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Geophysical characterization of permafrost terrain at Iqaluit International Airport, Nunavut

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ABSTRACT

Iqaluit International Airport presently suffers from instabilities and subsidence along its runway, taxiways and apron. In particular, asphalt surfaces are significantly impacted by settlement and cracking. These instabilities may be related to permafrost, permafrost degradation and associated drainage conditions. Low induction number electromagnetic measurements along with galvanic and capacitive electrical resistivity surveys were performed over selected areas within the airport boundary and in the near vicinity to assist with permafrost characterization and to investigate active permafrost processes. Electrical resistivity images suggest distinct electrical signatures for different terrain units and sediment types, and for ice-rich material including ice wedges. Anomalous regions are identified that are coincident with localized settlement problems. Repeated resistivity maps reveal seasonal changes indicative of high unfrozen water content and freeze/thaw of groundwater beneath airport infrastructure in distinct regions related to surficial geology. Even with continuous permafrost and cold permafrost temperatures, the resistivity models reveal anomalously conductive material at depth that is not obviously correlated to mapped surficial sediments and that may represent thaw susceptible sediments or significant unfrozen water content.

1. Introduction

In cold climates such as northern Canada, the ground may remain at or below 0 °C due to sub-zero mean annual air temperature, in combination with other factors such as reduced solar radiation, ground cover and hydrology (Davis, 2001). Permafrost or perennially frozen ground covers almost half of the Canadian landmass (Heginbottom et al., 1995) and is overlain by an active layer which freezes and thaws seasonally. Permafrost and associated ground ice can significantly affect land-based infrastructure through its influence on drainage and ground stability (e.g., Fortier et al., 2011). Climate change and/or infrastructure development itself can alter the ground thermal regime, resulting in permafrost degradation, changes to drainage patterns, and changes in the engineering properties of the substrate. For ice-rich ground, thawing may lead to surface settlement, and unfrozen water contributes to thermal and mechanical erosion (de Grandpré et al., 2012).

Permafrost characterization for infrastructure is often performed using terrain analysis and inference of propensity for ground ice occurrence or thaw sensitivity guided by site-specific observations (e.g., Kreig and Reger, 1982; Allard et al., 2012b; Stephani et al., 2014; Wolfe et al., 2014). Detection of ice-rich ground or thaw zones can often only be confirmed by drilling boreholes which are costly and provide point data that may not be representative of the surrounding conditions. As a complimentary tool, geophysical surveys can provide multidimensional information on subsurface permafrost and ground ice conditions over extensive areas, and are valuable in the planning and maintenance of land-based infrastructure (Kawasaki and Osterkamp, 1984; Brown et al., 1985). The unique electrical properties of frozen ground make electrical and electromagnetic geophysics applicable for characterization of permafrost terrain (e.g., King, 1977; Scott and Hunter, 1977; Scott et al., 1990; Hauck et al., 2001).

In permafrost terrain, measurements of electrical resistivity can generally be used to infer some combination of the pore-fluid conductivity and the moisture content, or similarly, the material type and the amount of frozen/unfrozen water. As such, electrical and electromagnetic geophysics can be applied in an attempt to map material type and to characterize occurrence of ice-bearing permafrost, thaw zones and thermophysical transitions underground (Hoekstra, 1978; Fortier et al., 2008; You et al., 2013; Supper et al., 2014). However, interpretation of geophysical results may be subject to significant uncertainty and non-uniqueness (e.g., Kneisel et al., 2008; Hauck, 2013) such that results may be considered unreliable or uninformative for engineering purposes (McGregor et al., 2010). Given the large number of variables, it is not a simple task to unravel the exact cause of a geophysical response, or to correlate electrical resistivity observations over a study region.

As part of permafrost characterization efforts for Iqaluit International Airport in northern Canada, electrical and electromagnetic geophysical surveys were performed over runway, taxiway and apron surfaces of

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the airport, in addition to sections of natural ground in the vicinity of the airport (Oldenborger et al., 2015). Data collection was both reconnaissance in nature and targeted based on areas of known permafrost-related problems of infrastructure distress, knowledge of surficial geology and observations of permafrost landscape. We utilize the geophysical survey results to isolate electrical resistivity signatures for different types of permafrost terrain and processes by relating observed resistivity and seasonal changes in resistivity to mapped surficial geology and permafrost features. We interpret distinct electrical resistivity signatures in terms of sediment texture and ground ice occurrence. Electrical resistivity maps and images are used to identify features such as ice-rich regions, ice-bearing sediment and thaw-sensitive sediments that are related to permafrost conditions and observed infrastructure damage.

2. Study area

Iqaluit International Airport (YFB) is located in Iqaluit, Nunavut at the head of Frobisher Bay on Baffin Island (Fig. 1). YFB is a critical component of Canada's northern infrastructure. Originally constructed as part of the Second World War efforts of the United States Air Force, YFB serves as a regional transportation hub, a diversion airport for polar flights, a cold-weather testing destination and a Forward Operating Location for the Royal Canadian Air Force.

Airport infrastructure is built on flat terrain surrounded by hills and rocky plateaus of the Precambrian Shield within the continuous permafrost zone with low to high occurrence of ground ice, including ice wedges and massive ice bodies (Heginbottom et al., 1995; St-Onge et al., 2006; Allard et al., 2012a). The present-day Runway 17/35 was originally constructed in part in 1942 followed by a runway extension in 1958. The 1942 portion of Runway 17/35 was built on glaciomarine delta deposits composed of sand, silt, boulders and gravel; the 1958 portion was built on glaciofluvial outwash, bedrock and fill material (Allard et al., 2012a; Fig. 1). Alluvial channels and lacustrine deposits are present under the embankments of taxiways, aprons and access roads, and till and marine sediments are observed in the immediate vicinity.

The modern hydrology in the vicinity of the airport is comprised of several small intermittent streams, drainage ditches and several small lakes, some of which are kettle lakes (Mathon-Dufour, 2014). In areas of low relief such as along the eastern boundary of Sylvia Grinnell Territorial Park (Fig. 1), the lakes and connecting streams expand into local depressions creating wet regions with mats of wild grass that are observed in 1948 air photos. To the east of the airport, Carney Creek runs through the city, and to the west of the airport, runs the Sylvia Grinnell

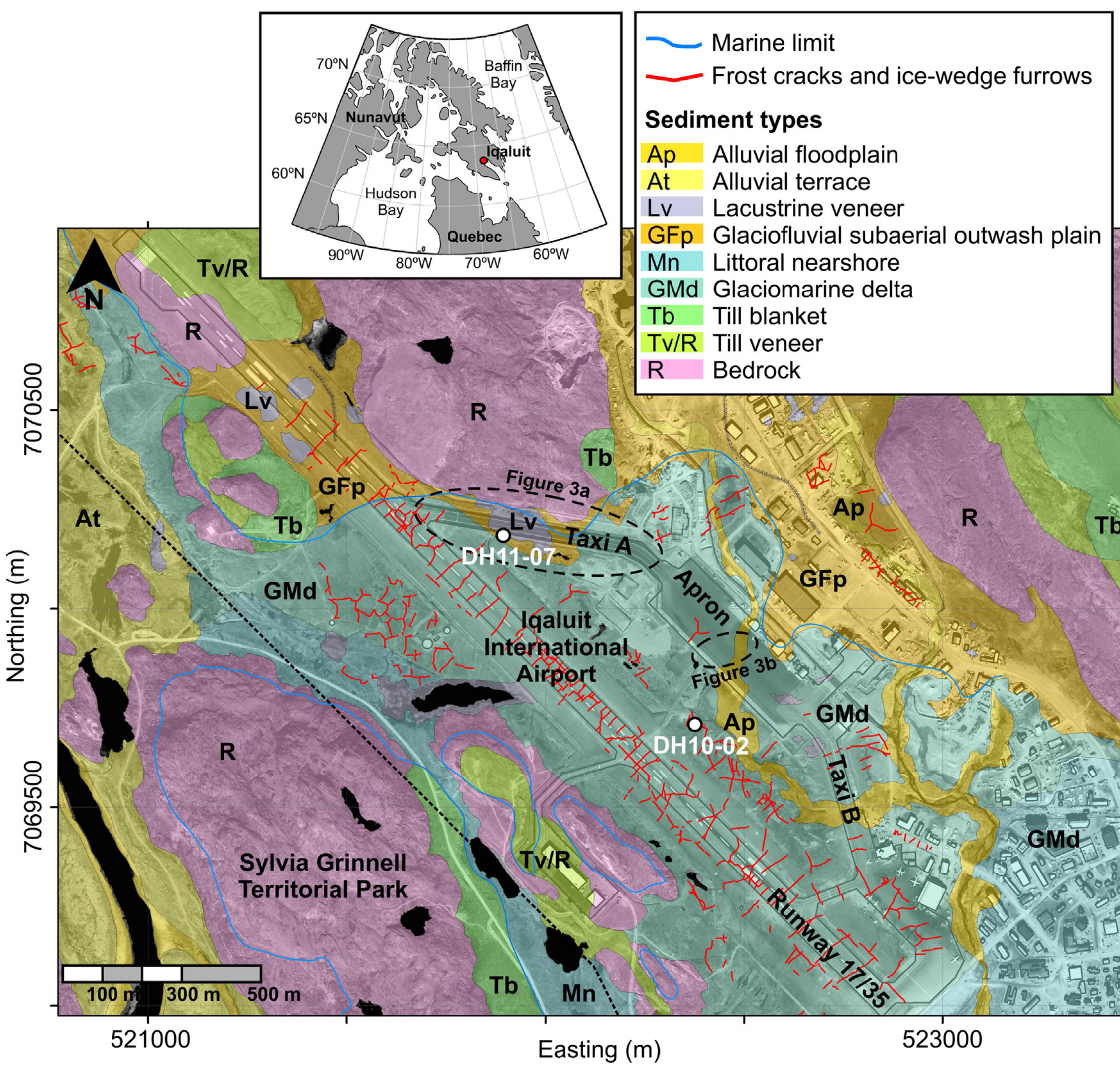

Fig. 1. Surficial geology of the region around YFB (Allard et al., 2012a). Inset shows location of Iqaluit at the head of Frobisher Bay on Baffin Island. Location of thermistor cables (Fig. 2) are shown for natural ground (DH10-02) and infrastructure (DH11-07). The approximate fields of view for Fig. 3 are indicated. QuickBird satellite image 25/07/2006, copyright DigitalGlobe Inc., all rights reserved.