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Geophysical and cryostratigraphic investigations for road design in northern Alaska

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ABSTRACT

This study used combined geophysical and cryostratigraphic methods for permafrost characterization in Arctic road design and engineering. Two major study areas located in the continuous permafrost zone represented a range of terrain conditions including yedoma (syngenetically frozen ice-rich silts with large ice wedges) plateaus and hills, thaw-lake basins, river terraces, and modern floodplains. Direct-current resistivity - electrical resistivity tomography (DCR-ERT) using a Wenner array was applied over transects. Complementary site data including the results of drilling and active layer depths measurements were also obtained. The boreholes provided cryostratigraphic information on soil texture, cryostructures, ground ice, and gravimetric moisture content of frozen soils. The resistivity data supported evaluation of the presence/absence of permafrost; location and depth of the active and intermediate layers; and in some conditions changes in ice content. In contrast, the cryostratigraphic interpretation generally offered more nuanced analysis of the subsurface, but was limited in its ability to detect unconformities and the depth of drilling. Both techniques were enhanced by the availability of high-resolution geospatial information and can be used to optimize the location and density of the boreholes for road construction.

1. Introduction

Design, construction and maintenance of roads in Arctic Alaska requires identification of permafrost distribution and its properties. The nature and extent of permafrost, in turn, strongly influences route selection, mitigation techniques and cost. Ice content along with ground temperature, and soil stratigraphy and composition are fundamental parameters for planning, designing and evaluating engineering applications.

This study employs geophysical techniques and cryostratigraphic analysis to identify permafrost characteristics in a proposed road corridor connecting the Dalton Highway and Umiat on the Colville River in Northern Alaska. The proposed road corridor is located within the continuous permafrost zone and crosses the Itkillik, Anaktuvuk, Chandler, and potentially Colville rivers between the Dalton Highway and Umiat (Fig. 1 and Fig. 2). Thickness of permafrost in northern Alaska can range from 200 m in the foothills to 600 m on the coast (Osterkamp and Payne, 1981). Estimated ground ice distribution (Jorgenson et al., 2008) indicated that finer grain soils tended to be more ice rich, however features such as ice-wedge polygons occurred in a variety of environments. Silt-dominated ice-rich deposits more than 30 m thick with syngenetic ice-wedges formed in the late Pleistocene (Yedoma) have been documented in the adjacent area along the Itkillik River (Kanevskiy et al., 2011a; Kanevskiy et al., 2011b).

The main goal of a geophysical survey as part of a geotechnical investigation is evaluation of the homogeneity of a studied geological body and the uncovering of heterogeneities in it. Geophysical methods used in geotechnical investigations in the permafrost region—electrical, seismic, magnetic, and gravity—uncover differences between properties of geological bodies in the earth's crust, and use of these methods is time- and cost-efficient. In general, geophysical methods are indirect. Direct evaluation of soil properties by geophysical methods is limited. To make a direct conclusion, geophysical data should be calibrated by using information on soil obtained by direct methods, such as trenching and drilling. The application of geophysical methods at a key site can be used for calibration, and the application of calibrated geophysical methods can be used for extrapolation of geotechnical data on similar landforms and for design of a drilling program. Geophysical methods can theoretically greatly reduce the number of boreholes.

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Fig. 1. Stream meandering along ice wedges of high center ice-wedge polygons with the high bank of the Colville River in the background. Photo: E. D. Trochim, September 6, 2010.

Cryostratigraphy analysis is a main method of identification of genesis and properties of permafrost soils. This analysis and geophysics represent complementary methods of collecting and interpreting information about permafrost characteristics. Cryostratigraphy is a branch of geocryology originally developed in Russia for analyzing the structures specific to permafrost and has been used to understand the particularities of permafrost environments and Arctic engineering applications (French and Shur, 2010). Previous studies in Alaska have indicated a strong relationship between cryostratigraphy and corresponding terrain units derived from interpreting imagery via remote sensing (Jorgenson et al., 1998; Kanevskiy et al., 2014). The limitations to the cryostratigraphic technique include a high-level of localized permafrost knowledge being necessary to construct the interpretations and the time required to complete the analysis. The soils and permafrost data for cryostratigraphic analysis can be obtained from either boreholes or outcrops as available.

A variety of geophysical techniques have been used to delineate permafrost distribution and ice morphology (Kneisel et al., 2008). These include ground penetrating radar (GPR) and various types of electrical resistivity tomography (ERT) including: 1) direct-current resistivity (DCR-ERT) (Hilbich et al., 2008; Isaksen et al., 2011; Katasonov, 1978; Kneisel, 2010; Lewkowicz et al., 2011; McClymont et al., 2013; Overduin et al., 2012; Rodder and Kneisel, 2012; You et al., 2013), and 2) capacitive-coupled resistivity (CCR-ERT) (De Pascale et al., 2008; Fortier and Savard, 2010; Kuras et al., 2006; Timofeev et al., 1994). Others have used a combination of either GPR and DCR-ERT (Sjöberg et al., 2015) or CCR- and DCR-ERT (Oldenborger and LeBlanc, 2013). Ideally all investigations should be supported by subsurface data based on outcrops, boreholes, or excavation methods.

Interpreting geophysical data, in both permafrost and non-permafrost environments, greatly benefits from information derived from remotely sensed data and boreholes in order to increase the understanding of pertinent landscape characteristics (Hubbard et al., 2013). Cryostratigraphic analysis can be used to constrain geophysical models as described by Fortier et al. (2008) where they examined the ice-content of permafrost mounds. Translating these ideas into practices that can be reasonably applied over large scales where there can be substantial variation both within and between terrain units is important for Arctic road construction. This project used DCR-ERT to detect soil properties as resistivity (the reciprocal of conductivity). As soil particles and ice are both highly resistive compared to liquid water, the relative fractions of ice, soil particles, and liquid water strongly influence the resistivity of different soil strata or formations (Hauck, 2002). The changes in resistivity directly relates to changes in soil properties (Scherler et al., 2010). However, other factors influencing resistivity include texture, temperature, salinity, and cryogenic structure of the soil (Samouëlian et al., 2005). Consequently application of DCR-ERT, like

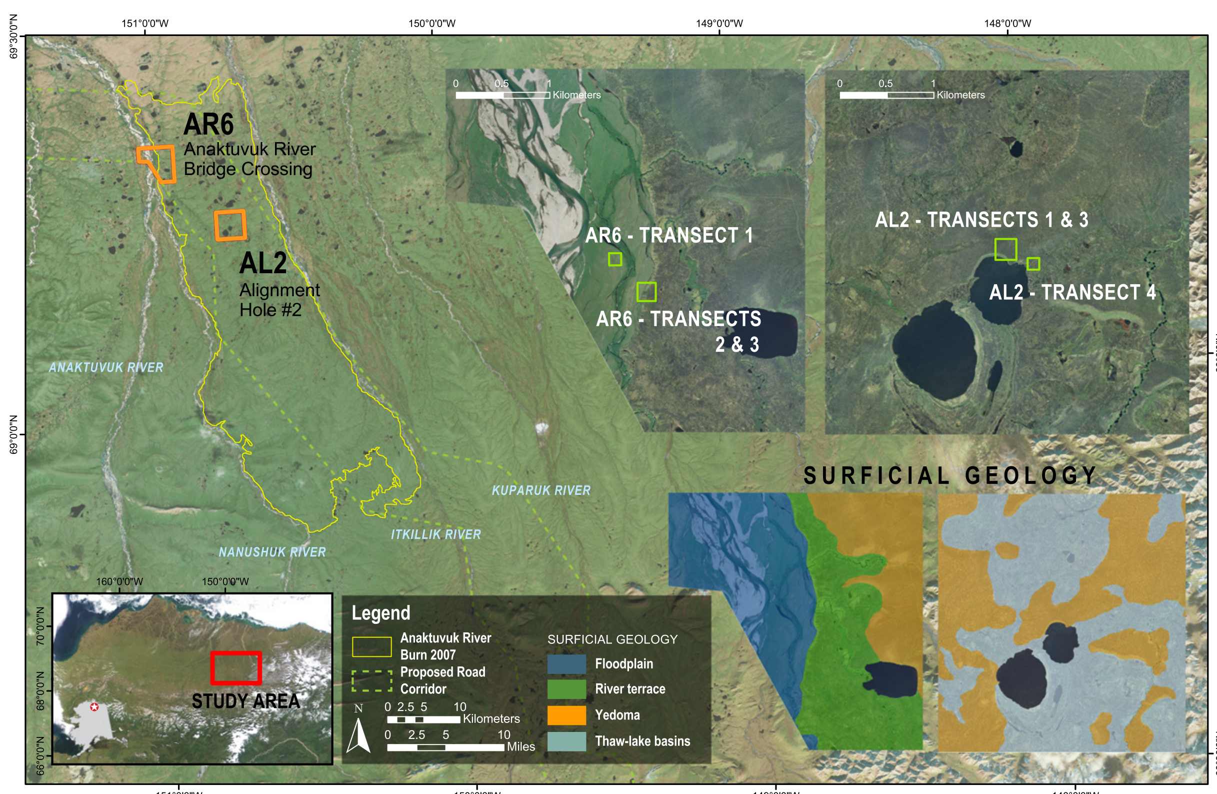

Fig. 2. Study area showing field sites AR6 and AL2 with inset versions of aerial photographs and surficial geology. Imagery: Main: Statewide Digital Mapping Initiative (SDMI) Best Data Layer showing medium resolution Landsat imagery via Geographic Information Network of Alaska (GINA), Insets: aerial photographs acquired July 2009.