STRATIGRAPHY AND PROPOSED GEOPHYSICAL SURVEY OF THE GROUNDBIRCH PALEOVALLEY: A CONTRIBUTION TO THE COLLABORATIVE NORTHEAST BRITISH COLUMBIA AQUIFER PROJECT

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ABSTRACT

In northeast British Columbia, the increasing pressure on water supply that supports domestic, agriculture and industrial activities has made water a valuable resource. The increasing rural population and expansion of industrial development have led to an escalating need to understand water systems and availability. To this end, the British Columbia Ministry of Forests, Lands and Natural Resource Operations has partnered with the British Columbia Ministry of Energy and Mines, the British Columbia Ministry of Environment, Simon Fraser University and the Geological Survey of Canada to investigate shallow bedrock and unconsolidated groundwater aquifers within the Montney natural gas play. One component of this project is to delineate the geological framework of the unconsolidated aquifers within the Groundbirch paleovalley. This will be achieved by integrating three geophysical surveys with other geological datasets. Downhole electromagnetic and gamma surveys will be conducted in a recently drilled 85 m deep British Columbia observation well constructed with a nonconductive casing. The detailed geology provided by this well will be used to calibrate the other surveys. A ground-based time-domain electromagnetic survey and a shallow seismic reflection survey will be carried out to provide two-dimensional sections across the paleovalley. This information will be supplemented by field data from an exposure of the paleovalley succession along the Coldstream River canyon, along with water well data from the British Columbia Ministry of Environment's WELLS database, the latter of which houses British Columbia's water well information.

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INTRODUCTION

Water is a valued resource in British Columbia. There is, however, increasing pressure on water supplies from a variety of stakeholders in various regions of the province. In northeast British Columbia, water supports domestic, agriculture and industrial activities. As populations grow and industry expands, there is an increasing need to understand water systems and availability so that best management practices can be developed to ensure equitable use, economic development and sustainability of this valuable resource. In 2011, the British Columbia Ministry of Forests, Lands and Natural Resource Operations (FLNRO) partnered with the British Columbia Ministry of Energy and Mines (MEM), the British Columbia Ministry of Environment (MoE), Simon Fraser University (SFU) and the Geological Survey of Canada (GSC) to investigate shallow bedrock and unconsolidated groundwater aquifers in the rural area surrounding Dawson Creek falling within the Montney natural gas play (Wilford et al., 2012). This collaborative project includes three main objectives:

- to characterize the water chemistry of bedrock and unconsolidated aquifers;
- to expand the British Columbia Observation Well Network in oil and gas regions;
- to delineate the geological framework of the unconsolidated aquifers.

Objectives 1 and 2 are discussed in Wilford et al. (2012). This paper introduces objective 3; it discusses the impetus for this part of the project and provides some preliminary results.

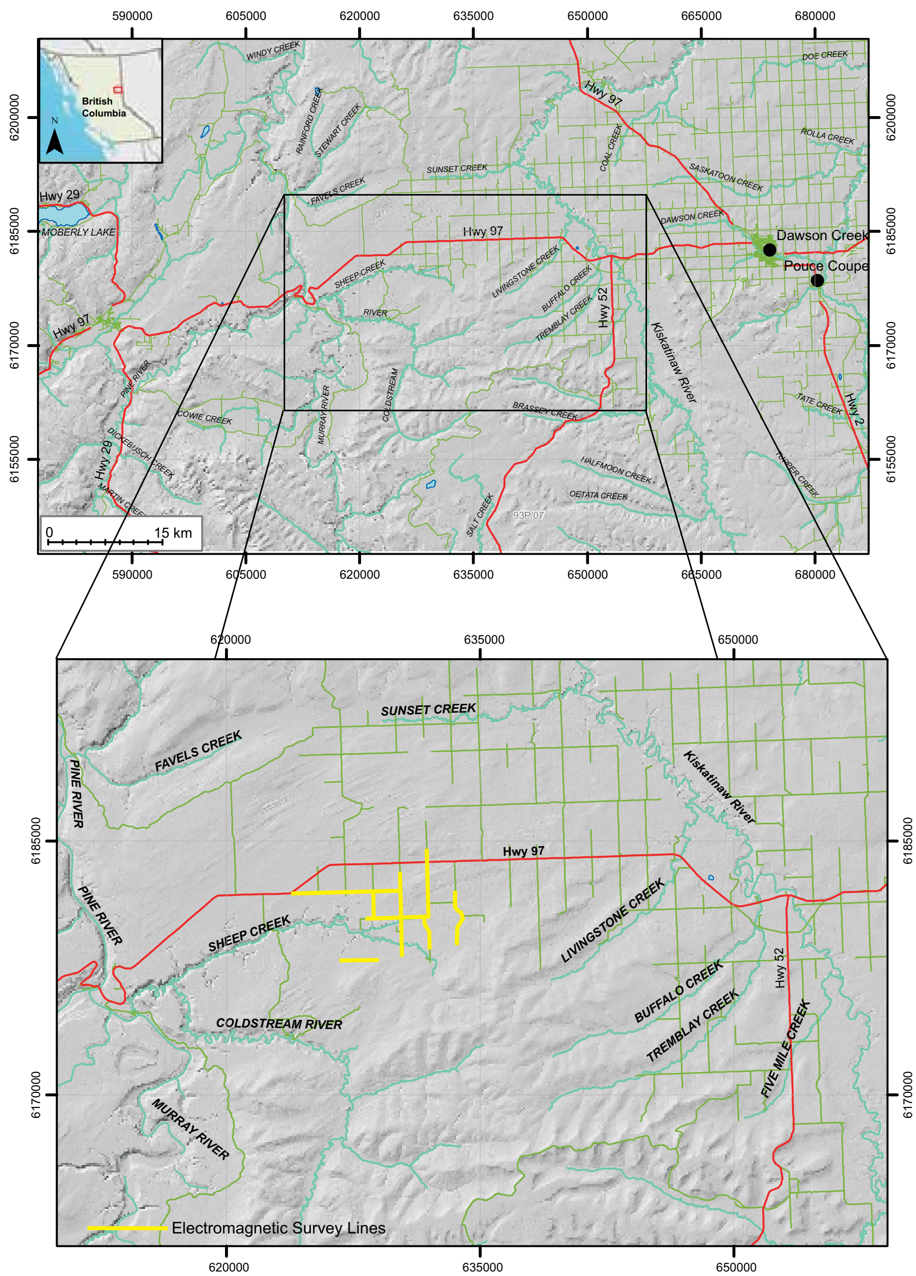


Figure 1. The study area is located in the Groundbirch area of northeast British Columbia.

Natural gas production from shale and other impermeable deposits has become a significant contribution to British Columbia's energy inventory (Adams, 2012). Petroleum exploration and production is also an essential component of British Columbia's economy. The Canadian Association of Petroleum Producers (CAPP) indicates that the oil and gas sector was responsible for more than $8 billion[1] of capital investment in British Columbia in 2010 (Canadian Association of Petroleum Producers, 2012). The province received more than $8.4 billion in oil and gas royalties for the fiscal years from 2005 to 2011 (Chapman et al., 2011). Although land sale activity has declined recently, cumulative land sale bonus revenue since 2005 exceeds $6.8 billion (Chapman et al., 2011). Development of these resources is possible through hydraulic fracturing and advances in horizontal drilling. Because hydraulic fracturing requires significant quantities of water, industry and government are working to evaluate all source-water options. A comprehensive understanding of water availability will aid in developing water sourcing and usage strategies that balance economic benefit with sustainability.

The study area is located in northeastern British Columbia and encompasses the region between the British Columbia–Alberta border and east to the Murray–Pine

[1] Net cash expenditures include geophysical and geological exploration and drilling, development drilling, field equipment, gas plants, operating wells and flow lines.

rivers (Fig. 1). Dawson Creek is the largest settlement in the region (population approximately 11 000) and the region is dominantly agricultural land and boreal forest. The area has a long history of oil and gas activity, with the first wells drilled as early as 1920 and significant activity continuing from the 1950s through to present (Janicki, 2008). The region has been the centre of recent natural gas activity and has received international attention because natural gas producers have been targeting the Triassic Montney Formation, a world-class shale and tight natural gas play.

Although hydraulic fracturing is often identified as a relatively new technology in shale and tight gas development, this stimulation technique has been used in British Columbia for more than 40 years to increase production efficiency from reservoirs. The difference between historic practices and current activity is the increase in the scale associated with shale gas development. With the advent of horizontal drilling and advances in hydraulic fracturing, producers are now able to economically recover natural gas from rocks not previously considered reservoirs because of low permeability (e.g., unconventional shale and tight gas). In the Montney play area, the target horizon is located approximately 2.5–3.5 km below the ground surface (Fig. 2). To liberate gas from the relatively impermeable shale and siltstone, long horizontal sections are drilled into the formation and the rock is hydraulically fractured, thereby providing conduits (increasing the permeability) for gas to move from the rock to the wellbore. Fracturing is achieved by pumping large volumes of water (Johnson and Johnson, 2012) at high pressure into the horizontal wellbore and out into the rock. Induced fractures in the rock are prevented from closing by incorporating proppants such as quartz sand with the hydraulic fluid as it is being injected into the fractures. Every production well in this play area uses hydraulic fracturing to induce economic production of natural gas. As development continues to expand, water management will be of paramount concern for industry, government and regulators.

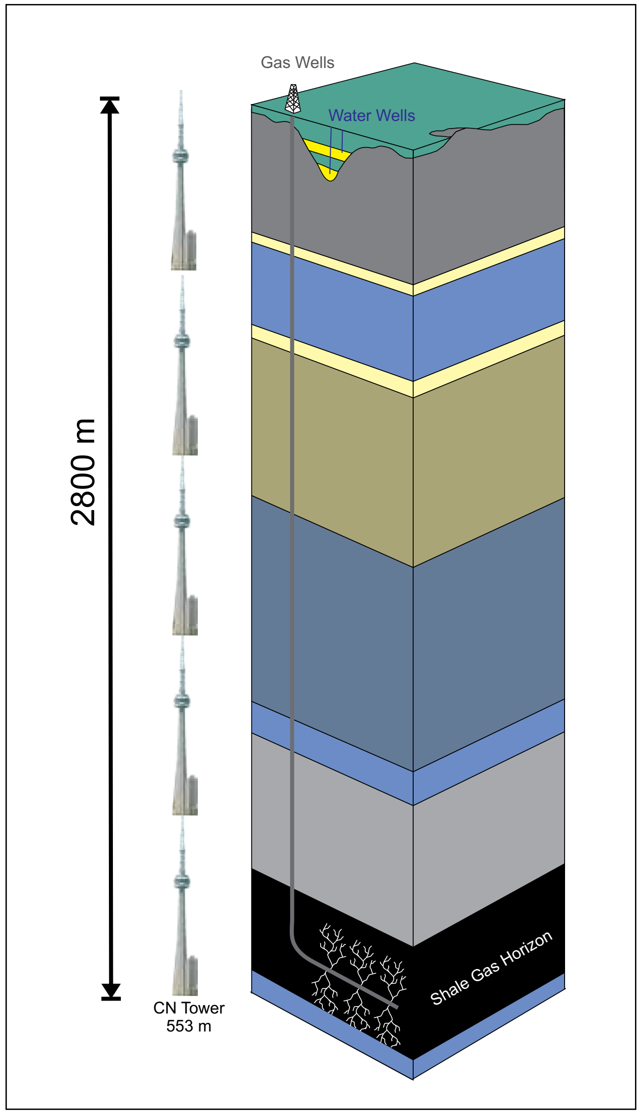


Figure 2. Hydraulic fracturing of the Montney Formation occurs between 2.5 and 3.5 km below the ground surface. This is the equivalent of five CN Towers, one on top of another, underground. Groundwater wells in the area are typically less than 250 m deep.

WATER SOURCES

Three natural sources of water are available for industrial use: surface, shallow subsurface (<600 m) and deep saline (<1000 m) water. Surface water, which includes lakes and rivers, continues to be the most abundant and most commonly used source. Shallow subsurface water may also be a significant source in the future. Saline water (or formation water) from deep underground reservoirs (well below drinking water) may also represent a potential source (e.g., Debolt Formation water has recently been used for hydraulic fracturing in the Horn River Basin, north of the study area; Hayes et al., 2011).

An inventory of water sources in the Montney play area was recently undertaken by Geoscience BC and partners (Brown, 2011) from which much of this study has evolved. Geoscience BC's collaborative initiative involved industry and various government agency partners, including MEM, MoE and FLNRO. Activities focused on compiling and analyzing publically available data. One of the projects in Geoscience BC's initiative involved a modelling exercise that assessed surface water resources through the collection of climate and precipitation data, stream flow, lake volume and related hydrometric information (Foundry Spatial, 2011). Analysis was aimed at determining surface water availability and seasonal variation at a watershed level. Another initiative updated MoE's WELLS database (which houses the province's water-well information) with previously unsubmitted water-well records from the Montney play area. These data were integral in aquifer classification (Lowen, 2011) and bedrock topography mapping (Hickin, 2011). The work by Lowen (2011) and Hickin (2011) confirmed the geometry of a buried paleovalley in the Groundbirch area, which is the focus of the work proposed in this study.

GROUNDBIRCH PALEOVALLEY

Buried Cenozoic paleovalleys are relatively common in northeast British Columbia (Mathews, 1978, 1980; Hickin et al., 2008; Hartman and Clague, 2008; Hickin, 2011). In many cases, these paleovalleys may contain late Neogene and late Pleistocene sediments (Reimchen and Rutter, 1972; Mathews, 1978; Edwards and Schafe, 1996; Hickin et al., 2008). Some paleovalleys are buried with little or no surface expression (Pawlowicz et al., 2005, 2007; Hickin et al., 2008), while others, like those within the study area, occur within modern bedrock-controlled valleys (Mathews, 1978). Since deglaciation, many of these paleovalleys have been incised by 150–250 m, exposing the sediments of the paleovalley-fill succession and bedrock.

Cowen (1998) suggested that buried paleovalleys in the Peace Region are significant sources of groundwater because they typically have higher yields than other potential aquifers. Buried paleovalleys are host to significant accumulations of heterogeneous sediment. Depending on the stratigraphy and hydrogeological constraints, coarse-grained units within the succession may be host to both confined and unconfined aquifers. The thickness, lateral extent and connectivity of these horizons are integral to understanding groundwater availability.

Hickin (2011) delineated nine paleovalleys in the Montney play area, including the Groundbirch paleovalley (GPV; Fig. 3), which was originally identified by Callan (1970). The bedrock topography, model by Hickin (2011), predicts the GPV to be approximately 6000 m wide, 100 m deep and trending west-southwest from the Kiskatinaw River to the Pine–Murray river confluence, paralleling Highway 97. This paleovalley has, in part, been described by Cowen (1998) but is depicted as a tributary of the Kiskatinaw paleovalley. Cowen (1998) reports good-quality fresh water hosted within interglacial sand and gravel of the GPV. His test drilling indicates that the local stratigraphy differs from that presented by Callan (1970) and that the basal gravel and related aquifer expected at the bedrock contact was not present in their drillholes. This suggests that there may be several aquifers at various elevations within the valley-fill succession and the geology is complex.

The GPV is exposed along the canyon sections of Coldstream River and Sheep Creek (Fig. 1). At the mouth of Coldstream River, there is a nearly continuous, 170 m thick section of valley-fill sediments and underlying bedrock exposed along a 3 km stretch of the canyon (Fig. 4, 5). This section provides an opportunity to observe the bedrock and six unconsolidated stratigraphic units that may be potential aquifers elsewhere in the buried paleovalley (Fig. 6).

COLDSTREAM RIVER SECTION

Cretaceous

UNIT 1: BEDROCK (DUNVEGAN FORMATION)

The GPV has incised into Cretaceous bedrock, through shale of the Kaskapau Formation, into the underlying Dunvegan Formation (Stott, 1961; McMechan, 1994). Dunvegan rocks at the base of the Coldstream River canyon include flat-lying, well-bedded, recessive fine-grained mudstone with interbedded 1–2 m thick resistant sandstone beds (Fig. 7). The Dunvegan Formation is interpreted as a succession of shingled, nonmarine to marine deltaic sediments consisting of mudstone, sandstone and conglomerate (Bhattacharya, 1989, 1993; Bhattacharya and Walker, 1991; Plint, 2000; Plint el al., 2001). Despite significant variation in the texture of the Dunvegan Formation, it has been identified by Mathews (1955), Jones (1966), Cowen (1998) and Lowen (2011) as a significant bedrock aquifer (Riddell, 2012). Hayes et al. (2011) suggest, however, that this unit has limited aquifer potential deeper in the subsurface. Fractures, joints and near-surface weathering may have created the shallow productive water zones of this unit, although coarse-grained facies should be considered as potential aquifers.

Pre-glacial/Interglacial

UNIT 2: SAND AND GRAVEL

The lowest and oldest unconsolidated unit preserved in this section is poorly exposed. Where encountered, it consists of partially cemented, oxidized and indurated interbedded sand and gravel (Fig. 8). The gravel is clast supported, poorly sorted, pebble to small cobble sized with a coarse sand matrix. In some places it is open-framework gravel; in other places, matrix is present. The medium to coarse sand occurs as moderately sorted, stratified lenses. The unit has a maximum thickness of 2–3 m where exposed, but both upper and lower contacts were obscured. The unit is discontinuous and where exposed could not be traced laterally for more than 40 m. It is interpreted to be a nonglacial fluvial deposit and would have excellent aquifer potential where present in the subsurface.

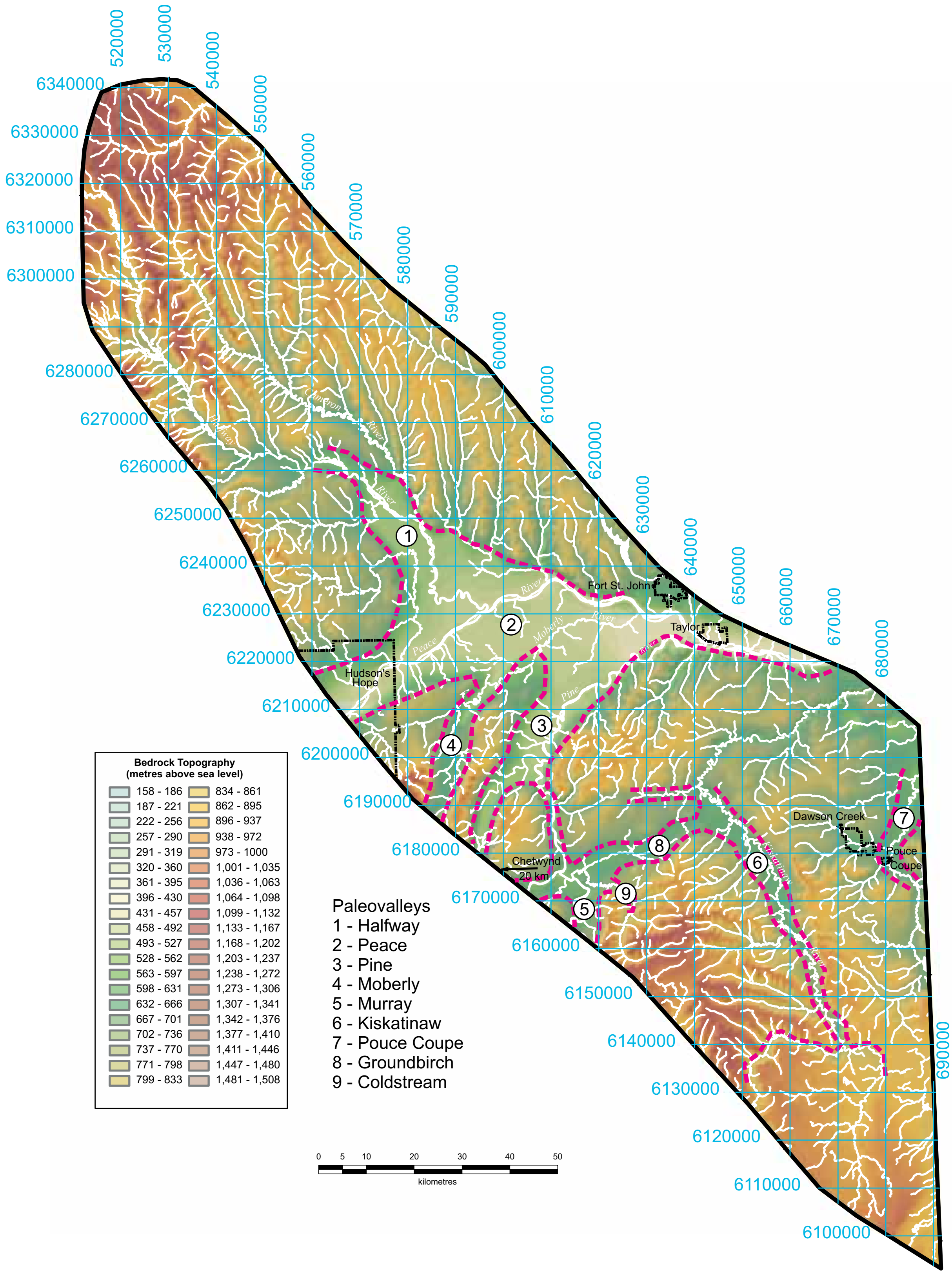
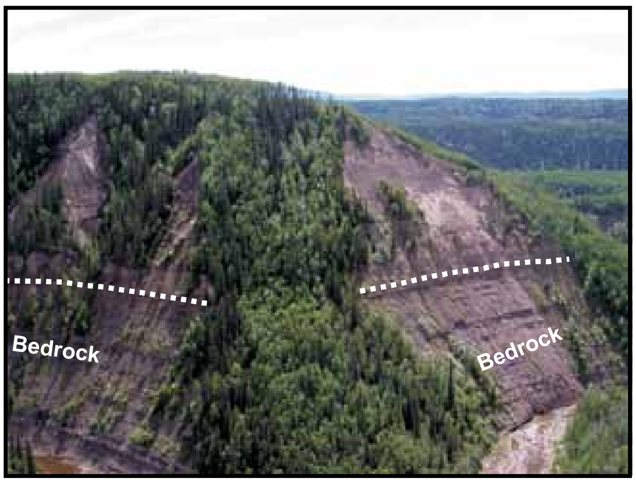


Figure 3. The Groundbirch paleovalley is one of nine paleovalleys identified from bedrock topography mapping by Hickin (2011).

Figure 4. Incision of the Coldstream River near its confluence with the Murray River has exposed the valley-fill succession of the Groundbirch Paleovalley. These exposures provide an excellent opportunity to observe the character and relationship of the stratigraphic units within the succession.



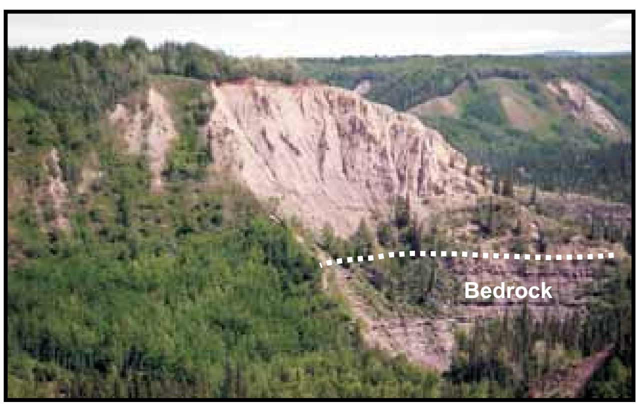


Figure 5. a) The south side of Coldstream River canyon exposes Dunvegan Formation bedrock, overlain by Groundbirch paleovalley-fill sediments; b) the north side of Coldstream River canyon has a thicker and likely more complete section of GPV-fill succession.

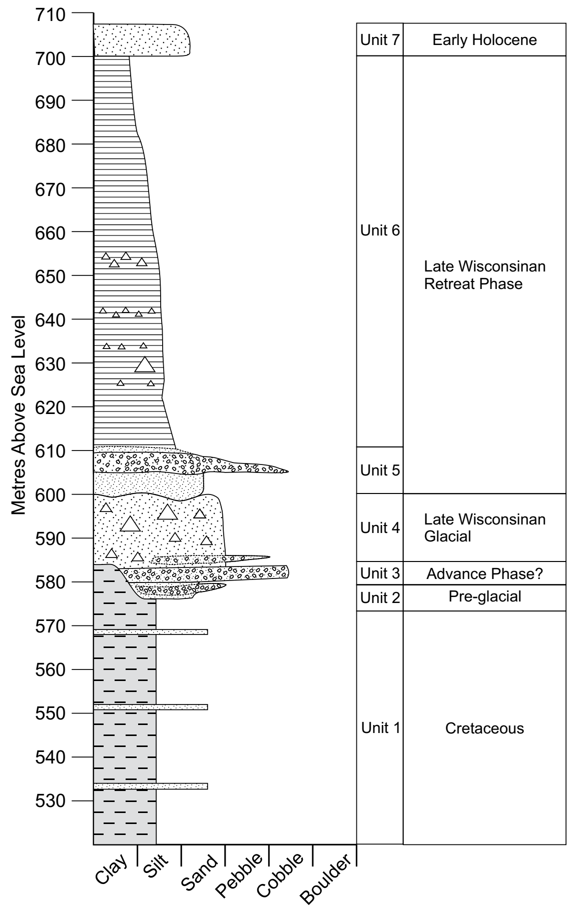


Figure 6. An idealized composite stratigraphic section of the Groundbirch paleovalley-fill succession that consists of seven units.

Figure 7. Dunvegan Formation bedrock is exposed at the base of the Coldstream River section.

Preglacial–Late Wisconsinan: Advance phase (?)

UNIT 3: SAND AND GRAVEL

Unit 3 consists of clast-supported, moderately oxidized, poorly sorted, pebble- to cobble-sized gravel in a silt to granule matrix (Fig. 9). It is 6 m thick at its maximum but pinches and swells laterally or is absent. It was observed along the north-facing canyon wall where it extends laterally for 150 m as a discontinuous body at the bedrock contact. The lower contact is sharp and presumed to be erosional. The matrix is poorly sorted and ranges from silt to granule in size, coarse sand being the modal size. Modal clast size is large pebble but ranges from small pebbles to cobbles. Clast lithologies are dominantly sandstone and silicified mudstone with abundant quartzite and no lithologies associated with eastern provenance (i.e., Canadian Shield; Mathews, 1980). This unit is interpreted to be a nonglacial fluvial deposit that transitions to an advance-phase glaciofluvial deposit. It would be an excellent host for an aquifer if present in the subsurface.

Late Wisconsinan: Glacial phase

UNIT 4: DIAMICT

Unit 4 is a matrix-supported, poorly sorted, granule to boulder diamict (Fig. 10). Matrix textures range from silty clay to sand. Clasts are well faceted, striated and have a glacial origin. The unit is 12–20 m thick and laterally extensive for kilometres (Fig. 10). It has either a sharp lower contact with bedrock or has an intercalated, gradational contact with the gravel of unit 3 (Fig. 10d). The diamict is interpreted as till associated with Late Wisconsinan glaciations. This unit is predicted to have limited porosity or permeability and is expected to be an aquitard/aquiclude in the stratigraphic succession.

Late Wisconsinan: Retreat phase

UNIT 5: SAND AND GRAVEL

Unit 5 consists of coarsening-upward medium sand to gravel at its base that transitions to a fining-upward succession of subhorizontally stratified, clast-supported, moderately sorted, pebble to small cobble gravel (Fig. 11). The lower contact is obscured; however, it is estimated that the unit consists of approximately 5 m of medium sand and 5 m of gravel. The gravel subunit could only be traced laterally for 25 m and was not observed above the exposure on the north-facing wall of the canyon. Unit 5 is interpreted to be a glaciofluvial or subaqueous deposit associated with retreating ice within Glacial Lake Peace (Mathews, 1980). The unit would be an excellent aquifer if present in the subsurface.

UNIT 6: CLAY, SILT, SAND AND DIAMICT

Unit 6 is a regionally extensive succession that makes up the majority of the Coldstream section. It generally fines upwards and consists of well-bedded, horizontally stratified clay, silt and diamict. In this section, the unit ranges from 70 to 100 m thick (Fig. 12a). The lower contact is conformable both over the diamict of unit 4 and over the gravel of unit 5 (Fig. 12b). The base of the unit, above unit 5, consists of sand with abundant type-A and type-B climbing ripples (Fig. 12c) indicative of a high bedload (Ashley et al., 1982) and likely associated with density underflows common in glaciolacustrine environments. Upsection, the unit transitions to horizontally stratified silt and sand with abundant dropstones as large as boulders (Fig. 12d). In general, the succession continues to fine upwards to rhythmically bedded silt, sand and clay, although throughout the middle portion of the unit, there are numerous beds of diamict (Fig. 12e, f). These are likely debris-flow diamicts or ice-rafted debris. Toward the top of the section, the unit consists of silt and clay with minor sand and no dropstones or diamict. This package is interpreted to represent waterlain sediment of a glaciolacustrine environment. This unit is heterolithological with a variety of sedimentary structures that reflect variation in ice position, seasonality, ice cover and location within the basin. The complexity of the unit means that its aquifer potential is unpredictable. Lowen (2011) indicates that in places this unit might be a main aquifer in the Peace Region, but this would depend on the local texture and thickness of potential water-bearing horizons.

Early Holocene

UNIT 7: SANDY SILT

Unit 7 occurs at the top of the section and is marked by a colour change where the sediment is heavily oxidized in bands (Fig. 13). This unit is uniform, poorly sorted sandy silt. Oxidized horizons are moderately indurated. Although the banding implies some stratification, it mimics topography, which suggests that the colour change results from diagenetic or pedogenic processes. Unit 7 is 5–6 m thick and the lower contact is gradational, marked by a subtle transition from rhythmically bedded silt and fine sand to sandy silt. This unit is interpreted to have an eolian origin, and is perhaps loess.

Figure 8. Unit 2 is the oldest unit in the Groundbirch paleovalley succession. It consists of sand and gravel and is likely a pre-Late Wisconsinan fluvial unit.

Figure 9. a) Weathered face of unit 9 showing the abundance of white quartzite and silicified siltstone clasts that comprise this preglacial/advanced-phase gravel; b) cleaned section of unit 9 shows the abundant matrix and the oxidation associated with this unit.

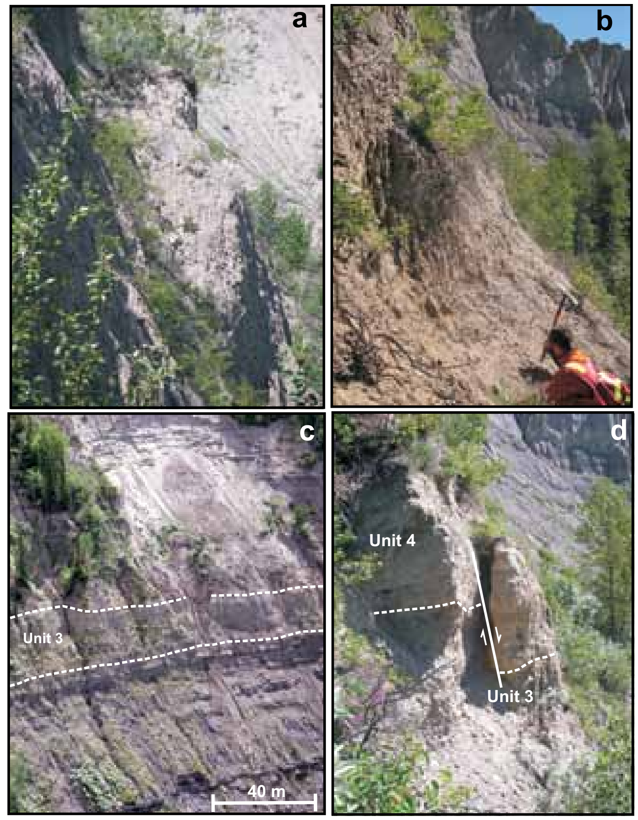


Figure 10. Unit 4 is a diamict: a) it forms competent vertical cliffs towards the base of the Coldstream River section; b) it consists of grey to brown diamict; c) it is laterally extensive and can be traced for kilometres on the south side of the Coldstream River canyon (north-facing exposure); d) the low contact is conformable and intercalated with unit 3.

DISCUSSION AND PROPOSED WORK

The Groundbirch paleovalley was identified in several studies as an important groundwater feature (Callan, 1970; Cowen, 1998; Lowen, 2004, 2011). These same studies suggest that there is a need for a more thorough groundwater evaluation to understand the aquifers in this groundwater system. Although there is abundant water-well information available in this area from the MoE WELLS database, the quality of the geological data is questionable. Discrepancies between the stratigraphy presented by Callan (1970) and that presented by Cowen (1998) indicate units vary from place to place and geology is unpredictable. This complexity is clearly apparent in the lower Coldstream River section where coarse-grained units are laterally discontinuous. Given the importance of this area in terms of economic development and water stewardship, more information on the geological framework that hosts the groundwater system is necessary. To address this, several geophysical surveys are proposed as part of the Northeast British Columbia Aquifer Project (Wilford et al., 2012).

1) Borehole electromagnetic (EM) and gamma surveys

One of the new observation wells drilled in a deep section of the paleovalley (85 m) was constructed with a polyvinyl chloride (PVC) casing (Fig. 1). The nonconductive casing will allow an EM-39 (Geonics Ltd.) slim-hole induction tool and a gamma probe to log the electrical and natural radioactivity of the valley-fill sediments. From these data, detailed lithological information can be inferred. The information will be combined with data from the Coldstream River section and used to calibrate the surface geophysical surveys.

Figure 11. Unit 5 is a sand and gravel unit: a) the upper portion of unit 5 consists of a fining-upward gravel; b) the gravel in this unit is pebble to cobble sized and consists mainly sandstone and mudstone clasts of a western provenance.

2) Ground-based EM survey

Electromagnetic surveys have been used in hydrogeological investigations since the 1970s (Reynolds, 1997). For this survey, the ProTEM 47 (Geonics Ltd.) will be implemented, using a 100 m square transmitter loop with the receiver located at the centre of the loop (McNeil, 1994). This instrument is a time-domain EM system that measures voltage as a function of time after the current in a transmitter loop has been switched off. The change in voltage of the decaying signal is used to model the electrical properties (resistivity) of the subsurface. The resistivity of the layers is related to grain size, water content and water salinity. Because the anticipated depth of investigation is approximately 100 m, the ProTEM 47 was selected for two main reasons: 1) the method is nondestructive and after a measurement is collected, i.e., there is no surface disturbance and 2) this instrument is more portable than the larger ProTEM 57 because it is battery operated and needs no external power source (e.g., a generator), which increases the efficiency of data collection.

Measurements will be combined and a one-dimensional layered-earth model will be generated using Interpex software (Interpex Ltd., Golden, Colorado). The one-dimensional depth models will be integrated into two-dimensional resistivity sections to provide a representation of the geology within the valley fill and offer insight into the geometry and extent of potential water-bearing horizons.

3) Shallow reflection seismic survey

A shallow reflection seismic survey has been proposed for a later phase of the project. The seismic data will complement the EM survey by providing information on the location of boundaries between lithological units of contrasting acoustic impedance. This provides information on the geometry of the paleovalley and the architecture of the valley-fill sediments, which is critical to hydrogeological investigations (Rabbel, 2006). By combining the two surveys, information on both the texture and valley-fill architecture can be deduced (Hickin et al., 2009). The ideal seismic method is the land streamer–Minivib system developed by the GSC (Pugin et al., 2009a, b). This system uses a Minivib (Industrial Vehicles International Inc.) vibrating source consisting of a 140 kg mass that sweeps through a frequency range of 10–550 Hz (Pugin et al., 2009b). The Minivib tows a land streamer array of small metal sleds, equipped with a three-component geophone (Fig. 14). The land streamer approach eliminates the need to set geophones and the vibrating source eliminates the necessity for a percussion source. Data acquisition is very efficient; the system can collect 1000 records per day (4–8 km/day). Fortuitously, many of the roads in the Groundbirch area are oriented perpendicular to the trend of the GPV, which offers an excellent opportunity to image multiple cross-sections across the buried valley.

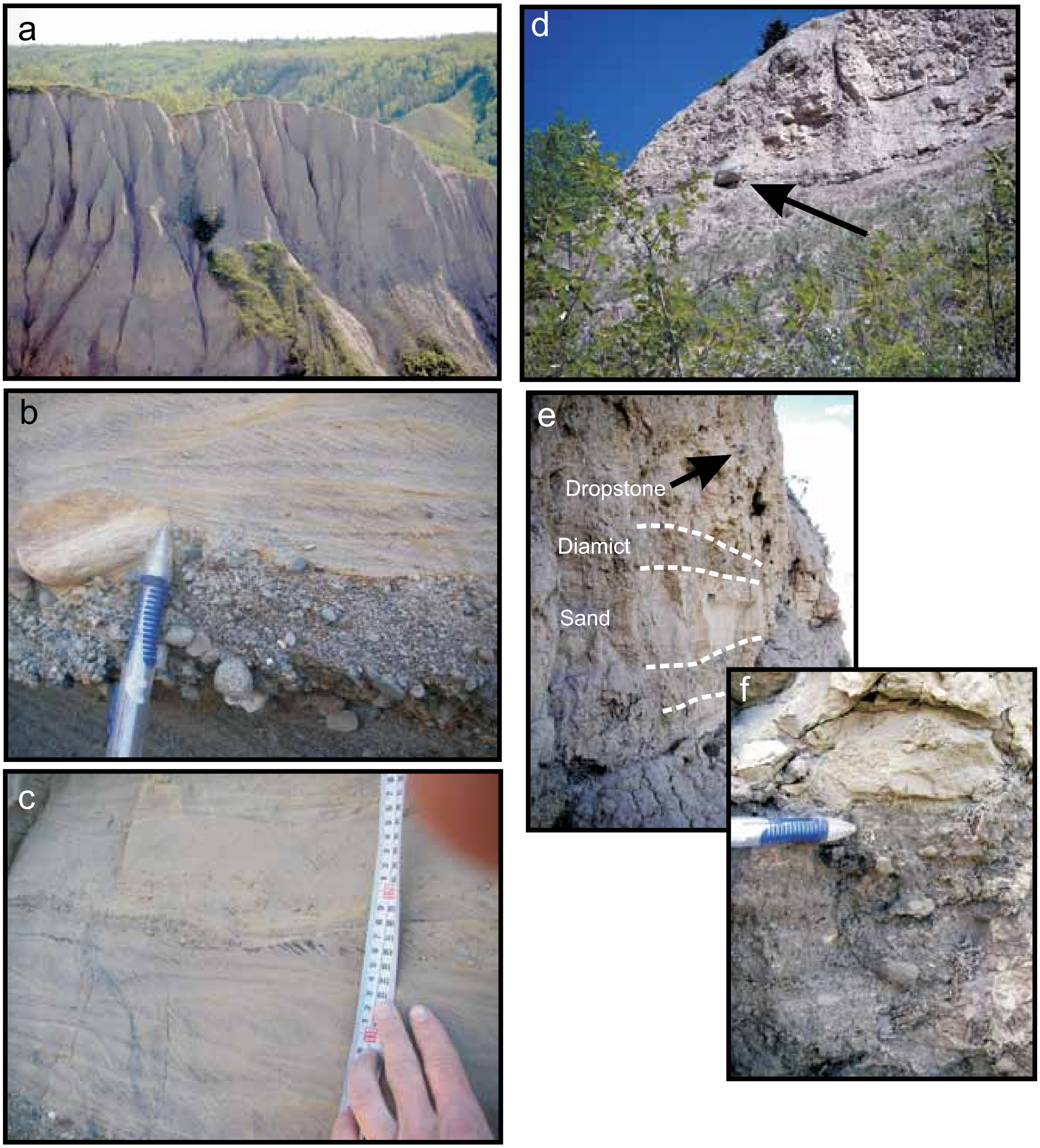


Figure 12. Unit 6 is a hetrolithologic glaciolacustrine unit: a) the unit is the thickest (70–100 m) and most voluminous unit in the Groundbirch paleovalley succession; b) the lower contact is conformable over unit 5; c) the lower part of unit 6 consists of sand with well-developed climbing ripples likely associated with underflows; the ripples are highlighted by sand-sized fragments of black coal; d) the middle part of unit 6 has an abundance of dropstones, some of which can be large boulders (indicated by the arrow); e) the bulk of the middle portion consists of interbedded sand, silt and diamict with common dropstones; f) laterally continuous, massive, matrix-supported diamict beds are commonly interbedded with sandy glaciaolacustrine deposits of unit 6; the diamict likely represents subaqueous debris flows and ice-rafted debris.

Figure 13. Unit 7 is the youngest unit in the succession and is demarcated by a distinct colour change (oxidation) at the top of the section. There is only a very subtle decrease in the grain size between the top of unit 6 and the base of unit 7. The origin of this unit is speculated to be eolian.

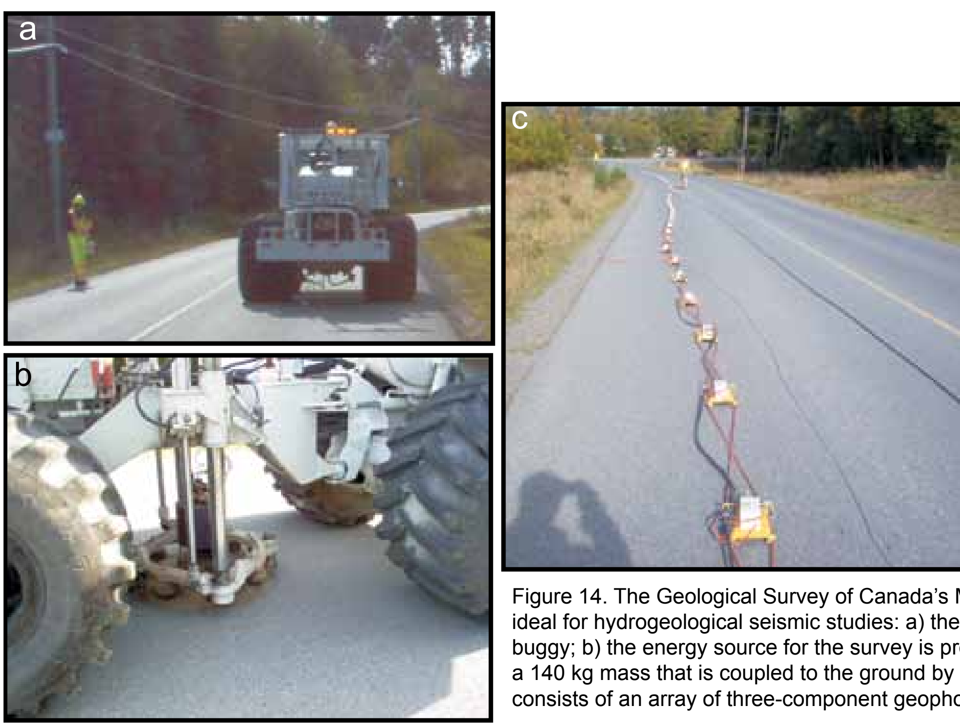


Figure 14. The Geological Survey of Canada's Minivib with land streamer is ideal for hydrogeological seismic studies: a) the vibrator is mounted on a Minivib buggy; b) the energy source for the survey is provided by a vibrator, consisting of a 140 kg mass that is coupled to the ground by hydraulics; c) the land streamer consists of an array of three-component geophones mounted on metal sleds.

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