INTERPRETATION OF QUATERNARY SEDIMENTS AND DEPTH TO BEDROCK THROUGH DATA COMPILATION AND CORRECTION OF GAMMA LOGS

FINAL REPORT

for

GEOSCIENCE BC

Geoscience BC Report 2015-04

December, 2015

Petrel Robertson

Petrel Robertson Consulting Ltd.

CERTIFICATE OF QUALIFICATION

BRAD J.R. HAYES, Ph.D., P.Geol.

I, Brad J.R. Hayes, Professional Geologist at Petrel Robertson Consulting Ltd., Suite 500, 736 – Eighth Avenue SW, Calgary, Alberta, Canada and author of a report dated December, 2015, do hereby certify that:

- I am a professional geologist employed by Petrel Robertson Consulting Ltd., which Company did prepare a report titled *Interpretation of Quaternary Sediments and Depth to Bedrock Through Data Compilation and Correction of Gamma Logs*, for Geoscience BC.

- I attended the University of Toronto, and that I graduated with a Bachelor of Science (Honours) Degree, Geology Specialist Program (1978), and obtained a Doctor of Philosophy Geology (1982) from the University of Alberta (Edmonton, Alberta); that I am a member of APEGGA; that I have in excess of 30 years experience including geological studies relating to both Canadian and international oil and gas properties.

- I have not, directly or indirectly, received an interest, and I do not expect to receive an interest, direct or indirect, in any associate or affiliate of GeoScience BC.

- The evaluation was prepared based on information available in the public domain.

PROFESSIONAL
PROVINCE OF
Dr. B. J. R. HAYES
#30134
BRITISH COLUMBIA
GEOSCIENTIST

Brad J.R. Hayes, Ph.D., P.Geo. (BC)

EXECUTIVE SUMMARY

Substantial volumes of water are required to drill and complete Montney Formation tight siltstone reservoirs in northeastern B.C. Operators look to access water and efficiently and economically as possible, while minimizing impacts on other stakeholders. Geoscience BC has worked with industry, government agencies, and local stakeholders to assess available water resources in the BC Montney play fairway. Substantial progress has been made in understanding water resources in deep saline aquifers and in surface water bodies, but non-saline groundwater resources in unconsolidated aquifers and shallow bedrock are not as well known.

Geoscience BC has undertaken the Peace Project to map groundwater resources in an 8000+ km^2 area in the Peace Region, through the use of airborne geophysics. In support, Petrel Robertson Consulting Ltd. (PRCL) and Quaternary Geosciences Inc. (QGI) have completed a geological characterization of Quaternary and other near-surface formations in the Peace Project area. Building on existing geological mapping and hydrogeological reports, our investigation used cased-hole gamma logs run through surface casing in petroleum boreholes to map depth to bedrock (and hence thickness of Quaternary cover), and the distribution of aquifer sands in the Quaternary section.

Existing regional maps show the Quaternary section in the Peace Project area to consist primarily of a thin mantle of undifferentiated glacial material, and glaciolacustrine veneer over till. Glaciolacustrine sediments occupy large portions of present-day river valleys. Glaciofluvial, colluvial, alluvial, and eolian sediments are mapped along the Peace River and major tributaries. Bedrock is at surface in northern parts of the project area and northward. Most petroleum boreholes and many waters are in upland / interfluve areas mantled by thin glacial deposits, and thus exhibit very thin Quaternary sections.

Quaternary paleovalley outlines were drawn based on existing literature and maps, but are refined and analyzed using the well data compiled in this study. Most paleovalleys are strongly associated with existing drainage systems, particularly the Peace River in the south, but many present-day stream valleys show no direct evidence of paleovalleys. Well data allow identification of relatively thick paleovalley fills, but these are difficult to quantify because of the irregular distribution and variable reliability of well information. Sands and gravels were identified tentatively from well data, but data are not sufficient to create stratigraphic subdivisions or correlations within the Quaternary section.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF MAPS

INTRODUCTION

Montney Formation tight siltstone reservoirs in northeastern B.C. are being developed intensively for gas, liquids and oil production, using horizontal drilling and multiple hydraulic fracture completions. Drilling and completions operations require substantial volumes of water, which must be obtained while minimizing impacts on other stakeholders such as First Nations, and agricultural and municipal consumers. As well, costs to source and transport water can be critical components of project economics.

Geoscience BC has worked in partnership with industry, government agencies, and local stakeholders to assess available water resources in the BC Montney play fairway; results to date are summarized in the Montney Water Project[1]. Substantial progress has been made in understanding water resources in deep saline aquifers and in surface water bodies, but non-saline groundwater resources in unconsolidated aquifers and shallow bedrock are not as well known. The Peace Project has been undertaken to map groundwater resources in an 8000+ km^2 area in the Peace Region, through the use of airborne geophysics (Fig. 1). Three offsetting areas were added to the project outline after initiation – the Sikanni Chief area to the immediate northeast, the Doig River area to the east, and the Charlie Lake area to the immediate southeast (Fig. 1, Map 1).

Information from the Project will serve as a key component of the Northeast Water Strategy, currently under development by the Provincial government in partnership with local governments, regulatory bodies, Treaty 8 First Nations, Geoscience BC and industry, by providing knowledge to enable the Northeast Water Strategy's Enhanced Water Monitoring System.

The Peace Project is a collaborative effort involving the Ministry of Forests, Lands and Natural Resource Operations, the Ministry of Environment, the BC Oil and Gas Commission, the Ministry of Natural Gas Development, Progress Energy Canada Ltd., ConocoPhillips Canada, Northern Development Initiative Trust, and the BC Oil & Gas Research and Innovation Society, with additional support from the Peace River Regional District and the Canadian Association of Petroleum Producers.

Current Study

Petrel Robertson Consulting Ltd. (PRCL) and Quaternary Geosciences Inc. (QGI) have completed a geological characterization of Quaternary and other near-surface formations in Geoscience BC's Peace Project area. Building on existing geological mapping and hydrogeological reports, our investigation used cased-hole gamma logs

[1] http://www.geosciencebc.com/s/Montney.asp

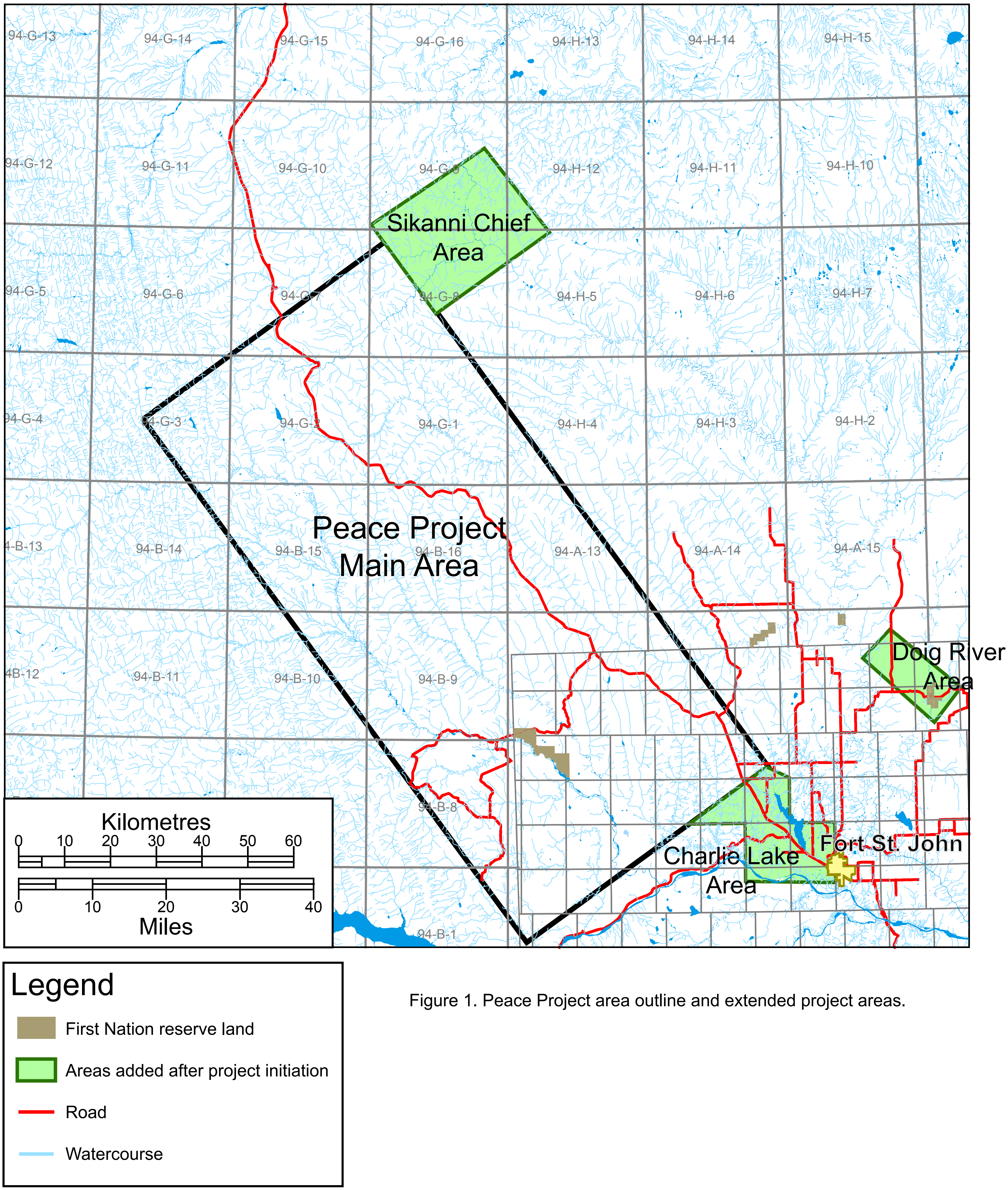


Figure 1. Peace Project area outline and extended project areas.

run through surface casing in petroleum boreholes to provide valuable information about the depth to bedrock (and hence thickness of Quaternary cover), and the nature and distribution of aquifers and aquitards in unconsolidated Quaternary sediments. Drillers' logs from shallow water wells were also incorporated where available.

Deliverables from the study include a stratigraphic database summarizing interpretations from all petroleum boreholes (Appendix 1), a database tabulating depth to bedrock picks for water wells (Appendix 2), and surficial geology maps showing composition and thickness of the Quaternary section (depth to bedrock surface), along with interpreted outlines of paleovalley systems (Map 1, 2). These will be used to calibrate interpretations of Quaternary thickness and aquifers derived from airborne geophysical mapping in the main phase of Geoscience BC's Peace Project.

METHODOLOGY

Petroleum Borehole Gamma Logs

Log Selection and Processing

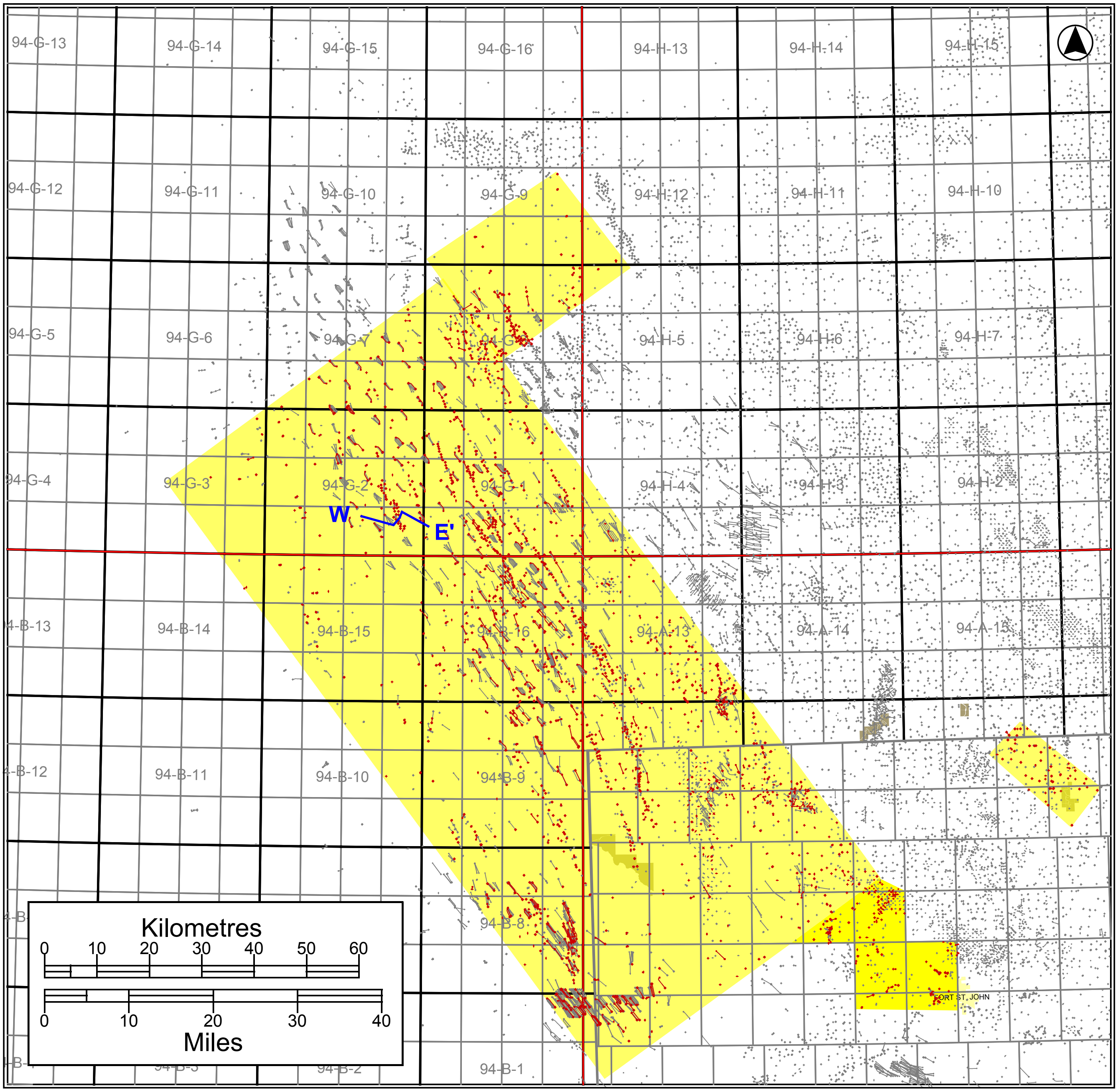
PRCL reviewed all available cased-hole gamma logs from petroleum boreholes in the project area, and selected those having cased-hole gamma logs with coverage shallower than 50 m true vertical depth (TVD). Particular attention was paid to areas where 3D seismic data may be available to calibrate mapping, as designated by Geoscience BC. A small number of twinned wells, or other wells very close to wells already selected, were not digitized, as they would add little significant information to the study. In total, 1381 wellbores were used across the entire project area, including the three supplemental areas (Appendix 1, Fig. 2).

The statistical technique of Quartero *et al.* (2014) was then applied to each cased-hole gamma curve to correct for attenuation effects, producing a corrected gamma curve. For each well, the upper portion of the uncorrected open-hole gamma curve was merged with the corrected cased-hole gamma curve to create continuous stratigraphic coverage across the bedrock section. Results are presented as .pdf images showing both original and corrected curves, and as final corrected curves in .las format (Fig. 3; Appendix 3, 4).

Note that the distribution of petroleum boreholes is strongly influenced by northwest-southeast structural trends which control the distribution of many conventional gas pools. Well locations listed in Appendix 1 are the official unique well identifiers (UWI's), which are generally bottomhole locations in horizontal or directional wells; we have used surface hole locations to plot data values, as the Quaternary section is obviously logged at the surface location. Therefore, petroleum borehole locations plotted on Maps 1 and 2 (at surface) may be offset from the database UWI (bottomhole) by up to two kilometres.

Log Interpretation

The top of the bedrock surface was identified by both gradual and sudden deviations from the predictable Cretaceous bedrock gamma stratigraphy. Commonly, these unexpected changes include sharp and often large magnitude (60 to 120 API units) declines in gamma values crossing the bedrock / Quaternary sediment interface. Such gamma declines are most pronounced where the upper part of the local bedrock consists of shales and fine siltstones of the Sully or Buckinghorse Formation. Other indicators of Quaternary sediments on gamma logs include unusually erratic data, sections of highly uniform readings and, rarely, anomalous gamma spikes.



Legend
Shallow Well Control
Project Wells
Study Area
Cross Section W - E'

Figure 2. Petroleum borehole well control in Peace Project area. Wells highlighted red have suitable cased-hole gamma logs and were used in the project. Line of section for Figure 4 is shown.

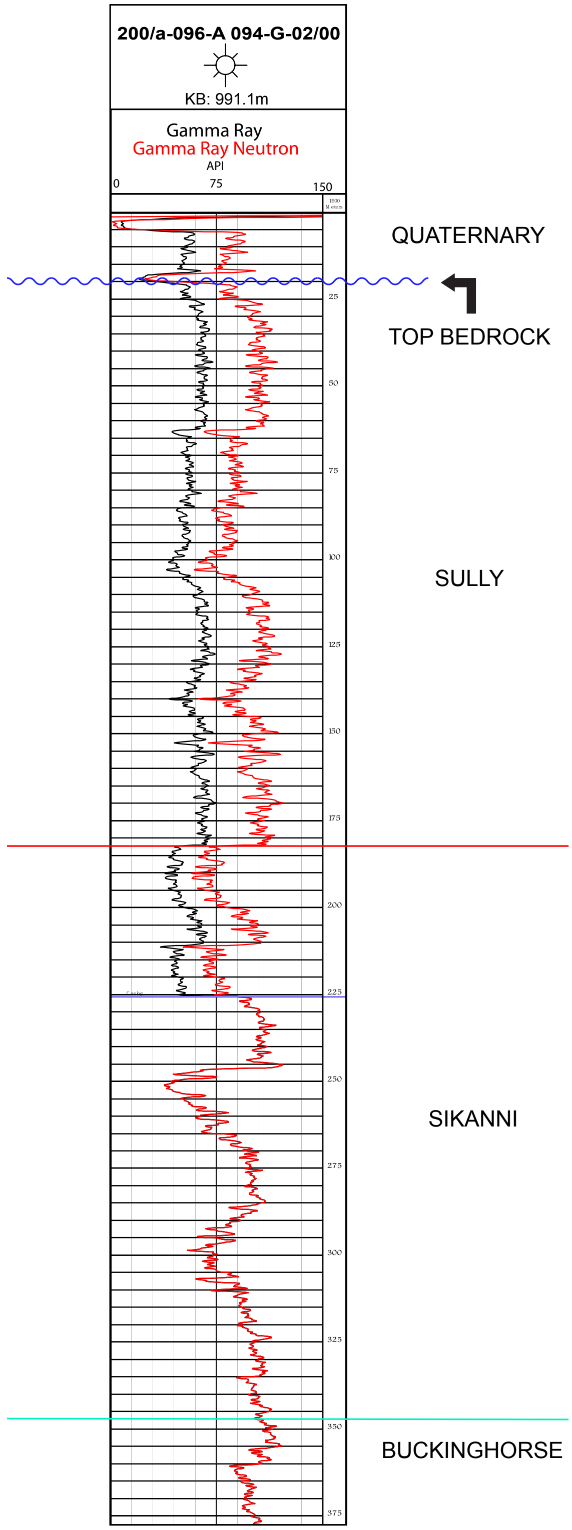


Figure 3. Sample gamma ray log, well 200/a-96-A/94-G-2. Base of surface casing is at drill depth 229m; the open-hole gamma log is shown below that depth. Above, the cased-hole gamma log is shown in black, while the log corrected with the Quartero method is shown in red. Stratigraphic picks can be made readily on the composite red curve.

A significant challenge in making the top bedrock pick is the similar gamma signal presented by bedrock sandstones, such as the Sikanni and Dunvegan formations, versus coarse glacial sediments; shales and Quaternary clay successions such as glaciolacustrine units can also be difficult to distinguish. Also challenging is the occurrence of glaciotectonic disruption of bedrock surfaces where they are directly overlain by till. Such contacts exhibit more gradual changes on the gamma logs than would be the case without deformation. In most areas, however, consistent bedrock stratigraphy and comparison with offsetting wells lends certainty to the top bedrock pick (Fig. 4).

Limitations of Gamma Log Interpretations

There are some significant limitations in interpreting stratigraphy from shallow gamma logs. The most serious is the absence of data in the uppermost part of many gamma logs. The reason for this is not always clear, but it is often likely a result of operators turning off the logging tool before it reaches surface. As a result, many of the gamma logs used in this study provide only a maximum depth of the Quaternary cover. The depth to bedrock interpreted from these logs is recorded as "less than" in Appendix 1, indicating that the bedrock surface is at some unknown depth shallower than the depth indicated (which is the top of the corrected gamma curve). In some cases, only a few metres may be missing at the top of the log and the impact in interpretation is minimal. However, in other cases, ten or more metres may be missing, leading to considerable uncertainty about the top bedrock depth.

Another important limitation in interpreting shallow gamma logs is related to the presence of conductor pipe or other near-surface infrastructure that can affect the gamma values. Conductor pipe is a large diameter (e.g., 40.64 cm or 16 inch) pipe that is placed in the starter hole. It is typically air hammered to refusal, and may or may not be cemented in place. Conductor pipes are commonly placed to depths of 10 to 40 m, or deeper if required by the local geological conditions, although some well sites do not have conductor pipes. Unfortunately, the depths to which conductor pipes are run are not available in public databases, nor are they recorded on borehole logs.

The base of the conductor pipe can be recognized in many gamma logs by a sharp decline in gamma readings, as the gamma signal is often muted within the conductor pipe due to the additional steel and/or cement between the tool and the sediment or bedrock. In some wells, a more gradual decline in gamma values is observed, possibly reflecting a gradual decrease in cement with depth. It is often difficult to determine the exact depth of the conductor pipe, and in some cases, the base of the pipe may be confused with the base of the Quaternary section. Since the pipe is hammered down to refusal, the base may in some cases coincide with the Quaternary/bedrock contact, but it may also just represent the point where the ground is sufficiently firm to resist further penetration.

It is also important to note that gamma logs are not corrected for the height of the drilling rig's Kelly Bushing (KB), which is usually about 5 m above ground level. It is

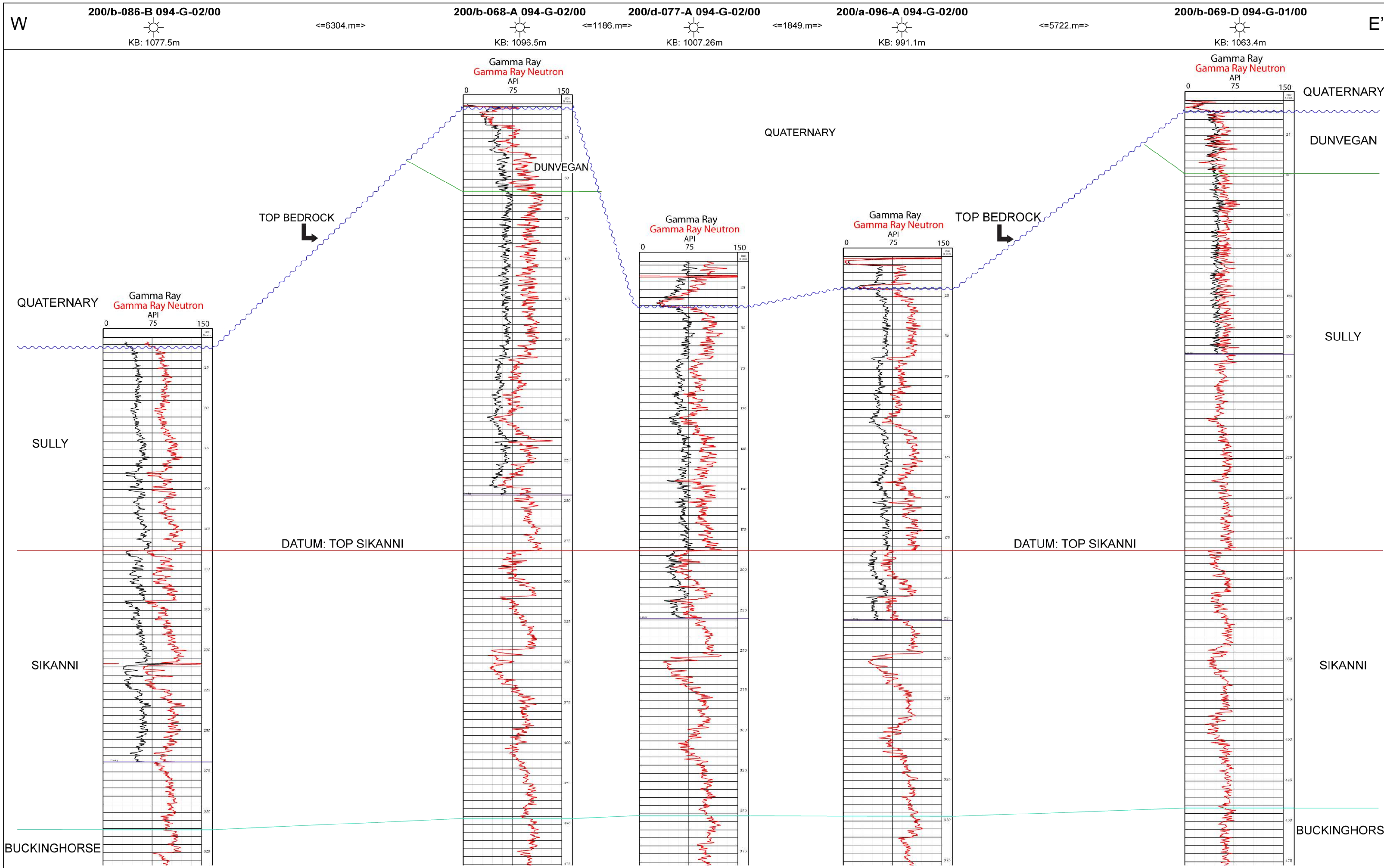


Figure 4. Well-log cross-section, showing erosional relief on the pre-Quaternary unconformity (wavy line). Line of section shown on Figure 3.

Petrel Robertson

Interpretation of Quaternary Sediments and Depth to Bedrock through Data Compilation and Correction of Gamma Logs

Beatton River Valley near Alaska Hwy

Cross Section W - E'

12

Date: October 2015 **Geologist:John Carey**

PETREL ROBERTSON CONSULTING LTD.

quite clear on most logs that there is a sharp decline in gamma at the height of the Kelly Bushing. The final depths to bedrock provided in Appendix 1 (Column I) have been corrected for the height of the KB at each individual well. Corrected depths are thus the actual depth below the ground surface. Uncorrected depths are also provided (Column E) for ease of comparison with the gamma logs, as the logs themselves have not been corrected.

Other Data Sources

Other information used to determine Quaternary and bedrock stratigraphy include: mapped surficial geology, bedrock geology (Okulitch *et al.*, 2002), topographic position, geomorphologic setting, and other subsurface data sets such as water well data and stratigraphic sections, where available. Data were derived from various sources, including government water well data and stratigraphic data from the BC Ministry of Energy and Mines (Hickin, 2011), the Geological Survey of Canada and university studies (Hartman, 2005; Hartman and Clague, 2008; Hickin 2013; Hickin and Best, 2013). Various hydrogeology reports were also consulted for relevant information on buried Quaternary paleochannels in the region (Ronneseth, 1994; Cowen, 1998; Lowen Hydrogeology Consulting, 2004, 2011).

Surficial geology data and maps were compiled for the study area from 1:250,000 scale surficial geology maps and reports produced by the Geological Survey of Canada (Mathews, 1978, 1980; Bednarski, 1999, 2000 and 2001), and from soils, landforms and surficial geology maps and reports produced by Agriculture Canada (1977), the BC Soil Survey (1986, 1988; Lord, 1977a,b) and the BC Ministry of Environment (1977a, 1977b, 19890, 1987, 1988a, 1988b) at a variety of scales ranging from 1:50,000 to 1:125,000. A regional 1:1,000,000 scale glacial features map was also used (Mathews *et al.*, 1975). Map polygon data for all areas were obtained digitally and compiled in GIS format. Reinterpretation of some map unit designations, grouping of map units and minor adjustments to map unit boundaries were required for overall consistency of the final compilation map and to eliminate artificial changes across map borders (Map 1, 2).

Water well logs are typically compiled by drillers without geological training and are based on descriptions of chip samples, so these logs are not considered to be highly reliable (Appendix 2). They are used with caution in this study and relied upon exclusively only in a few areas where no other data were available. It is common for water well drillers to log parts of the bedrock sequence as sediment (e.g., sand or clay) rather than as rock (e.g., sandstone or shale), and consequently water well logs commonly record top to bedrock depths that are too deep. For this reason, where there are conflicting deep and shallow bedrock depths in the water well data, the shallow values are considered more likely to be correct. On Maps 1 and 2, we have differentiated water wells with reasonably reliable information from those that appear unreliable. Where water wells have reached total depth in Quaternary sediment, we have indicated the depth to bedrock as being greater than the well depth (signified by the ‘>’ symbol on the data posting).

Quaternary Stratigraphy and Aquifer Interpretation

Coarse-grained Quaternary sediments, indicative of aquifer potential, were interpreted from all gamma logs with thick Quaternary sections. There is no established internal Quaternary stratigraphy in the study area, as thick paleovalley fills are widely scattered and highly variable.

In cases where a sand and/or gravel unit was inferred to overlie bedrock directly, the log depth to the top of the potential aquifer was estimated and recorded (Appendix 1, Column J). Also, the base and top of any other inferred coarse-grained units higher in the stratigraphy were recorded (Columns L, M), and the depths of prominent fine-grained units (probable aquitards) that overlie the basal aquifer were also determined (Column K). In the case of basal Quaternary aquifers, the first prominent gamma peak above the aquifer was identified. The identification of aquitards is intended to help differentiate confined and unconfined aquifers in the Quaternary stratigraphy. Wells containing potential aquifer sands and gravels are highlighted on Maps 1 and 2.

Other important information compiled for each well site included: surficial materials mapped at the site (Column C), topographic position of the well, and the underlying bedrock formation. All this information for every petroleum borehole is provided in Appendix 1. Comments are also provided on the local geomorphic setting, other possible interpretations of bedrock depth when uncertain, the inferred depth of the conductor pipe, and any other information relevant to the interpretation of the gamma log.

MAPPING RESULTS

Surficial Geology Overview

Compilation of regional maps shows the Quaternary section in the Peace Project area to consist primarily of a thin mantle of undifferentiated glacial material, and glaciolacustrine veneer over till (Map 1, 2). Glaciolacustrine sediments occupy large portions of present-day river valleys. Glaciofluvial, colluvial, alluvial, and eolian sediments are mapped along the Peace River and major tributaries. Bedrock is at surface in northern parts of the project area and northward.

Most petroleum boreholes and many water wells are in upland / interfluve areas mantled by thin glacial deposits, and thus exhibit very thin Quaternary sections. Paleovalley outlines shown on Map 1 and 2 were drawn based on the literature and maps described above, but are refined and analyzed using the well data compiled in this study, as described below. We have little or no information about paleovalley fills from the literature, but we have used well log data to semi-quantitatively distinguish areas of relatively thick fill (generally >20 m).

Main Study Area – South

The largest and deepest paleochannels in the study area are in the southern part of the area on the low plateau adjacent to the modern Peace River valley (Map 1). Paleochannels have been recognized in this region for many years, but their boundaries have only been broadly delineated. Mathews (1978) mapped a wide paleochannel valley that formed during the last interglacial along a path broadly parallel to the modern Peace River; it was estimated to be about 10 km wide, significantly wider than the modern river valley.

One major southeasterly-trending paleotributary valley was identified, broadly following the path of Cache Creek southward to where it joins the main Peace River paleochannel between Attachie and Bear Flat (Map 1, southern 94-A-6). Our mapping suggests there may be two paleotributaries within this system, one draining southward along the east side of the lower Halfway River with bedrock depths as great as 180-190 m at the southern margin of the map area. The second branch trends southeasterly and more closely follows the upper Cache Creek valley. Bedrock depths in water wells as deep as 188 m have been recorded in this area. Hartman (2005) presented water well data indicating the presence of both a higher paleovalley (224 m above the modern Peace River) and a lower paleovalley (49 m above the Peace) but the channel boundaries are all approximate or assumed.

In the southwestern corner of the map area (northwestern 94-A-4), there is a complicated pattern of deep bedrock data points, based on both water well and petroleum borehole data, that suggest that the northwestern margin of the Peace River paleochannel mapped by Mathews (1978) just south of the study area, may actually lie farther to the northwest, within the study area. Petroleum borehole bedrock depths range up to 49 m, and water wells show bedrock depths up to 119 m in this area. Mathews (1978) paleochannel boundary is drawn as an almost straight line trending northeasterly, but subsurface data suggest that the geometry of the paleovalley margin is much more complicated. Mathews (1978) did, however, record a bedrock depth of 393 m (ASL), about 90 m deeper than his lowest paleochannel gravels, from a drill site near Lynx Creek (southwestern-most corner of the study area). He interpreted these values to reflect a glacially over-deepened trench, which may explain some of the apparently complex, buried bedrock topography in this area.

A west-east paleochannel following Farrell Creek valley just to the north is indicated by numerous deep water well and petroleum borehole bedrock values. Unfortunately, there are no wells further to the east along the lower reaches of Farrell Creek, so it is not known if this paleochannel connects eastward with the lower Halfway River – Cache Creek buried channel system, or if it bends southward to join the old Peace River valley.

The up-valley extent of the Cache Creek paleochannel was not mapped beyond the lowermost Halfway River valley by Mathews (1978), but Hickin (2011) proposed that it extended up the Halfway River valley almost to the confluence with Kobes Creek (northeastern corner 94-B-8). He mapped the thalweg more or less following the modern river almost all the way to 57° North latitude, with east-draining tributaries along the Chowade and Graham rivers. Our mapping shows a similar paleochannel valley extending north of 57° latitude, and with additional eastward-draining paleotributaries likely present along the valleys of Groundbirch, Kobes, Grave, Horseshoe and Cypress creeks. We also identified a southward-draining paleotributary along the lower Cameron River (southern 94-A-12), but the northern extent of that paleochannel is not known due to the lack of data in the modern valley bottom. Although not mapped, this paleochannel could extend up valley at least as far as Townsend Creek. One deep bedrock site (21 m) in the upper Cameron Creek valley is likely in an alluvial fan.

The Halfway River valley and all of the above mentioned modern tributary valleys have extensive surface deposits of alluvial and glaciofluvial sands and gravels that comprise good potential unconfined aquifers.

Other south-flowing paleotributaries to the lower Halfway River / Cache Creek buried channel system likely include the lower reaches of the Coplin, West Cache, East Cache, North Cache and Red creeks, as indicated by sparse well data in these valleys. The lower reaches of other modern south-flowing tributaries of the Halfway River, such as Alexander and Deadhorse creeks, may also contain narrow paleochannels, but there are insufficient available well data to support this interpretation. Farther north, along the Blueberry River valley (northeastern 94-A-12), a number of data points suggest that a narrow paleochannel or remnants of a paleochannel are present in the lower reaches.

Several water wells with bedrock depths ranging from 20 to 36 m occur in the Wonowan area near the Blueberry River valley; they are closely spaced and surrounded by numerous other wells with shallow bedrock depths (<5 m), suggesting that bedrock may have been misidentified in these wells. Nevertheless, the possibility of a narrow paleochannel in this area connecting to the Blueberry River channel can't be ruled out.

Main Study Area – North

A number of probable paleochannels have been identified, including relatively narrow systems that follow the valleys of the Beatton, upper Halfway and upper Sikanni Chief rivers (Map 1). In addition to buried channel potential, all of these valleys have narrow floodplains with nearly continuous units of alluvial sands and gravels that form good potential unconfined surface aquifers.

A relatively high density of petroleum boreholes in two areas along the Beatton River valley show significant bedrock depths. The deepest tops, ranging from 37 to 52 m, occur along a north-south section across the valley in western 94-G-1, where the Beatton River valley makes a large northward bend. A low saddle directly to the northwest (northeastern 94-G-2), with bedrock depths ranging from 10 to 33 m, extends to the Sikanni Chief River valley, where a few wells show deep bedrock picks (up to >125 m). The central part of the saddle was mapped by Bednarski (2000) as a large meltwater channel, and Hickin (2011) mapped thick drift in the area. The alignment of the saddle with the adjacent reaches of the Sikanni Chief and Beatton valleys suggests that the valley may contain an old in-filled paleochannel along which the upper Sikanni Chief formerly flowed into the Beatton River system. Meltwater channel margins along the sides of the saddle (mapped by Bednarski (2000), but not shown in Map 1 because of the map scale) suggest, at a minimum, that meltwater flowed across the saddle during the last glacial advance, and that a glaciofluvial aquifer may underlie the glaciolacustrine deposits now at the surface.

Another similar low pass, occupied by Lily Lake at the headwaters of the Beatton River (western 94-G-2), also connects with the Sikanni Chief River valley, and may also host a buried valley. A third topographic saddle extends northward from the Sikanni Chief valley into a tributary valley of the Buckinghorse River at the northern-most edge of the map area (southern 94-G-7). Well data here are sparse, and all inferred paleochannels in this area including minor channels along Lick and Mason creeks are speculative.

Alluvial sands and gravels occur all along the Sikanni Chief River floodplain and glaciofluvial terraces are found periodically along the valley. These units form good potential unconfined surface aquifers.

Sikanni Chief Area

No significant paleochannels were identified in the Sikanni Chief region directly northeast of the main study area (Map 1). Most of the region is covered by rock outcrop or thin till. The valleys of the Sikanni Chief and Buckinghorse rivers cutting through the area are deeply incised into bedrock, with steep colluvial or rocky slopes. Almost all petroleum boreholes are on upland sites with shallow bedrock and little or no Quaternary cover. Glaciofluvial gravels that occur high on the north side of the Sikanni Chief River in the northeastern-most corner of the main study area have not been mapped farther to the northeast.

A narrow floodplain with alluvial sands and gravels occurs along the Sikanni Chief River at the northeastern-most corner of the Sikanni Chief area, and provides a good potential unconfined surface aquifer.

Doig River Area

Much of the Doig River study area, east of the main study region, is a low relief plateau covered by a till or glaciolacustrine blanket, except for a significant meltwater channel up to 4 km wide cutting through from north to south (Map 1). The modern Doig River follows this channel, which is floored by gravelly spillway deposits (Mathews, 1978). Wells in the valley indicate depths to bedrock of up to 30 m.

Mathews (1978) mapped a buried interglacial valley along the Beatton River, the eastern margin of which crosses the northwest corner of the Doig River study area, where it is mapped as an assumed to approximate contact. The only well in this area indicates a depth to bedrock of less than 10 m, but it is located on the slope of the valley wall so may not reflect the true depth of the buried valley, if present.

Three water wells in the northern-most corner of the Doig River area indicate bedrock depths of 12, 33 and 39 m, but gamma logs from offsetting petroleum boreholes lack near-surface sections, and are of limited value. However, petroleum boreholes closest to the 33 and 39 m deep water wells indicate bedrock depths of <19 m and <25 m, respectively, suggesting that the water wells are developed in bedrock, not Quaternary aquifers.

Charlie Lake Area

The Charlie Lake area, southeast of the main study area, exhibits complex bedrock topography (Map 1, 2). Although there are numerous water wells, especially in the southeast, there are relatively few petroleum boreholes.

A number of paleochannels have been mapped in the region in existing studies, including major interglacial valley fills along the Peace River in the southwest and along the Beatton River in the east (Mathews, 1978). The Beatton River buried channel extends southward along the west side of the modern river valley in an area of hummocky moraine, and crosses the lowermost ends of St John and Stoddart creeks. The western margin of the channel as mapped by Mathews (1978) crosses the eastern edge of the study area around lower Stoddart Creek. Mathews (1978) also mapped an older paleovalley that formed in the penultimate interglaciation, the northern margin of which extends eastward from the Peace River valley through Fort St. John, reaching almost as far north as the southern margin of the younger Beatton River paleochannel. Hartman (2005) extended the paleovalley margin even farther north. Ronneseth (1994) mapped southerly-trending buried channels along the Charlie Lake valley and just west of St. John Creek. These valleys are likely smaller paleotributary channels of the larger Peace River paleovalley complex.

Our subsurface data support the presence of all these paleovalleys. We found good evidence from water wells and petroleum boreholes for a large paleovalley complex along the Peace River, with bedrock generally 20 to 40 m deep. Within this general region, an area with deep bedrock is also observed in water wells along the southern margin of lower Stoddart Creek. We suggest that this paleochannel may connect northward with the Charlie Lake paleochannel, as indicated by a large number of deep water wells at the southern end of Charlie Lake. Limited data suggest that the Charlie Lake paleovalley may also extend north of the lake up the Stoddart Creek valley. Tributary paleochannels to this system may also extend up the valleys of modern tributaries at the northwest end of the lake, but these are not well defined.

On the west side of the lower St. John Creek valley, several water wells with bedrock depths up to a maximum of 78 m suggest the presence of a paleotributary valley. Most petroleum boreholes are at the northern end of the mapped area and indicate bedrock depths less than about 20 m; one well high on the west side of the valley showed bedrock at 11 m depth. Another broad, poorly-defined area of relatively deep bedrock in water wells occurs west of, and approximately parallel to, the Charlie Lake valley. Bedrock depths exceed 40 m in the central part of this broad zone. The Wilder Creek valley may also have an underlying paleochannel but well data are sparse. Lastly, petroleum boreholes on the east side of the Red Creek valley (south-central 94-A-6) with bedrock depths greater than 10 m suggest a south-trending paleotributary valley may occur in this area.

Due to limited data in all these areas, and a reliance primarily on water wells, these interpretations are considered speculative. Note as well that there are relatively few petroleum boreholes with evidence of coarse-grained Quaternary valley fill in this area.

FUTURE STUDIES

Paleochannel mapping completed for this study relied on data and interpretations from the literature, on various digital data sets such as water well databases, and on the interpretive work completed in this study. In the future, interpretations could be greatly improved using air photos and field studies, both of which were out of scope for this study.

Rocky outcrops and near-surface bedrock landforms can be identified with confidence on air photos, and this information alone would provide much better constraint on our mapping. Other data that can be obtained from air and satellite photos include: details of surface channel margins and terraces; locations and extents of alluvial fans; nature and thickness of the geologic materials in canyon and incised river reaches, in gullies, along lake shorelines and in excavations; extent and thickness of blanketing surficial sediments such as glaciolacustrine deposits (determined from shorelines, outlet and deltaic features), and the distribution of numerous other relevant deposits and landforms such as glaciofluvial features (eskers, kames, raised deltas, outwash plains, meltwater channels), glacial landforms (thick till blankets, hummocky moraine, glaciotectonic landforms), and colluvial deposits (thick talus, landslide deposits and slope colluvium). Little of this type of information was available for this study, because existing maps lack sufficient detail (most are at 1:250,000 scale), or focus only on shallow sediments (soils maps).

Field studies are an obvious next step to verify and refine the maps presented here. Reliable location of bedrock outcrops and documentation of the thickness of Quaternary exposures would provide significant new constraints to the locations and depths of mapped paleochannels, and would also allow for verification of interpretations. In particular, field verification is needed in areas where little or no subsurface data are available. Quaternary sections should be described, especially in and around mapped paleochannels, where paleotributaries may be present but were not resolvable with existing datasets.

It is recommended that data quality assessments be conducted on individual water well records, especially in critical areas, and in areas where conflicting data records were observed. Original logs are available for most water wells, and stratigraphic logs have been compiled for most wells by the Ministry of Environment. A review of these original data sets and compilation of new wells would greatly improve the interpretations presented here. Creation of interpreted geological cross-sections using both water well and petroleum borehole data would also provide an excellent tool for analysis of buried and surface aquifers.

With some or all of these additional datasets, more sophisticated and detailed mapping of paleovalleys, such as that demonstrated by Hickin *et al.* (2008), could be undertaken in the Peace Project area.

REFERENCES

Bednarski, J.M. 1999. Preliminary report of the Quaternary geology of the Trutch map area, northeastern British Columbia; in Current Research 1999A Geological Survey of Canada, p 35-43.

Bednarski, J.M. 2000. Surficial geology, Trutch, British Columbia, (NTS 94G), Geological Survey of Canada, Open File 3885, Scale 1:250,000

Bednarski J.M. (comp.) 2001: Drift composition and surficial geology of the Trutch map area (94G), northeastern British Columbia; Geological Survey of Canada Open File D3815

British Columbia Ministry of Environment, 1977a. Soils of the Rose Prairie - Blueberry River Area of BC (94A/NW); British Columbia Soil Survey report No. 17; Scale: 1:125,000 (TEI Map K06-2718)

British Columbia Ministry of Environment, 1977b. Soils and Landforms of the Ft St John Dawson Creek Areas, British Columbia; Aikman Creek (NTS 94B/9) and Chowade River (NTS 94B/10), Scale: 1:100,000 (TEI Map K06-4939)

British Columbia Ministry of Environment, 1980. Soils and surficial geology, NTS map 94B/NE, Terrain Inventory Mapping Project 4421.

British Columbia Ministry of Environment, 1987. Soils, Kobes Creek, NTS map 94B/08, TEI Map K15-2744 Scale 1:50,000.

British Columbia Ministry of Environment, 1988a. Soils, Dunlevy Creek, NTS map 94B/01, TEI Map K15-2738 Scale 1:50,000

British Columbia Ministry of Environment, 1988b. Soils of the Halfway River, British Columbia; British Columbia Soil Survey Report No. 18, Aikman Creek (NTS 94B/9) and Chowade River (NTS 94B/10), Scale: 1:50,000 (TEI Maps K06-2757, K15-2746 and K15-2748)

British Columbia Soil Survey. 1986. Soils and Landforms (Terrain) of the Cypress Creek Map area (NTS 94B/15), Scale 1:50,000 (TEI Map K15-2750)

British Columbia Soil Survey. 1988. Soils and Landforms (Terrain) of the Blair Creek Map area (NTS 94B/16), Scale 1:50,000 (TEI Map K15-2752)

Canada Department of Agriculture, 1977. Soils of the Nig Creek - Big Arrow Creek Map Areas, British Columbia; British Columbia Soil Survey report No. 19; Scale: 1:125,000 (TEI Maps K15-2778 and K06-2770)

Cowen, A. 1998. BC Peace Region, Groundwater Initiative, Interim Report 1998, Agriculture and Agri-Food Canada, Prairie Farm Rehabilitation Administration, Northern Alberta/BC Region.

Hartman, G.M.D. 2005. Quaternary stratigraphy and glacial history of the Charlie Lake (NTS 94A) map-sheet area, British Columbia; M.Sc. thesis, *Simon Fraser University*, 165 p.

Hartman, G.M.D. and Clague, J.J. 2008. Quaternary stratigraphy and glacial history of the Peace River valley, northeast British Columbia, *Canadian Journal of Earth Sciences,* v. 45, pp 549-564.

Hickin A.S. 2011. Preliminary bedrock topography and drift thickness of the Montney Play Area; *BC Ministry of Energy and Mines,* Energy Open File 2011-1, Geoscience BC Report 2011-07, 2 maps, 1:500,000.

Hickin A.S. 2013. Late Quaternary to Holocene Geology, Geomorphology and Glacial History of Dawson Creek and Surrounding area, Northeast British Columbia, Canada; Earth and Ocean Sciences, *University of Victoria*, unpublished Ph.D. thesis, 369 p.

Hickin, A.S. and Best, M.E. 2013. Mapping the geometry and lithostratigraphy of a paleovalley with a time-domain electromagnetic technique in an area with small resistivity contrasts, Groundbirch, British Columbia, Canada; *Journal of Environmental and Engineering Geophysics;* 18 (2): 119-135.

Hickin, A.S., Kerr, B., Turner, D.G., and Barchyn, T.E., 2008. Mapping Quaternary paleovalleys and drift thickness using petrophysical logs, northeast British Columbia, Fontas map sheet, NTS 94I. *Canadian Journal of Earth Sciences*, v. 45, pp. 577-591.

Lord T.M. 1977a. Soils of the Halfway River, British Columbia; British Columbia Soil Survey Report No. 18, Scale: 1:125,000 (TEI Maps K06-2757)

Lord T.M. 1977b. Soils of the Gold Bar, Dunlevy Creek & Chinaman Lake map areas (94B/SE), Scale: 1:100,000 (TEI Maps K06-2763)

Lowen Hydrogeology Consulting 2004. Aquifer classification mapping in the Peace River region—final report; unpublished report prepared for BC Ministry of Water, Land and Air Protection, 30 p.

Lowen Hydrogeology Consulting 2011. Aquifer Classification Mapping in the Peace River Region for the Montney Water Project, unpublished report prepared for Geoscience BC, 37 p.

Mathews W.H. 1978a. Surficial geology, Charlie Lake, Peace River District, British Columbia, (NTS 94A), Geological Survey of Canada, Map 1460A, Scale 1:250,000

Mathews, W.H. 1978b. Retreat of the last ice sheets in northeastern British Columbia and adjacent Alberta, Geological Survey of Canada, Bulletin 331, 22 p.

Mathews, W.H. 1980. Quaternary stratigraphy and geomorphology of Charlie Lake map area, British Columbia, Geological Survey of Canada, Paper 76-20, 25 p.

Mathews W.H., Gabrielse, H., and Rutter N.W. 1975. Glacial Map, Beaton River (2139), British Columbia, Geological Survey of Canada, Open File 274, Scale 1:1,000,000.

Okulitch, A.V., MacIntyre, D.G., Taylor, G.C., Gabrielse, H., Cullen, B., Massey, N. and Bellefontaine, K. 2002. Fort Nelson, British Columbia; Central Foreland Map No-10-G, *Geological Survey of Canada*, Open File 3604 (revised), scale 1:500,000.

Quartero, E.M., Bechtel, D., Leier, A.J., and Bentley, L.R. (2014): Gamma-ray normalization of shallow well-log data with applications to the Paleocene Paskapoo Formation, Alberta. Canadian Journal of Earth Sciences, v. 51, p. 452-465.

Ronneseth, K. 1994. Alberta Plateau, Chapter 10.3 in Groundwater Resources of British Columbia, British Columbia Ministry of Environment and Environment Canada, ISBN 0-7726-2041-5.