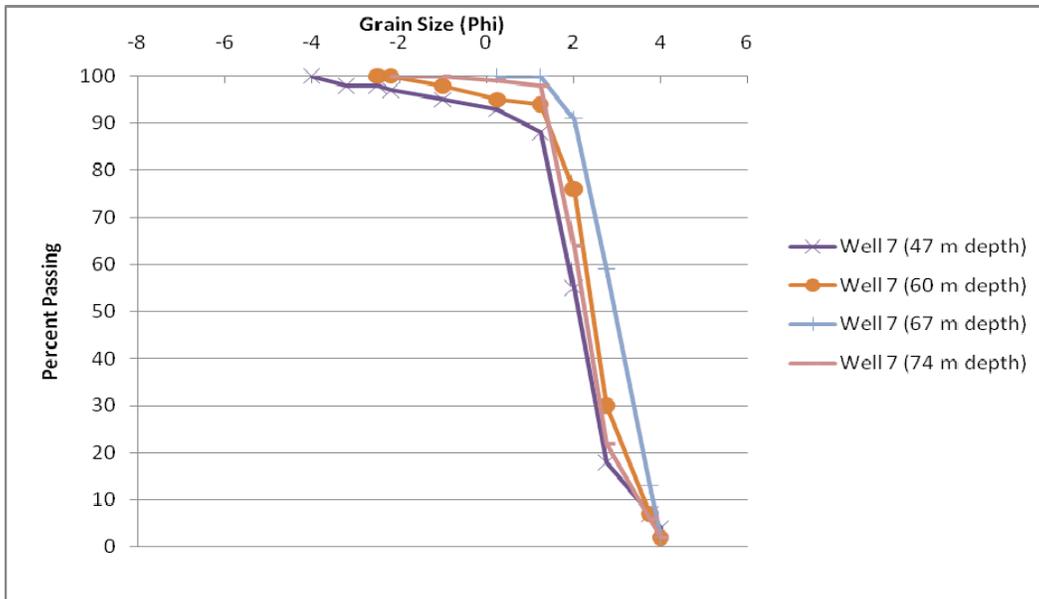


Figure 4.5: Particle size distribution for Well 7 grain size samples.

4.3 Stratigraphic Sections

Three geologic cross-sections were drawn for the study area (Figure 4.6).

Lithologic analysis of these cross-sections was based on borehole and ground water well logs obtained from the MoE WELLS database, sedimentologic characterization during borehole drilling, and detailed stratigraphic interpretations of exposures in the study area. Wells identified in the southwest edge of the study area were shallow and did not provide enough lithologic information to generate a cross-section; as a result these wells were excluded from analysis.

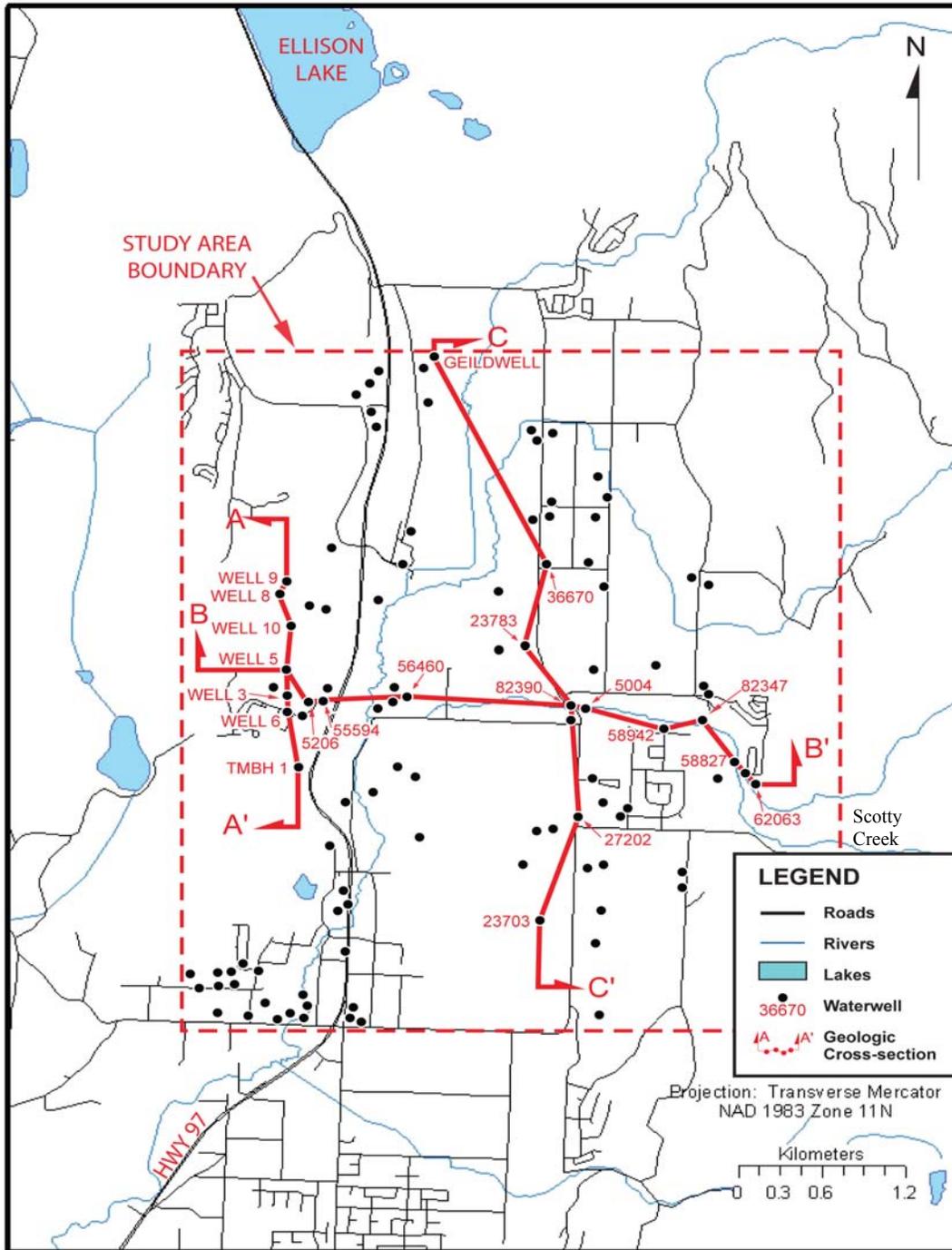


Figure 4.6: Location plan with water wells and geologic cross-sections.

4.3.1 Geologic Section A-A'

Geologic cross-section A to A' runs north-south through the western edge of the study area (Figures 4.6 and 4.7). The cross-section incorporates TMBH No. 1, and UBCO Wells No. 3, 5, 6, 8, 9 and 10. Bedrock was not noted on the well records for any of the boreholes used in this cross-section. The UBCO boreholes were terminated upon reaching a dense, compacted silty sand with subangular gravels and cobbles (Appendix A). This material was not water bearing and the drive shoe became locked in the formation at Well No. 3. and drilling ceased. Stratified, grey, fine to medium-grained sands with interbedded gravel and silt horizons overlies this dense material. This poorly-sorted sandy deposit ranges in thickness along A-A' from approximately 25 m in the north to 60 m in the south. Organic pieces were retrieved from within this sedimentary facies (Figure 4.7). Traces of gravel within the deposit ranged from subrounded to rounded in the lower section of this facies, to subrounded to subangular in the upper section of the facies.

Finer-grained laminated silt and clay overlie the lower sandy facies in the southern reaches of this cross-section. These sediments are evident in several exposures in the area and extremely good lithologic control can be placed on these fine-grained sediments. Individual laminations range from 0.5 mm to 10 mm in thickness with evidence of wavy sediment deformation structures. Thicker, massive silty clay-rich beds ranging from 10 mm to 30 mm in thickness were also observed.

The northern reaches of the cross-section near Quail Ridge Golf Course include a different sedimentologic assemblage (Figure 4.7). A clayey silt with traces of gravel overlies fine to medium-grained sandy facies. The gravel within the clayey silt facies are subrounded with clasts ranging from 2 cm to 5 cm in length. This material is overlain by poorly-sorted silty fine grained sand with varying amounts of gravel. Lenses of laminated silt were also reported within these sediments. These sediments are exposed at the site D exposure, described further in later sections of this thesis. They alternate between laminated silts and clays with dropstones and massive sand and gravel deposits. Several of the sandy deposits show cross-bedding and cross-lamination. Several undulatory unconformities cross-cut through these sediments suggesting periods of erosion. Loading structures are also present. Laminated silty clay overlies the poorly-sorted sandy facies. These laminations are also visible at the site D exposure. The fine-grained laminations range in thickness from 0.5 mm to 50 mm. They have alternating silt and clay layers suggesting a rhythmic deposition. Post-depositional deformation of these fine-grained deposits resulted in undulations in the laminations. Micro-scale normal faulting displaced the fine-grained sediments.

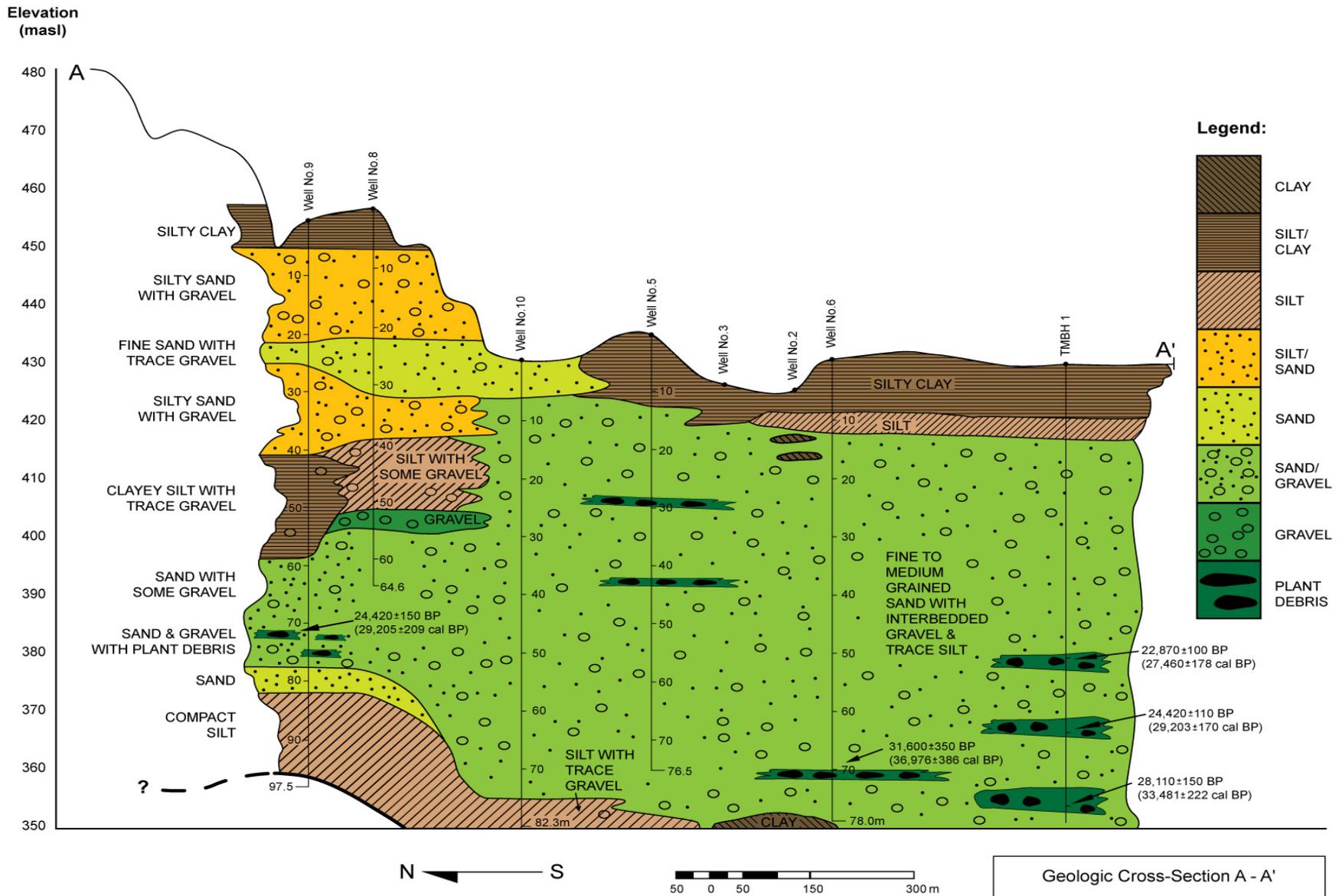


Figure 4.7: Geologic Cross-section A to A'. Line runs north-south through the UBCO campus including radiocarbon dates for wood samples retrieved from drill holes.

4.3.2 Geologic Section B-B'

A total of nine boreholes were examined for the cross-section B-B'. This cross-section originates in the west at the UBCO campus and heads east across the valley (Figures 4.6 and 4.8). The present day Scotty Creek drainage lies immediately to the east. Bedrock was encountered on the east side of the valley in Well Tag No. 62063. No other bedrock was encountered in this cross-section. A dense sand and gravel deposit similar to that in cross-section A-A' lies at the base of the cross-section B-B'. This deposit is believed to be valley wide, onlapping the bedrock on both sides of the valley up to 360 m asl. Vanderburgh and Roberts (1996) observed similar deposits in the North Okanagan. Grey, poorly-sorted, fine to medium-grained sandy facies with traces of gravel overlie this dense material. Significant organic material within these sediments on the west side of the valley (Figure 4.8) have no equivalents noted by drillers in the central or eastern parts of the cross-section. The absence of organics in the central and eastern part of the section may be due to the limited depth to which the boreholes were advanced or apparent oversight by the drillers. Thicknesses for this facies ranges from approximately 60 m in the west to an estimated 100 m in the valley centre. It is composed of laterally- extensive fine to moderately coarse sands, interbedded with pebbly gravels. In the centre of the valley, clayey sand and gravel deposits are interbedded with this sandy facies. The clayey deposits tend to thin to the west and thicken to the east. The beds are finer-grained to the west and coarser to the east,

suggesting a grading of materials sourced from the east. This unit is interpreted as subaqueous debris flow deposit into ice-marginal environments and glacial lakes extending from the Scotty Creek drainage. To the west of the cross-section, fine-grained laminated sediments overlie the sandy facies.

To the east, silty clayey gravelly deposits mantle the bedrock slope. These poorly-sorted sediments appear in several sections along roadcuts. They show poorly-sorted, stratified sand and gravel with cobbles. Localized sections contain compacted bouldery gravel with interbeds of pebbly coarse gravels and sands. Drillers logs report the unit to be dense and difficult to penetrate, with water-bearing lenses of sand and gravel. On the eastern flank of the section, this unit ranges in thickness from 30 to 40 m according to borehole logs. These dense sand and gravel units grade into silty sand with traces of gravel in the valley bottom.

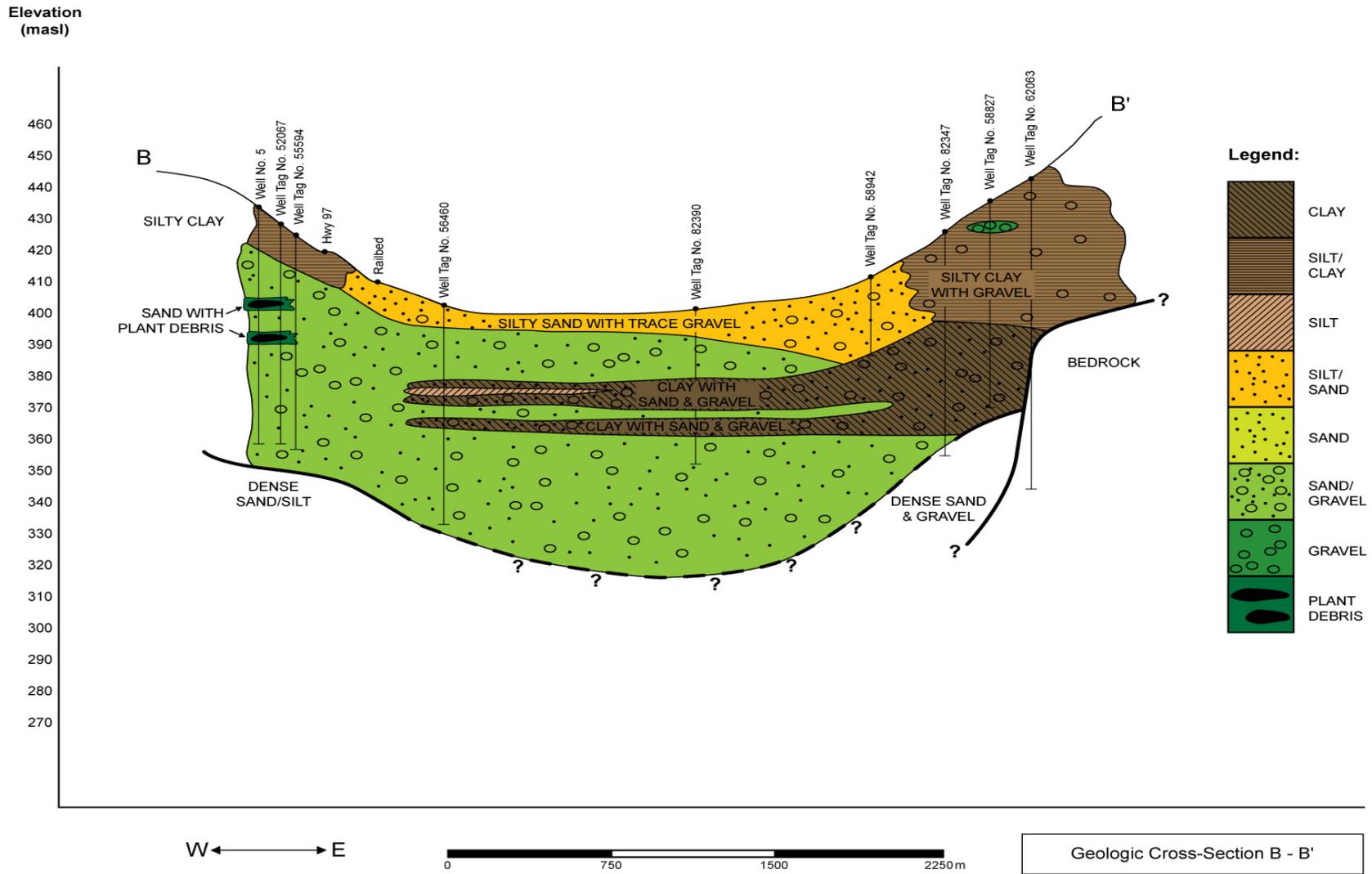


Figure 4.8: Geologic cross-section B to B'. Line runs east-west through the UBCO campus.

4.3.3 Geologic Section C-C'

A total of six water wells and boreholes were used in the reconstruction of Section C-C' (Figures 4.6 and 4.9). This cross-section intersects with geologic cross-section B-B' and runs north south through the centre of the valley. Given the limited number of boreholes and their limited depths and lithologic descriptions, some generalities were required to interpret this section. The upper sediments were described as primarily fine- to coarse-grained sand and gravel with varying amounts of silt and clay. The deepest borehole in this cross-section (Well Tag No 27202) terminates in a dense sand and gravel that is common to each section. The silty and clayey deposits that cross-cut the massive sands and gravels of the main trunk of the valley, may be the result of alluvial fan progradation towards the centre of the valley from the Scotty Creek drainage basin in the east.

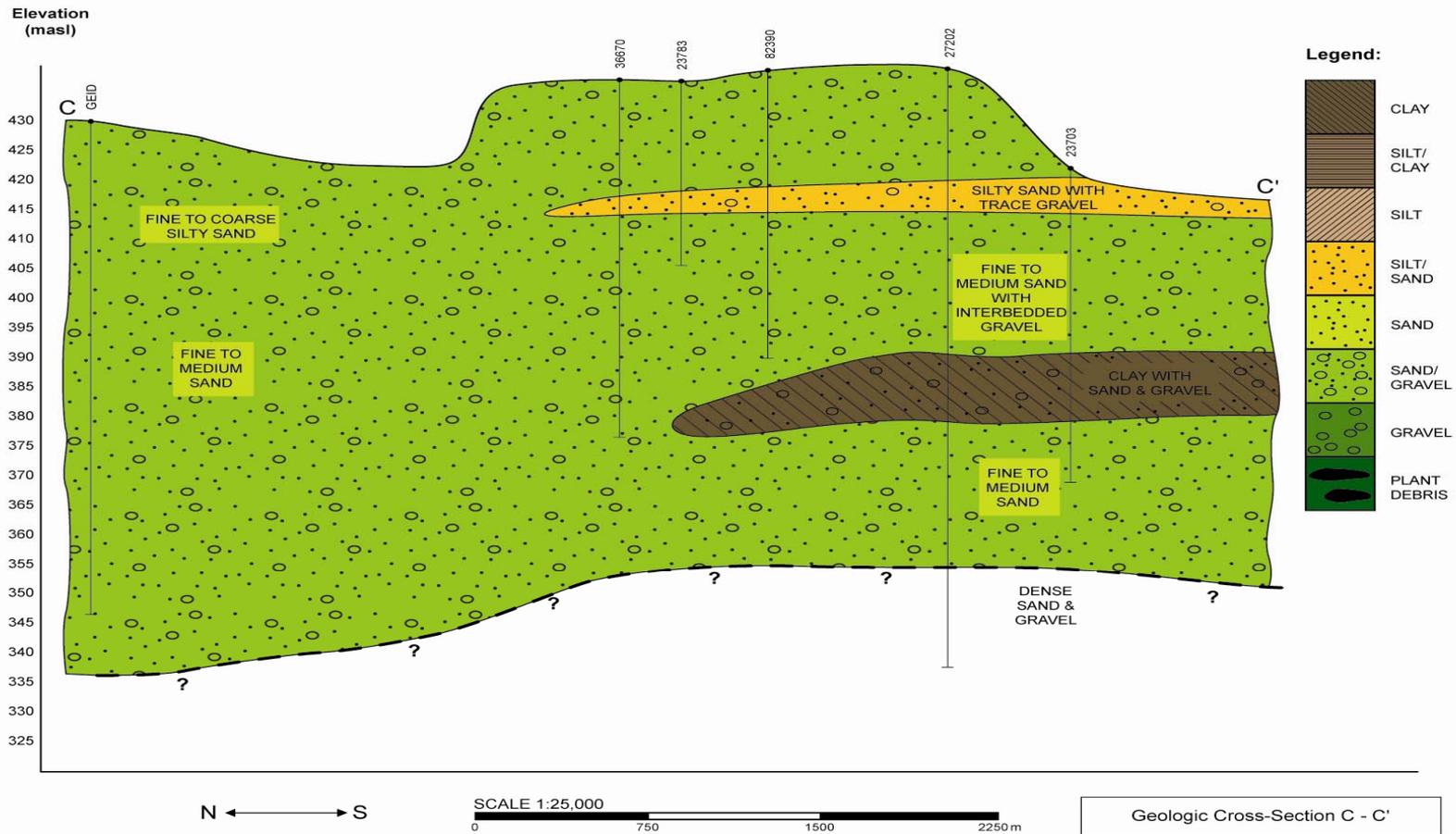


Figure 4.9: Geologic cross-section C to C'. Line runs north-south through the central region of the valley.

4.4 Other Well Records With Organics Present

A search of water well logs in the Ministry of Environment Wells Database, yielded a surprising number of drill logs that mention ‘organics’, ‘wood’ or similar descriptions within the lithologic report. Within the area immediately adjacent to the UBCO campus, the well tag numbers (WTN) that contained wood debris include: WTN 49865 (80 m below ground), WTN 30235 (51 m below ground), WTN 19922 (60-76 m and 79m below ground), WTN 55594 (17-70 m below ground), WTN 52067 (73-79 m below ground) and WTN 88163 (54-67 m below ground).

Other wells in the North Okanagan also mention wood debris in the lithologic descriptions. These wells include some of the deepest Ministry of Environment groundwater observation wells (OW) in the area: OW 117 (WTN 24062) at 247-340 m, 370-390 m and 560-574 m below ground; OW 118 (WTN 24080) at 115-150 m, 189-294 m, 320-350 m and 373-386 m below ground; and, OW 122 (WTN 24093) at 218-241 m below ground. Many other private, domestic wells in the Okanagan also report varying quantities of wood debris at depths ranging from 30 to 100 m below the ground surface, consistent with the organic-bearing beds located in the cross-sections above.

4.5 Campus Geomorphology

This section describes the different surficial sediments identified in the UBC Okanagan campus (Figure 4.10), including hummocky terrain, glaciolacustrine sediments, dense diamicton and esker networks.



Figure 4.10: Location plan of exposures on and adjacent to the UBCO campus.

4.5.1 Campus Esker Morphology

Eskers are long, narrow, sinuous ridges of glaciofluvial sediment deposited in tunnels and conduits under glaciers and ice-sheets (Gorrell and Shaw 1991). The esker in Figure 4.11 consists of a single ridge with steep sides. It is located in a gently sloping valley bottom setting. The feature ends abruptly at a roadcut as it meanders towards the valley centre from northwest to southeast. The esker was fully excavated to prepare foundations for the future engineering building, and detailed studies were possible during sequential excavation. Cross-sections show a composition of bedded sand and gravel with the arched beds conforming to the ridge form (Figures 4.12 and 4.13). Rounded to subrounded, gravel clasts indicate fluvial transport. Cobbles were imbricated showing fluvial transport from northwest to southeast. Laminated silts and blocks of soft sediments are present within the esker. Varied flow regimes in the meltwater discharges are indicated by the different sediment sizes and fining upward sequences. Faulting and sand dyking along the length of the feature demonstrates the withdrawal of lateral support. Injection structures (Figure 4.13) may be the result of uplift due to high water pressures. Sediments on the flanks of the esker were locally disturbed by post-depositional slumping. Gravel and cobble-sized clasts were aligned vertically along the flanks of the esker. The contact between the gravel and sands of the esker and the laminated silts and clays above could be a shear surface resulting from sudden weighting

of the esker from above, most likely the collapse of the ice sheet onto the esker sediments.

There are no till or lacustrine sediments overlying the central ridge of the esker, but lacustrine sediments may have been deformed vertically on both sides of the esker. It is possible that deformation may have rotated parallel laminated lacustrine sediments adjacent to the esker to their current vertical orientation, or shearing and collapse of glacial ice forced coarse grained sediments upwards. Another explanation may be that the silt laminae were draped over a hummocky bedform.

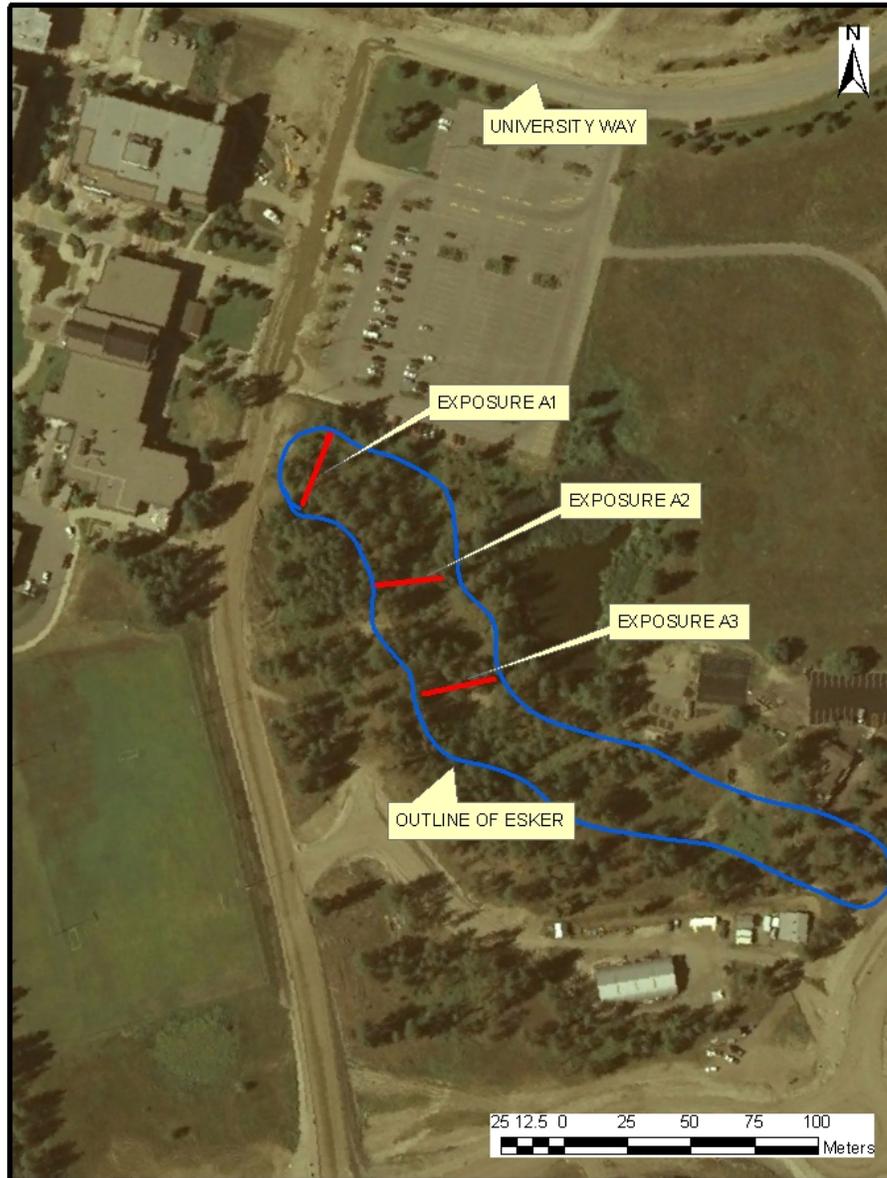


Figure 4.11: Location plan of exposures A1, A2 and A3. The esker runs NW to SE for approximately 250 m as shown by the solid blue outline.

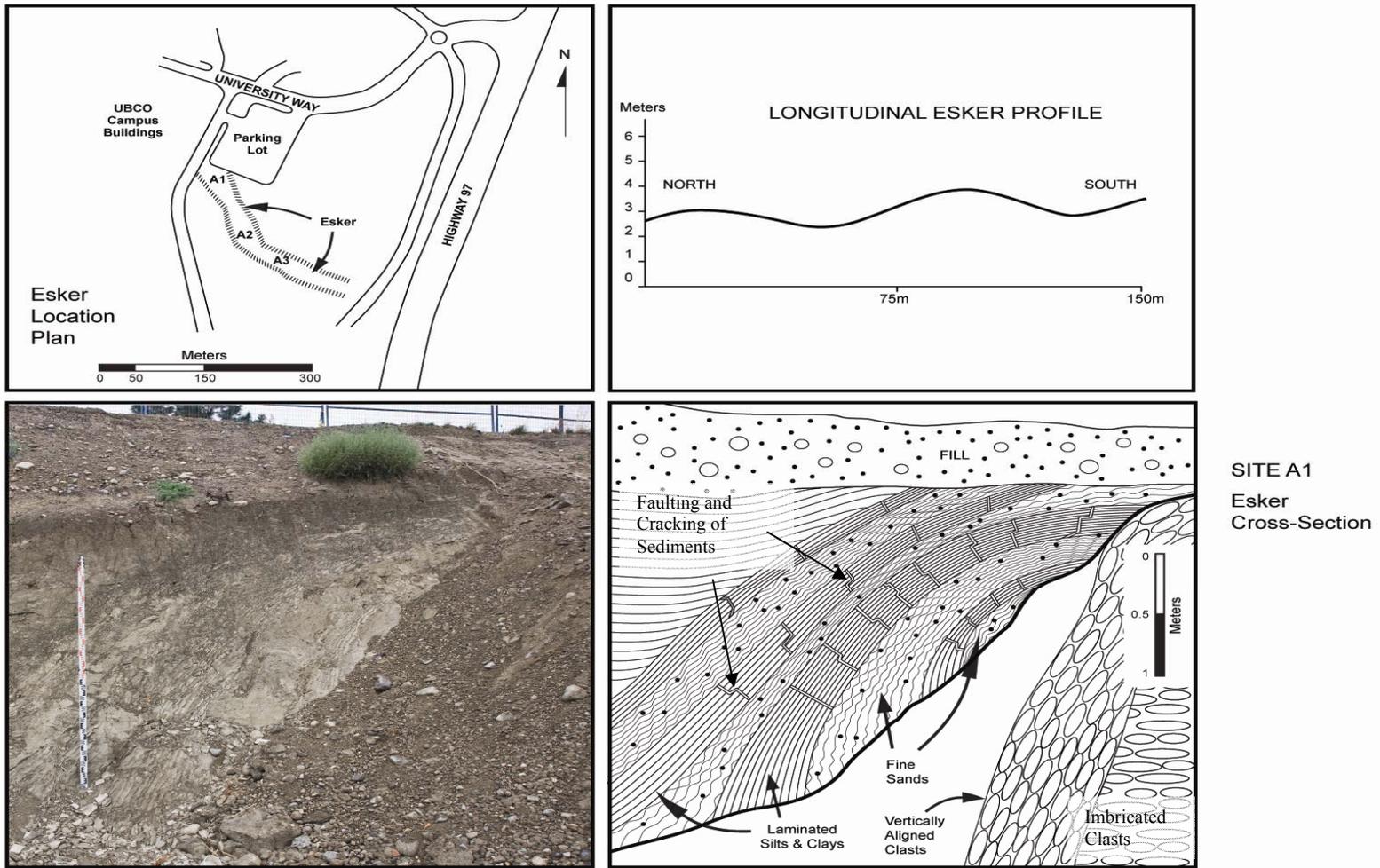


Figure 4.12: Esker location plan and exposure A1 cross-section.

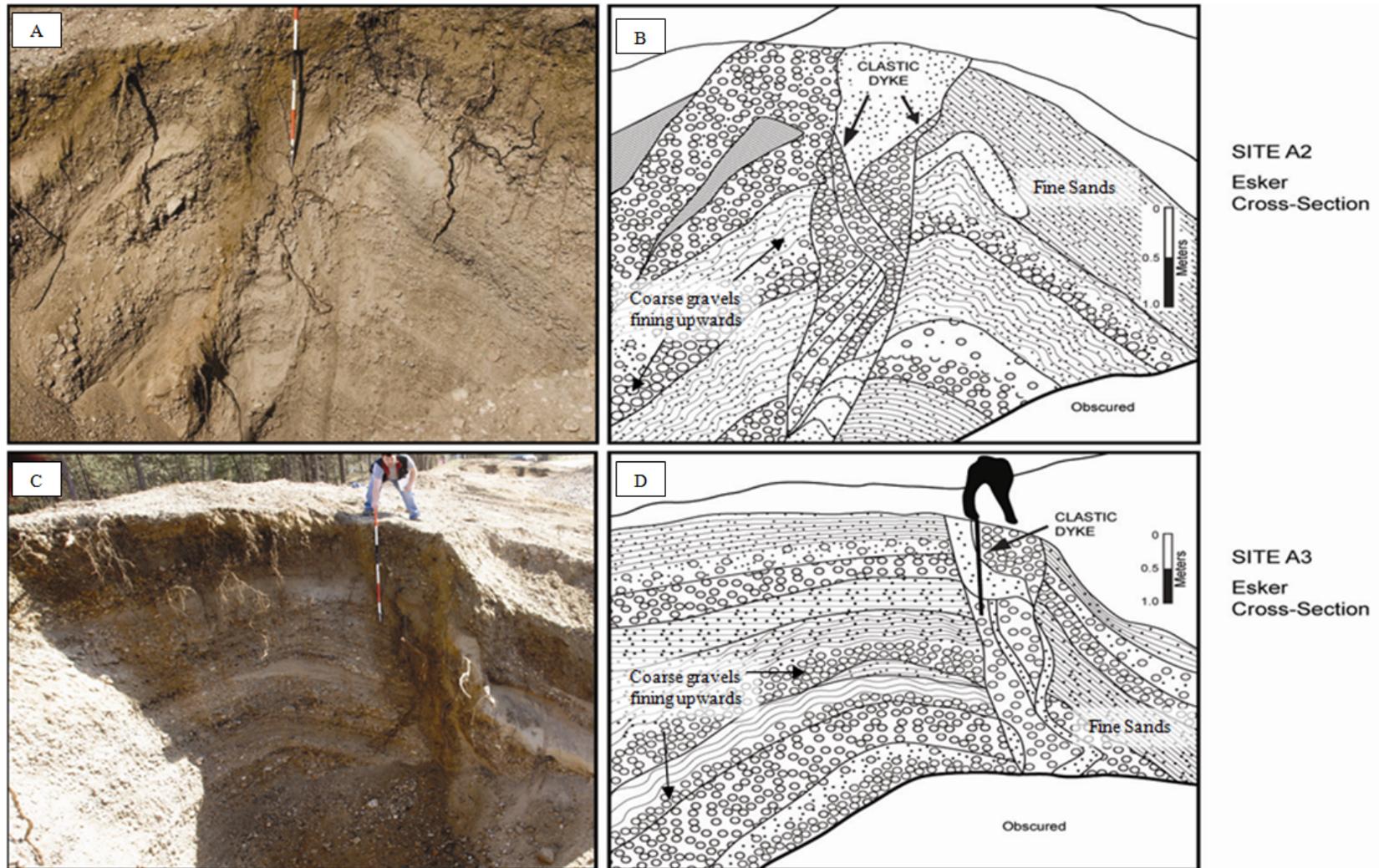


Figure 4.13: Esker cross-sections of exposures A2 and A3.

4.5.2 Campus Surface Exposures

Surficial exposures were available for sediment logging following recent construction activities on campus.

Sites B and C

Sites B and C (Figure 4.14) are located north of the Charles Fipke Centre, where the surficial sediments had been excavated for the construction of the new University Centre Building. At Site B (Figure 4.15), the sediments were primarily laminated silts and clays overlying massive sands that exhibit an overall mounded external shape. The silt laminations were not faulted or post-depositionally disturbed, suggesting they are depositional (conformable) on top of the fine-grained sands. The sands were therefore mounded in hummocky forms prior to the deposition of the silts and clays.

At Site C (Figures 4.16 and 4.17), the lower section exposes a moderately to very dense, massive, matrix-supported silty diamicton. Abundant granite clasts reflect derivation of the unit from local bedrock. Thin beds and lenses of sand, silt and clay occur locally in this unit. The diamicton ranges in thickness from 1 m on the north side of the section to 2 m on the south side. The lower boundary was obscured so definitive thicknesses could not be ascertained. The unit contains abundant cobbles to boulders as compared to finer-grained diamictons located further downslope (east) from this section. The upper boundary of this till unit is irregular and undulatory, suggesting erosion may have occurred after deposition. Stratified silts and clays overlie the diamicton. These

sediments range in thickness from about 1 m in the north to about 1.5 m in the south. They were interbedded with lenses of medium and coarse-grained sands. These sand lenses had bedding structures consistent with a source to the northwest. The sand lenses contain intra-clasts of deformed silt. Localized sands and gravels were also noted as lenses within adjacent lacustrine sediments.

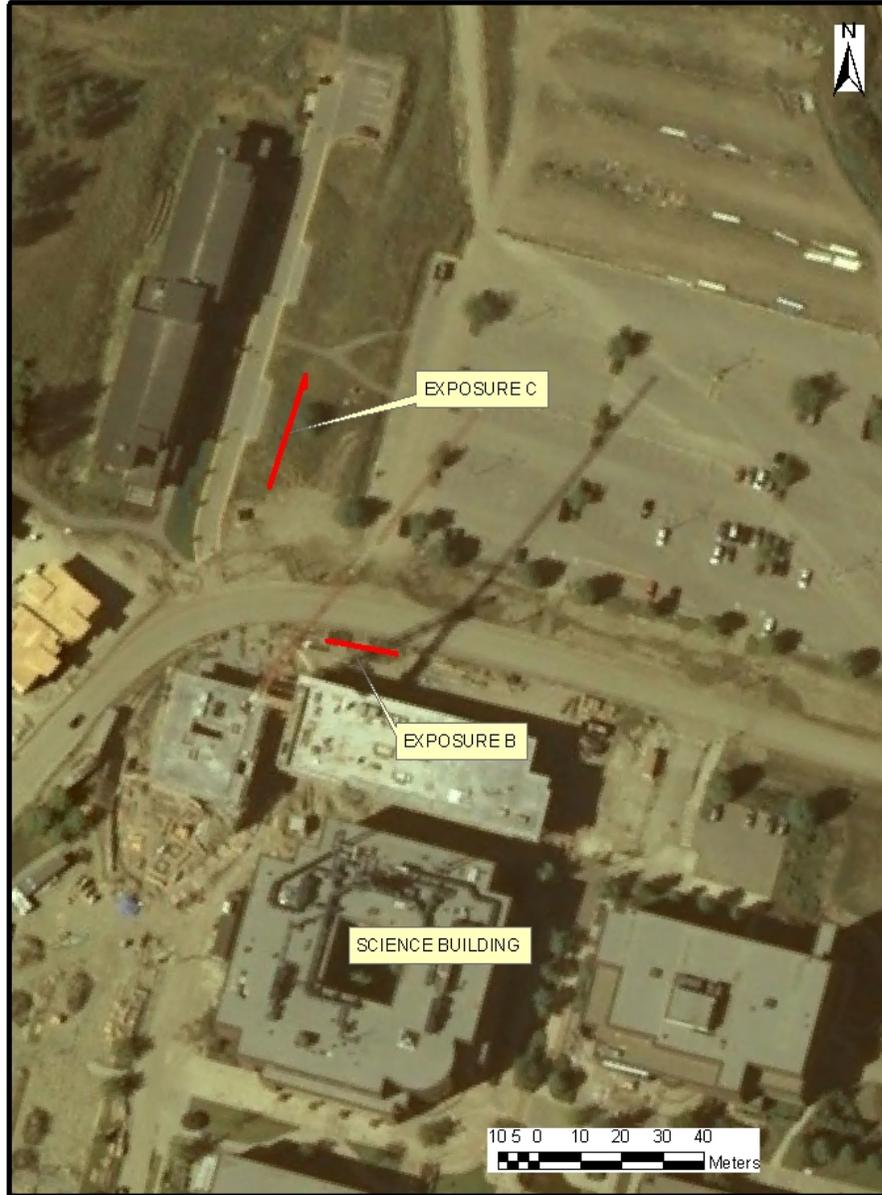


Figure 4.14: Location plan of exposures B and C.

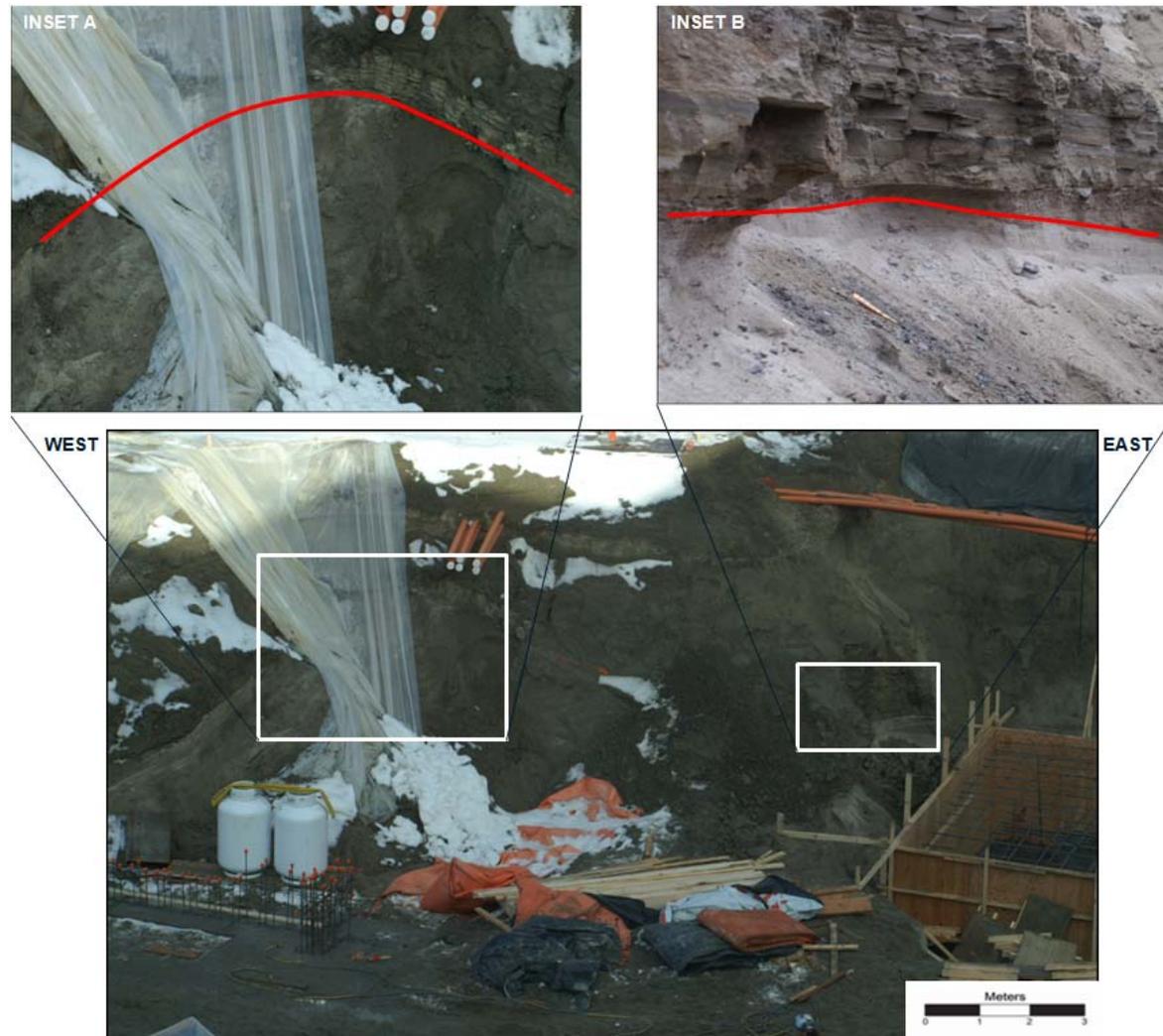


Figure 4.15: Exposure at site B. The thick red line in inset A and B indicates the separation of upper laminated silts from lower massive sands.

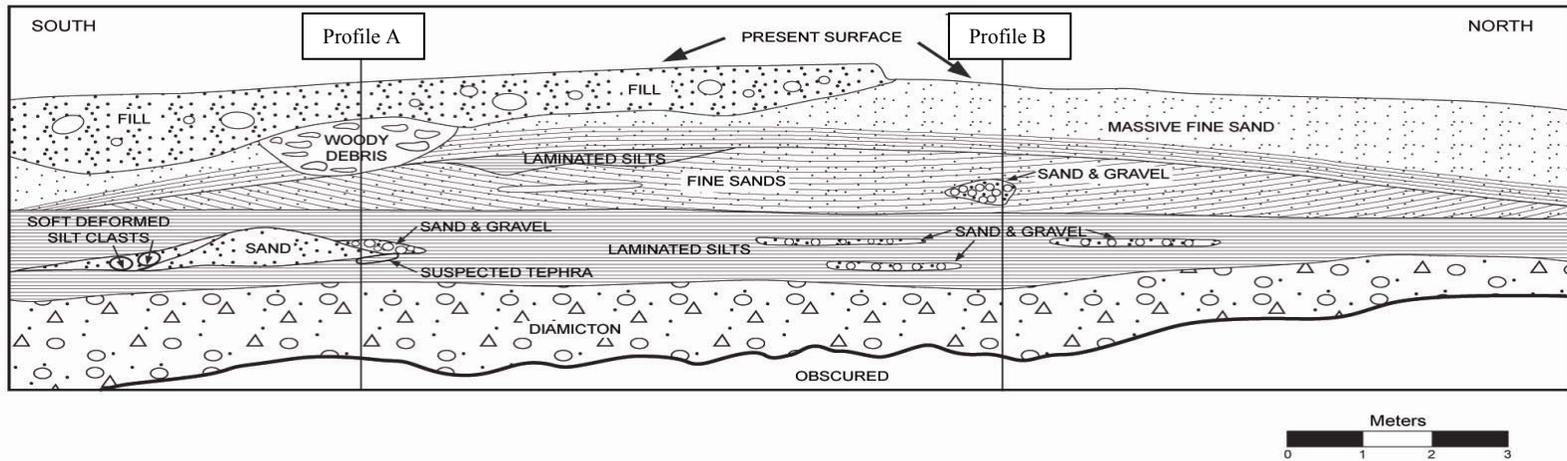
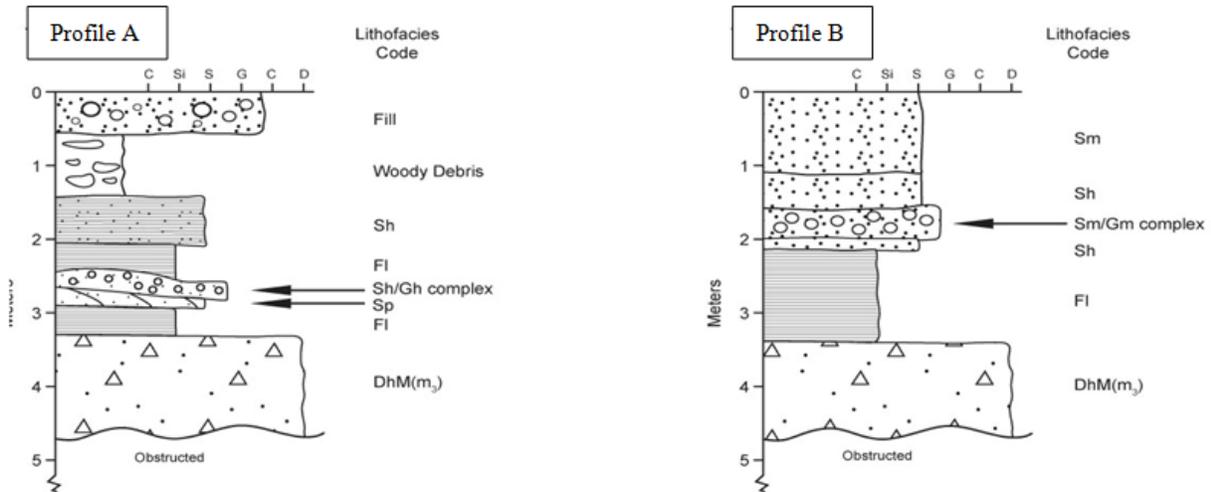


Figure 4.16: Exposure at site C.



Legend:

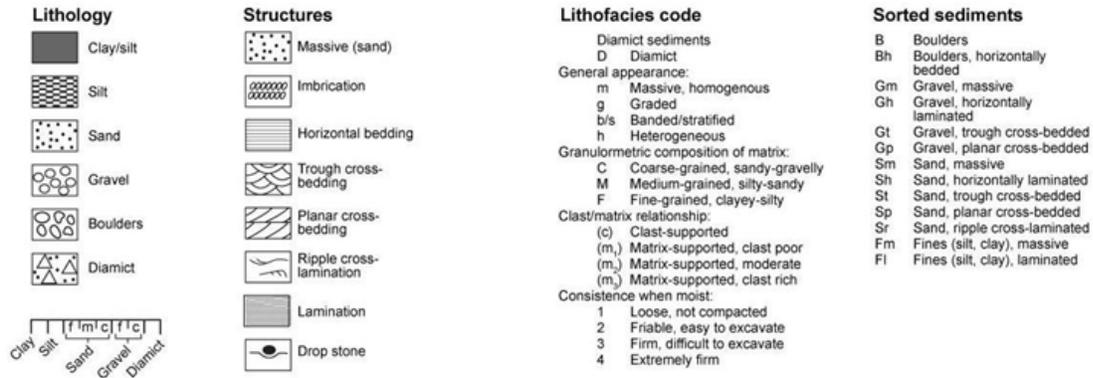


Figure 4.17: Profiles of sedimentology at site C as shown on Figure 4.16.

Sites D and E

Sites D and E are located in an active gravel quarry to the north of the UBCO campus, approximately 200 m north of University Way (Figures 4.18).



Figure 4.18: Exposures at sites D and E. Piermac quarry located north of UBCO (See Figure 4.10).

An active gravel quarry, to the northeast of the UBCO campus, has exposed a 15 m high cut into Quaternary sediments (Figure 4.19). Laminated silt and clay at the base of the exposure overlies cross-laminated and cross-bedded fine to medium-grained sand. The sediments coarsen from 437 m asl to 439 m asl from plane-bedded sands to plane-bedded coarse gravels indicating increasing stream power. The upper undulatory contact of the gravels suggests an erosional or bedform surface. The sediments fine upward to horizontally bedded sands. Dropstones were noted interspersed with the laminated silts at 440-441 m and 443-446 m asl, indicating an ice front in close proximity during deposition.

The sediments begin to coarsen in texture from 441 m asl to 443 m asl. This unit abruptly transitions to finely-laminated silt and clay with occasional dropstones. The presence of dropstones again suggests a glacial lake environment. Dewatering structures and minor faulting in these fine-grained sediments suggest loading by overlying sediments or ice. This loading may have been due to rapid deposition on saturated sediments which induced rapid dewatering. Deformation structures also may be glaciotectonic in origin resulting from ice let down processes. Matrix-supported sand and gravel abruptly overlies the deformed unit. Fabric analysis of clasts from Section D (from above 445 m asl) shows a north to northeasterly paleoflow direction (Figure 4.19). The paleoflow direction to the northeast is opposite to the present day southerly flow

direction. Fine-grained, rhythmically-laminated silt and clay overlie the matrix-supported sand and gravel. This rhythmic unit shows evidence of post-depositional slumping and faulting. Extensive glaciolacustrine sedimentation is indicative of widespread ponding during the retreat of glaciers in the valley.

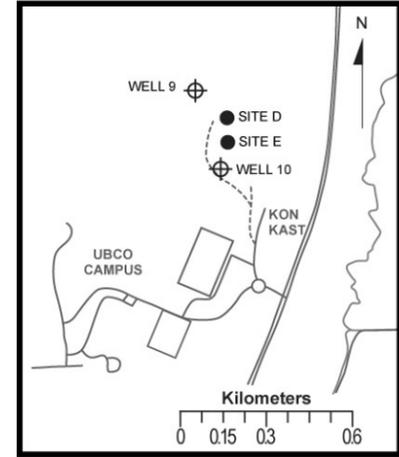
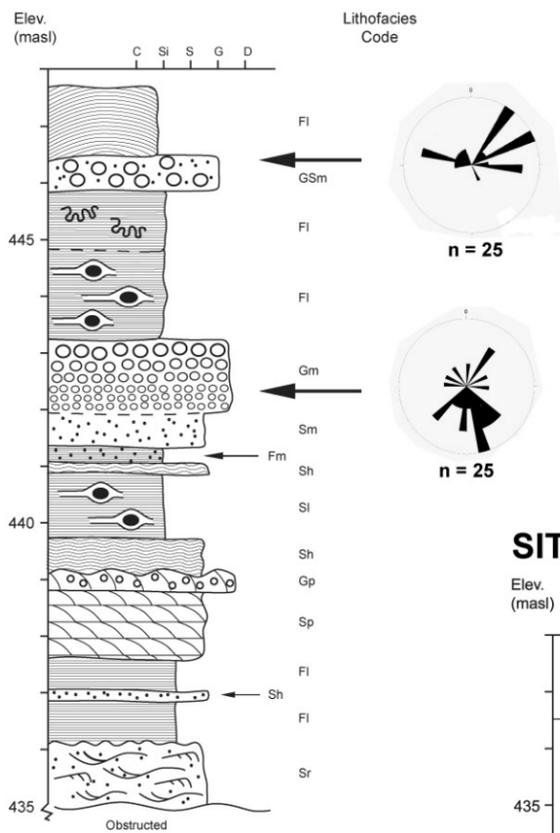
The lowest units at Site E consist of laterally extensive fine- to coarse-grained sands and gravels in horizontal planar beds (Figure 4.19). The sands and gravels alternate throughout the sequence, indicating changing flow regimes. Imbricate gravels throughout the sequence point to a southerly paleoflow direction. This lower unit is approximately 5.5 m in thickness and is oxidized, coated with iron and manganese oxides imparting a reddish-yellowish hue to the deposit. The exposure had been recently exposed during gravel operations. The erosional upper contact of this unit suggests a depositional hiatus of unknown duration.

There is a gradual upward shift in stratification types from horizontally bedded sands and gravels to cross-bedded and trough-bedded sands and gravels. These well-sorted sands and minor lenses of clast-supported gravels coarsen upwards. The gravels are moderately to poorly sorted, crudely layered to planar cross-bedded. The coarsening upwards of these sediments may be the result of ice advance phase sedimentation, lateral migration of meltwaters, or temporal changes in discharge related to weather or glacial plumbung. Two dense diamict units overlie the coarse sands and gravels (Figure 4.19).

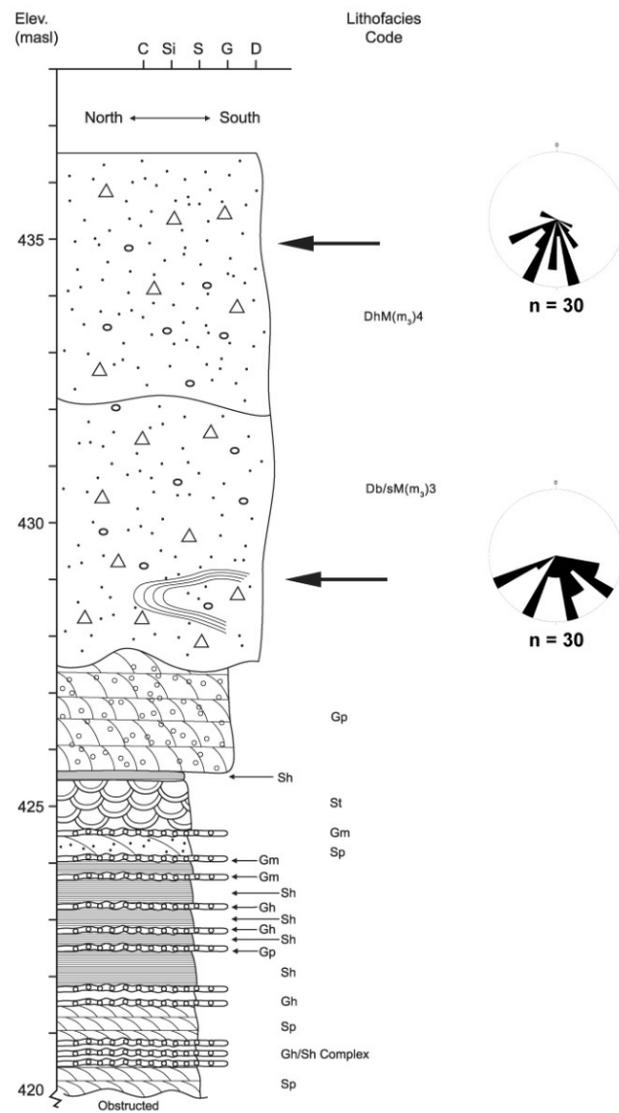
The lower diamicton may be interpreted as a debris-flow deposit from destabilized sediments along the valley margin as evidenced by minor flow laminations. The source of the debris flows could also have been glacial debris (flow till). Alternatively, the deposit could be the product of reworked till from adjacent steep slopes. Crude laminations noted at several locations indicate periods of current deposition. The upper diamicton is dense and matrix supported, with a bimodal fabric with the majority of clasts dipping to the south. The clasts are of varied composition (e.g. granites, basalts and gneisses) that could be derived from local outcrops. The deposit contains striated clasts attributed to glacial action. The upper diamicton is interpreted to be from the Fraser Glaciation.

The presence of current bedded glaciofluvial sediments below the diamicton suggests the valley was free draining to the south prior to the onset of the Fraser Glaciation or that water was flowing beneath the ice. The observed sequence of stratified sediment to diamicton indicates an ice advance.

SITE D EXPOSURE



SITE E EXPOSURE



Legend:

Lithology	Structures	Lithofacies code	Sorted sediments
Clay/silt	Massive (sand)	Diamict sediments	B Boulders
Silt	Imbrication	D Diamict	Bh Boulders, horizontally bedded
Sand	Horizontal bedding	General appearance:	Gm Gravel, massive
Gravel	Trough cross-bedding	m Massive, homogenous	Gh Gravel, horizontally laminated
Boulders	Planar cross-bedding	g Graded	Gt Gravel, trough cross-bedded
Diamict	Ripple cross-lamination	b/s Banded/stratified	Gp Gravel, planar cross-bedded
Clay Silt Sand Gravel Diamict	Lamination	h Heterogeneous	Sm Sand, massive
	Drop stone	Granulometric composition of matrix:	Sh Sand, horizontally laminated
	Dewatering Structures	C Coarse-grained, sandy-gravelly	St Sand, trough cross-bedded
		M Medium-grained, silty-sandy	Sp Sand, planar cross-bedded
		F Fine-grained, clayey-silty	Sr Sand, ripple cross-laminated
		Clast/matrix relationship:	Fm Fines (silt, clay), massive
		(c) Clast-supported	FI Fines (silt, clay), laminated
		(m ₁) Matrix-supported, clast poor	
		(m ₂) Matrix-supported, moderate	
		(m ₃) Matrix-supported, clast rich	
		Consistence when moist:	
		1 Loose, not compacted	
		2 Friable, easy to excavate	
		3 Firm, difficult to excavate	
		4 Extremely firm	

Figure 4.19: Exposures at sites D and E.

Site F

Site F is located along Hollywood Road and runs north-south as shown in Figure 4.20. Recent roadway construction exposed approximately 150 m of sediments along the roadway. Photographs taken of the site (Figure 4.21 and Figure 4.22) show mounded medium to coarse-grained sand and gravel conformably draped with laminations of silt and clay. The mounds ranged in height from 1 to 2.5 m.



Figure 4.20: Location plan of site F exposure.



Figure 4.21: Photo of Site F exposure. Undulating silt beds are outlined with thick red line to show the morphology. Meter stick for scale.



Figure 4.22: Second photo of Site F exposure taken 5 m to the north of Figure 4.21. Undulating silt beds outlined in thick red line to show the morphology. Meter stick for scale.

Site G

The exposures at Site G (Figures 4.23 to 4.27) have provided excellent examples of the sedimentology of the campus area. Recent excavations for the campus residence buildings to the north of Site C (Figures 4.10 and 4.23) afforded an opportunity to further understand the depositional processes and environments and chronology of the sediments.

In Exposures G1 through G4 (Figures 4.24 to 4.27), the lowermost sediments include gravels and cobble gravels. The material generally fines upwards to the top of each cross section, abruptly changing to gravelly sand which forms the uppermost beds. Sediment inputs were spatially and temporally variable, resulting in intercalating beds of ripple cross-lamination and density flow deposits. Remnants of current-bedded sands and gravels seen in Exposures G1 and G2 (Figures 4.24 and 4.25) with Type A climbing ripples, indicates the varying inputs of sediments and relatively high deposition from bedload. Rippled and cross-bedded fine sand overlying the coarse gravel suggests bedload deposition; however, silts and clays mantle these deposits suggesting later deposition by suspension settling. Frequent sand-filled scours and cross-cutting beds are also evidence for pulses in sediment delivery and flow, as well as variable flow directions.



Figure 4.23: Location plan of the site G exposures.

Laminated silt and clay facies occur in each of the exposures at Site G. Rip-up clasts were noted in exposure G1, on the eastern flank of the undulating sand and gravel structure. The sand and gravel beds on the western edge of the exposure were inclined 5 to 10 degrees and tended to steepen and then level off to 5 degrees. Common to this unit are rhythmically-bedded silt and clay, with minor lenses of sand. Whereas the uppermost silt beds are relatively undisturbed, the lowermost silt beds are sheared, folded and in some locations, faulted. The overall geomorphic shape of the bedform is that of large-scale (5-15 m length and 2-5 m height) ridges. Fabric analyses were done on each of the gravelly units to infer the paleoflow directions and are depicted as rose diagrams in Figures 4.24 to 4.27. The ridges of the gravelly units are oriented southwest to northeast, perpendicular to the inferred northwest to southeast paleoflow direction. These bedform ridges are transverse to the paleoflow direction and are more or less evenly spaced. The bedforms can be best described as antidunes, based on the observed properties. Antidunes are formed in very fast, shallow waters at high flow velocities (i.e. Froude number exceeds 1) (e.g., Boggs 2001 page 40). Some antidunes migrate upstream during flow, producing low angle crossbeds directed upstream (Boggs 2001 page 40). The formation of transverse antidunal bedforms is related to flow separation, whereby sediment is transported by traction up the stoss side of the bedform to the crest and separation causes a zone of reverse circulation, producing an eddy (Boggs 2001 page 40). Exceedingly high flow velocities are required to produce antidunes in water depths greater than a few metres; however, antidunes are known

to also occur in turbidity currents (Boggs 2001 page 40). Because antidunes relate to the densimetric Froude number, turbidity underflow antidunes occur at much lower velocity for a given depth than stream antidunes. The overlying, rhythmic sediments, which were formed in standing water or low energy flows, support this interpretation.

Abrupt transitions between each of the sedimentary units were noted, which is typical of sediments deposited by meltwater with widely varying fluxes (Munro-Stasiuk, 1999).

As discussed in Chapter 2, turbidites and debris flow deposits, rip-up clasts and suspension settling are all features common to subglacial lake environments (Munro-Stasiuk, 1999).

The uppermost massive matrix supported, fissile, blue-grey diamicton contains occasional clasts in exposures G1 and G2. It is possible that the upper diamict facies is a lodgement till, given the observed properties.

There are two possible explanations for the sequence of sediments in the Site G exposures. Firstly, a proglacial lake environment may have existed in the area during onset of the last glaciation. Given the location of present day lakes to the north and south of the campus, the idea of a proglacial lake system seems plausible. Widespread lacustrine sediments may be preserved in the sediment record if a proglacial lake had covered the region, however, only isolated relict glaciolacustrine sediments remain at the campus. The

rhythmic lacustrine sequences from the central portion of the valley may have been eroded during the onset of glaciation as an explanation for their absence there.

The observed features at Site G can also be explained by deposition in a subglacial system. At the G1 exposure, sand, silt and clay interfinger and grade conformably into one another. This suggests pulses of sediment delivery into a standing water body. The antidune bedforms are well preserved and record a paleoflow direction from the northwest. The antidunes may have formed beneath standing waves associated with a sheetflow originating from the northwest. Transverse bedforms are seen in subglacial environments (Beaney and Shaw 2000). The upper silt beds in the exposures are relatively intact and drape over the coarse-grained materials.

If the lake was proglacial, the advance and retreat of an ice sheet may have caused extensive shearing of pre-existing sediments. However, the upper silt beds are intact and undeformed and in some places interfinger with the diamicton which implies an environmental and genetic relationship for the sediments if they grade into one another. The landforms described above are best explained through deposition in a subglacial meltwater environment, and more specifically as stationary bedforms in subglacial meltwater flows.

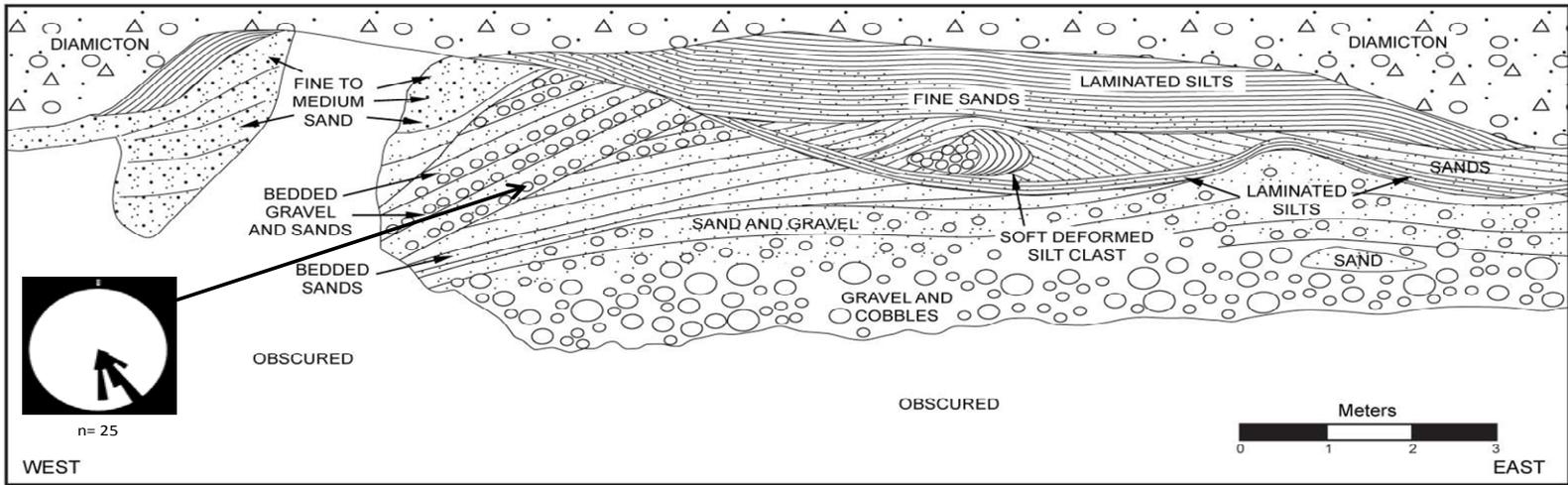


Figure 4.24: Photograph and interpreted section at site G1.

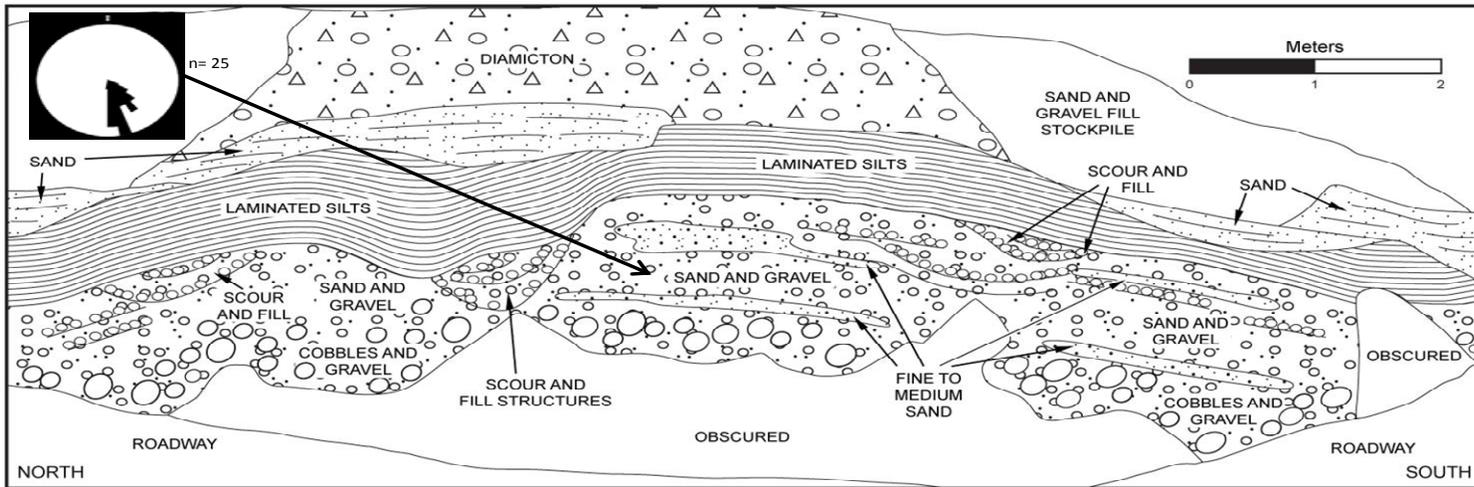


Figure 4.25: Photograph and interpreted section at site G2.

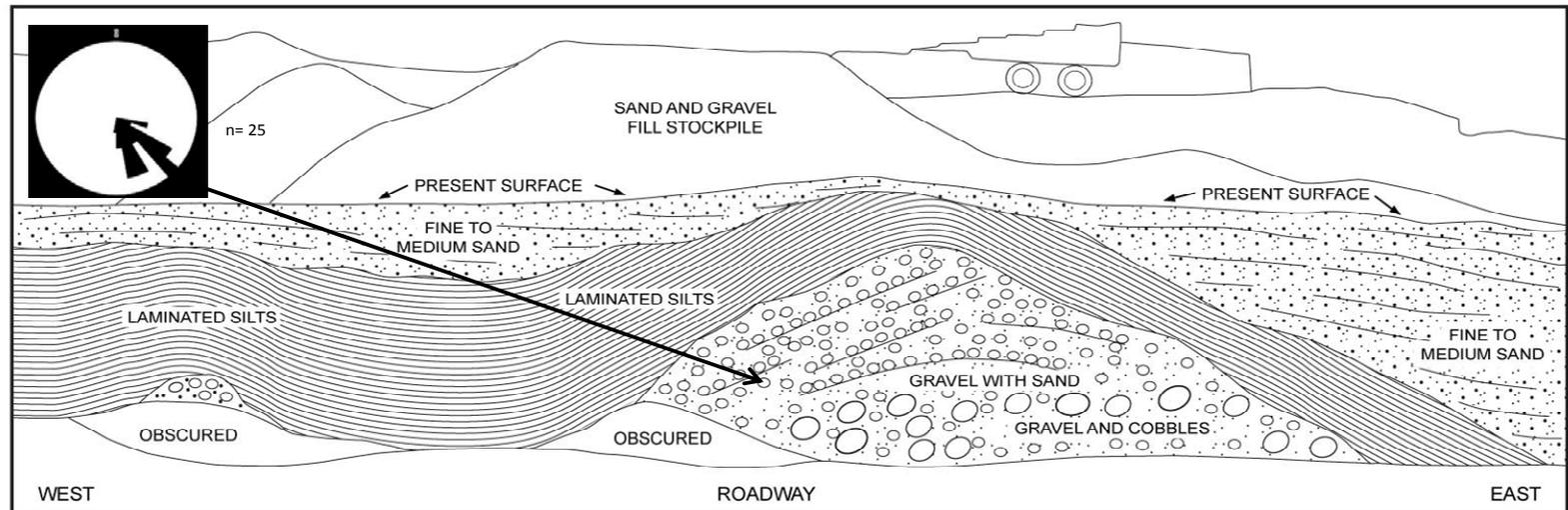
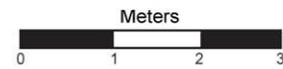


Figure 4.26: Photograph and interpreted section at site G3.

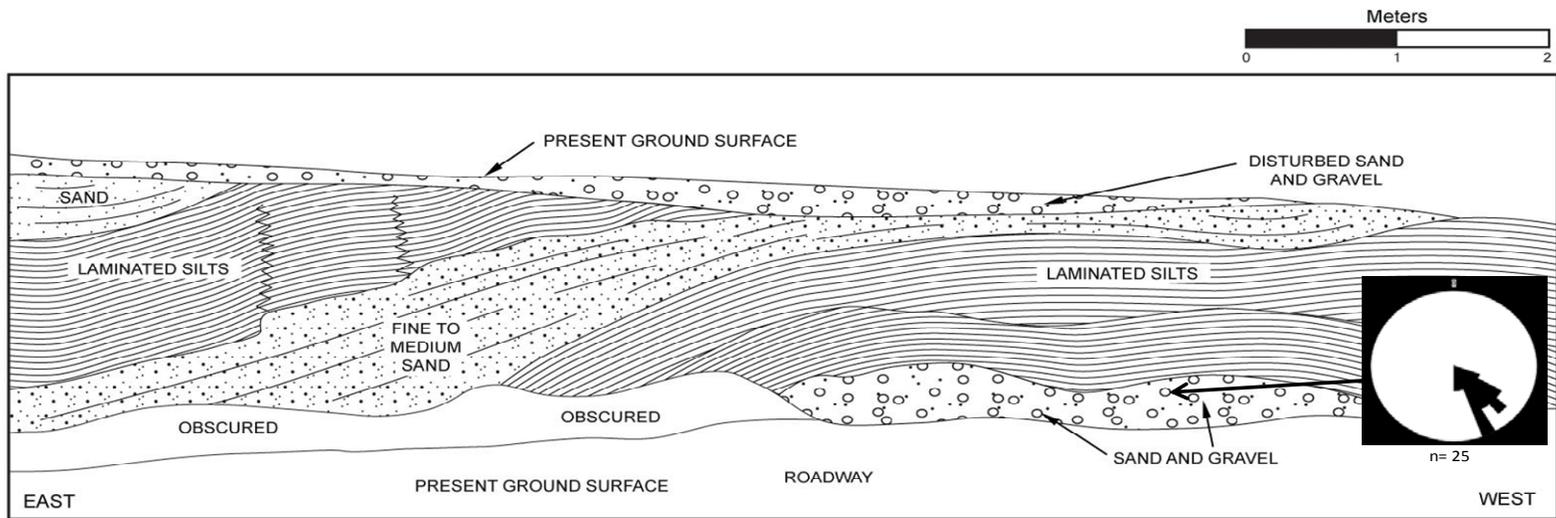


Figure 4.27: Photograph and interpreted section at site G4.

4.6 Seismic Stratigraphy

Ambient background noise was generally high at each of the seismic sections.

The Kelowna International Airport, construction at the UBCO campus, gravel quarrying, and vehicular traffic all combined to make data acquisition difficult (Figure 3.1). Signals were locally contaminated by a high-voltage electrical substation on Bulman Road, which limited the length of the useable portion of that road. Severe trace editing was required to provide useable images because of the localized noise contamination.

4.6.1 Seismic Line 00-01

Seismic Line 00-01 was oriented west-east along a gravel parking lot on the UBCO property (Figure 3.1). UBCO Well No. 4 is located 50 m to the east of the seismic line and provides ground truthing to aid in the interpretation of the section. Shallow, undulatory, high amplitude reflections cross-cut and impinge on each other (Figure 4.28). Photos taken at recent excavations of building foundations in the area (Site C, Figure 4.16), verify structures seen in Line 00-01 and suggest that they may be related to silt beds. The undulatory silt draped structures range from 10 to 30 m in wavelength, with the larger structures seen lower in the profile and successively smaller structures at higher levels. The darker lines in the section may be due to larger contrasts in physical properties of the sediments (i.e. larger amplitudes and longer wavelengths due to sharp

contrasts in sediment characteristics).

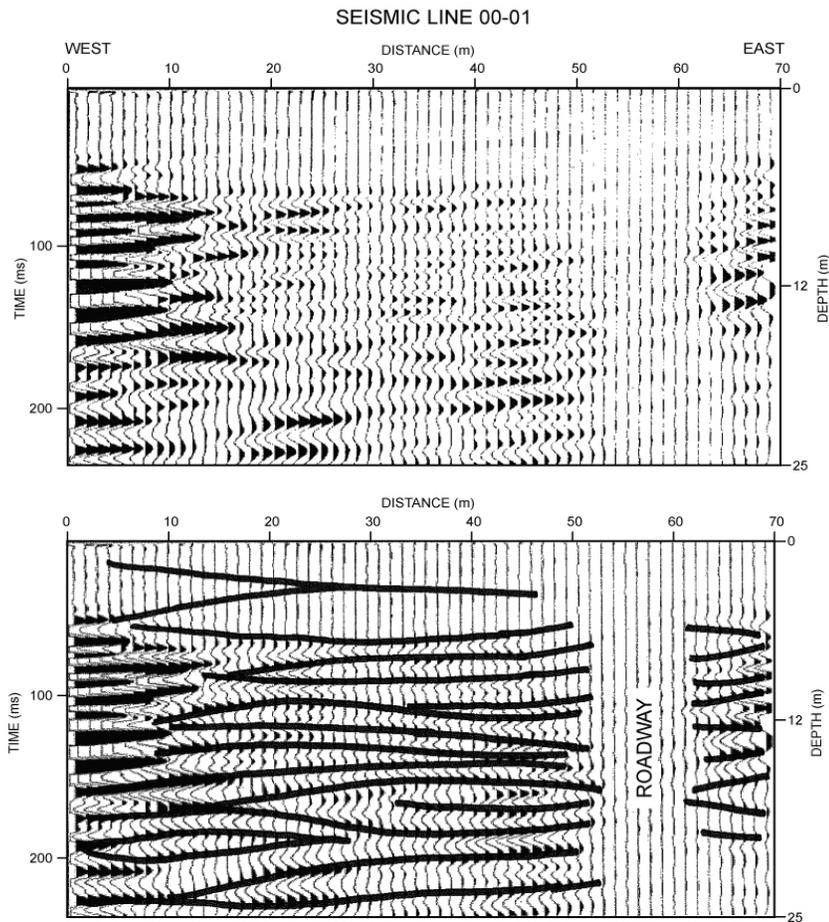


Figure 4.28: Seismic line 00-01. Paved roadway located in this section did not allow for data capture because geophones could not be inserted in the roadway.

4.6.2 Seismic Line 00-02

Seismic Line 00-02, located approximately 200 m east of Line 00-01, is also oriented west-east (Figure 3.1). Wells No. 2, 3, and 4 provide lithologic control for this section. Borehole lithologies indicate the upper 15 to 20 m of sediments are alternating sand and silty clay. As with Line 00-01, multiple highly coherent reflections can be seen in the section. A photo taken of an exposure 50 m from the most easterly end of this line shows the undulating laminated silts separating arcuate lenses of fine sand (Figure 4.30).

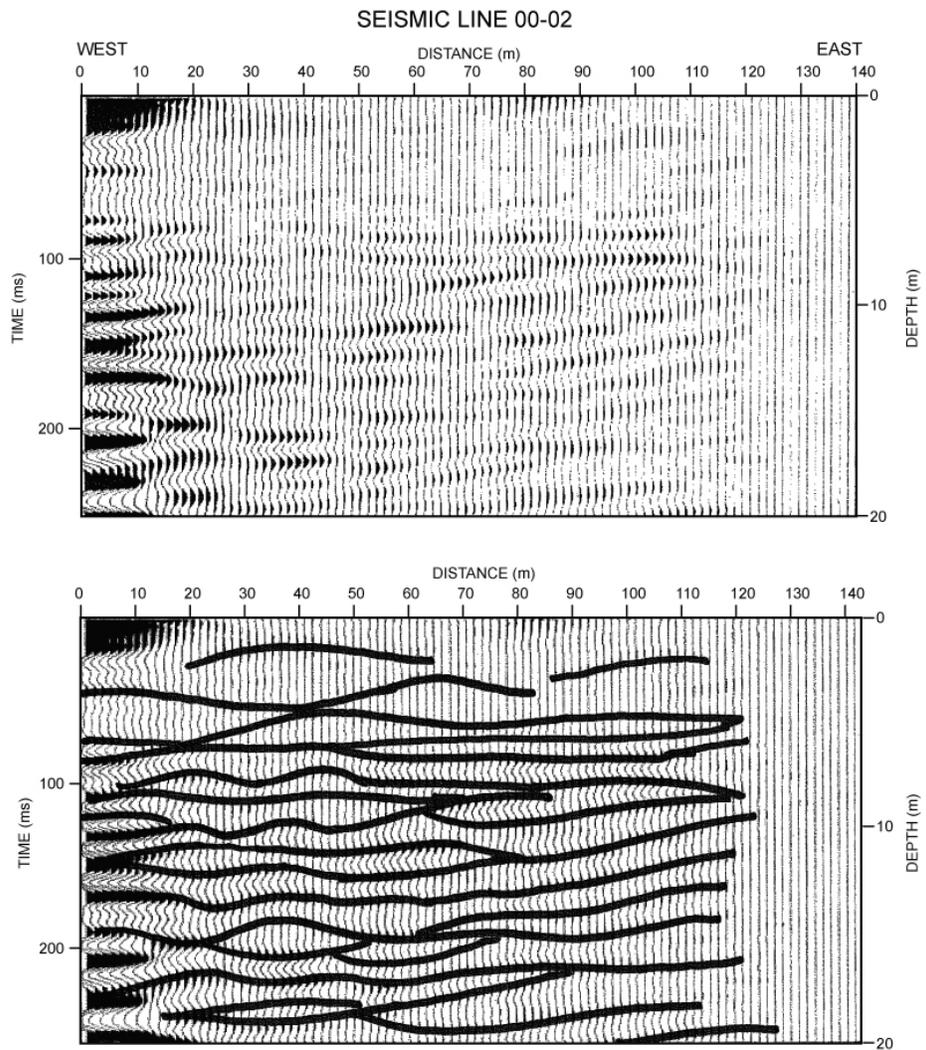


Figure 4.29: Seismic Line 00-02



Figure 4.30: Photo of undulating silts adjacent to Seismic line 00-02. The thick red line indicates the separation of upper laminated silts from lower massive sands.

4.6.3 Seismic Line 00-03

Seismic Line 00-03, located approximately 100 m southeast of Line 00-02, is also oriented west-east (Figures 3.2 and 4.31). Wells No. 6 and 7 provide lithologic control for this section. Borehole lithologies indicate the upper 15 to 20 m of sediments are alternating sand and silty clay. As with Lines 00-01 and 00-02, multiple highly coherent reflections can be seen in the section. Construction activity in the area was considerable during seismic surveying, and as a consequence, background noise prevented a clean seismic section.

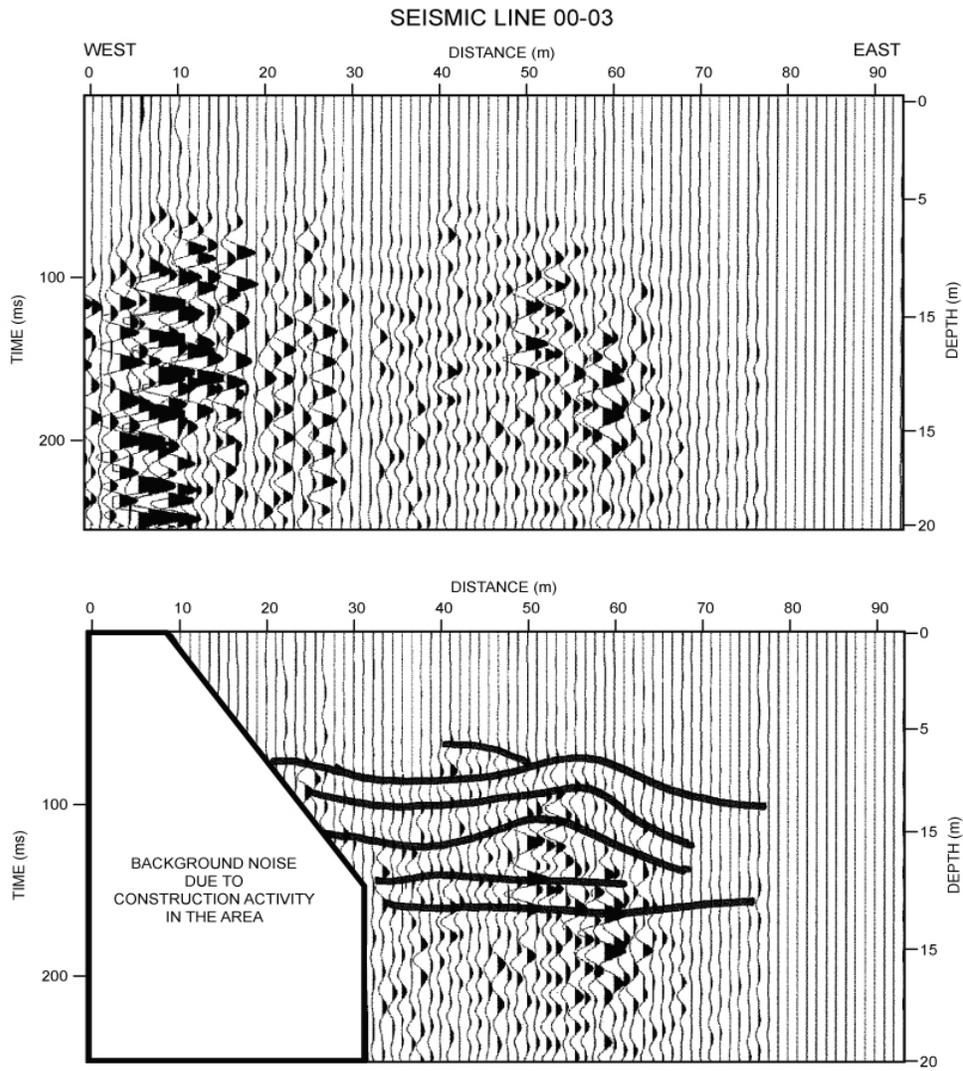


Figure 4.31: Seismic line 00-03.

4.6.4 Seismic Line 00-04

Seismic Line 00-04 is located along Bulman Road, approximately 600 m to the east of Seismic Line 00-03, and 500 m east of Highway 97 (Figure 3.1). Seismic Line 00-04 was 320 m in length and terminated in close proximity to an airport antenna building at the south end of the Kelowna Airport. This seismic line is located along the same roadway as a seismic line that was performed by the GSC (2008)(Figure 4.3). The GSC (2008) described the upper unit in the section as containing a thin surface unit characterized by relatively high-amplitude shear wave reflections, interpreted to be fine-grained sand and gravel. This unit is underlain by a uniformly low amplitude (transparent) seismic unit interpreted to be a massive, finer sand unit or diamicton (GSC 2008). On the western edge of the profile, the GSC observed the greatest depth penetration of the seismic signal and weak indications of reflections at approximately 150 m in depth. The GSC (2008) described this reflection as a potential bedrock surface.

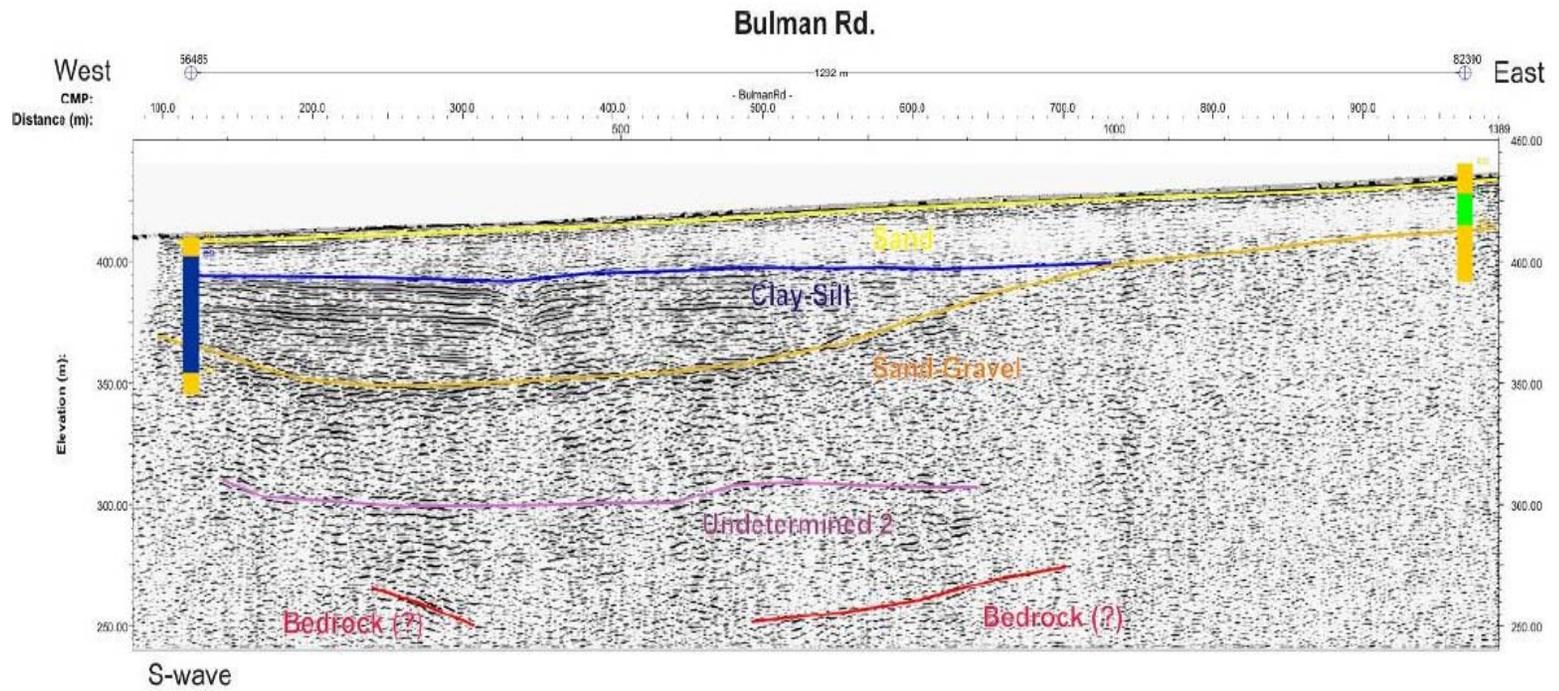


Figure 4.32: GSC seismic reflection survey along Bulman Road (modified from GSC 2008). Seismic Line 00-04 consistent with western edge of GSC survey line above.

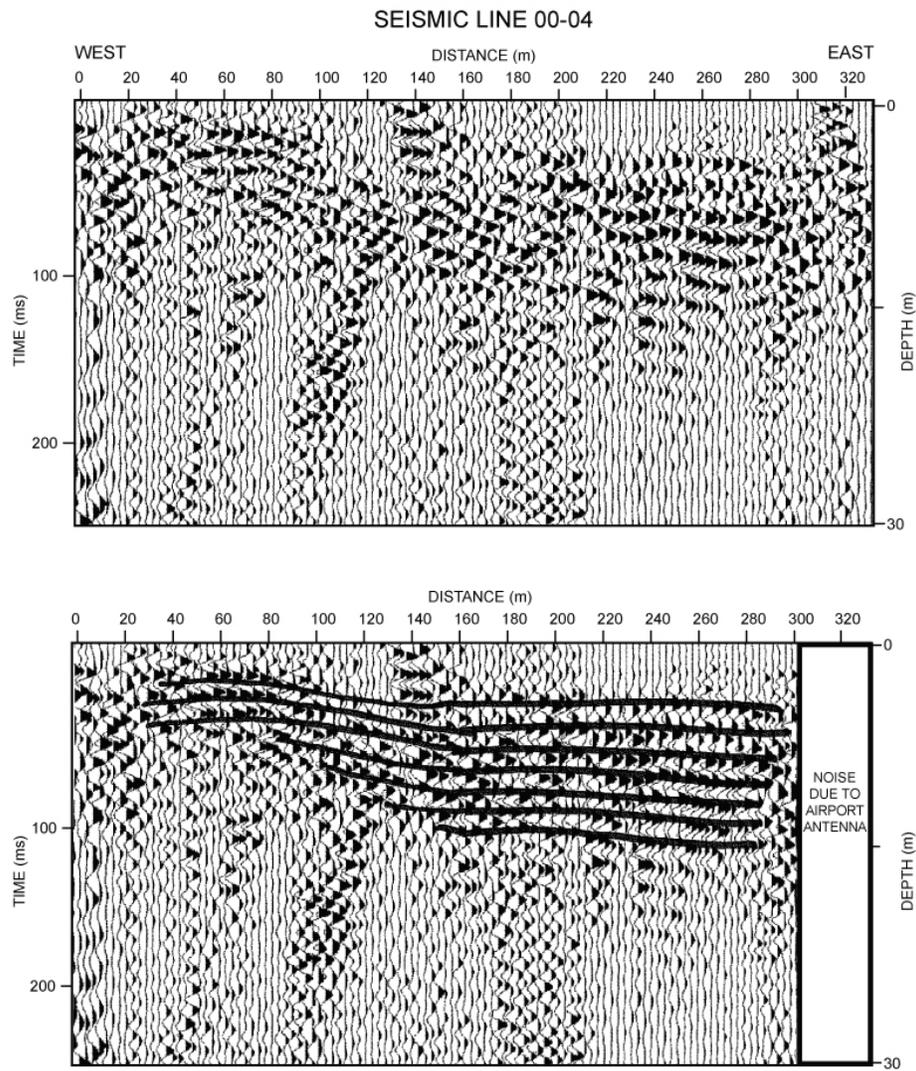


Figure 4.33: Seismic line 00-04

The seismic line 00-04 (Figure 4.33) performed in this study yielded a similar seismic profile as seen in the first 300 m of the GSC (2008) section. Several coherent high amplitude reflections can be traced laterally from east to west, attributed to laminated silts and clays. The east-west geologic cross-section (Figure 4.8) highlights the stratigraphic features that are present in the valley.

4.6.5 Seismic Line 00-05

Seismic Line 00-05 was located along Hollywood Road, running north-south. Wells No 6 and 7 are located approximately 100 m to the northwest of the northern end of this line (Figure 3.1). This seismic section also shows undulatory reflectors interpreted to be silt beds separating lenses of fine to medium sand. The undulations range from 10-30 m in wavelength, based on the seismic section as well as exposures along the roadcut. The distance from crest to trough for the undulations ranges from 3 to 5 m, which match structures in the Hollywood Road exposure (Site F, Figures 4.21 and 4.22).

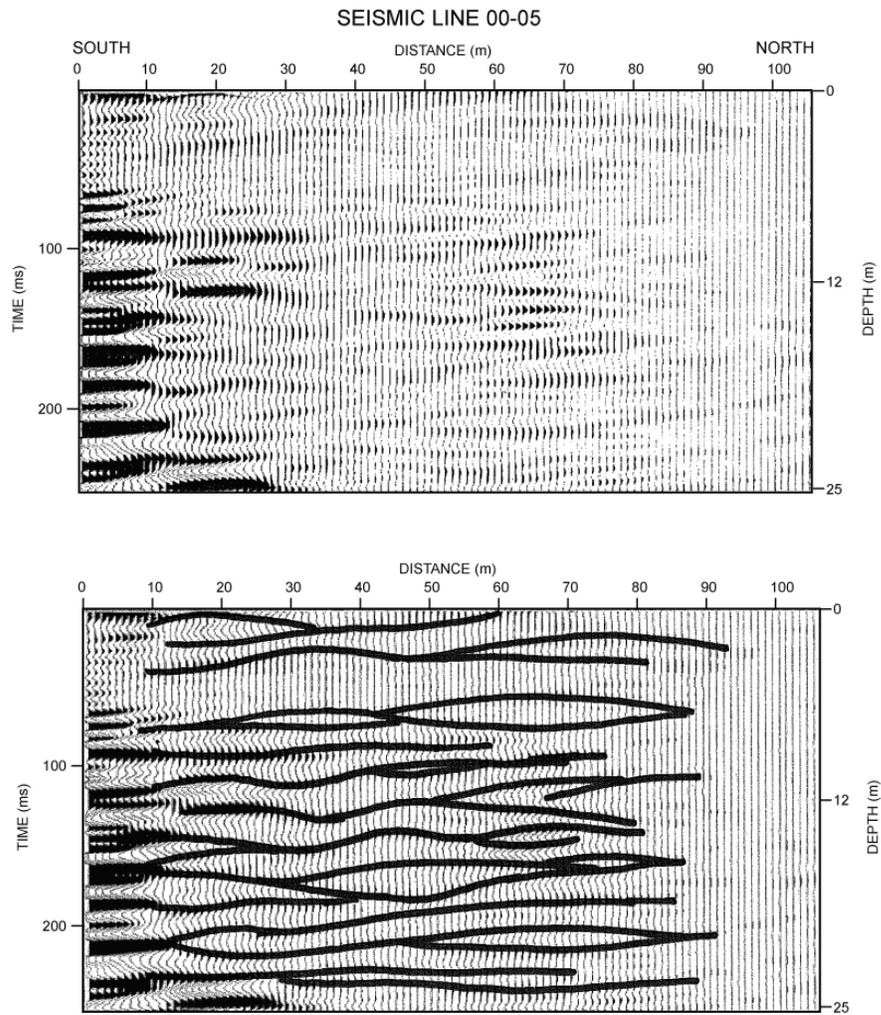


Figure 4.34: Seismic line 00-05.



Figure 4.35: Photograph of roadcut adjacent to seismic line 00-05. Metre stick for scale. The thick red lines delineate the boundaries between sandy bedforms and draped silt laminations.

4.6.6 Discussion of Seismic Survey

The seismic surveying on the UBCO campus provides confirmation of the lateral and vertical continuity of structures that are observed in the surficial exposures A through G. The stated aim of the seismic survey was to characterize the subsurface structures and rationalize the structures using well lithologies and field observations. Seismic reflection surveying was useful in delineating the stratigraphy of near surface sediments and showing their lateral extent. Seismic surveying is an efficient means of gathering high-

resolution shallow seismic data in more urbanized applications. Some seismic lines provided detailed sedimentary architecture (Seismic Lines 00-01 and 00-02), whereas other lines proved to be problematic because of construction activities (Seismic Lines 00-03 and 00-05). Seismic surveying was limited because suitable, accessible areas for seismic surveying were hampered due to the network of paved roads and construction activity on campus. Also, the problems with the low energy source created by the hammer and steel plate approach could potentially be eliminated in future seismic surveys by using a buffalo gun. After discussions with the GSC (Andre Pugin, personal communication, 2008), it was advised that future seismic surveys would benefit from a larger (50+ m) offset as well as a longer seismic record window (500+ ms) to allow for greater depth penetration and longer seismic record. As well, it would have been beneficial to intersect the seismic line directly with known water wells; but limitations in access at the time of this study prevented this.

5.0 DATA SYNTHESIS AND CHRONOLOGY

Synthesis of the observations reported in Chapter 4 is used to reconstruct an integrated stratigraphic model, and to begin to understand the valley fill genesis.

5.1 Stratigraphy

The identification of stratigraphic sequences in areas of limited surficial exposures is a challenge faced by geomorphologists. The stratigraphy of the Central Okanagan region was analyzed using rudimentary techniques such as water well lithologies, but was complemented with inexpensive and sophisticated shallow seismic reflection techniques and surficial geology mapping. The integration of both techniques provides a method to satisfactorily understand the subsurface processes related to Quaternary geomorphology and stratigraphy.

Two models have been presented to explain the valley-fill sequences in the Central Okanagan region. The first model puts forward the idea that all valley-fill sediments are glacial and post-glacial, related to the latest Fraser Glaciation, whereas the second model puts forward the idea that pre-Fraser sediments remain in the Okanagan Valley. Subsurface sediments collected during drilling at the UBCO campus contained organic materials radiocarbon dating from 29,204 to 36,976 calendar years BP. Samples were collected from three different well boreholes and were stratigraphically consistent between the three well locations. As well, THBH 1 yielded samples from three distinct sedimentary horizons that were chronostratigraphically significant, with the oldest

samples collected the lowest in the profile. These samples put the sediments within the Olympia Non-glacial period from 65,000 to 23,000 yrs BP. Radiocarbon dateable material was also collected by Vanderburgh (1993) in the North Okanagan, but the sample was discounted because there was only one sample retrieved and this was interpreted to be a reworked organic sample from older sediments. Other samples recently collected around the province (Section 2.11) provide further evidence of locales in the Cordillera where sediments of interglacial age have been discovered. Radiocarbon dates for these sediments lead me to conclude that sediments deposited during the Olympia Non-glacial period are present in the Central Okanagan and that Model 2 (Section 2.6) best explains the presence of these sediments.

The sands and gravels of the deepest observable sediments at site D are attributed to early stages of Fraser Glaciation and the last stages of the Olympia Non-glacial period (Figure 4.19). The sediments are trough cross-bedded, plane bedded and massive. The cross-beds indicate a palaeoflow from north to south during early onset glaciations. Aggradation of gravel and sand may have occurred due to an increase in sediments supplied from expanding ice during early stages of the Fraser Glaciation. The fluvial sands and gravels coarsen upwards from interglacial sediments to early glacial cross-bedded gravels. The gravel is overlain by a dense diamicton (Site E). The contact between these two units is undulatory and cross cuts beds suggesting a period of erosion.

The advance sequence of the Fraser Glaciation is dominated by diamict (debris-flow) facies. These facies are predominantly reworked older sediments. The debris flow facies underlies fine grained glaciolacustrine sediments. The diamict could be the product of sub-aqueous debris flow deposition into the valley from destabilized valley deposits during glacial onset or it could be the product of focusing of large volumes of sediments into glacial lakes. The cross-valley sequence of silty sand and gravel seen in Figure 4.8 is attributed to an alluvial fan progression from drainages to the east. The sedimentary wedge is inferred to thicken and coarsen from west to east, which further suggests an alluvial fan genesis. Temporary ponding of glacial meltwaters behind the alluvial fan would have created a proglacial lake.

Sediments of a given age are discontinuous throughout the study area with erosion, truncation and interfingering with alluvial fan sediments originating to the east from the Scotty Creek drainage system (Figure 4.8). The variability in thickness and complexity of the uppermost sediments seen in Figure 4.7 may be attributed to localized instability during ice recession with massive meltwater erosion, slumping of valley side deposits, and the creation of alluvial deposits.

A depositional model is developed for the glacial succession seen in the Central Okanagan (Figure 5.1). The deepest sediments are inferred to be from the Okanagan Centre Glaciation (Table 2.1). Although, samples were not collected from this unit for analysis, the geophysical evidence (GSC 2008), the compactness and poorly sorted

texture of this unit, the onlapping sequence and its position stratigraphically below interglacial sediments points to sediments predating the Olympia Non-glacial sequence. This sequence is represented as Unit B1 in Figure 5.1. Nonglacial sediments, correlated to the Olympia Nonglacial interval, overlie these glacial sediments (B2). Non-glacial sediments are overlain by ice marginal, ice advance sediments, diamicton of the Fraser Glaciation (C), interfingering with alluvial fan deposits (E) and finally late-stage glacial sediments (D) and contemporary fluvial deposits (F).

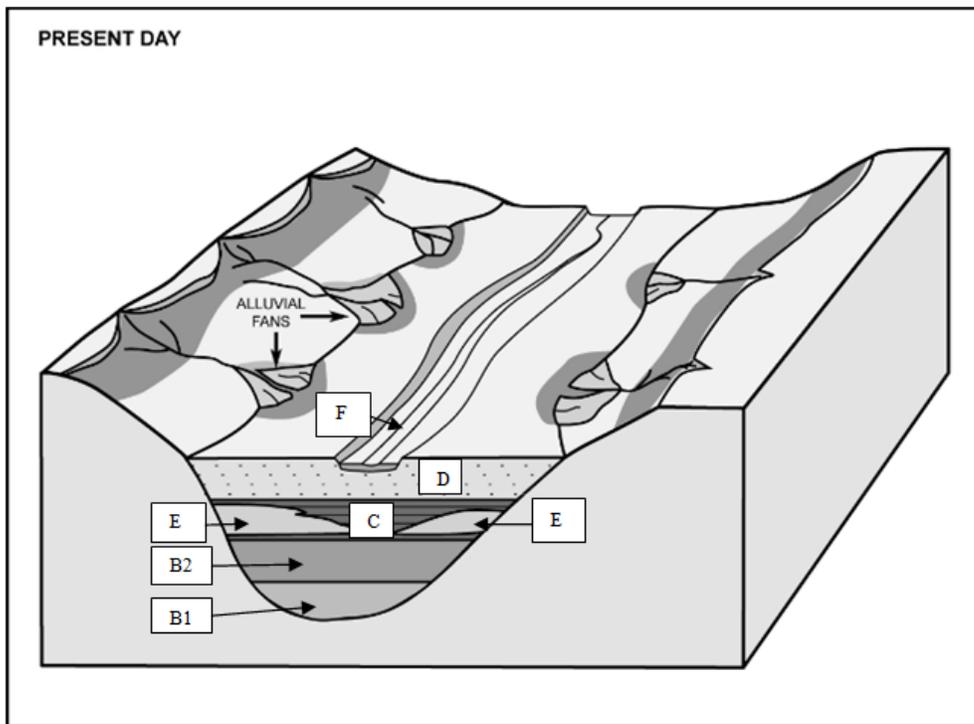


Figure 5.1: Model of valley-fill sequence in the Central Okanagan Valley. Sediment units described as subglacial fluvial of the Okanagan Centre Glaciation (B1), nonglacial of Olympia Nonglacial age (B2), glacial sediments of the Fraser Glaciation (C), alluvial fan (E), and Holocene age sediments (D and F).

5.2 Geomorphology

Landforms in the Central Okanagan region were analyzed using principles of sedimentology and geomorphology to determine if their origin was related to direct glacial ice effects or to meltwater erosion and deposition mechanisms. The relative timing of the eskers and hummocks described here is important in determining the paleoenvironment.

Subglacial ponding is inferred to have formed lake basins in preglacially-formed valley depressions similar to the deep basins seen today in the Okanagan Valley. The entire region was covered with glacial ice during the Fraser Glaciation, causing localized subglacial lakes and changes in drainage networks with changing physiographic divides (Lesemann and Brennand 2009). Drainage of these subglacial lake systems may explain the formation of drumlins (Shaw 1983, 1989; Shaw and Kvill 1984), tunnel channels (Beaney and Shaw 2000), hummocky terrain (Munro and Shaw 1997), and transverse bedforms (Beaney and Shaw 2000).

After the initial ice advance from the north into the study area, water was impounded. Sediment and meltwater fluxes are attributed to diurnal or seasonal drainages of supraglacial lakes to subglacial positions (Munro-Stasiuk 1999). Water flowing into the temporary subglacial lakes may have caused the formation of subaqueous fans. Such fans are created when flowing water enters a standing body of water. The flowing water decelerates through flow expansion upon entering the water

body and deposits sediment (Russell *et al.* 2003). High-energy flood deposition can create a subaqueous fan in a matter of days or weeks (Gorrell and Shaw 1991; Russell *et al.* 2003). Sedimentary features associated with subaqueous fans include antidunes, climbing ripples, dunes, scours and diffusely graded sands (Russell *et al.* 2003). From the general fining upwards sedimentary sequences seen in the site G exposures I invoke two genetic hypotheses (Figures 4.24 to 4.27): 1) the erosional and depositional sequences are due to a catastrophic flood event (i.e. changes in flow velocity allow for coarse-grained materials to contain interbeds of silt), or 2) the erosional and depositional sequences are the result of numerous flood events. The recent high resolution seismic profiling performed by the GSC within the Kelowna area revealed relatively high amplitude reflections near the ground surface (GSC 2008). These high amplitude reflections were inferred through limited borehole lithologies to be from coarse-grained sediment (GSC 2008). A relatively continuous, flat lying unit of discontinuous reflections mantles an underlying sand/gravel package. From the seismic sections, an undulatory contact between each unit suggests periods of erosion alternating with periods of deposition. This is consistent with the erosion of pre-existing units through subglacial meltwater scouring and subsequent deposition of a denser material. This denser, probably coarser, unit is interpreted to be diamicton (GSC 2008). Alternatively, during periods of destabilization as hydrostatic pressure gradients waned, sediments along the hillsides may have sloughed into the valley bottom creating subaqueous fans with

intervening deposition of sorted sediment by meltwater. Such fans, if forming locally during meltwater discharge, would have involved pulses in sediment delivery.

Occasionally, large volumes of meltwater would have drained into the subglacial lake, causing transverse bedforms (Figures 4.19, and 4.24 to 4.27). Paleoflow reconstructions suggest an initial northerly source of meltwaters, but late stages of northwesterly flows suggest additional sources of meltwaters (Section 4.5.1). Drainage of an entire subglacial reservoir could have taken hours to days, depending on the spatial extent of the basin (Wingham *et al.* 2006). Cobbles and gravels would have been reorganized in the high intensity flow, creating megaripples and undulating antidunal bedforms (Figures 4.24 to 4.27). As flows subsided, finer-grained materials mantled the gravel. Repeated pulses probably caused by drainage of impounded subglacial reservoirs would be recorded as thick sedimentary cycles. These cycles are identified in Figures 4.28 and 4.29 extending to depths of 15-20 m.

As the ice settled back to the ground surface, diamicton would have been deposited. Later surges in meltwaters would have elevated subglacial pore pressures, creating meltwater conduits and causing the ice to be repeatedly lifted off the bed floor. As ice settled back to the substrate, diapirs would have penetrated overlying sediments (as seen in the esker in Figure 4.13). Ice pressed deformation is seen in Exposure A (Figure 4.13), where overlying lacustrine beds are vertically aligned adjacent to the esker.

To the north of the UBCO campus, a glaciolacustrine sequence overlies diamicton (Figure 4.19). The presence of dropstones suggests proglacial or subglacial lake sedimentation. The lacustrine sediments are post-depositionally faulted and contorted suggesting initial ice support of the sediments. Extensive glaciolacustrine sediments overlie the entire sedimentary package indicating late-stage ponding of shallow lakes.

This sedimentologic reconstruction of the deposits leads to a possible explanation that catastrophic drainage of a subglacial lake(s) produced deposition of large-scale transverse bedforms prior to grounding of the ice sheet. These bedforms are overlain by an esker containing gravel and sand and formed in an ice walled conduit. Laminated silt and clay were deposited over the sand and gravel with intervening episodes of erosion. Ice overburden pressure on the esker sediments caused gravel and rhythmic silt and clay on the outer margin of the esker to be deformed vertically. This suggests a subglacial origin for the rhythmites. Subsequent ice melting created marginal lakes. Evidence to support this conclusion can be seen in the ice-rafted drop stones in the glaciolacustrine sediments overlying the diamicton at the site D exposure (Figure 4.19).

Fluvial erosion of the topographic high to the west of the UBCO campus would require subglacial meltwater flow. The hydraulic gradient drives the flow of subglacial meltwater (Shreve 1972). In zones where water pressure was close to the overburden pressures, flow could have been driven across a topographic divide and against the regional gradient. Scoured bedrock and remnant glacial sediments west of the

campus (see Figure 2.5) can be explained by processes of differential erosion, whereby incomplete meltwater scouring removed sediment in some areas but retained it in others. The erosion of sediments in some locations and the preservation of sediments in other locations cannot be explained by direct ice or ice deformation mechanisms. Instead, subglacial meltwater processes best explain the differentially eroded substrate and preservation of undisturbed glaciofluvial deposits. The Fraser Glaciation geomorphic landforms described above are therefore best explained through erosion and deposition by subglacial meltwaters.

The large-scale transverse ridges identified in the Site G exposures (Figures 4.24 to 4.27) and in the seismic lines (Figures 4.28 to 4.33; Figures 4.29 and 4.30) may be primary bedforms resulting from internal waves in subglacial sheetflows (Brennand 1994). They are interpreted to be antidune deposits. Antidunes are commonly observed in fluvial environments, though features on the scale of those reported here were probably formed by internal waves in turbidity flows (Russell *et al.* 2003). Similar transverse bedforms have been sculpted in bedrock (Kor *et al.* 1991).

An esker was observed on campus (Figure 4.11). The esker is flanked by steeply dipping glaciolacustrine sediments, suggesting the laminated beds were in place when the esker was deposited. A second explanation for this sequence is that the silts and clays were deposited in a glacial lake environment after the esker had formed; however, lacustrine sediments do not mantle the top of the esker. A third explanation for the

observation is that sand and gravel was deposited in a subterranean conduit beneath the ice sheet, in which case the observed feature would not be an esker. The meltwaters with associated high hydrostatic pressures could have preferentially migrated through the coarser-grained hummocky deposits and eroded upwards through the silts beds. This third explanation requires that the conduit remains open in soft lacustrine sediment with no lateral strength, which is not plausible. A fourth explanation involves the initial development of an esker in an ice walled conduit. The ice lifts temporarily from the glacial base and lacustrine sedimentation occurs in a subglacial lake environment. The subglacial lake drains and the ice resettles to the ground surface, resuming esker sedimentation. This may explain the observations of the vertically aligned lacustrine sediments and the vertically-aligned clasts along the external margin of the esker. As well, the observed dykes in sites A2 and A3 exposures (Figure 4.13) could be attributed to glacial loading from above. However, in this case, the glaciolacustrine sediments would be expected to have greater deformation than was observed. Given the field observations, the fourth explanation is the most plausible. A model outlining the proposed development of this esker is provided in Figure 5.2.

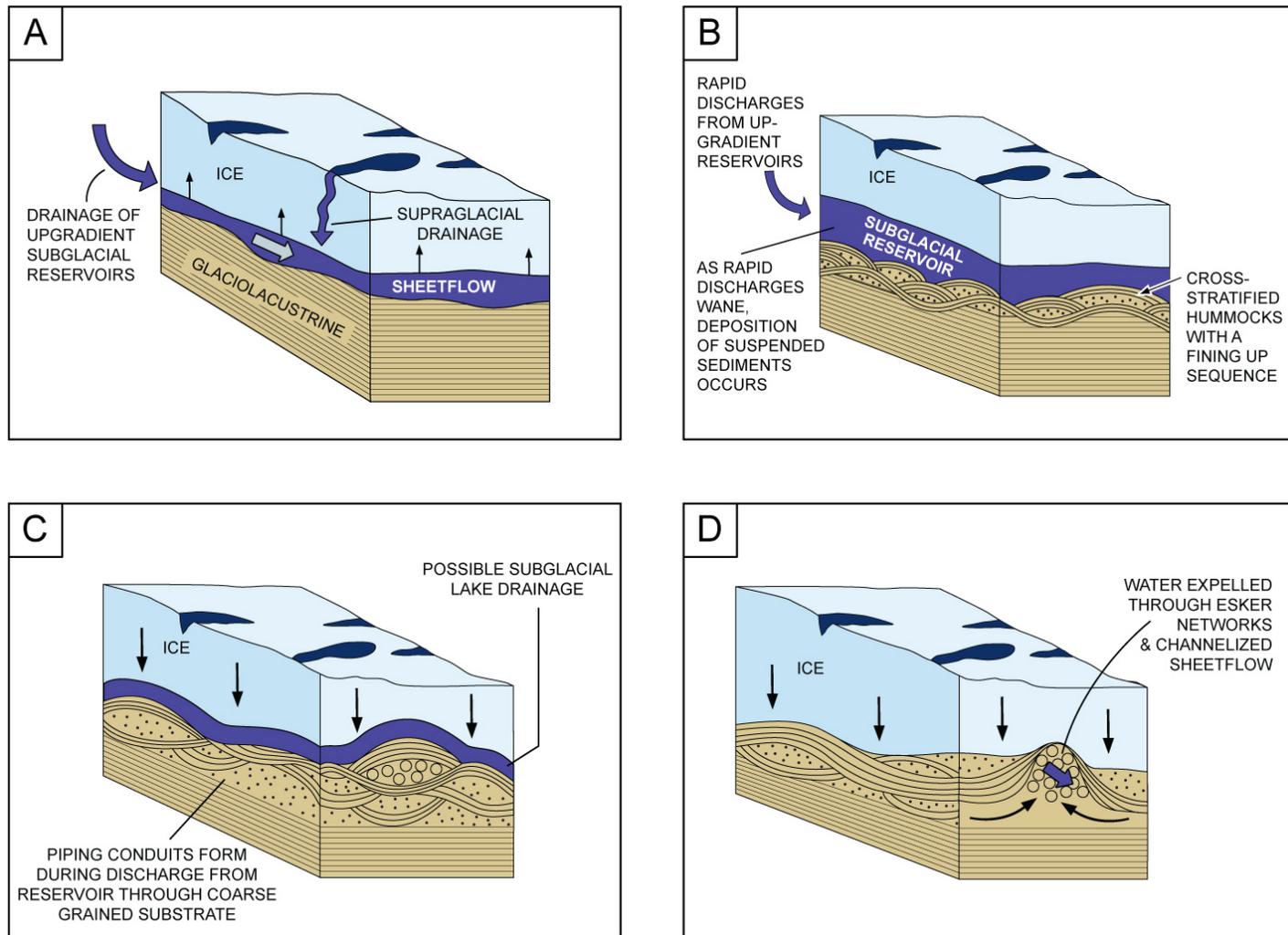


Figure 5.2: Model of hummocky bedforms and esker genesis.

6.0 DISCUSSION AND CONCLUSIONS

The origin of the valley fill sequence in the Central Okanagan has been contentious for many years. This thesis has shown through radiocarbon dateable samples that sediments in the study area may be as old as 65,000 yrs BP, and potentially even from the Early Wisconsin based on their stratigraphic position. Previous studies had concluded that the absence of radiocarbon dateable materials in other areas of the Okanagan Valley is evidence for complete meltwater scouring of pre-Fraser Glaciation sediments. However, recent studies in other regions of the Cordillera show sediments attributed to the Olympia Non-glacial stage, and they are preserved relatively intact. The survival of these sediments may be related to differential glacial erosion that allows for the preservation of sediments in discrete and isolated sedimentary packages in some locations, and complete scouring in others.

The fine-grained sediments on the west side of the study area do not correlate well with the sediments in the central part of the study area (Figures 4.7 and 4.8). Sediment on the western edge of the study area includes a fine- to medium-grained sandy unit overlain by hummocky silt and sand. In contrast, the central part of the study area is made up of relatively flat lying finer-grained silt and clay overlying denser, coarser-grained sediments. A possible explanation for the non-correlative sediments is that late-glacial meltwater erosion scoured through the central part of the valley, depositing hummocky sands and silts on the margins of the flow. During flood waning and the collapse of the

ice sheet, destabilized side valley deposits flowed into the water body in high density subaqueous flows, creating moderately sorted, coarse-grained deposits extending out into the valley centre.

Further studies are required in the Okanagan to understand the lateral extent of the Olympia Nonglacial sediments, and how they relate to the paleohydrology of the region.

The late stages of glaciations in the Okanagan Valley remain equally contentious. For ease of explanation, the late-glacial glaciolacustrine sediments described in this thesis are interpreted to have been deposited through suspension settling in a calm water body as well as by lacustrine (flood) currents. Glaciolacustrine sediments in the valley are superimposed on a diamicton, leading to the hypothesis that the glaciolacustrine sediments formed in proglacial lake systems during deglacial episodes. Subaerial proglacial lakes are generally inferred from beach strandlines that developed during wave action (Johnsen and Brennand 2004). Strandlines are absent from the study area, suggesting either the lake was not proglacial or that subsequent recessional processes (e.g. meltwater erosion) removed all traces of these landforms (Johnsen and Brennand 2004). Another explanation is that the lake(s) was subglacial.

The occurrence of glaciolacustrine sediments overlying diamicton could represent the gradual infilling of a lake as the ice retreats. This conclusion would make sense given the sediments seen at the site D exposure, where dropstones are embedded within

glaciolacustrine sediments. However, debris rain-out from the basal portion of a valley glacier into a subglacial lake could also produce such dropstones.

Hummocky terrain may be produced in a variety of environments. Massive flows of subaerial flood waters eroded hummocks into basalt of the Channeled Scablands of Central Washington (Baker 1978). Hummock forms were also attributed to be products of erosion by subglacial meltwater sheetflows in South Central Alberta (Munro and Shaw 1997; Fisher *et al.* 2002). Large-scale hummocks and transverse bedforms are present in many exposures on the UBC Okanagan campus. Stratigraphically, the features are overlain by a general fining up sequence, from coarse sand and gravel to draped silt and clay. The silt and clay drape the bedforms, suggesting a waning of meltwater flow and rhythmic suspension settling between formative events. Alternating silty sand and silty clay is a common occurrence in these deposits. Each set of hummocks may represent a sedimentation event with relatively high flow power. Pulses in sediment delivery attributed to turbiditic sequences, though not so powerful, were also seen by Shaw and Archer (1978) in glaciolacustrine sediments in other locales in the Okanagan Valley.

If the hummocks were the result of glacigenic deformation from overriding ice, the glaciolacustrine unit would show distinct folding and faulting structures consistent with overriding ice. However, this interpretation is improbable since the laminated units are relatively undisturbed, with only a few syndimentary microscale dewatering structures and centimeter-scale normal faulting consistent with settling.

Based on the meltwater hypothesis, eskers superimposed on hummocks are evidence for a subglacial genesis (Figure 5.2). If we interpret the current bedforms as forming by a glacial deformation mechanism, this would require the hummocks to survive a full glacial advance before the deposition of the esker. Field observations in the study area support a subglacial origin to the landforms. The landform assemblages suggest that subglacial meltwater scour and deposition has led to the late glacial landscape evolution.

The inferred sequence of events is therefore as follows:

1. The Okanagan Valley operated as a interglacial river valley from 65,000 to 23,000 years BP.
2. An advancing ice sheet deposited outwash around 23,000 years BP. The ice sheet eroded local bedrock and deposited fine grained tills. As well, an influx of sediments into preglacial streams and lakes caused the massive accumulation of glaciofluvial and glaciolacustrine sediments.
3. Till, debris flow facies, glaciolacustrine sediments, and eskers reflect varying glacial environments. Widespread scouring of glacial sediments by subglacial outburst floods eroded large tracts of the landscape, but the valley fill sediments near UBCO were not completely removed. The UBCO campus landscape is characterized by hummocky terrain with a till mantling, an esker, and late stage glaciolacustrine

sediments. Transverse ridges, inferred to be primary structures, most likely formed beneath stationary waves during subglacial sheetflows.

4. Esker erosion or alteration of glaciolacustrine sediments indicate that glacially ponded and catastrophically-draining lakes subglacial occupied positions to the west. The progressive channelization of sheetflows from the west (i.e. Glenmore Valley and potentially the Okanagan Lake Valley) across a topographic high during waning stages of glaciation, may have resulted in partial ice-bed recoupling, concentration of meltwater flows, and varied flow velocities that resulted in the formation of an esker. Since the esker was one of the last features formed as the ice settled back onto its bed following the release of floodwaters, it has remained well remarkably preserved to this day. Caps of glacial lacustrine sediments indicate sheetflows had sufficient volume to decouple the glacier from its bed and form a subglacial reservoir that remained long enough to form repeated series of varve-like sediments.
5. During late stages of deglaciation, the establishment of glacial lakes and modern rivers only partially modified the landscape. Contemporary riverine processes have incised through the valley fill (<10,000 yrs BP), depositing present day fluvial sequences.

Suggestions for Further Study

This thesis tested the hypotheses that subglacial lakes were present in the Central Okanagan region during the Wisconsin Glaciation and the question of whether widespread erosion had removed the majority of pre-Fraser Glaciation sediments. This research focused on a small study area and future research could be expanded to other areas of the Okanagan Valley or Southern BC. Suggested further studies include:

- 1) Continued radiocarbon dating of organic samples collected from the subsurface from other locales in the Cordillera. This would demonstrate, with greater confidence, the spatial extent of Olympia Nonglacial sediments.
- 2) Glaciolacustrine sediments in other regions of BC should be studied in conjunction with geomorphic landforms (e.g. subaqueous fans, drumlins, eskers) to determine if the sediments are subglacial or subaerial in origin.
- 3) Continued seismic investigations of the Okanagan region to ascertain the sedimentary fill characteristics of the valley and provide a better understanding of glacial deposits.

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APPENDIX A – Well Records

Subsurface Conditions at Well No. 2

Depth in Metres		Lithological Description
from	to	
0.0	0.9	Sandy SILT with pebbles, brown, dry
0.9	2.1	SILT, with pebbles, brown, dry
2.1	6.1	CLAY, high plasticity, grey, dry
6.1	9.1	SAND, with gravel, dry
9.1	9.4	CLAY, high plasticity, grey, dry
9.4	12.2	SAND, with gravel and pebbles (20% ~ 2 to 3 cm diameter)
12.2	12.8	CLAY, grey
12.8	15.2	SAND, with gravel and pebbles, yellow, dry - water bearing at 14.6 m (48 ft)
15.2	19.8	SAND, clean, medium grained, yellow-brown
19.8	24.4	SAND, medium grained, grey
24.4	27.4	SAND, coarse grained, some pebbles, grey
27.4	33.5	SAND, medium grained, some cobbles, grey
33.5	42.1	SAND, medium grained, traces of gravel, grey
42.1	66.4	SAND, medium grained, traces of gravel and pebbles, grey
66.4	70.1	SAND, fine to medium grained, 1% gravel, minor wood fragments, grey
70.1	73.2	SAND, fine grained, traces of gravel
73.2	76.2	CLAY, with 2% gravel - END OF HOLE at 76.2 m (250 ft depth)

Subsurface Conditions at Well No. 4

Depth in Metres		Lithological Description
from	to	
0.0	2.7	SILT, brown, with wood debris (FILL)
2.7	5.2	CLAY, silty, brown, medium plasticity, moist
5.2	5.5	BOULDER
5.5	6.1	SILT, yellow, dry
6.1	7.0	SAND, poorly sorted, yellow, dry
7.0	10.4	SAND, fine to medium grained, some silt, traces of gravel
10.4	11.0	SAND, fine to medium grained, yellow, moist, some gravel, some silt
11.0	12.2	SAND, fine to medium grained, yellow, moist, some silt
12.2	12.8	SAND, fine grained, yellow, well sorted, dry
12.8	15.5	SAND, fine to medium grained, yellow, some gravel, some silt
15.5	16.8	SAND, fine grained, poorly sorted, traces of silt, yellow, dry
16.8	18.9	SAND, fine to medium grained, traces of silt, moist
18.9	21.3	SAND, fine to medium grained, traces of gravel and silt
21.3	23.5	SAND, fine to medium grained, some subrounded gravel, wet
23.5	25.9	SAND, fine grained, poorly sorted, trace gravel, yellow-brown
25.9	27.1	SAND, fine grained, poorly sorted, trace gravel, yellow-brown, some gravel
27.1	29.3	SAND, fine to medium grained, poorly sorted, grey-brown, traces of gravel
29.3	32.6	SAND, fine to medium grained, poorly sorted, grey-brown, traces of gravel
32.6	34.7	SAND, fine grained, poorly sorted, grey, traces of subangular gravel
34.7	35.1	SAND, fine grained, grey, poorly sorted, some subangular to angular gravels
35.1	38.1	SAND, fine grained, grey, poorly sorted, traces of gravel
38.1	39.0	SAND, fine to medium grained, some subangular gravel, wet
39.0	45.4	SAND, fine to medium grained, grey, poorly sorted, traces of subrounded gravel
45.4	46.6	SAND, fine to medium grained, grey, some subrounded to subangular gravel, wet
46.6	52.7	SAND, fine to medium grained, grey, traces of gravel, decrease in gravel content with depth
52.7	58.5	SAND, fine to medium grained, less fines than layer above, grey, water bearing
58.5	59.7	SAND, fine to medium grained, some subangular gravel, grey, poorly sorted
59.7	62.5	SAND, silty, fine grained
62.5	64.0	SAND, silty, fine grained, some gravel
64.0	67.1	SAND and SILT, cemented and dense, lenses of angular to subangular gravel - END OF HOLE at 67.1 m (220 ft depth)

Subsurface Conditions at Well No. 5

Depth in Metres		Lithological Description
from	to	
0.0	1.5	SILT, dry, brown, loose
1.5	2.4	SAND, fine grained, some silt, moist, dark brown, traces of gravel
2.4	3.0	SILTY CLAY, dark brown, traces of gravel, moist
3.0	4.6	SAND, fine to medium grained, traces of gravel, moist
4.6	6.1	SAND, fine grained, yellow-brown colour, well graded, some gravel
6.1	8.5	SAND, fine to medium grained, yellow-brown colour, traces of gravel
8.5	8.8	SAND, medium grained, poorly graded, dark yellow-brown colour, moist
8.8	10.1	SAND, well graded, some gravel, yellow-brown colour, wet
10.1	13.7	CLAY, silty, brown, high plasticity, traces of gravel
13.7	14.0	SAND, medium grained, silty, traces of gravel, dark yellow-brown colour, wet
14.0	18.3	SAND, fine grained with some gravel, dark yellow-brown colour, wet, poorly graded
18.3	26.8	SAND, fine to medium grained with some gravel, dark yellow-brown colour, wet, poorly graded
26.8	28.3	SAND, fine grained, some gravel, yellow-brown colour
28.3	28.7	SAND, fine to medium grained, yellow-brown, some sub-angular gravel, moist
28.7	29.9	SAND, silty, fine grained, some sub-angular gravel, moderate water production during drilling
29.9	32.3	SAND, silty, fine grained, some sub-angular gravel, wood debris
32.3	33.5	SAND, fine to medium grained, grey colour, some subangular gravel
33.5	38.1	SAND, medium grained, dark grey colour, some gravel
38.1	38.7	SAND, medium grained, grey colour, some sub-angular gravel
38.7	40.8	SAND, fine to medium grained, grey colour, some gravel
40.8	42.7	SAND, fine to medium grained, well graded, grey colour, with subangular gravel
42.7	43.9	SAND, medium grained, grey colour
43.9	44.2	SAND, fine to medium grained, grey colour, with sub-angular gravel, wood debris
44.2	45.7	SAND, fine to medium grained, grey colour, some gravel
45.7	52.1	SAND, fine to medium grained, poorly graded, grey colour
52.1	54.3	SAND, fine to medium grained, traces of gravel
54.3	58.8	SAND, fine to medium grained, well sorted, grey colour
58.8	59.7	SAND, fine to medium grained, well sorted, grey colour, traces of gravel
59.7	60.4	SAND, fine to medium grained, well sorted, grey, some gravel
60.4	71.6	SAND, fine grained, poorly sorted, grey
71.6	73.8	SAND, fine grained, poorly sorted, grey, traces of gravel
73.8	75.9	SAND, fine grained, gravelly, grey colour, hydrogen sulfide odours
75.9	76.5	SAND, silty, dense, gravelly, difficult to drill
		- END OF HOLE at 76.5 m (251 ft depth)

Subsurface Conditions at Well No. 6

Depth in Metres		Lithological Description
from	to	
0.0	1.8	CLAY, silty, dark brown, medium plasticity, loose
1.8	9.8	CLAY, silty, some sand, dark brown, medium plasticity, loose, moist
9.8	13.7	SILT, yellow, brown
13.7	27.7	SAND and GRAVEL, coarse grained, some silt and clay
27.7	29.9	SAND, silty, fine grained, traces of gravel, yellow-brown colour
29.9	34.1	SAND, medium grained, traces of gravel, yellow-grey colour
34.1	36.0	SAND, fine to medium grained, grey, some gravel, high water production
36.0	39.0	SAND, fine to medium grained, grey colour, traces of gravel
39.0	42.1	SAND, fine to medium grained, grey colour, well graded, some silt, traces of gravel, low water production
42.1	48.8	SAND, medium grained, well graded, grey color, trace sof gravel, some silt
48.8	54.9	SAND, medium grained, grey colour, well graded, some silt, traces of gravel
54.9	59.7	SAND, medium grained, grey colour, well graded, traces of gravel and silt
59.7	61.3	SAND, medium grained, well graded, some silt, traces of gravel
61.3	78.0	SAND, fine grained, traces of silt and gravel, wood fragments
		- END OF HOLE at 78 m (256 ft depth)

Subsurface Conditions at Well No. 7

Depth in Metres		Lithological Description
from	to	
0.0	1.5	SAND, silty, brown, fine grained, loose, some organics
1.5	4.6	CLAY, silty, light brown, medium to high plasticity, moist
4.6	6.1	SILT, clayey with fine grained sand, yellow, low plasticity, moist
6.1	11.0	SAND, silty, fine grained, yellow-brown colour, some clay
11.0	15.8	CLAY, high plasticity, lenses of fine grained sand and silt, yellow-brown colour, moist
15.8	18.3	SAND, silty, fine grained, some sub-angular gravel
18.3	19.5	GRAVEL, subangular to subrounded, some fine to medium grained sand, well graded, yellow-brown colour
19.5	22.9	SAND, silty, fine grained, yellow-brown colour, traces of gravel, poorly sorted
22.9	24.4	SAND, silty, fine grained, yellow-brown colour, some subrounded to subangular gravel, poorly sorted
24.4	25.3	GRAVEL, subangular to subrounded, traces of fine grained sand and silt, yellow-brown colour
25.3	26.2	SAND and GRAVEL, medium grained, moderately sorted, yellow-brown colour
26.2	32.0	GRAVEL, traces of fine grained sand, subangular to subrounded, yellow-brown colour
32.0	32.6	SAND, fine grained, some subrounded gravel, wet, yellow-brown, poorly sorted, traces of silt
32.6	33.5	SAND, fine grained, traces of subrounded gravel, wet, yellow-brown colour, poorly sorted, traces of silt
33.5	39.3	SAND, fine grained, some subrounded gravel, saturated, light grey colour, poorly sorted
39.3	44.2	SAND, fine grained, poorly sorted, grey
44.2	48.8	SAND, fine to medium grained, grey colour, traces to some subrounded gravel, well graded
48.8	55.2	SAND, fine to medium grained, grey, subrounded, poorly sorted
55.2	58.2	SAND, fine to medium grained, grey, subrounded, poorly sorted, traces of subrounded gravel
58.2	59.1	SAND, fine to medium grained, subrounded, poorly sorted
59.1	61.0	SAND, fine to medium grained, grey, well graded, traces of subrounded gravel
61.0	66.4	SAND, fine grained, grey, well graded, traces of gravel, wood debris
66.4	72.5	SAND, fine grained, poorly sorted
72.5	73.2	SAND, fine grained, poorly sorted, wood debris
73.2	78.3	SAND, fine grained, grey, poorly sorted, traces of subrounded gravel, drillers reported formation very tight
		- END OF HOLE at 78.3 m (257 ft depth)

Subsurface Conditions at Well No. 8

Depth in Metres		Lithological Description
from	to	
0.0	2.1	SILT, loose, dry, yellow-brown
2.1	15.2	SAND, fine grained, well sorted, yellow-brown colour
15.2	19.5	SAND, fine grained, well sorted, some gravel and silt
19.5	22.3	SAND, fine grained, some gravel, traces of silt, brown, moist
22.3	23.2	SAND, fine to medium grained, traces of gravel, some silt
23.2	27.1	SAND, fine to medium grained, some gravel and silt, moist
27.1	30.2	SAND, fine to medium grained, increasing amounts of gravel with depth, some silt, moist
30.2	32.9	SAND and GRAVEL, some silt, producing water during drilling
32.9	37.5	SILT, some sand and gravel
37.5	52.4	SILT, grey, some gravel
52.4	53.6	GRAVEL and SAND, coarse grained, producing water during drilling
53.6	64.6	SAND, dense, white-grey colour - END OF HOLE at 64.6 m (212 ft depth)

Subsurface Conditions at Well No. 9

Depth in Metres		Lithological Description
from	to	
0.0	3.0	SAND, fine grained, silty, yellow, dry
3.0	6.1	SAND, fine grained, traces of gravel, dry
6.1	14.3	SILT, with sand, traces of gravel, yellow-brown colour, dry
14.3	16.5	SAND, fine grained, with silt, some gravel, yellow-brown, moist
16.5	22.9	SAND, fine grained, some gravel, traces of silt, moist
22.9	25.0	SAND, fine to medium grained, silty, poorly sorted, traces of gravel, grey, moist
25.0	39.6	SILT, sandy, grey colour, some gravel, moist
39.6	58.5	SILT, clayey, traces of gravel, grey
58.5	61.9	SAND, fine to medium grained, yellow-brown, traces of gravel, wet
61.9	64.0	SAND, silty, fine grained, saturated
64.0	70.1	SAND, medium grained, poorly sorted, traces of silt and gravel, saturated
70.1	75.3	SAND, fine grained, poorly sorted, some silt, wood fragments
75.3	77.1	SAND with gravel, fine to medium grained, poorly sorted, some silt
77.1	78.3	GRAVEL and SAND, poorly sorted, grey-yellow colour, wood fragments
78.3	83.5	SAND, fine to medium grained, some gravel, traces of silt
83.5	94.5	SILT, compacted
94.5	97.5	SAND, dense - END OF HOLE at 97.5 m (320 ft depth)

Subsurface Conditions at Well No. 10

Depth in Metres		Lithological Description
from	to	
0.0	7.0	SILT, clayey, brown, traces of gravel
7.0	10.1	SILT, sandy, brown, traces of gravel
10.1	13.7	SAND, fine to medium grained, traces of silt, moist
13.7	23.2	SAND, fine grained, well sorted, yellow-brown colour, moist
23.2	29.9	SAND, fine grained, poorly sorted, brown, traces of gravel
29.9	37.8	SAND, poorly sorted, traces of gravel and silt, grey colour
37.8	43.3	SAND, fine to medium grained, poorly sorted, some gravel
43.3	44.8	SAND, medium to coarse grained, poorly sorted, some gravel, grey colour
44.8	55.2	SAND, fine to medium grained, traces of gravel
55.2	67.7	SAND, fine grained, poorly sorted, traces of silt, grey colour
67.7	76.2	SAND, fine to medium grained, traces of gravel, grey colour
76.2	82.3	SAND, silty, traces of gravel, compact

- END OF HOLE at 82.3 m (270 ft depth)

Well Tag Number: 52067	Construction Date: 1983-04-25 00:00:00.0			
Owner: GLENMORE ELLISON IMPROVEMENT DISTRICT	Driller: Nor-West Drilling			
Address: GLENMORE ROAD	Well Identification Plate Number: 19091			
Area: KELOWNA	Plate Attached By:			
WELL LOCATION: OSOYOOS (ODYD) Land District District Lot: Plan: 1638 Lot: 3 Township: 23 Section: 11 Range: Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 082E094133 Well: 1	Where Plate Attached:			
Class of Well: Subclass of Well: Orientation of Well: Vertical Status of Well: New Well Use: Water Supply System Observation Well Number: Observation Well Status: Construction Method: Unknown Constru diameter: 8.0 inches Casing drive shoe: Well Depth: 230 feet Elevation: 1384.5 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: Y File Info Flag: N Sieve Info Flag: N Screen Info Flag: Y	PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 870 (Driller's Estimate) U.S. Gallons per Minute Development Method: Pump Test Info Flag: N Artesian Flow: Artesian Pressure (ft): Static Level: 21 feet			
Site Info Details: Other Info Flag: Other Info Details:	WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: N Field Chemistry Info Flag: Site Info (SEAM): N Water Utility: Y Water Supply System Name: GLENMORE-ELLISON IMPROVEMENT DISTRICT Water Supply System Well Name: GLENMORE-ELLISON IMP DIST - VECTOR WELL #2			
Screen from	to feet	Type	Slot Size	
100	120		25	
120	150		0	
150	160		20	
160	190		0	
190	200		15	
200	220		0	
220	230		20	
Casing from	to feet	Diameter	Material	Drive Shoe
0	65	10	null	null
0	100	8	null	null
GENERAL REMARKS: CASING STICKUP 3' 6". WELL CURRENTLY BEING USED.				
LITHOLOGY INFORMATION:				
From	0 to	3 Ft.	SANDY LOAM	0 nothing entered 0 nothing entered 0 nothing entered
From	3 to	30 Ft.	DRY SAND & GRAVEL	0 nothing entered 0 nothing entered 0 nothing entered
From	30 to	70 Ft.	SILTY SAND & GRAVEL COBBLES; DAMP.	0 nothing entered 0 nothing entered 0 nothing entered
From	70 to	200 Ft.	SAND MEDIUM TO FINE SOME PEBBLES WATER BEARING	0 nothing entered 0 nothing entered 0 nothing entered
From	200 to	240 Ft.	SAND GETTING FINER	0 nothing entered 0 nothing entered 0 nothing entered
From	240 to	260 Ft.	FINE SAND WOOD & MICA	0 nothing entered 0 nothing entered 0 nothing entered
From	260 to	265 Ft.	HARD COMPACT SILT	0 nothing entered 0 nothing entered 0 nothing entered
From	265 to	270 Ft.	COMPACT SILT (OPEN HOLE)	0 nothing entered 0 nothing entered 0 nothing entered
From	230 to	270 Ft.	BACKFILLED 1" STONES	0 nothing entered 0 nothing entered 0 nothing entered

<p>Well Tag Number: 56460</p> <p>Owner: TED ZELMER</p> <p>Address: ELLISON GOLF & COUNTRY CLUB</p> <p>Area: KELOWNA</p> <p>WELL LOCATION: OSOYOOS (ODYD) Land District District Lot: 122 Plan: Lot: 3 Township: 24 Section: 12 Range: Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 082E094133 Well: 4</p> <p>Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Irrigation Observation Well Number: Observation Well Status: Construction Method: Drilled Diameter: 9.0 inches Casing drive shoe: Well Depth: 260 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: N File Info Flag: N Sieve Info Flag: N Screen Info Flag: N</p> <p>Site Info Details: Other Info Flag: Other Info Details:</p>	<p>Construction Date: 1986-09-05 00:00:00.0</p> <p>Driller: Capri Drilling Well Identification Plate Number: Plate Attached By: Where Plate Attached:</p> <p>PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 0 (Driller's Estimate) Development Method: Pump Test Info Flag: N Artesian Flow: 5 Gallons per Minute (U.S./Imperial) Artesian Pressure (ft): Static Level:</p> <p>WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: Field Chemistry Info Flag: Site Info (SEAM):</p> <p>Water Utility: Water Supply System Name: Water Supply System Well Name:</p> <p>SURFACE SEAL: Flag: N Material: Method: Depth (ft): Thickness (in):</p> <p>WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:</p>
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Screen from	to feet	Type	Slot Size	
Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
ARTESIAN

LITHOLOGY INFORMATION:

From	0 to	18 Ft.	silts and sands
From	18 to	25 Ft.	fine sand and gravel
From	25 to	40 Ft.	silty clays
From	40 to	80 Ft.	clay
From	80 to	89 Ft.	silt
From	89 to	100 Ft.	clay
From	100 to	105 Ft.	sand, water flow outside casing
From	105 to	115 Ft.	sand and gravel, water flow outside casing
From	0 to	0 Ft.	ing
From	115 to	120 Ft.	sand w/traces of clay
From	120 to	190 Ft.	clay
From	190 to	220 Ft.	sand and gravel
From	220 to	260 Ft.	fine heaving sand

Well Tag Number: 55594	Construction Date: 1985-01-01 00:00:00.0
Owner: GLENMORR ELLISON IMPROVEMENT DISTRICT	Driller: A. C. Drillers
Address: 3430 UNIVERSITY WAY	Well Identification Plate Number: 19084
Area: XELOWNA	Plate Attached By: JAMES HUBER
WELL LOCATION:	Where Plate Attached:
OSOYOOS (ODYD) Land District	PRODUCTION DATA AT TIME OF DRILLING:
District Lot: Plan: 1638 Lot: 3	Well Yield: 1976 (Driller's Estimate) U.S. Gallons per Minute
Township: 23 Section: 11 Range:	Development Method:
Indian Reserve: Meridian: Block:	Pump Test Info Flag: N
Quarter:	Artesian Flow:
Island:	Artesian Pressure (ft):
BCGS Number (NAD 27): 082E094133 Well: 8	Static Level: 27 feet
Class of Well:	WATER QUALITY:
Subclass of Well:	Character:
Orientation of Well: Vertical	Colour:
Status of Well: New	Odour:
Well Use: Water Supply System	Well Disinfected: N
Observation Well Number:	SMS ID:
Observation Well Status:	Water Chemistry Info Flag: N
Construction Method: Drilled	Field Chemistry Info Flag:
Diameter: 16 inches	Site Info (SEAM): N
Casing drive shoe:	Water Utility: Y
Well Depth: 240 feet	Water Supply System Name: GLENMORR-ELLISON IMPROVEMENT DISTRICT
Elevation: 1381.2 feet (ASL)	Water Supply System Well Name: WELL #1 - VECTOR WELL (NORTH)
Final Casing Stick Up: 12.37 inches	SURFACE SEAL:
Well Cap Type:	Flag: N
Bedrock Depth: feet	Material:
Lithology Info Flag: Y	Method:
File Info Flag: Y	Depth (ft):
Sieve Info Flag: N	Thickness (in):
Screen Info Flag: Y	WELL CLOSURE INFORMATION:
Site Info Details:	Reason For Closure:
Other Info Flag:	Method of Closure:
Other Info Details:	Closure Sealant Material:
	Closure Backfill Material:
	Details of Closure:

Screen from	to feet	Type	Slot Size
126.4	229		30

Casing from	to feet	Diameter	Material
0	126.4	16	Other

GENERAL REMARKS:
VECTOR WELL (NORTH) . 1.6' CASING STICK UP.WELL PUMP INSTALLATION REPORT AVAILABLE.

LITHOLOGY INFORMATION:

From	to	Soil Description	0	nothing entered	0	nothing entered	0	nothing entered
From	0 to	58 Ft. COARSE SAND WITH COBBLY BOULDERY GRAVEL; BROWN.	0	nothing entered	0	nothing entered	0	nothing entered
From	58 to	230 Ft. FINE TO MED SAND WITH OCCASIONAL STONES & TRACES OF GRAVEL; MINOR WOOD FRAGMENTS & MICA GREY.	0	nothing entered	0	nothing entered	0	nothing entered
From	230 to	240 Ft. FINE SAND WITH SILT & CLAY.	0	nothing entered	0	nothing entered	0	nothing entered

Well Tag Number: 82390	Construction Date: 1988-12-05 00:00:00.0			
Owner: ELLISON IRRIGATION DISTRICT	Driller: Field Drilling Contractors			
Address: OLD VERNON AND ANDERSON RD	Well Identification Plate Number: 19095			
Area: KELOWNA	Plate Attached By: JAMES HUBER			
WELL LOCATION:	Where Plate Attached: ON PUMP HOUSE			
OSOYOOS (OBYD) Land District	PRODUCTION DATA AT TIME OF DRILLING:			
District Lot: 122 Plan: 43454 Lot: A	Well Yield: 650 (Driller's Estimate) U.S. Gallons per Minute			
Township: Section: Range:	Development Method:			
Indian Reserve: Meridian: Block:	Pump Test Info Flag: Y			
Quarter:	Artesian Flow:			
Island:	Artesian Pressure (ft):			
BCGS Number (NAD 27): 082E094134 Well: 17	Static Level: 63 feet			
Class of Well: Water supply	WATER QUALITY:			
Subclass of Well: Domestic	Character:			
Orientation of Well:	Colour:			
Status of Well: New	Odour:			
Well Use: Water Supply System	Well Disinfected: N			
Observation Well Number:	EMS ID:			
Observation Well Status:	Water Chemistry Info Flag: N			
Construction Method: Drilled	Field Chemistry Info Flag:			
Diameter: 10 inches	Site Info (SEMI): N			
Casing drive shoe: N	Water Utility: N			
Well Depth: 161.9 feet	Water Supply System Name: GLENMORE-ELLISON IMPROVEMENT DISTRICT			
Elevation: 1437 feet (ASL)	Water Supply System Well Name: GLENMORE-ELLISON I D - ELLISON WELL			
Final Casing Stick Up: inches	SURFACE SEAL:			
Well Cap Type: WELL ELBOW	Flag: N			
Bedrock Depth: feet	Material:			
Lithology Info Flag: Y	Method:			
File Info Flag: N	Depth (ft):			
Sieve Info Flag: Y	Thickness (in):			
Screen Info Flag: Y	WELL CLOSURE INFORMATION:			
Site Info Details:	Reason For Closure:			
Other Info Flag:	Method of Closure:			
Other Info Details:	Closure Sealant Material:			
	Closure Backfill Material:			
	Details of Closure:			
Screen from	to feet	Type	Slot Size	
124.8	130.1		25	
130.1	140.7		20	
140.7	161.9		25	
Casing from	to feet	Diameter	Material	Drive Shoe
0	46	16	null	N
0	124	10	Other	null
GENERAL REMARKS:				
WELL PUMP INSTALLATION REPORT AVAILABLE.				
LITHOLOGY INFORMATION:				
From	to	2 Ft.	SILTY LOAM TOPSOIL	0 nothing entered 0 nothing entered 0 nothing entered
From	2 to	7 Ft.	SILTY SAND	0 nothing entered 0 nothing entered 0 nothing entered
From	7 to	8 Ft.	STONY CLAY	0 nothing entered 0 nothing entered 0 nothing entered
From	8 to	21 Ft.	SILTY SAND WITH MINOR GRAVEL	0 nothing entered 0 nothing entered 0 nothing entered
From	21 to	32 Ft.	CEMENTED GRAVEL WITH SAND	0 nothing entered 0 nothing entered 0 nothing entered
From	32 to	46 Ft.	CEMENTED GRAVEL WITH CLAY LAYERS	0 nothing entered 0 nothing entered 0 nothing entered
From	46 to	48 Ft.	VERY HARD TILL	0 nothing entered 0 nothing entered 0 nothing entered
From	48 to	49 Ft.	BOULDER	0 nothing entered 0 nothing entered 0 nothing entered
From	49 to	60 Ft.	HARD DENSE TILL	0 nothing entered 0 nothing entered 0 nothing entered
From	60 to	66 Ft.	VERY HARD, SANDY PACKED CLAY	0 nothing entered 0 nothing entered 0 nothing entered
From	66 to	73 Ft.	HARD GREY TILL AND COBBLES	0 nothing entered 0 nothing entered 0 nothing entered
From	73 to	74 Ft.	CLAY AND GRAVEL	0 nothing entered 0 nothing entered 0 nothing entered
From	74 to	83 Ft.	VERY HARD STONY CLAY	0 nothing entered 0 nothing entered 0 nothing entered
From	83 to	86 Ft.	COBBLES AND BOULDERS	0 nothing entered 0 nothing entered 0 nothing entered
From	86 to	90 Ft.	SANDY, STONY CLAY	0 nothing entered 0 nothing entered 0 nothing entered
From	90 to	107 Ft.	STONY, SILTY SAND AND CLAY, SOME WATER	0 nothing entered 0 nothing entered 0 nothing entered
From	107 to	161 Ft.	FINE TO MEDIUM SAND WITH SOME GRAVEL. WATER-BEARING.	0 nothing entered 0 nothing entered 0 nothing entered
From	161 to	164 Ft.	TIGHT SAND AND GRAVEL, SOME WATER	0 nothing entered 0 nothing entered 0 nothing entered

Well Tag Number: 58942	Construction Date: 1989-07-15 00:00:00.0			
Owner: JIM HANSEN	Driller: Capri Drilling			
Address: BULMAN RD.	Well Identification Plate Number:			
Area: KELLOWNA	Plate Attached By:			
WELL LOCATION:	Where Plate Attached:			
OSOYOOS (ODYD) Land District	PRODUCTION DATA AT TIME OF DRILLING:			
District Lot: Plan: 33240 Lot: 22	Well Yield: 40 (Driller's Estimate) Gallons per Minute (U.S./Imperial)			
Township: 23 Section: 12 Range:	Development Method:			
Indian Reserve: Meridian: Block:	Pump Test Info Flag:			
Quarter:	Artesian Flow:			
Island:	Artesian Pressure (ft):			
BCCS Number (NAD 27): 082E094134 Well: 16	Static Level: 34 feet			
Class of Well:	WATER QUALITY:			
Subclass of Well:	Character:			
Orientation of Well:	Colour:			
Status of Well: New	Odour:			
Well Use: Private Domestic	Well Disinfected: N			
Observation Well Number:	EMS ID:			
Observation Well Status:	Water Chemistry Info Flag:			
Construction Method: Drilled	Field Chemistry Info Flag:			
Diameter: 6.0 inches	Site Info (SEAM):			
Casing drive shoe:	Water Utility:			
Well Depth: 70 feet	Water Supply System Name:			
Elevation: 0 feet (ASL)	Water Supply System Well Name:			
Final Casing Stick Up: inches	SURFACE SEAL:			
Well Cap Type:	Flag:			
Bedrock Depth: feet	Material:			
Lithology Info Flag:	Method:			
File Info Flag:	Depth (ft):			
Sieve Info Flag:	Thickness (in):			
Screen Info Flag:	WELL CLOSURE INFORMATION:			
Site Info Details:	Reason For Closure:			
Other Info Flag:	Method of Closure:			
Other Info Details:	Closure Sealant Material:			
	Closure Backfill Material:			
	Details of Closure:			
Screen from	to feet	Type	Slot Size	
Casing from	to feet	Diameter	Material	Drive Shoe
GENERAL REMARKS:				
THIS IS A DEEPENING OF A 64FT.WELL				
LITHOLOGY INFORMATION:				
From	0 to	64 Ft.	existing well	
From	64 to	70 Ft.	sand and gravel	

Well Tag Number: 82347	Construction Date: 2003-10-23 00:00:00.0											
Owner: SUNSET RANCH GOLF DEVELOPMENTS LTD	Driller: Field Drilling Contractors											
Address: SCOTTY CREEK ROAD	Well Identification Plate Number: 19085											
Area: KELOWNA	Plate Attached By: JAMES HUBER											
WELL LOCATION:	Where Plate Attached:											
OSOYOOS (ODYD) Land District	PRODUCTION DATA AT TIME OF DRILLING:											
District Lot: 1 Plan: 72369 Lot: 1	Well Yield: 375 (Driller's Estimate) U.S. Gallons per Minute											
Township: Section: Range:	Development Method:											
Indian Reserve: Meridian: Block:	Pump Test Info Flag: Y											
Quarter:	Artesian Flow:											
Island:	Artesian Pressure (ft):											
BCGS Number (NAD 27): 082E094134 Well: 19	Static Level: 132 feet											
Class of Well:	WATER QUALITY:											
Subclass of Well:	Character:											
Orientation of Well:	Colour:											
Status of Well: New	Odour:											
Well Use: Water Supply System	Well Disinfected: N											
Observation Well Number:	ENS ID: E288659											
Observation Well Status:	Water Chemistry Info Flag: Y											
Construction Method: Drilled	Field Chemistry Info Flag:											
Diameter: 10 INCH inches	Site Info (SEAM): N											
Casing drive shoe:	Water Utility: N											
Well Depth: 229 feet	Water Supply System Name: SUNSET RANCH WATER SYSTEM											
Elevation: 1505.9 feet (ASL)	Water Supply System Well Name: PW02-03 (WELL 2)											
Final Casing Stick Up: inches	SURFACE SEAL:											
Well Cap Type:	Flag: N											
Bedrock Depth: feet	Material:											
Lithology Info Flag: Y	Method:											
File Info Flag: N	Depth (ft):											
Sieve Info Flag: N	Thickness (in):											
Screen Info Flag: Y	WELL CLOSURE INFORMATION:											
Site Info Details:	Reason For Closure:											
Other Info Flag:	Method of Closure:											
Other Info Details:	Closure Sealant Material:											
	Closure Backfill Material:											
	Details of Closure:											
Screen from	to feet	Type	Slot Size									
214	229		150									
Casing from	to feet	Diameter	Material	Drive Shoe								
null	217	10	Other	null								
GENERAL REMARKS:												
LITHOLOGY INFORMATION:												
From	to	FEET	DESCRIPTION	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	27	to	39 FT. GRAVELLY TILL AND COARSE GRAVEL	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	39	to	68 FT. GRAVELLY TILL, NOT AS COARSE WITH SILTY CLAY	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	68	to	101 FT. CLAYEY GRAVELLY TILL WITH SMALL BOULDERS	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	101	to	112 FT. DENSE SANDY GRAVEL WITH SMALL BOULDERS AND TILL, NO CLAY	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	112	to	127 FT. DRY SAND	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	127	to	145 FT. SANDY DRY GRAVEL, VERY ANGULAR	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	145	to	158 FT. FINE VERY BROWN SILTY SAND WITH TRACE OF FINE ANGULAR GRAVEL	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	158	to	164 FT. BOULDERS WITH FINE BROWN SAND AND COARSE GRAVEL	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	164	to	175 FT. BOULDERS WITH FINE BROWN SAND AND COARSE GRAVEL WITH A TRACE OF WATER	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	175	to	200 FT. DRY SAND AND GRAVEL, TRACE OF SILT	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	200	to	229 FT. SANDY GRAVEL, UP TO 1", ANGULAR WITH LOTS OF BROWN SILT, TRACE OF WATER	0	nothing	entered	0	nothing	entered	0	nothing	entered
			W.B. SAND AND GRAVEL, UP TO 1"	0	nothing	entered	0	nothing	entered	0	nothing	entered

<p>Well Tag Number: 58827</p> <p>Owner: SUNSET RANCH GOLF DE</p> <p>Address: 5360 SCOTTY CREEK RD.</p> <p>Area: KELOWNA</p> <p>WELL LOCATION: OSOYCOOS (ODYD) Land District District Lot: Plan: 39857 Lot: A Township: 24 Section: 7 Range: Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 082E094143 Well: 1</p> <p>Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Irrigation Observation Well Number: Observation Well Status: Construction Method: Drilled Diameter: 8.0 inches Casing drive shoe: Well Depth: 241 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: N File Info Flag: N Sieve Info Flag: N Screen Info Flag: N</p> <p>Site Info Details: Other Info Flag: Other Info Details:</p>	<p>Construction Date: 1989-05-25 00:00:00.0</p> <p>Driller: Capri Drilling Well Identification Plate Number: Plate Attached By: Where Plate Attached:</p> <p>PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 540 (Driller's Estimate) Gallons per Minute (U.S./Imperial) Development Method: Pump Test Info Flag: N Artesian Flow: Artesian Pressure (ft): Static Level: 146 feet</p> <p>WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: Field Chemistry Info Flag: Site Info (SEAM):</p> <p>Water Utility: Water Supply System Name: Water Supply System Well Name:</p> <p>SURFACE SEAL: Flag: N Material: Method: Depth (ft): Thickness (in):</p> <p>WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:</p>
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Screen from	to feet	Type	Slot Size	
Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:

LITHOLOGY INFORMATION:

From	0 to	12 Ft.	coarse sand, trace of gravel (fill)
From	12 to	31 Ft.	cobbles and boulders with sand & gravel
From	31 to	44 Ft.	sand and gravel
From	44 to	53 Ft.	wet sand and gravel
From	53 to	97 Ft.	wet silty sand with some gravel with
From	0 to	0 Ft.	clay streaks
From	97 to	121 Ft.	tight sand and gravel with silt seams
From	121 to	143 Ft.	fine silty sand with trace of gravel
From	143 to	154 Ft.	clay and gravel with cobbles
From	154 to	213 Ft.	very tight cemented sand and gravel
From	213 to	241.6 Ft.	w.b. sand and gravels
From	241.6 to	0 Ft.	fine sand with some gravel

<p>Well Tag Number: 62063</p> <p>Owner: SUNSET RANCH GOLF</p> <p>Address: 4001 ANDERSON ROAD</p> <p>Area: KELOWNA</p> <p>WELL LOCATION: OSOYOOS (ODYD) Land District District Lot: Plan: 39857 Lot: A Township: 24 Section: 7 Range: Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 082E094141 Well: 2</p> <p>Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Private Domestic Observation Well Number: Observation Well Status: Construction Method: Drilled Diameter: 6.0 inches Casing drive shoe: Well Depth: 340 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: 197 feet Lithology Info Flag: File Info Flag: Sieve Info Flag: Screen Info Flag:</p> <p>Site Info Details: Other Info Flag: Other Info Details:</p>	<p>Construction Date: 1991-05-09 00:00:00.0</p> <p>Driller: Dan Gare Drilling Well Identification Plate Number: Plate Attached By: Where Plate Attached:</p> <p>PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 0 (Driller's Estimate) Development Method: Pump Test Info Flag: Artesian Flow: Artesian Pressure (ft): Static Level:</p> <p>WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: Field Chemistry Info Flag: Site Info (SEAM):</p> <p>Water Utility: Water Supply System Name: Water Supply System Well Name:</p> <p>SURFACE SEAL: Flag: Material: Method: Depth (ft): Thickness (in):</p> <p>WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:</p>
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Screen from	to feet	Type	Slot Size	
Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
BACK FILLED WITH CUTTINGS

LITHOLOGY INFORMATION:
From 0 to 143 Ft. Glacial till
From 143 to 150 Ft. Soft bedrock
From 150 to 340 Ft. Bedrock

Well Tag Number: 23703	Construction Date: 1970-07-01 00:00:00.0			
Owner: CLIFF CLEMENT	Driller: Okanagan Rotary Well Drilling			
Address:	Well Identification Plate Number:			
	Plate Attached By:			
	Where Plate Attached:			
Area: RUTLAND	PRODUCTION DATA AT TIME OF DRILLING:			
WELL LOCATION:	Well Yield: 458 (Driller's Estimate) Gallons per Minute (U.S./Imperial)			
OSOYOOS (CDYD) Land District	Development Method:			
District Lot: Plan: 13387 Lot:	Pump Test Info Flag: Y			
Township: 23 Section: 12 Range:	Artesian Flow: 104 U.S. Gallons per Minute			
Indian Reserve: Meridian: Block:	Artesian Pressure (ft):			
Quarter: SE	Static Level:			
Island:	WATER QUALITY:			
BCGS Number (NAD 27): 082E094132 Well: 13	Character:			
	Colour:			
Class of Well:	Odour:			
Subclass of Well:	Well Disinfected: N			
Orientation of Well:	EMS ID: 1401159			
Status of Well: New	Water Chemistry Info Flag: Y			
Well Use: Irrigation	Field Chemistry Info Flag:			
Observation Well Number:	Site Info (SEAM): Y			
Observation Well Status:				
Construction Method: Drilled	Water Utility: N			
Diameter: 8.0 inches	Water Supply System Name:			
Casing drive shoe:	Water Supply System Well Name:			
Well Depth: 166 feet				
Elevation: 0 feet (ASL)	SURFACE SEAL:			
Final Casing Stick Up: inches	Flag: N			
Well Cap Type:	Material:			
Bedrock Depth: feet	Method:			
Lithology Info Flag: N	Depth (ft):			
File Info Flag: Y	Thickness (in):			
Sieve Info Flag: N				
Screen Info Flag: N	WELL CLOSURE INFORMATION:			
Site Info Details:	Reason For Closure:			
Other Info Flag: E LOG	Method of Closure:			
Other Info Details:	Closure Sealant Material:			
	Closure Backfill Material:			
	Details of Closure:			
Screen from	to feet	Type	Slot Size	
Casing from	to feet	Diameter	Material	Drive Shoe
GENERAL REMARKS:				
FLOWS AT 104 GPM AND FOR MOR INFO SEE G.W. NTS FILE 82E/14 #1 GOOD WATER AQUIFER. POSSIBLE ARTESIAN.				
LITHOLOGY INFORMATION:				
From	0 to	4 Ft.	hard, clean clay	
From	4 to	20 Ft.	gravel, br. clay, sand, water	
From	20 to	33 Ft.	clean sand, gravel	
From	38 to	75 Ft.	grey, clean, sticky clay	
From	75 to	100 Ft.	clean, sandy gravel	
From	100 to	112 Ft.	gravelly clay	
From	112 to	119 Ft.	gravel, little more free of clay	
From	119 to	141 Ft.	gravelly clay	
From	141 to	149 Ft.	coarse sand	
From	149 to	166 Ft.	fine, clean br. and gr. sand	

<p>Well Tag Number: 27202</p> <p>Owner: ALF CHARDON</p> <p>Address: OLD VERNON RD</p> <p>Area: KELOWNA</p> <p>WELL LOCATION: OSOYOOS (ODYD) Land District District Lot: Plan: 23162 Lot: C Township: 23 Section: 12 Range: Indian Reserve: Meridian: Block: Quarter: SE Island: BCGS Number (NAD 27): 082E094132 Well: 14</p> <p>Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Unknown Well Use Observation Well Number: Observation Well Status: Construction Method: Drilled Diameter: 0.0 inches Casing drive shoe: Well Depth: 0 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: File Info Flag: Sieve Info Flag: Screen Info Flag:</p> <p>Site Info Details: Other Info Flag: Other Info Details:</p>	<p>Construction Date: 1972-11-01 00:00:00.0</p> <p>Driller: Lakeside Drilling Well Identification Plate Number: Plate Attached By: Where Plate Attached:</p> <p>PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 150 (Driller's Estimate) Gallons per Minute (U.S./Imperial) Development Method: Pump Test Info Flag: Artesian Flow: Artesian Pressure (ft): Static Level:</p> <p>WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: Field Chemistry Info Flag: Site Info (SEAM):</p> <p>Water Utility: Water Supply System Name: Water Supply System Well Name:</p> <p>SURFACE SEAL: Flag: Material: Method: Depth (ft): Thickness (in):</p> <p>WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:</p>			
Screen from	to feet	Type	Slot Size	
Casing from	to feet	Diameter	Material	Drive Shoe
GENERAL REMARKS:				
LITHOLOGY INFORMATION:				
From	0 to 280 Ft.	No log (Kelowna Drilling)		
From	0 to 302 Ft.	brown till		
From	0 to 337 Ft.	coarse gravel (pea size)		

Well Tag Number: 82390	Construction Date: 1988-12-05 00:00:00.0							
Owner: ELLISON IRRIGATION DISTRICT	Driller: Field Drilling Contractors							
Address: OLD VERNON AND ANDERSON RD	Well Identification Plate Number: 19095							
Area: KELOGNA	Plate Attached By: JAMES HUBER							
WELL LOCATION: CSOYOOS (ODYD) Land District District Lot: 122 Plan: 43454 Lot: A Township: Section: Range: Indian Reserve: Meridian: Block: Quarter: Island: BCQS Number (NAD 27): 082R094134 Well: 17	Where Plate Attached: ON PUMP HOUSE							
Class of Well: Water supply Subclass of Well: Domestic Orientation of Well: Status of Well: New Well Use: Water Supply System Observation Well Number: Observation Well Status: Construction Method: Drilled Diameter: 10 inches Casing drive shoe: N Well Depth: 161.9 feet Elevation: 1437 feet (ASL) Final Casing Stick Up: inches Well Cap Type: WELL ELBOW Bedrock Depth: feet Lithology Info Flag: Y File Info Flag: N Sieve Info Flag: Y Screen Info Flag: Y	PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 650 (Driller's Estimate) U.S. Gallons per Minute Development Method: Pump Test Info Flag: Y Artesian Flow: Artesian Pressure (ft): Static Level: 63 feet							
Site Info Details: Other Info Flag: Other Info Details:	WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: N Field Chemistry Info Flag: Site Info (SPAM): N							
	Water Utility: N Water Supply System Name: GLENMORE-ELLISON IMPROVEMENT DISTRICT Water Supply System Well Name: GLENMORE-ELLISON I D - ELLISON WELL							
	SURFACE SEAL: Flag: N Material: Method: Depth (ft): Thickness (in):							
	WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:							
Screen from	to feet	Type	Slot Size					
124.8	130.1		25					
130.1	140.7		20					
140.7	161.9		25					
Casing from	to feet	Diameter	Material	Drive Shoe				
0	46	16	null	N				
0	124	10	Other	null				
GENERAL REMARKS: WELL PUMP INSTALLATION REPORT AVAILABLE.								
LITHOLOGY INFORMATION:								
From	to		0	nothing entered	0	nothing entered	0	nothing entered
0	2	SILTY LOAM TOPSOIL	0	nothing entered	0	nothing entered	0	nothing entered
2	7	SILTY SAND	0	nothing entered	0	nothing entered	0	nothing entered
7	8	STONY CLAY	0	nothing entered	0	nothing entered	0	nothing entered
8	21	SILTY SAND WITH MINOR GRAVEL	0	nothing entered	0	nothing entered	0	nothing entered
21	32	CEMENTED GRAVEL WITH SAND	0	nothing entered	0	nothing entered	0	nothing entered
32	46	CEMENTED GRAVEL WITH CLAY LAYERS	0	nothing entered	0	nothing entered	0	nothing entered
46	48	VERY HARD TILL	0	nothing entered	0	nothing entered	0	nothing entered
48	49	BOULDER	0	nothing entered	0	nothing entered	0	nothing entered
49	60	HARD DENSE TILL	0	nothing entered	0	nothing entered	0	nothing entered
60	68	VERY HARD, SANDY PACKED CLAY	0	nothing entered	0	nothing entered	0	nothing entered
68	73	HARD GREY TILL AND COBBLES	0	nothing entered	0	nothing entered	0	nothing entered
73	74	CLAY AND GRAVEL	0	nothing entered	0	nothing entered	0	nothing entered
74	83	VERY HARD STONY CLAY	0	nothing entered	0	nothing entered	0	nothing entered
83	86	COBBLES AND BOULDERS	0	nothing entered	0	nothing entered	0	nothing entered
86	90	SANDY, STONY CLAY	0	nothing entered	0	nothing entered	0	nothing entered
90	107	STONY, SILTY SAND AND CLAY, SOME WATER	0	nothing entered	0	nothing entered	0	nothing entered
107	161	FINE TO MEDIUM SAND WITH SOME GRAVEL, WATER-BEARING.	0	nothing entered	0	nothing entered	0	nothing entered
161	164	TIGHT SAND AND GRAVEL, SOME WATER	0	nothing entered	0	nothing entered	0	nothing entered

<p>Well Tag Number: 23783</p> <p>Owner: ROBERT W BERRY</p> <p>Address: OLD VERNON RD</p> <p>Area: KELOWNA</p> <p>WELL LOCATION: OSOYOOS (ODYD) Land District District Lot: 122 Plan: 16500 Lot: A Township: Section: Range: Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 082E094134 Well: 11</p> <p>Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Unknown Well Use Observation Well Number: Observation Well Status: Construction Method: Unknown Constru Diameter: 6.0 inches Casing drive shoe: Well Depth: 103 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: File Info Flag: Sieve Info Flag: Screen Info Flag:</p> <p>Site Info Details: Other Info Flag: Other Info Details:</p>	<p>Construction Date: 1970-07-21 00:00:00.0</p> <p>Driller: Okanagan Rotary Well Drilling Well Identification Plate Number: Plate Attached By: Where Plate Attached:</p> <p>PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 105 (Driller's Estimate) Gallons per Minute (U.S./Imperial) Development Method: Pump Test Info Flag: Artesian Flow: Artesian Pressure (ft): Static Level:</p> <p>WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: Field Chemistry Info Flag: Site Info (SEAM):</p> <p>Water Utility: Water Supply System Name: Water Supply System Well Name:</p> <p>SURFACE SEAL: Flag: Material: Method: Depth (ft): Thickness (in):</p> <p>WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:</p>
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Screen from	to feet	Type	Slot Size	
Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:

LITHOLOGY INFORMATION:

From	0 to	12 Ft.	rocks and gravel -in bronw clay
From	12 to	37 Ft.	all big rocks with sand and gravel and
From	0 to	0 Ft.	silty brown clay
From	37 to	42 Ft.	brown silty clay with sand and gravel
From	42 to	54 Ft.	clean sand, gravel and rocks with water
From	54 to	61 Ft.	very fine silty brown sand (water)
From	61 to	67 Ft.	clean rock and gravel with fine sand,
From	0 to	0 Ft.	water
From	67 to	78 Ft.	very hard packed brown silty sand with
From	0 to	0 Ft.	fine mica
From	78 to	87 Ft.	clean fine sand somewhat more free of
From	0 to	0 Ft.	silt, water
From	87 to	92 Ft.	fine silty sand (water)
From	92 to	103 Ft.	clean fine sand, free of silt (best
From	0 to	0 Ft.	water aquifer)

<p>Well Tag Number: 36670</p> <p>Owner: SCHOOL DIST 23 CENTR</p> <p>Address: ELLISON SCHOOL</p> <p>Area: KELOWNA</p> <p>WELL LOCATION: OSOYCOS (ODYD) Land District District Lot: 121 Plan: 11862 Lot: 1 Township: Section: Range: Indian Reserve: Meridian: Block: Quarter: Island: BCGS Number (NAD 27): 082E094134 Well: 12</p> <p>Class of Well: Subclass of Well: Orientation of Well: Status of Well: New Well Use: Unknown Well Use Observation Well Number: Observation Well Status: Construction Method: Drilled Diameter: 4.0 inches Casing drive shoe: Well Depth: 187 feet Elevation: 0 feet (ASL) Final Casing Stick Up: inches Well Cap Type: Bedrock Depth: feet Lithology Info Flag: File Info Flag: Sieve Info Flag: Screen Info Flag:</p> <p>Site Info Details: Other Info Flag: Other Info Details:</p>	<p>Construction Date: 1977-02-08 00:00:00.0</p> <p>Driller: Okanagan Water Well Drilling Well Identification Plate Number: Plate Attached By: Where Plate Attached:</p> <p>PRODUCTION DATA AT TIME OF DRILLING: Well Yield: 12 (Driller's Estimate) Gallons per Minute (U.S./Imperial) Development Method: Pump Test Info Flag: Artesian Flow: Artesian Pressure (ft): Static Level: 57 feet</p> <p>WATER QUALITY: Character: Colour: Odour: Well Disinfected: N EMS ID: Water Chemistry Info Flag: Field Chemistry Info Flag: Site Info (SEAM):</p> <p>Water Utility: Water Supply System Name: Water Supply System Well Name:</p> <p>SURFACE SEAL: Flag: Material: Method: Depth (ft): Thickness (in):</p> <p>WELL CLOSURE INFORMATION: Reason For Closure: Method of Closure: Closure Sealant Material: Closure Backfill Material: Details of Closure:</p>
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Screen from	to feet	Type	Slot Size	
Casing from	to feet	Diameter	Material	Drive Shoe

GENERAL REMARKS:
 WATER VERY IRONY, SMELLS LIKE SULPHUR, STAINS BROWN.

LITHOLOGY INFORMATION:
 From 0 to 125 Ft. (till) rock, gr. and sand with silty
 From 0 to 0 Ft. clay
 From 125 to 178 Ft. fine sand with some rocks
 From 178 to 185 Ft. clean gr. and s.
 From 185 to 200 Ft. gr. with fine silty sand

Well Tag Number: 83202	Construction Date: 1999-01-01 00:00:00.0		
Owner: GLENMORE ELLISON IMPROVEMENT DISTRICT	Driller:		
Address: OLD VERNON ROAD & HWY 97 NORTH	Well Identification Plate Number:		
Area: KELOWNA	Plate Attached By:		
WELL LOCATION:	Where Plate Attached:		
OSOYOOS (ODYD) Land District	PRODUCTION DATA AT TIME OF DRILLING:		
District Lot: 32A Plan: H-318 Lot:	Well Yield: 325 (Driller's Estimate) U.S. Gallons per Minute		
Township: Section: Range:	Development Method:		
Indian Reserve: Meridian: Block:	Pump Test Info Flag: N		
Quarter:	Artesian Flow:		
Island:	Artesian Pressure (ft):		
BCGS Number (NAD 27): 062E094313 Well: 9	Static Level: 45 feet		
Class of Well:	WATER QUALITY:		
Subclass of Well:	Character:		
Orientation of Well: Vertical	Colour:		
Status of Well: Alteration	Odour:		
Well Use: Test	Well Disinfected: N		
Observation Well Number:	EMS ID:		
Observation Well Status:	Water Chemistry Info Flag: Y		
Construction Method: Drilled	Field Chemistry Info Flag:		
Diameter: 6 inches	Site Info (SEAM): N		
Casing drive shoe:	Water Utility: Y		
Well Depth: 200 feet	Water Supply System Name:		
Elevation: feet (ASL)	Water Supply System Well Name:		
Final Casing Stick Up: inches	SURFACE SEAL:		
Well Cap Type:	Flag: N		
Bedrock Depth: feet	Material:		
Lithology Info Flag: Y	Method:		
File Info Flag: N	Depth (ft):		
Sieve Info Flag: N	Thickness (in):		
Screen Info Flag: Y	WELL CLOSURE INFORMATION:		
Site Info Details:	Reason For Closure:		
Other Info Flag:	Method of Closure:		
Other Info Details:	Closure Sealant Material:		
	Closure Backfill Material:		
	Details of Closure:		
Screen from	to feet	Type	Slot Size
180	200		null
Casing from	to feet	Diameter	Material
			Drive Shoe
GENERAL REMARKS:			
SPECIFIC CAPACITY 8.3 USG/FOOT OF DRAWDOWN			

LITHOLOGY INFORMATION:

From	0	to	6 Ft.	SANDY TO GRAVEL SOIL	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	6	to	12 Ft.	BROWN CLAY WITH SAND	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	12	to	25 Ft.	BROWN SANDY CLAY	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	25	to	30 Ft.	BROWN SAND WITH GRAVEL; DIRTY	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	30	to	33 Ft.	DIRTY GRAVEL WITH BROWN CLAY	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	33	to	37 Ft.	FINER SAND; DIRTY WITH SMALL GRAVEL	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	37	to	40 Ft.	BROWN SAND LITTLE CLEANER WITH SOME SMALL GRAVEL	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	40	to	45 Ft.	CLEANER BROWN SAND WITH PEBBLES	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	45	to	55 Ft.	BROWN SAND WITH PEBBLES	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	55	to	65 Ft.	DIRTY PASTY BROWN SAND	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	65	to	70 Ft.	BROWN SAND & SMALL GRAVEL; LITTLE DIRTY	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	70	to	80 Ft.	FINE BROWN SAND; PASTY	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	80	to	82 Ft.	FINE SAND; GETTING CLEANER & COARSER	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	82	to	88 Ft.	BROWN SAND WITH COARSER GRAVEL; CLEANER	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	88	to	90 Ft.	FINE BROWN CLEAN SAND	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	90	to	100 Ft.	FINE BROWN SAND WITH SOME COARSE SAND	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	100	to	101 Ft.	STRIP OF CLAY	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	101	to	107 Ft.	CLEAN COARSE SAND WITH GRAVEL	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	107	to	110 Ft.	COARSE BROWN SAND (GETTING FINER) WITH ROCKS	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	110	to	116 Ft.	FINE BROWN SAND	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	116	to	119 Ft.	BROWN SAND; GETTING COARSER	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	119	to	120 Ft.	COARSE CLEAN BROWN SAND & GRAVEL	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	120	to	125 Ft.	COARSE CLEAN BROWN SAND WITH SOME GRAVEL	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	125	to	130 Ft.	COARSE CLEAN SAND WITH SOME FINES & GRAVEL	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	130	to	131.5 Ft.	COARSE CLEAN SAND WITH GRAVEL & SOME FINES	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	131.5	to	139 Ft.	FINE DARK BROWN SAND	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	139	to	145 Ft.	COARSE CLEAN SAND WITH GRAVEL	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	145	to	148 Ft.	FINE BROWN SAND (VERY CLEAN)	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	148	to	158 Ft.	COARSE CLEAN BROWN SAND	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	158	to	164 Ft.	FINER BROWN SAND WITH FINES	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	164	to	175 Ft.	DIRTY PASTY SAND	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	175	to	183 Ft.	DIRTY SAND WITH CLAY STREAKS (DRILLED)	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	183	to	188 Ft.	DIRTY BROWN SAND (DRILLED)	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	188	to	190 Ft.	BROWN SAND; GETTING CLEANER & LOOSER	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	190	to	198 Ft.	CLEAN BROWN SAND WITH SOME SHARP GRAVEL	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	198	to	200 Ft.	BROWN SAND (FINER)	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	200	to	206 Ft.	FINE BROWN SAND	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	206	to	208 Ft.	BROWN SAND; TURNING TO GREY	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	208	to	210 Ft.	FINE GREY SAND & FINES IN WATER	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	210	to	216 Ft.	FINE GREY SAND WITH FINES IN WATER	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	216	to	220 Ft.	FINE GREY SAND; GETTING CLEANER	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	220	to	230 Ft.	FINE GREY SAND	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	230	to	236 Ft.	FINE GREY SAND WITH PEBBLES	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	236	to	238 Ft.	GREY SAND WITH PEBBLES; GETTING COARSER & CLEANER	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	238	to	240 Ft.	CLEAN GREY SAND	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	240	to	248 Ft.	GREY SAND (CLEANER) WITH PEBBLES & SMALL GRAVEL	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	248	to	250 Ft.	GREY SAND (COARSER) WITH GRAVEL; VERY CLEAN	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	250	to	258 Ft.	VERY CLEAN GREY SAND WITH SMALL GRAVEL	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	258	to	266 Ft.	CLEAN GREY SAND	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	266	to	268 Ft.	GREY SAND; LITTLE DIRTY WITH FINES	0	nothing	entered	0	nothing	entered	0	nothing	entered
From	268	to	270 Ft.	FINER GREY SAND	0	nothing	entered	0	nothing	entered	0	nothing	entered
From		to	Ft.	SCREENS ORIGINALLY SET FROM 244' TO 264'.	0	nothing	entered	0	nothing	entered	0	nothing	entered
From		to	Ft.	AUG 1999 SCREENS PULLED FROM ORIGINAL SETTING. RESET FROM 180' TO 200'.	0	nothing	entered	0	nothing	entered	0	nothing	entered

APPENDIX B – Grain Size Analyses

