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Timing and drivers of mid- to late Holocene ice-wedge polygon development in the Western Canadian Arctic

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Abstract

Ice-wedge polygon formation and development from low-centred to high-centred types are thought to be either linear processes acting on long time-scales or rapid shifts between different regimes. We analyzed six sediment cores from three ice-wedge polygons on the Yukon Coastal Plain to examine the timing and drivers of these dynamics. All sites developed from shallow lakes or submerged polygon environments to low-centred polygons before rapid degradation and drying during the last century. We found that ice-wedge polygon initiation was linked to moderate climatic cooling during the mid-Holocene combined with drainage of lakes. The further conversion to high-centred polygons appeared to have been a rapid process linked to modern climatic warming. Continued warming may thus lead to increasing ice-wedge melt on larger scales and subsequent degradation of ice-wedge polygons, especially if paired with increasing geomorphic disturbances caused by thermokarst and thermo-erosion.

Keywords: coastal lowlands; permafrost degradation; tundra vegetation; plant macrofossils, Yukon Coastal Plain

Introduction

In Arctic lowlands, ice-wedge polygons are widespread features that determine carbon storage and landscape hydrology. These properties differ between high-centred polygons and low-centred polygons, from which the latter are thought to develop. It is not entirely clear, however, to which extent climate and geomorphology influence polygon development. This study investigated past landscape development in modern ice-wedge polygons, focusing on timing and triggers of possible tipping points between polygon types.

Methods

We addressed these questions by analyzing six cores from three ice-wedge polygons on the arctic coastal plain of the Yukon Territory, Canada. Grain size distribution, carbon and nitrogen contents, and stable carbon isotope signatures were determined for each 1 cm subsample. We conducted plant macrofossil analyses on 44 selected samples, and obtained radiocarbon dates for 24 of these samples. Constrained incremental sum of squares (CONISS) analysis validated by broken stick analysis and principal component analysis (PCA) aided data interpretation.

Results and Discussion

Fig. 1 shows the reconstructed landscape development together with climate reconstructions for the region. All sites showed a general development from aquatic to wetland environments. Sediment analyses and plant macrofossils supported these shifts from aquatic vegetation typical for shallow lake margins (e.g. *Potamogeton*, *Batrachium*, *Menyanthes trifoliata*, Charophytes, cf. Fritz et al., 2016; Wolter et al., 2017) to wetland vegetation typical for low-lying areas in ice-wedge polygons (e.g. *Carex*, cf. Wolter et al., 2016), and finally to vegetation typical for elevated, better drained areas in ice-wedge polygons (e.g. *Betula glandulosa*, *Ledum decumbens*, *Eriophorum vaginatum*, cf. Wolter et al., 2016).

In the mid-Holocene portion of our reconstruction (ca. 7000-6000 cal yrs BP) shallow lakes and partly submerged ice-wedge polygons existed at the studied sites. At two sites where high- and intermediate-centred polygons exist today, a hiatus of ca. 5000 years, accompanied by strong shifts in grain size distribution and organic carbon contents, indicated substantial disturbance during a time of stable temperatures and increased precipitation (Fig. 1). The initiation or re-initiation of ice-wedge polygon development roughly fell within the last millennium, when temperatures dropped. Lake drainage is one major factor promoting ice-wedge development. Our reconstructions suggest that all sites indeed hosted lake environments before developing into ice-wedge polygons (Fig. 1). Finally, all three polygons experienced recent degradation and drying. Low-lying surfaces were converted into elevated surfaces and the vegetation composition changed markedly. This phenomenon accompanied recent climatic warming and accelerated coastal erosion, which led to a landscape-scale increase in surface drainage.

Our findings suggest that both, climatic and geomorphic drivers caused changes to the landscape in this specific region of low-Arctic lowland tundra. The conversion of low-centred polygons to high-centred polygons likely happened during the last 100 years.

In our study, geomorphology outweighed climatic influence on ice-wedge polygon development during the late Holocene, with the possible exception of recent warming, which caused ice wedge degradation at all studied sites. The initiation of ice-wedge polygons was linked to lake drainage. The conversion of low-centred polygons into intermediate- or high-centred forms was triggered by ice-wedge degradation and changes in the local topographic gradient through geomorphic disturbance attributable to thermokarst and thermal erosion as well as coastal erosion. Stable conditions were found where no geomorphic change or disturbance was evident and a stable water balance was maintained. Our study showed that in areas with strongly impeded drainage, low-centred forms might persist for millenia, while any drainage may trigger self-enhancing degradation.

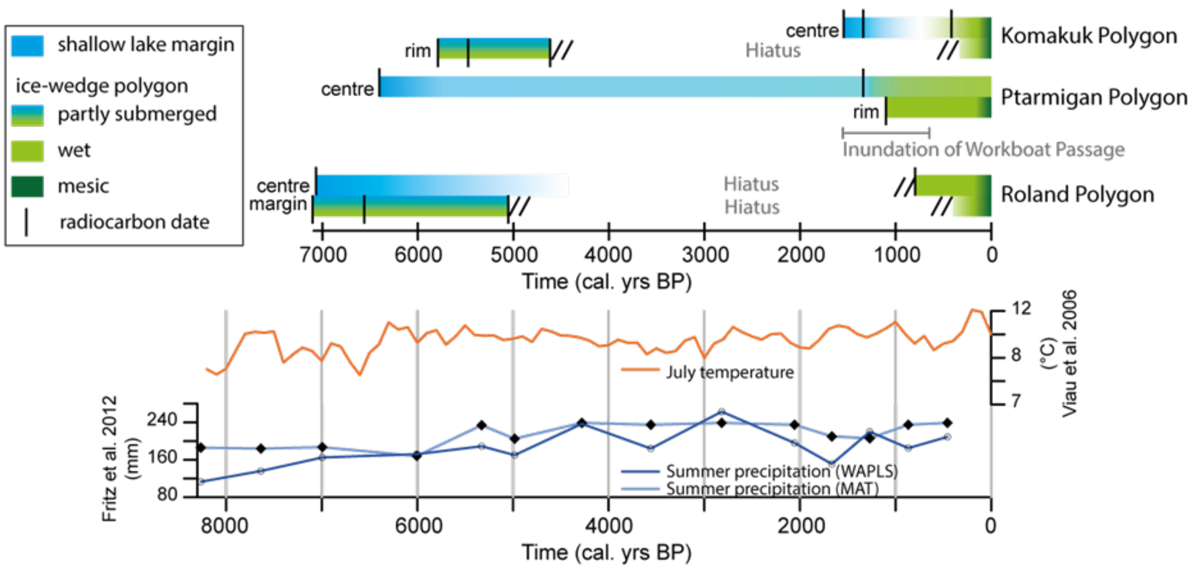

Figure 1. Environmental reconstruction for the studied ice-wedge polygons on the Yukon Coastal Plain and climate reconstructions. Black vertical lines indicate calibrated median radiocarbon ages.

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