THE ROLE OF QUATERNARY GEOLOGY IN NORTHEASTERN BRITISH COLUMBIA'S OIL AND GAS INDUSTRY: A SUMMARY

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ABSTRACT

Quaternary geology, the field within the earth sciences that is concerned with the geological record of the last 2.6 million years, has typically received little attention from the oil and gas industry. Quaternary-aged sediments are, however, significant to the oil and gas industry for a variety of reasons. This paper discusses four aspects of Quaternary geology in northeast British Columbia that have a direct impact on the development of oil and gas resources: (1) shallow gas; (2) groundwater aquifers; (3) surficial geology; and (4) aggregate resources.

Quaternary-aged sediments host natural gas in northeast British Columbia and northwest Alberta. Gas was discovered in Quaternary reservoirs in Alberta in 1988 and has seen modest development. Several wells in British Columbia have produced from reservoirs within Quaternary sediments. These reservoirs are likely associated with the valley-fill sediments of incised paleovalleys that have little or no surface expression. The reservoirs are fluvial and glaciofluvial units underlying clay-rich till and glaciolacustrine seals. Gas in these reservoirs is rare; however, these same units commonly host water, of which some form artesian aquifers. With water demand continuing to increase, particularly where tight or shale gas plays require large volumes of water for hydraulic fracturing, groundwater aquifers may be an important water source.

Surface engineering and infrastructure development associated with the oil and gas industry require an understanding of the properties and distribution of surface materials, most of which are Quaternary deposits. Surficial geology mapping, therefore, provides important baseline data for these activities. The British Columbia Ministry of Energy, Mines and Petroleum Resources and its partners, the Geological Survey of Canada and the University of Victoria, are currently mapping regions of northeast British Columbia at the 1:50 000 scale in an effort to provide industry with this fundamental data. In addition, the Ministry's Oil and Gas Division, through the Aggregate and Surficial Mapping Program, is continuing to work with industry, government, and academic partners to identify and evaluate local sources of construction aggregate for new, quality roads into undeveloped areas and to extend the drilling season to non-winter months.

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Key Words: Quaternary geology, surficial geology, surficial mapping, shallow gas, groundwater, sand and gravel, aggregate, infrastructure, roads

INTRODUCTION

Quaternary geology typically involves the study of poorly consolidated or unconsolidated sediment that occurs above bedrock. These sediments are sometimes referred to as overburden or drift and have received little attention from the oil and gas industry, yet the distribution and character of these deposits have significant impact on the economics, safety, and marketability of British Columbia's oil and gas resources. This paper introduces some aspects of Quaternary geology that are significant to oil and gas industry in northeast British Columbia.

The Quaternary was marked by worldwide climatic deterioration and cyclic global temperature oscillation that began at the end of the Piacenzian stage of the Pliocene (2.6 million years ago). Marine oxygen isotope data from the shells of foraminifera recovered in deep ocean cores offer extensive record of global ice build-up and melt (Urey, 1947; Emiliani, 1955; Emiliani, 1966; Shackleton, 1967; Imbrie and Imbrie, 1980; Gibbard et al., 2005; Bassinot, 2007; Rohling, 2007). These data suggest that a little over 50 oscillations have occurred during which temperatures were sufficiently low to have allowed global ice sheets and glaciers to grow and retain enough water to isotopically fractionate the Earth's oceans. These oscillations, termed Marine Isotope Stages (MIS), count back from the present warm period (MIS 1; Figure 1). This implies that the Earth has experienced repeated glaciations, which have modified the landscape. Each successive event obliterated much of the

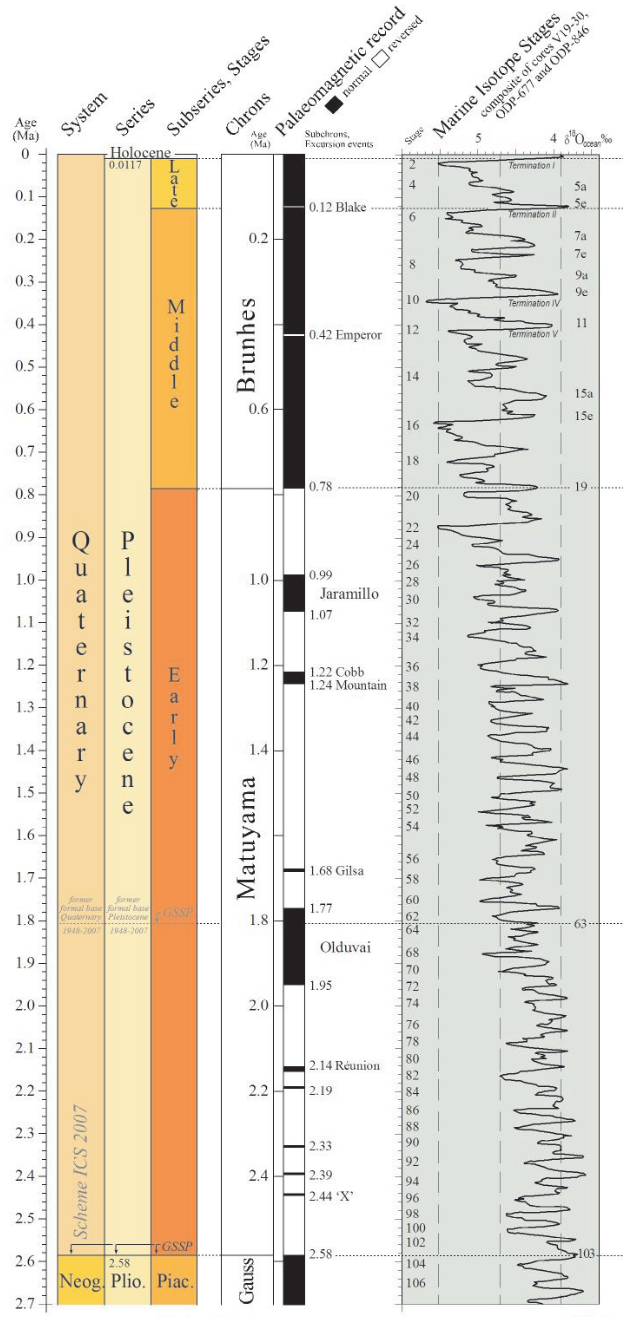

Figure 1. Quaternary geological timescale (modified from Gibbard, et al., 2005). *The Marine Isotopic Stages (MIS), on the right, show the cyclical nature of ocean isotopic fractionation associated with global temperature oscillations. Glacial conditions are inferred where dO18 values deviate to the left (oceans are enriched in 18O isotopes; even numbered MIS). Warmer interstadial or interglacial conditions are inferred where dO18 values deviate to the right (oceans enriched with light isotopes; odd numbered MIS).*

evidence of its predecessor, with the exception of rare deposits that were buried, protected, and therefore preserved. The most recent glacial event to affect northeast British Columbia is referred to in North America as the Wisconsinan glaciation, which is further divided into Early Wisconsinan cold period (MIS 4 to 5e), Middle Wisconsinan interstadial or warm period (MIS 3), and Late Wisconsinan cold period (MIS 2). Although there is some contention regarding the timing of events, it is likely that most of the surface geology in northeast British Columbia is the product of Late Wisconsinan glaciation, which occurred between 22,000 and 10,000 years ago, although it is possible that some is associated with the Early Wisconsinan (between 100,000 and 60,000 years ago) (Mathews 1978; Mathews 1980; Liverman et al. 1989; Bobrowsky and Rutter 1992; Catto et al. 1996; Bednarski and Smith 2007; Bednarski 2008a; Hartman and Clague 2008).

During the Wisconsinan, northeast British Columbia was affected by three glacial systems: (1) local montane glaciers; (2) the Cordilleran Ice Sheet; and (3) the Laurentide Ice Sheet (Catto et al. 1996). The Montane glaciers originated in high mountains as ice caps and ice fields that were drained by topographically controlled valley glaciers. The Cordilleran Ice Sheet was a continental-scale ice sheet that formed when ice accumulating in both the Rocky Mountains and the Coast Mountains merged to form a single ice mass over much of British Columbia. The ice centre was located in the Intermontane Belt in central British Columbia and reached sufficient thickness and elevation to radiate outward and flow across major mountain belts to the coast and onto the interior plains (Clague 1989; Jackson et al. 1999; Stumpf et al. 2000; McCuaig and Roberts 2002; Bednarski and Smith 2007). The Laurentide Ice Sheet occupied most of Canada and portions of northern United States at its maximum extent (Figure 2). The western sector of the Laurentide sheet advanced to the west and southwest from the Keewatin Ice Dome in the Canadian Arctic. It advanced up the regional slope, blocked major drainage routes, and caused large glacial lakes to develop along its margins. In the Late Wisconsinan, the Cordilleran and Laurentide ice sheets converged, resulting in continuous ice cover from Atlantic to Pacific Canada (Dyke and Prest 1987; Dyke et al. 2003). As climate warmed at the end of the Wisconsinan, ice sheets could not be sustained, and they eventually retreated. The Cordilleran Ice Sheet retreated into the mountains and was reduced to ice caps and fields, again, sourcing montane glaciers in the major valleys. The Laurentide Ice Sheet retreated to the east, once again blocking regional drainage and impounding large glacial lakes along its margin (Mathews 1980; Dyke and Prest 1987; Dyke et al. 2003; Bednarski 2008a). Northeast British Columbia was ice free by approximately 13,000 years ago (Wolfe et al. 2004; Wolfe et al. 2007).

QUATERNARY HOSTED ULTRA-SHALLOW GAS

Quaternary sediments in British Columbia have potential to host natural gas, particularly in buried paleovalleys, therefore these Quaternary deposits have direct economic

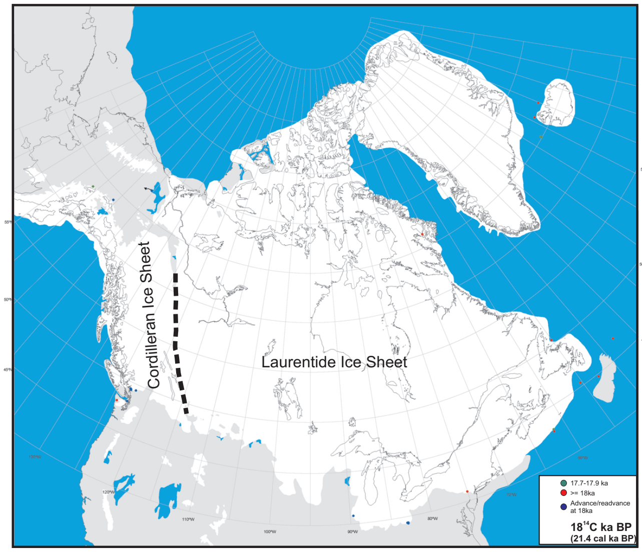

Figure 2. Maximum extent of the Laurentide and Cordilleran ice sheets (modified from Dyke et al. 2003).

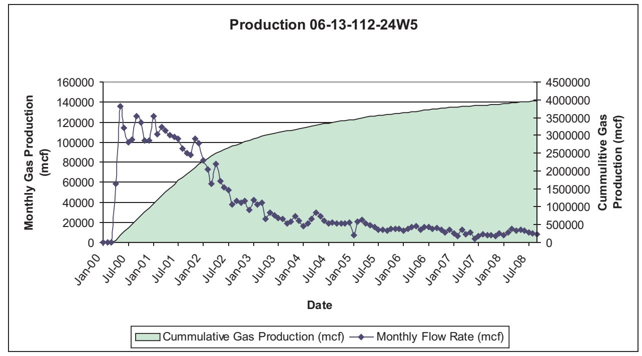

Figure 3. Natural gas production from a Quaternary reservoir in northwest Alberta (well 6-13-112-24W5) (source: IHS Accumap).

importance to the oil and gas industry (British Columbia Ministry of Energy, Mines and Petroleum Resources 2006). Gas was first discovered in Quaternary reservoirs in northern Alberta in 1988 and was brought into production in 1993 (Clare 1988; Canadian Discovery Digest 2001). The initial discovery was the result of a drilling accident during the completion of a water well 80 km west of High Level, Alberta. This well was drilled to 91 m, when a gas blow-out ignited and burned down the water drill rig (Clare 1988). Since discovery, there has been moderate success in developing Quaternary pools in the area; for example, well 6-13-112-24W5 had a cumulative production of 3.97 billion cubic feet (bcf) of gas between April 2000 and September 2008 (Figure 3). In British Columbia, three non-confidential wells (Figure 4) and one confidential well have produced from reservoirs designated as Quaternary. The reservoirs are likely hosted within the fill succession of buried paleovalleys. These pools are less than 300 m deep, are small, and have low pressure, but may be economic if developed near existing infrastructure (i.e., pipelines) or as a supplementary target in deeper wells. The valley-fill successions consist of a variety of lithologic units, including sand and gravel associated with fluvial and glaciofluvial deposits, silt and clay-rich glaciogenic diamicts (till), and sand, silt, and clay glaciolacustrine units (e.g., Figure 5). The reservoir units are likely the porous sand and gravel deposits, and the seal units are clay-rich glaciolacustrine and till units. Potential coarse-grained reservoir units can often be differentiated from fine-grained seal units in gamma logs, even behind casing, and it is recommended that exploration and development companies complete gamma logs to surface to identify these horizons (Figure 6). Source gas for these units is likely derived from the underlying bedrock. Gas may have migrated from gas-bearing bedrock incised by paleovalleys or through subcropping faults that provide a conduit for gas in bedrock units to escape into the valley-fill sediments (Figure 7).

Quaternary ultra-shallow gas was an active exploration target in British Columbia during the early part of this decade but has declined in more recent years. Identifying and mapping paleovalleys, however, remains important for other reasons, such as drilling safety and seismic processing and interpretation (Levson et al. 2006).

Inadvertent intersection of Quaternary hosted artesian aquifers or natural gas reservoirs without appropriate diverters or blowout preventers has cost the oil and gas industry millions of dollars through lost time, abandonment of wells, and destruction of equipment (Levson et al. 2006; Hickin et al. 2008). Blowouts have resulted in injury and even fatalities. These dangers prompted the British Columbia Oil and Gas Commission to issue an alert to drilling operators in 2005, warning of the potential to encountering natural gas and water in Quaternary sediments in northeast British Columbia, even while setting surface casing. Therefore, understanding the location, geometry, and stratigraphy of paleovalleys is of considerable importance for safety in the oil and gas industry. The thick packages of unconsolidated sediments of paleovalleys also present a challenge to the seismic industry. These sediments tend to reduce the propagation velocity of seismic waves relative to consolidated rock. The results are ‘slow zones’ that can distort later, deeper reflections. Processing can mitigate distortion if the depth and geometry of the unconsolidated zone can be determined.

Bedrock topography and drift thickness mapping and regional airborne electromagnetic surveys are initiatives that can help identify paleovalleys and thick sections of Quaternary sediments (Hickin and Kerr 2005; Levson et al. 2006). The Fontas map sheet (NTS 094I) is the only area in northeast British Columbia in which the bedrock topography has been mapped and is available as public domain data (Hickin et al. 2008), though work is being conducted in the Charlie Lake area (NTS 094A).

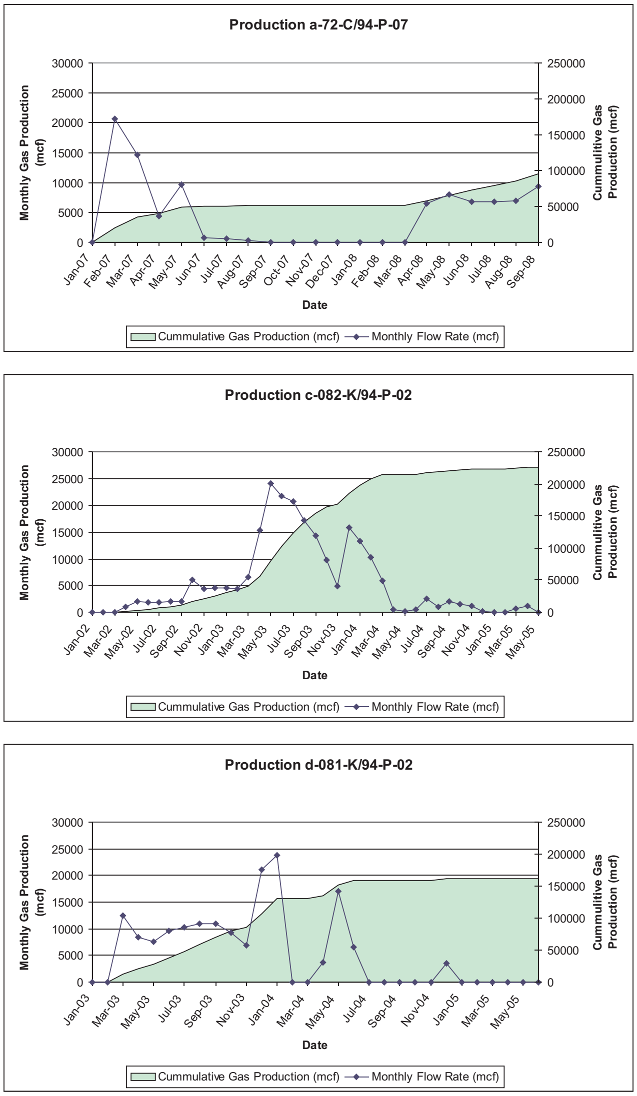

Figure 4. Natural gas production from three non-confidential wells that have been designated by the British Columbia Oil and Gas Commission as producing from Quaternary reservoirs (source IHS Accumap).

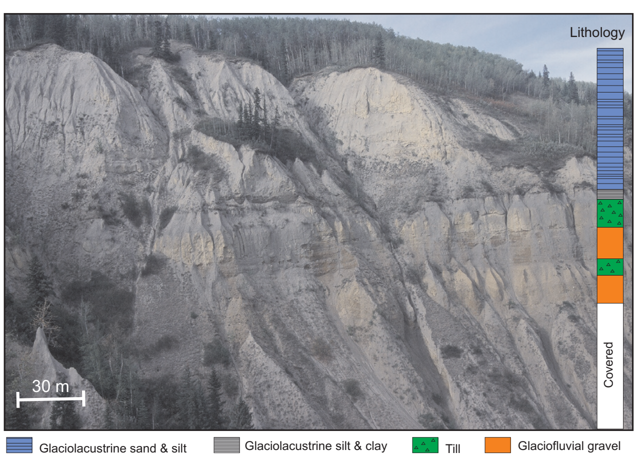

Figure 5. Incising of the Pine River into its paleovalley has revealed large sections of Quaternary valley-fill sediments.

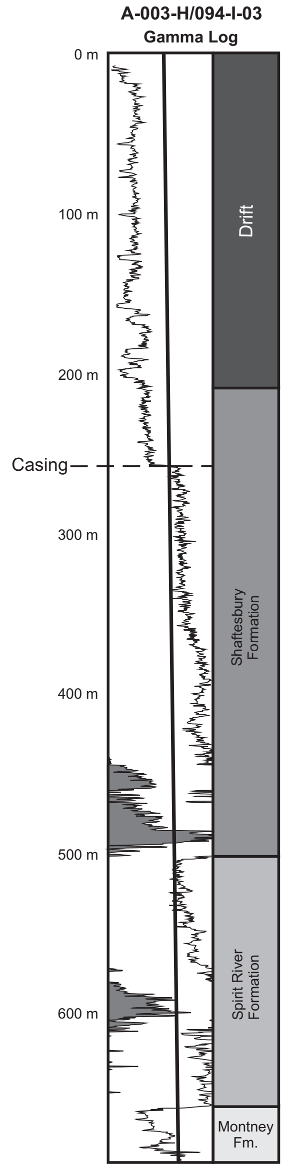

Figure 6. Example of a gamma log that shows over 200 m of Quaternary valley-fill sediments (Drift) from a paleovalley in northeast British Columbia (from Hickin and Kerr, 2005).

GROUNDWATER AQUIFERS

Groundwater is becoming an important resource for oil and gas activity in northeast British Columbia. This is especially true in the development of shale and tight gas, relatively new unconventional natural gas plays that have become the focus of recent exploration in British Columbia (Adams et al. 2008). Though traditionally shale has been considered a source rock or reservoir seal, organic-rich silty shale is now being developed as a reservoir rock. To develop shale gas, flow is stimulated by hydraulically fracturing (“fracing”) the target rock, thereby increasing its permeability and surface area. Fracing is accomplished by pumping large volumes of frac fluid (usually water based) and proppant (typically well rounded quartz sand)

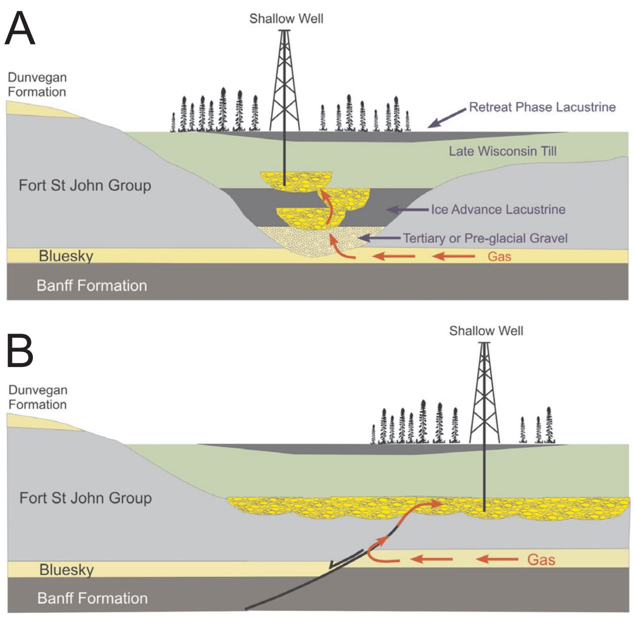

Figure 7. Two conceptual models for the emplacement of natural gas in Quaternary hosted reservoirs (Pawlowicz et al. 2004). A) The incised paleovalley has intersected a gas bearing sandstone unit, permitting the gas to migrate into channel gravel. B) Bedrock faulting provides a conduit for natural gas to migrate from gas bearing units, through the seal, to be trapped in the basal gravel units of the Quaternary sequence.

into the well bore at sufficient pressure to fracture the rock. Proppants keep the fractures open and allow liberated gas to flow back up the well bore. Surface water, deep bedrock aquifers, and Quaternary/Tertiary groundwater aquifers are the main sources of fracing water in northeast British Columbia. Surface water has environmental and competing resource considerations. Deep bedrock formations may host a significant source of saline water. Unfortunately, the geological character of deep bedrock formations, such as the Mississippian Debolt, are not suitable everywhere to host aquifers (i.e., there is insufficient porosity or permeability), consequently, these formations may not be available as a water source or for water disposal. Groundwater from Quaternary aquifers may be an important alternative water source, especially in remote areas.

The same coarse-grained units within valley-fill successions that potentially host gas, more commonly host water. The British Columbia Ministry of Environment's water well database reports 1660 water wells in the Fort St. John and Peace River South area (Alberta Plateau). Of these, 58.9% draw water from unconsolidated aquifers, 29.3% from bedrock aquifers, and 11.8% have no designation. Mean yields from wells that report data (53% of all the wells) are higher in the unconsolidated aquifers than in the bedrock (Table 1). North of the Fort St. John area, there are very little data reported, and almost all comes from around Fort Nelson. The limited data available show that unconsolidated aquifers have substantially higher yields than do bedrock aquifers. In some extreme cases, artesian Quaternary aquifers have extremely high yields that have compromised oil and gas drilling operations. Hickin et al. (2008) report water blowouts from three wells with flow rates of 83 L/s, 283 L/s, and 350 L/s from depths of 89 m, 115 m, and 150 m, respectively. Though intersecting these aquifers resulted in undesirable effects on drilling, it demonstrates that Quaternary aquifers may represent excellent source water targets for the oil and gas industry. Understanding and evaluating these aquifers is, therefore, imperative for meeting water demands in northeast British Columbia, not only for the oil and gas industry, but for residents, agriculture, and other concerned stakeholders.

SURFICIAL GEOLOGY

Surficial geology and high resolution topographic mapping provide important baseline data for oil and gas surface engineering. These data are fundamental for planning and construction of roads and pipelines, locating suitable ground for well lease development, exploring for construction aggregate, land management, and delineating terrain hazards such as unstable slopes. Surficial geology mapping is the foundation for derivative products such as gravel prospect maps and bio-terrain mapping (which delineates areas of ecological significance for wildlife, wetlands, and forest management).

TABLE 1. DESCRIPTIVE STATISTICS OF WATER WELL YIELDS FOR THE ALBERTA PLATEAU (FORT ST. JOHN AND FORT NELSON).

Statistic	Alberta Plateau						Fort Nelson			
	Bedrock		Unconsolidated		Unknown		Bedrock		Unconsolidated	
	L/s	gpm (US)	L/s	gpm (US)	L/s	gpm (US)	L/s	gpm (US)	L/s	gpm (US)
Mean	0.59	9.32	1.09	17.34	1.91	30.34	0.25	3.89	2.64	41.79
Standard Error	0.06	0.98	0.17	2.74	0.52	8.20	0.05	0.79	0.63	9.99
Median	0.38	6.00	0.50	8.00	0.79	12.50	0.19	3.00	1.42	22.50
Mode	0.63	10.00	0.32	5.00	1.26	20.00	0.19	3.00	0.25	4.00
Standard Deviation	1.11	17.53	3.68	58.35	5.28	83.64	0.21	3.37	2.96	46.86
Sample Variance	1.22	307.29	13.56	3405.18	27.85	6995.38	0.05	11.37	8.74	2196.01
Minimum	0.01	0.10	0.00	0.03	0.03	0.50	0.06	1.00	0.06	1.00
Maximum	15.78	250.00	43.16	684.00	50.48	800.00	0.95	15.00	9.47	150.00
No. Wells	323	323	453	453	104	104	18	18	22	22

Source: British Columbia Ministry of Environment water well database

Surficial mapping is done at a variety of scales for various purposes. These scales can be divided into three general categories: (1) reconnaissance (≥ 1:100,000); (2) regional (1:50 000 to 1:100,000); or (3) local (< 1:50,000). Reconnaissance mapping is typically done at 1:100,000 or 1:250,000 and is best suited for contextual purposes such as reconstructing glacial history. Context is important as it provides insight necessary to guide more focused studies. For example, understanding the location and evolution of a large glacial lake will assist aggregate exploration by directing activities to the former lake margins, where ancient deltas and beaches may have occurred, rather than expending resources exploring in the central portions of the lake basin, where fine-grained materials would dominate. Perhaps the most useful mapping for operational activities in the oil and gas industry is the regional scale, typically 1:50,000. This scale minimizes generalizations and offers enough detail to differentiate surface sediments while presenting sufficient area to be beneficial for planning. Local mapping is generally completed at 1:5,000 to 1:20,000 and is most useful for engineering or site-specific evaluations. This scale typically focuses on a limited number of surficial materials, specific properties of materials, or the evaluation of individual landforms and features (e.g., aggregate deposit, river crossing, or pad location).

Generally, northeast British Columbia has limited coverage of regional surficial geology maps despite recent resource exploration activity. The Ministry of Energy, Mines and Petroleum Resources and its partners, the Geological Survey of Canada and the University of Victoria, are currently conducting 1:50 000-scale mapping in several areas in northeast British Columbia, including portions of map sheets 93P, 94O, and 94P (Figure 8).

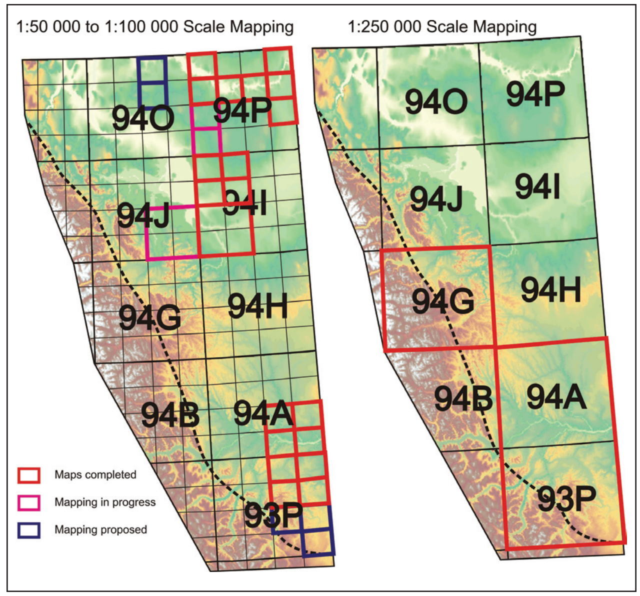

Figure 8. Index of mapping in northeast Britiish Columbia by the British Columbia Ministry of Energy, Mines and Petroleum Resources and its partners, the Geological Survey of Canada and the University of Victoria.

AGGREGATE

In 2003, the Province of British Columbia's Oil and Gas Development Strategy identified road infrastructure as one of the four initiatives necessary for making British Columbia one of the most competitive oil and gas jurisdictions in North America. Physical access to the land represents a challenge for oil and gas development in northeast British Columbia. Traditionally the drilling season in remote muskeg-covered areas was restricted to winter months, when ice roads can be built to bear industry traffic. Road construction is difficult in these areas because of the unfavourable terrain, poor road base, and a general lack of locally available, quality construction aggregate. To address these challenges, the British Columbia Aggregate and Surficial Mapping Program was established in 2002 with two objectives: (1) the regional assessment of aggregate resources and Quaternary geology in areas of oil and gas development; and (2) identification and evaluation of local, area-specific, aggregate resources. This program is meant to facilitate the construction and maintenance of all-season roads throughout British Columbia's traditional oil and gas region.

Conventional aggregate exploration techniques, such as aerial photographic interpretation, have had limited success in the subdued topography of northeast British Columbia. Quaternary geological expertise has, therefore, been called upon to apply new and innovative approaches and technology to locate and evaluate gravel deposits. The program has been exceptionally successful and to date has discovered 12 new deposits, some of which are now at the mining stage. Through these discoveries, the Province has realized cost savings in excess of $40 million on partnership road projects, which is more than a $30 return on investment for every dollar spent on the program. A list of published maps, articles, and theses produced as part of the program is provided in Table 2.

The program is highly collaborative with partnerships in other government agencies, academia, and industry. Contributing government partners include several municipalities, other provincial agencies, the Alberta Geological Survey, the Canadian Centre for Remote Sensing, and the Geological Survey of Canada. The program has involved collaboration with the University of Victoria, the University of Calgary, and the University of the Fraser Valley. Eight major energy companies and three consulting or contracting companies have partnered directly with the program.

In general terms, the project relies on the expertise of provincial, federal, and academic Quaternary geoscientists affiliated with the program to recognize, locate, and evaluate deposits from new and often confidential data shared by

TABLE 2. PUBLICATION FROM THE BRITISH COLUMBIA AGRREGATE AND SURFICIAL MAPPING PROGRAM.

Publications	Title	References
Aggregate Prospecting Reports	Aggregate potential of the Kimea Creek Area, northeastern British Columbia (2008-1)	Ferbey, 2008
	Aggregate potential of selected terraces along the East Kiskatinaw River, northeastern British Columbia (2006-1)	Hickin, 2006
Maps	Surficial Geology, TBD (094I/SE)	Trommelen and Levson, (in progress)
	Surficial Geology, Komie Creek, British Columbia (094P/05)	Demchuk and Levson, (in progress)
	Surficial Geology, Corvoisier Creek, British Columbia (094P/04)	Demchuk and Levson, (in progress)
	Surficial Geology, Lichen Creek, British Columbia (094/14)	Smith, 2009d
	Surficial Geology, Gunnell Creek, British Columbia (094I/13	Smith, 2009c
	Surficial Geology, Nogah Creek, British Columbia (094I/12)	Smith, 2009b
	Surficial Geology, Kyklo Creek, British Columbia (094I/11)	Smith, 2009a
	Surficial Geology, Thinahtea Lake, British Columbia (094P/09)	Bednarski, 2008d
	Surficial Geology, Pesh Creek, British Columbia (094P/08)	Bednarski, 2008c
	Surficial Geology, June Lake, British Columbia (094P/16)	Bednarski, 2008b
	Surficial Geology, Kimea Creek, British Columbia (094P/10)	Bednarski, 2007b
	Surficial geology, Etset Lake, British Columbia (094P/11)	Bednarski, 2007a
	Surficial geology, Dazo Creek, British Columbia (94I/SW)	Trommelen and Smith, 2007
	Surficial geology, Gote Creek, British Columbia (094P/12)	Bednarski, 2005b
	Surficial geology, Estsine Lake, British Columbia (094P/13)	Bednarski, 2005a
BC Government Geoscience Articles	Surficial geology and aggregate potential mapping in northeast British Columbia using LiDAR imagery	Demchuk et al., 2005
	Implementing Geomatics technology for aggregate exploration, northeast British Columbia	Kerr et al., 2005
	Northeast British Columbia Aggregate Mapping Program: a summary of selected aggregate occurrences northeast of Fort Nelson	Ferbey et al., 2005
	Bedrock topography mapping and shallow gas in Northeastern British Columbis	Hickin and Kerr, 2005
	Quaternary geology of Fort Nelson (NTS 094J/SE) and Fontas River (NTS 094I/SW), northeastern British Columbia	Trommelen et al., 2005
	Surficial mapping and granular aggregate resource assessment in northwest Alberta	Smith et al., 2005
	Surficial geology and aggregate studies in the boreal plains of northeast British Columbia	Levson et al., 2005
	Sand and gravel mapping in northeast British Columbia using Airborne Electromagnetic surveying methods	Best et al., 2004
	Quaternary geology and aggregate potential of the Fort Nelson airport area	Johnsen, 2004
	Preliminary report on Aggregate potential investigation of Fort Nelson airport area, Fort Nelson, British Columbia	Ferbey et al., 2004
	Quaternary geology and aggregate mapping in northeast British Columbia: Applications for oil and gas exploration and development	Levson et al., 2004
Consultant Reports	Sierra-YoYo-Desan Road area gravel investigation, northeastern BC	Dewer and Polysou, 2003
External Journal Paper	Using ground-penetrating radar and capacitively coupled resistivity to investigate 3-D fluvial architecture and grain-size distribution of a gravel floodplain in northeast British Columbia, Canada	Hickin et al., 2009
	Landform assemblages produced by the Laurentide Ice Sheet in northeastern British Columbia and adjacent Northwest Territories — constraints on glacial lakes and patterns of ice retreat	Bednarski, 2008a
	Mapping Quaternary paleovalleys and drift thickness using petrophysical logs, northeast British Columbia, Fontas map sheet, NTS 94I	Hickin et al., 2008
	Quaternary stratigraphy of the Prophet River, northeastern British Columbia	Trommelen and Levson, 2008
	Airborne electromagnetic mapping for buried Quaternary sand and gravel in northeast British Columbia	Best et al., 2006
	Mapping High Resistivity Buried Channel Deposits with Airborne Electromagnetic Surveys and Other Methods	Levson et al., 2006
Thesis	Landscape Evolution of the Dawson Creek map area (93P)	Hickin, PhD (in progress)
	TBD	Demchuk, MSc (in progress)
	Quaternary stratigraphy and glacial history of the Fort Nelson (southeast) and Fontas River (southwest) Map Areas (094J/SE and 094I/SW), Northeastern British Columbia	Trommelen, MSc 2007

industry partners. For example, the Program has been successful in identifying aggregate deposits from high-resolution light detection and ranging (LiDAR) data sets, which are routinely collected by the oil and gas industry. These data are the most effective tool for identifying deposits with subtle surface expression (e.g., Figure 9).

In addition to the collaborative use of industry data, the program has invested in developing innovative techniques to explore for gravel. The program has successfully employed airborne and ground-based geophysical methods to identify and evaluate prospects. Frequency domain airborne electromagnetics (EM) was successfully used to delineate a gravel deposit (Best et al. 2004; Levson et al. 2006). This method proved to be an effective tool for determining the lateral extent of the deposit and providing an estimate of the thickness, even under as much as 5 m of clay-rich till (Figure 10). Helicopter-borne frequency domain EM with a line spacing of 100 to 200 m offers high-resolution data over relatively large areas with vertical depth of penetration on the order of several tens of metres. Because gravel has

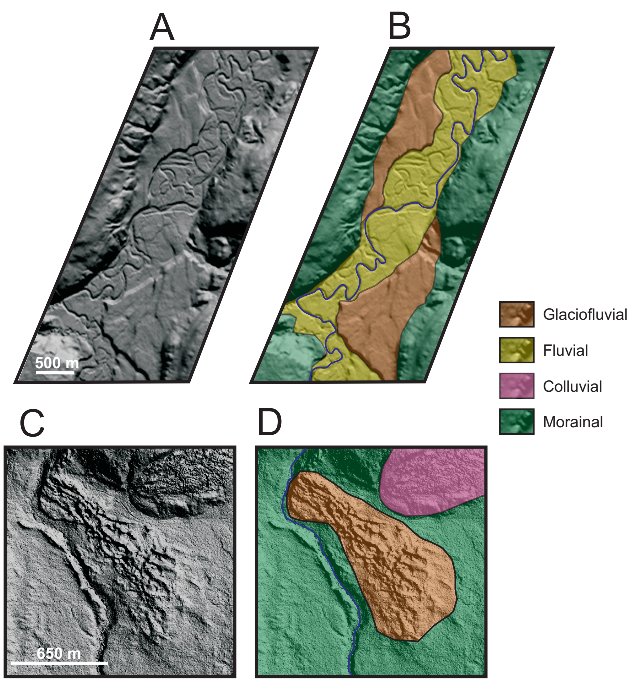

Figure 9. LiDAR is the most useful tool for mapping subtle features in northeast BC A) Digital elevation model (DEM) from LiDAR of a river floodplain and adjacent terraces along the East Kiskatinaw River (modified from Hickin, 2006). B) Interpretation of LiDAR where glaciofluvial terraces are excellent targets for aggregate deposits. C) LiDAR DEM of an esker complex in the Komie area. D) Interpretation of LiDAR where the glaciofluvial deposit is an aggregate target (Modified from Demchuk et al., 2005).

high resistivity relative to the clay-rich till and local shale, high resistivity regions correlate well with gravel deposits in northeast British Columbia. With the success of airborne EM surveys, the program looked to develop cost-effective ground-based methods to evaluate specific areas without incurring the cost of employing expensive heavy equipment. Capacitively-coupled resistivity (CCR), a relatively new variation of traditional ground-based resistivity, is routinely used by the program for rapid evaluation of potential targets (Figure 11). CCR uses capacitively-coupled dipoles towed behind a snowmobile to measure the apparent resistivity to a depth of about 5 or 6 m (Geometrics 2001). The processed data provide very high resolution 2-D resistivity pseudosections that are used to differentiate conductive fine-grained sediments from resistive granular material (Hickin et al. 2009). In addition, it has been shown that the data can discriminate sand from gravel, and resistivity distributions can even be used as a proxy for sorting. This method has been deployed on several targets to establish preliminary volumes and quality (in very general terms) of granular deposits, therefore helping to determine if additional evaluation through test pitting is justified.

CONCLUSION

Quaternary sediments in northeast British Columbia includes all of the surface materials that lies above bedrock. These materials have received little attention from the oil and gas community, as there is typically more interest in the deeper, petroleum-bearing bedrock formations. Surface materials are, however, significant to the oil and gas industry in northeast British Columbia. The simplest connection for the industry to make with Quaternary sediments is the economic implications of Quaternary natural gas reservoirs. These reservoirs occur between 100 and 300 m below surface, where gas may be hosted in the coarse-grained sand and gravel units within thick sequences that make up the valley-fill successions of incised paleovalleys. Where these units do not host gas, they may host water. Water is becoming increasingly important in the development of tight and shale gas reservoirs. These gas plays typically need huge volumes of water for hydraulic fracturing to stimulate gas flow. Quaternary hosted aquifers, therefore, may be significant sources of frac water in the absence of productive bedrock aquifers.

Surficial geology has important implications for the development of a gas field. Surface engineering, pipeline and road construction, land use planning, and development strategies are closely linked to topography and surficial material. The demand for Quaternary geology and surficial mapping continues to increase as development escalates in northeast British Columbia. Mapping is the baseline dataset necessary for responsible development and is the foundation for derivative products. The British Columbia Ministry of Energy, Mines and Petroleum Resources and its partners, the Geological Survey of Canada and the University of Victoria, are currently mapping surficial geology at a scale of 1:50 000 in two regions of northeast British Columbia.

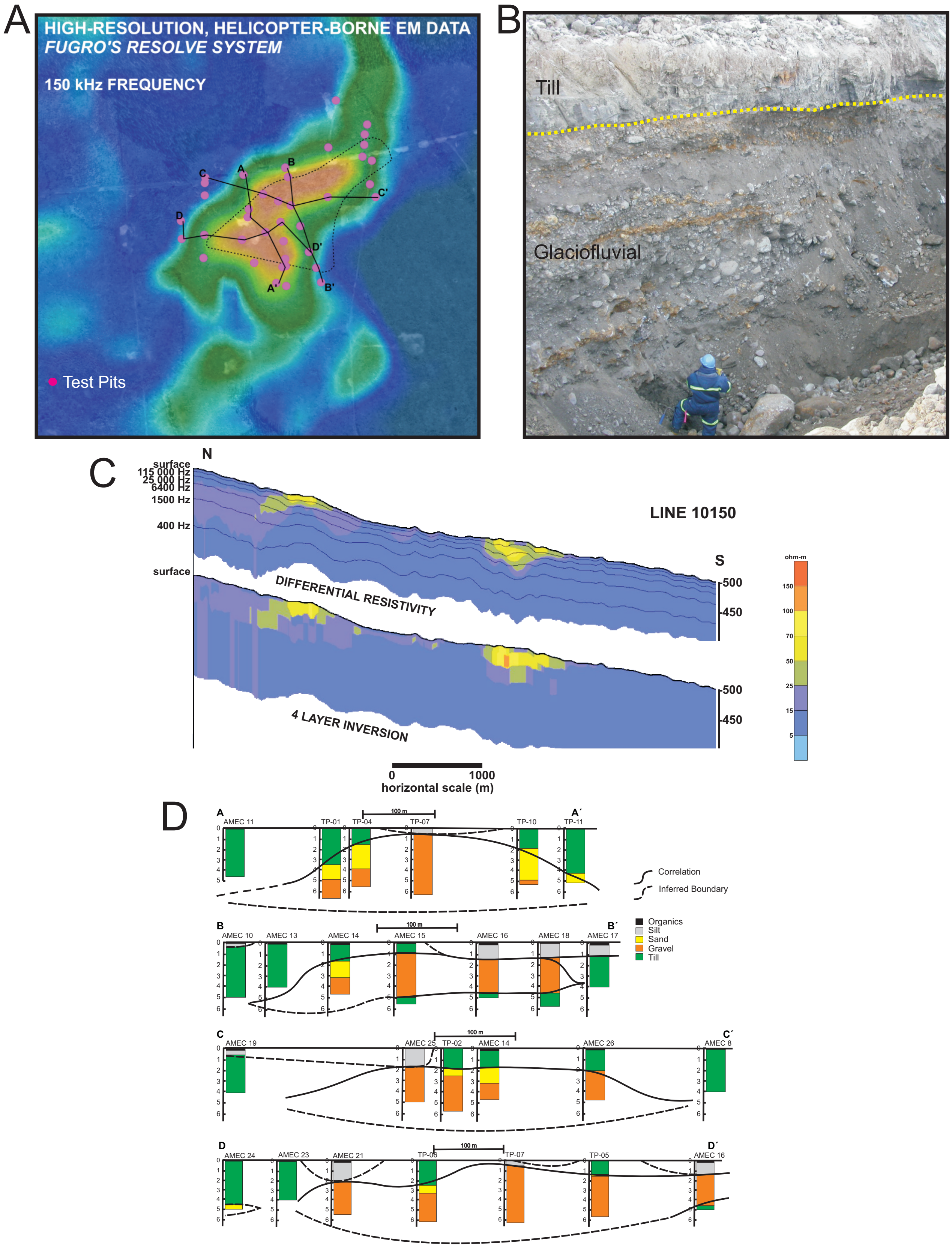

Figure 10. Airborne EM has been used by the British Columbia Aggregate and Surficial Mapping Program to identify and delineate buried aggregate (modified from Levson, et al. 2006 and Ferbey et al., 2007). A) 150 kHz depth slice with test pit locations and cross-section locations (Figure 10D). B) The deposit consists of glaciofluvial gravel under till. C) Pseudosection of EM data indicating thickness of the gravel (warm colours). D) Cross-sections of the gravel deposit, based on test pit data.

Quality aggregate for oil and gas infrastructure development and maintenance has been identified as a critical limitation for road construction to gain access to the land and for establishing all-season roads that will extend the drilling season to non-winter months. Since inception in 2002, the program has experienced significant success and continues to work with partners to ensure gravel is available in high-demand areas.

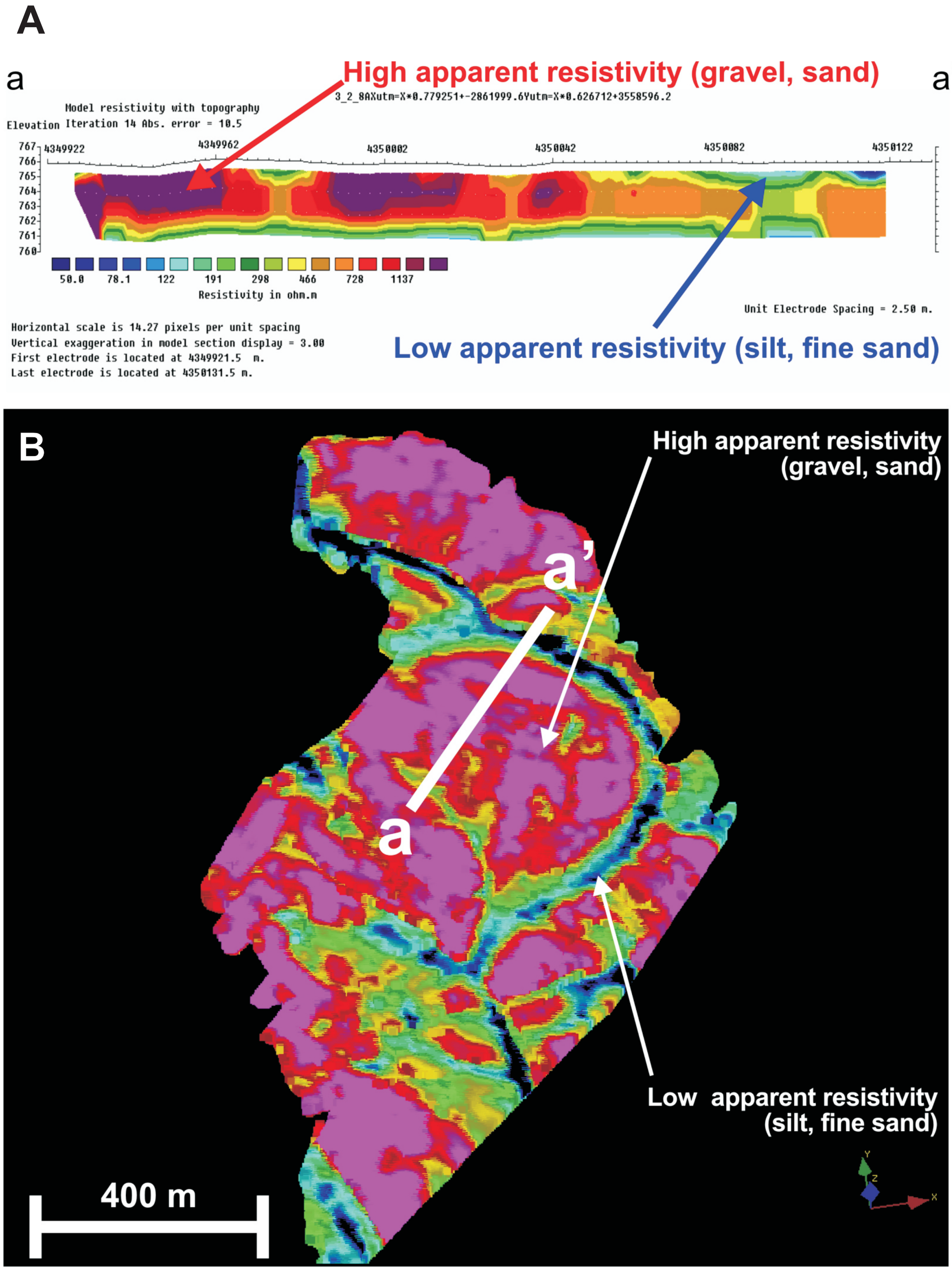

Figure 11. CCR has proven to be an effective tool for prospecting for sand and gravel. A) The 2-D psudosection (see Figure 11B) shows high resistive gravel bars and low resistivity channel deposits. B) The gravel bars can be easily differentiated from the fine-grained channel deposits in this plan view depth slice of the Halfway River floodplain approximately 0.5 m below surface.

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