Available online at www.sciencedirect.com
ScienceDirect
Polar Science 8 (2014) 96–113
http://ees.elsevier.com/polar/

Geocryological characteristics of the upper permafrost in a tundra-forest transition of the Indigirka River Valley, Russia

Go Iwahana [a,b,e,*], Shinya Takano [b], Roman E. Petrov [c,e], Shunsuke Tei [b], Ryo Shingubara [b], Trofim C. Maximov [c,e], Alexander N. Fedorov [d,e], Alexey R. Desyatkin [c], Anatoly N. Nikolaev [d,e], Roman V. Desyatkin [c], Atsuko Sugimoto [b]

[a] *International Arctic Research Center, University of Alaska Fairbanks, AK, USA*
[b] *Faculty of Environmental Earth Science, Hokkaido University, Sapporo, Japan*
[c] *Institute for Biological Problems of Cryolithozone, Siberian Branch of the Russian Academy of Sciences, Yakutsk, Sakha, Russia*
[d] *Melnikov Permafrost Institute, Siberian Branch of the Russian Academy of Sciences, Yakutsk, Sakha, Russia*
[e] *North-Eastern Federal University in Yakutsk, Yakutsk, Sakha, Russia*

Received 26 April 2013; revised 17 January 2014; accepted 24 January 2014
Available online 5 March 2014

Abstract

Understanding geocryological characteristics of frozen sediment, such as cryostratigraphy, ice content, and stable isotope ratio of ground ice, is essential to predicting consequences of projected permafrost thaw in response to global warming. These characteristics determine thermokarst extent and controls hydrological regime—and hence vegetation growth—especially in areas of high latitude; it also yields knowledge about the history of changes in the hydrological regime. To obtain these fundamental data, we sampled and analyzed unfrozen and frozen surficial sediments from 18 boreholes down to 1–2.3 m depth at five sites near Chokurdakh, Russia. Profiles of volumetric ice content in upper permafrost excluding wedge ice volume showed large variation, ranging from 40 to 96%, with an average of 75%. This large amount of ground ice was in the form of ice lenses or veins forming well-developed cryostructures, mainly due to freezing of frost-susceptible sediment under water-saturated condition. Our analysis of geocryological characteristics in frozen ground including ice content, cryostratigraphy, soil mechanical characteristics, organic matter content and components, and water stable isotope ratio provided information to reconstruct terrestrial paleo-environments and to estimate the influence of recent maximum thaw depth, microtopography, and flooding upon permafrost development in permafrost regions of NE Russia.

Keywords: Ground ice; Permafrost; Indigirka; Siberia; Stable isotope; Chokurdakh

1. Introduction

The Arctic tundra ecosystem is expected to undergo rapid and significant changes, as amplified climate change and the anticipated permafrost thaw potentially

---

* Corresponding author. International Arctic Research Center, University of Alaska Fairbanks, AK 99775-7340, USA. Tel.: +1 9074742444.
E-mail address: giwahana@alaska.edu (G. Iwahana).

http://dx.doi.org/10.1016/j.polar.2014.01.005
1873-9652/

alter its landscape entirely. The increase in average surface air temperature in the Arctic is expected to be nearly double the global average, with precipitation to increase as well (IPCC, 2007). Warming of permafrost has been reported in Siberia (Romanovsky et al., 2007, 2010), Alaska (Osterkamp, 2005) and Canada (Smith et al., 2012) over the last several decades. Additionally, numerical models project substantial permafrost degradation during the 21st century (Koven et al., 2011; Lawrence et al., 2012), a loss that will be accentuated by rapid sea ice loss (Lawrence et al., 2008). Permafrost degradation implies the mobilization of not only a huge amount of currently confined soil organic carbon, but also a certain extent of water previously preserved as ground ice (Ping et al., 2011). The landscape change associated with permafrost thaw largely depends on ice content of the permafrost; thawing of ice-rich permafrost leads to thermokarst.

Thermokarst development in ice-rich permafrost regions is a natural hazard, and causes irreversible geomorphological changes (Haeberli and Burn, 2002). Thermokarst is the process by which characteristic landforms result from the thawing of ice-rich permafrost or the melting of massive ice (Everdingen, 1998). The formation of large depressions in the ground surface produced by thermokarst processes results in lakes or swamps, and is frequently observed in continuous permafrost zone, including Northeastern Siberia. Extremely ice-rich syngenetic permafrost, known as Yedoma, which is strongly affected by thermokarst processes, is often found in various permafrost regions. Yedoma is a Pleistocene organic-rich silty deposit, containing excessive amounts of ground ice (50–90% in volume) including huge ice wedges (Kanevskiy et al., 2011; Schirrmeister et al., 2011, 2013). Since Yedoma is distributed in a large part of permafrost regions (NE Russia, NW Alaska, central Yukon, and area across the Bering Strait referred as "Beringia"), the impacts of Yedoma thaw or erosion on related ecosystems—including rivers, estuaries, deltas, and seas—are widespread. Zimov et al. (1997) and Walter et al. (2006) concluded that the thawing of Yedoma may release a significant amount of methane (∼3.8 Tg/yr), leading to further climate warming. Therefore, the feedbacks from permafrost degradation to ecological, geomorphological, and hydrological processes have been of great scientific and social concern, and the need for elucidation of its role in the ecosystem and global climate system are emphasized by many authors (Schuur et al., 2008; Francis et al., 2009; Jorgenson et al., 2010; Rowland et al., 2010; Grosse et al., 2011).

Changes in the hydrological processes and geochemistry of aquatic systems due to thawing permafrost have been examined and reported by recent studies. Shiklomanov and Lammers (2009), for example, concluded that more intensive permafrost thawing was one of the possible causes for the 2007 record Eurasian pan-Arctic river discharge into the Arctic Ocean. Thawing of organic-rich and ice-rich sediments results in the increased flow of organic matter and water into adjacent seas and rivers, promptly changing the surrounding topography and aquatic ecosystems. Attempts to determine permafrost change from geochemical analysis of river water (Bagard et al., 2011) or streamflow characteristics (Brutsaert and Hiyama, 2012; Sjoberg et al., 2013) have been conducted and have demonstrated implications of permafrost degradation. Although spatial and temporal distribution and geocryological properties of ice-rich/organic-rich permafrost have critical importance in these studies, these characteristics remain insufficiently understood. Several studies focusing on the quantification of volumetric ground ice content in tundra regions have been conducted in Arctic Alaska (e.g., Pullman et al., 2007; Kanevskiy et al., 2013), Canada (e.g., Morse et al., 2009), and Siberia (e.g., Grave and Turbina, 1980; Ershov, 1989; Strauss et al., 2012); however, the remoteness of sites, insufficient resources for frozen ground coring, and time-consuming analyses of volumetric measurements of frozen samples keep field evidence in other permafrost regions scarce.

On the other hand, geocryological characteristics such as cryostratigraphy and stable isotope ratio of cryostructure ice or ice wedges provide some information about freezing conditions and the paleoclimatic conditions under which stratigraphic parts were formed (e.g., Arkhangelov et al., 1986; Vaikmae, 1989; Michel, 2011; Mackay, 1983). The stable isotope ratio of ground ice have been intensively studied with high sampling resolution, primarily regarding ice wedges and other types of massive ground ice, in order to reconstruct mean winter temperature for the period when the ice wedges formed (e.g. Meyer et al., 2010; Opel et al., 2011). Although similar investigations regarding cryostructure ice have rarely occurred, together with the information obtained from massive ground ice, the spatial distribution of stable isotope ratio of cryostructure ice has a potential to provide important clues for the reconstruction of past environments. In addition to the geocryological information archiving the paleo-environment, the isotope ratio of near-surface permafrost that is anticipated to thaw in