SkyTEM Airborne Electromagnetic Systems for Hydrogeological Mapping in Northeastern British Columbia

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Brown, B., Gisselø, P. and Best, M. (2016): SkyTEM airborne electromagnetic systems for hydrogeological mapping in northeastern British Columbia; *in* Geoscience BC Summary of Activities 2015, Geoscience BC, Report 2016-1, p. 43–48.

Introduction

Information presented in this report is the result of the Peace Project, a Geoscience BC–funded project focused on mapping and assessing groundwater in the Peace Region of British Columbia. This report presents data from a SkyTEM airborne electromagnetic (AEM) geophysical survey that was employed to map the hydrogeology in the Peace Project area.

The Montney gas play in the Peace Region of BC contains significant volumes of gas. The region is also an important agricultural area. Water in the region supports communities, First Nations' activities and various industrial sectors. For the first time in over 100 years, BC has a Water Sustainability Act, which protects and regulates the use of groundwater. To make appropriate policies, make regulations, aid in the regulator's permit decisions and support public discussion on issues related to water, it is necessary to obtain detailed information on the location, depth, extent and recharge of aquifers.

Several studies have been carried out by various agencies and companies to increase understanding of surface water and groundwater resources within the Fort St. John region. These projects have included the acquisition of data from ground time-domain electromagnetic (TDEM) and shallow 3-D seismic investigations, as well as recalibrated gamma-ray log data from wells in the area. These initiatives provide useful information on groundwater aquifers; however, data collection points are widely dispersed across the region, with most being in the vicinity of producing gas fields. There are currently no large-scale surveys that tie the hydrogeology of the entire Peace Region together. To address this gap, the Peace Project was planned to deliver regional hydrogeological data through an integration of pre-existing data from shallow wells and 3-D seismic surveys with the results of an airborne geophysical survey. Airborne geophysics was considered an essential tool to provide more cost-effective and time-efficient coverage of a large area, than ground-based geophysical methods. The AEM system employed for the project was SkyTEM312^{FAST}, a helicopter-borne TDEM system. The 8000 km^2 area was covered in 43 days.

Project Summary

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

Historically, to increase understanding of the surface water and groundwater resources within the greater Peace Region, several geophysical techniques have been, and continue to be, applied. The BC government completed a combined ground TDEM and shallow seismic investigation within the Groundbirch paleovalley designed to map the bedrock topography and locate potential aquifers within the Quaternary sediments. Monitoring wells, lined with PVC casing, were installed and gamma-ray and resistivity logs were run. In an attempt to use as much of the pre-existing geophysical data as possible, the current Peace Project will correct gamma-ray logs within the shallow cased-hole sections of petroleum wells for attenuation effects and use these corrected logs to map the Quaternary sediments and provide depth-to-bedrock maps of the region (Hayes et al., 2016). The gamma-ray log study will partially fill this gap; however, the well spacing is concentrated around producing fields with limited coverage between them.

In order to cost-effectively acquire the data needed to identify potential Quaternary and bedrock aquifers within the large study area and obtain information on the bedrock topography, AEM was chosen. Geoscience BC tested the ap-

Keywords: *airborne geophysical survey, groundwater, hydrogeology, aquifer, geology, SkyTEM, dual moment*

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plicability of AEM in 2011 during the Horn River Basin Aquifer Project (SkyTEM Canada Inc., 2014) and the method showed its ability to map deep paleochannels as well as near-surface aquifers and recharge areas. It was therefore decided to use AEM for the Peace Project as it was expected to provide similar results.

The objective of the AEM survey was to collect resistivity data from near surface to depths up to 300 m and combine this new information with prior data to 1) interpret potential Quaternary and bedrock aquifers within the area; 2) provide a map of the Quaternary–bedrock interface and thus Quaternary sediment thickness; and 3) generate a magnetic structure map of the basement. In general, it is expected that a joint interpretation of all geophysical data will help to determine optimal places for accessing and/or protecting the groundwater and finding nonpotable sources of water for energy sector use.

The AEM survey involved collecting over 21 000 line-km of data, covering an area of about 8000 km^2 as shown in Figure 1. The depth of interest in the study area was from surface to a 300 m depth. Flight lines were flown with 600 m spacing and tie lines used for levelling the magnetic data flown at a line spacing of 2400 m. The electromagnetic loop was towed at an average height of 58.4 m above terrain and its depths of investigation ranged from <10 m to approximately 300 m. The airborne system used, SkyTEM312^{Fast}, collected TDEM and magnetic data with an average speed of 118.8 km/h over the entire survey area. Preliminary data was delivered for quality assurance–quality control purposes every 48 to 72 hours to a third-party consulting firm. At the time of writing this paper, the final data and inversion results were still in the processing stage.

An important component of the airborne survey was communication and outreach with Treaty 8 First Nations and communities within the survey area. Flights were planned and co-ordinated daily to avoid disturbance of First Nation cultural events, farmers and ranchers in the area. Through discussions with the Blueberry River, Doig River and Halfway River First Nations, the original survey area was expanded to include areas of interest over sections of their traditional lands. Additionally, an area around Fort St. John was flown in response to a request from the Peace River Regional District.

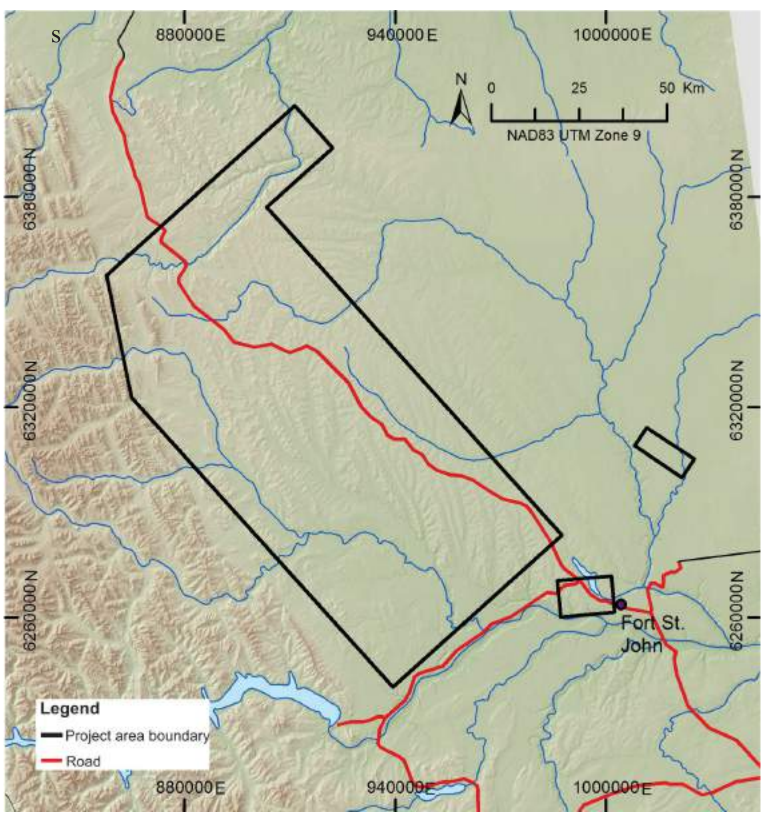

Figure 1: Location of the 2015 airborne electromagnetic survey, Peace Project area, northeastern British Columbia (background data from GeoBC, 2015a–d).

Method

SkyTEM is a helicopter-borne TDEM geophysical system designed for hydrogeological, environmental and mineral investigations. The basic concepts of the SkyTEM system are described by Sørensen and Auken (2012). The system is shown in operation in Figure 2.

SkyTEM energizes the ground in dual-moment mode. This patented feature provides shallow imaging concurrently with penetration of the ground for deep imaging. The SkyTEM receiver is null-coupled to eliminate noise from the primary field improving discrimination between subtle changes in resistivity and maximizing depth of penetration. Ancillary data collected includes laser altitude, GPS elevation, and the attitude of both transmitter and EM receivers. All sensors are installed on the rigid carrier frame, which is flown as close as possible to the ground in order to obtain high data accuracy and highest possible resolution. This enables rigorous quantitative interpretation of the EM data and delivery of products within hours of acquisition. The system is lightweight, operator-less and easily configured to operate at a range of base frequencies and delay times to optimize for a range of geological mapping objectives. SkyTEM data is clean and robust enough to process soon after the helicopter lands and simple inversions can be produced within 24 hours of data collection. The SkyTEM312^{Fast} system is carried as an external sling load that is independent of the helicopter. The transmitter, mounted on a lightweight aerodynamic frame, is a 12-turn, 341 m^2, eight-sided loop divided

Figure 2: The SkyTEM312^{Fast} system in operation.

into segments for transmitting a low moment (LM) in two turns and a high moment (HM) in 12 turns. The LM transmits approximately 5.9 amperes (A) with a turn-off time of about 18 µs; the HM transmits approximately 120 A and has a turn-off time of about 320 µs. This yields a maximum magnetic moment of approximately 490 000 A·m^2.

Two lasers, placed on the frame, measure the distance to terrain continuously and an inclinometer measures the tilt of the frame. Two differential GPS (DGPS) units are used for positioning and time stamping of the collected data. Power is supplied by a generator placed between the helicopter and the frame. The magnetic sensor is situated in the front boom and records the Earth's magnetic field during the off-times of the electromagnetic HM pulses.

The z-component receiver coil is placed approximately 2 m above the frame in what is practically a null-coupled position relative to the transmitter loop. Measurements are carried out continuously while flying. Every single transient is stored in a binary format, and prestacked. The stack size for LM is 140 transients for a stacklength of 0.333 s and the stack size for HM is 60 transients for a stacklength of 1.0 s. The transients are recorded in time windows. The 19 LM time windows have gate centre times from 4.7 to 1396 µs. The 26 HM windows have gate centre times from 385 to 11 400 µs. The overlap in gate centre times between the LM and HM windows provides continuous information from the very early times of 4.7 µs to the late times of 11 400 µs.

SkyTEM312^{Fast} is aerodynamically engineered to remain straight and level at speeds approaching 150 km/h. This allows a marked increase in heliborne data acquisition rates. At this speed, over 21 000 line-km of data were collected for the Peace Project in 43 days. This efficiency is due in part to the aerodynamically engineered composite carrier frame, which consists of composite elements with an enhanced material strength. This design improves manoeuvrability of the system and also permits a larger frame area, allowing for increased magnetic moments and depth of investigation (DOI).

Results and Discussion

The collected electromagnetic and magnetic data are presented in Figure 3. The two supplemental areas shown in Figure 1 (in the southeast) have not been included in Figures 3 and 4. The acquisition of laser altimeter data and DGPS data has provided the digital elevation model. The magnetic data has been processed to provide a total magnetic intensity for the entire block. The raw EM data presented below show the different structures revealed by the early LM and late HM gate centre times. The nearly identical signal pattern from the overlapping late LM gate centre times and the early HM gate centre times verifies the unbroken data collection obtained by the SkyTEM dual-moment system.

Based on the raw data presented above, data-inversion was carried out using the laterally constrained inversion (LCI) method developed at Aarhus University, Denmark (Auken et al., 2005). The LCI technique is a relatively new inversion methodology whereby field data are filtered then modelled against a subsurface layer structure that is constrained laterally on a number of chosen model parameters (including layer conductivity and layer thickness). The results of

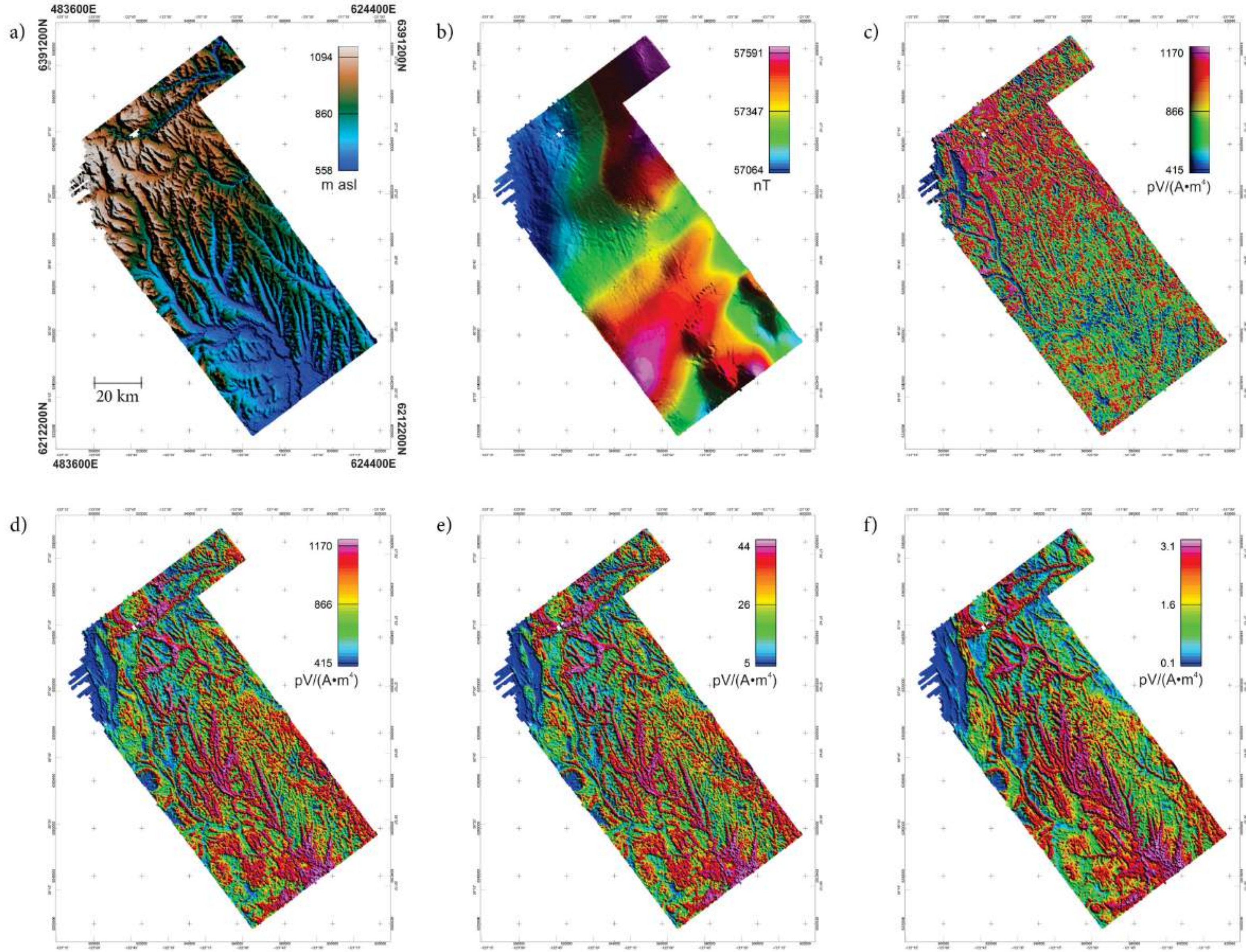

Figure 3: Presentation of gridded survey results from the Peace Project area: **a)** digital elevation model; **b)** total magnetic intensity; **c)** early low-moment raw electromagnetic data; **d)** late low-moment raw electromagnetic data; **e)** early high-moment raw electromagnetic data; and **f)** late high-moment electromagnetic data. Abbreviations: A, ampere; n, nano; p, pico; T, tesla; V, volt.

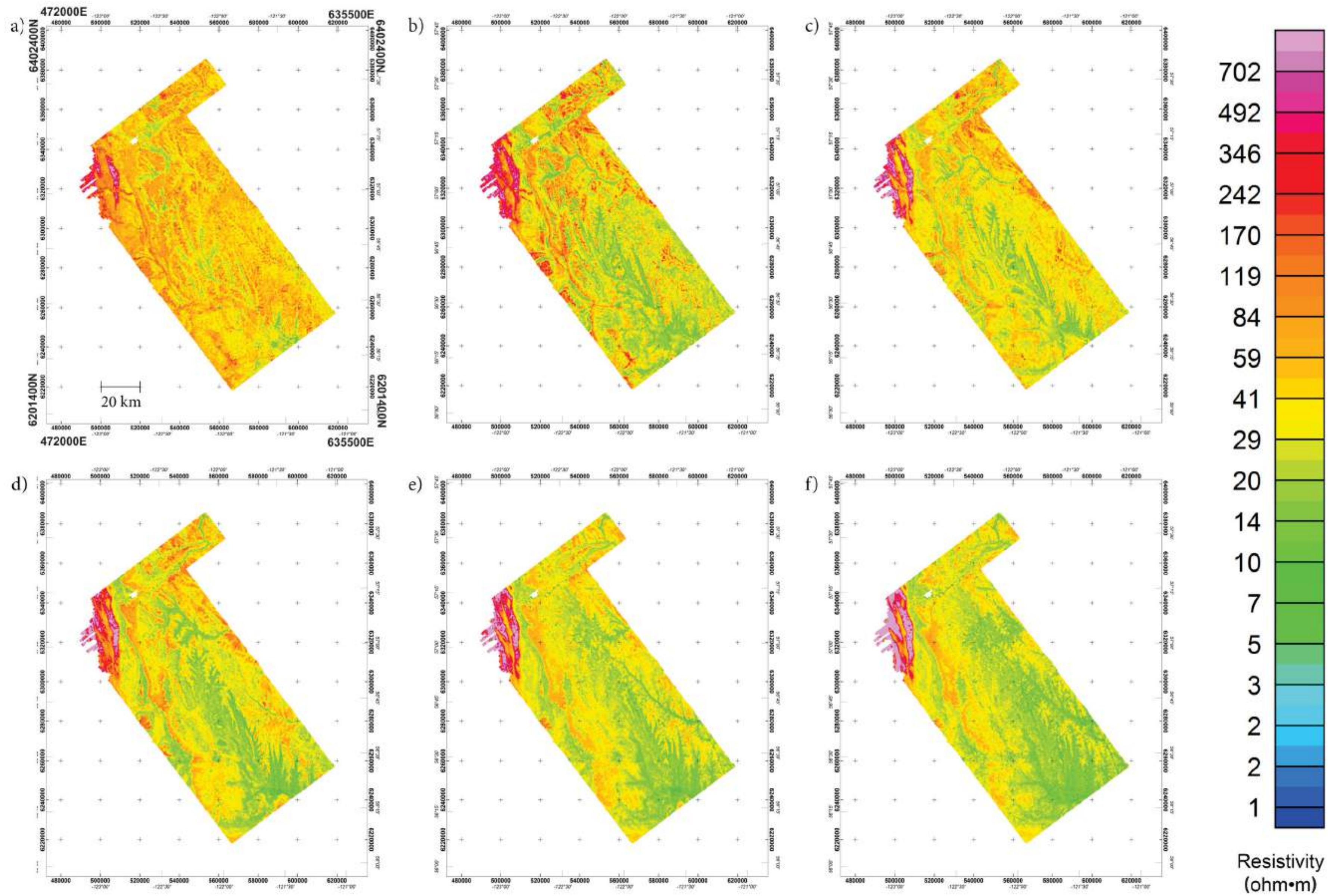

Figure 4: Laterally constrained inversions of survey results from the Peace Project area. Each image, from upper left to lower right, show survey responses at progressively deeper intervals below surface: **a)** 9.7–12.9 m; **b)** 25.4–30.6 m; **c)** 50.7–59.2 m; **d)** 91.8–105.6 m; **e)** 138.6–158.4 m; and **f)** 180.7–205.9 m.

the LCI for the Peace Project area are presented in Figure 4 for six different depth intervals. These depth intervals represent the changes in the resistivity model with depth for the Peace Project area.

The inversion results show very detailed structures in both the near-surface and deeper layers. Higher resistivities in the northwestern corner at all depths correlate with the presence of bedrock. High values of resistivity present in the shallower levels, indicate the presence of coarser material, such as sand, gravel and till, near the surface. The deeper levels are dominated by lower resistivities, which indicate the presence of more clay-rich material, till, water-saturated sediments and/or bedrock shale and siltstone.

Acknowledgments

The authors thank R. Whiten (InterraPlan Inc.), who worked closely with local First Nations and assisted in the communications with them throughout the project. The Devbrio Géophysique field crew, who adjusted day to day flight plans to accommodate First Nations cultural events and hunting season requirements, are thanked as are Bailey Helicopters Ltd. for their logistics support and skilled pilots. Finally, C. Salas (Geoscience BC) and staff are thanked for giving the authors the opportunity to work with the Geoscience BC staff and contribute to this important aquifer mapping project.

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