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Research paper

Sediment accumulation rates in subarctic lakes: Insights into age-depth modeling from 22 dated lake records from the Northwest Territories, Canada

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ABSTRACT

Age-depth modeling using Bayesian statistics requires well-informed prior information about the behavior of sediment accumulation. Here we present average sediment accumulation rates (represented as deposition times, DT, in yr/cm) for lakes in an Arctic setting, and we examine the variability across space (intra- and inter-lake) and time (late Holocene). The dataset includes over 100 radiocarbon dates, primarily on bulk sediment, from 22 sediment cores obtained from 18 lakes spanning the boreal to tundra ecotone gradients in subarctic Canada. There are four to twenty-five radiocarbon dates per core, depending on the length and character of the sediment records. Deposition times were calculated at 100-year intervals from age-depth models constructed using the 'classical' age-depth modeling software Clam. Lakes in boreal settings have the most rapid accumulation (mean DT 20 ± 10 yr/cm), whereas lakes in tundra settings accumulate at moderate (mean DT 70 ± 10 yr/cm) to very slow rates, (>100 yr/cm). Many of the age-depth models demonstrate fluctuations in accumulation that coincide with lake evolution and post-glacial climate change. Ten of our sediment cores yielded sediments as old as c. 9000 cal BP (BP = years before AD 1950). From between c. 9000 cal BP and c. 6000 cal BP, sediment accumulation was relatively rapid (DT of 20–60 yr/cm). Accumulation slowed between c. 5500 and c. 4000 cal BP as vegetation expanded northward in response to warming. A short period of rapid accumulation occurred near 1200 cal BP at three lakes. Our research will help inform priors in Bayesian age modeling.

1. Introduction

Lake sediment accumulation rates vary across space and time (Lehman, 1975; Terasmaa, 2011). Characterization of the spatial trends in accumulation rate for a region and within a lake basin is valuable for sample site selection in paleolimnological studies, as it is often favorable to sample lakes with sufficiently high accumulation rates to achieve a desirable temporal resolution in the data. Understanding the temporal variability and timing of major shifts in accumulation rate as well as the causes of major accumulation rate shifts for a region can be extremely valuable for deciding on levels in an age-depth model that would benefit from additional radiocarbon dates. Such changes in accumulation rate can be used to better understand the limnological system of study and the impact of climate change on that system. Moreover, there are many examples where changes in sediment accumulation rate have been linked to climatic change. For example, in the Cathedral Mountains of British Columbia, the highest Holocene levels of sediment yield are coincident with late Holocene (~4000 BP) climate cooling, reduced catchment vegetation and increased terrestrial erosion (Evans and Slaymaker, 2004). Similarly, in a crater lake in equatorial East Africa, Blaauw et al. (2011) found that cooler climate conditions also resulted in reduced vegetation cover and increased

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terrestrial erosion and allochtonous sediment input into the lake. Knowledge of accumulation rate is also necessary for proxy-based reconstructions of mean fire return interval, rates of vegetation change (Koff et al., 2000; Marlon et al., 2006), and carbon accumulation rate studies (e.g. Charman et al., 2013), for example, that are only as good as the chronologies they are based upon.

The integration of sediment accumulation rate information into Bayesian age-depth models as prior knowledge, or "priors" is particularly important for sections of an age-depth model where the behavior of the model is uncertain (e.g. sparse data, age reversals, age offsets, dates within a radiocarbon plateau). It can be a challenge, however, to estimate the accumulation rate prior. Goring et al. (2012) provided a summary of sediment accumulation rates from 152 lacustrine sites in the northeastern US/southeastern Canada region and found that, in general, sediment accumulated with a DT of around 20 yr/cm. This result is fairly similar to the previous findings of Webb and Webb (1988; 10 yr/cm) for the same region. However, these estimates are too rapid for subarctic and arctic lakes, where a short ice-free season and low availability of organic material relative to more southern sites lead to slow annual sediment accumulation rates (e.g. Saulnier-Talbot et al., 2009).

This paper expands upon the temperate lake research of Goring et al. (2012) and Webb and Webb (1988). We examine Holocene accumulation rate data for 22 lacustrine sites from a latitudinal gradient spanning boreal forest, treeline, and tundra settings in the Northwest Territories, Canada. While this is a much smaller dataset than Webb and Webb (1988) and Goring et al. (2012), it is significant given that it is logistically difficult to obtain sediment records in arctic and subarctic regions due to the lack of infrastructure. Goring et al. (2012) suggest that such regional datasets can provide important prior knowledge to inform Bayesian (and other) age models.

The age-depth models presented in this paper were constructed in support of an interdisciplinary project aimed at better understanding the natural variability of climate along the routed of the Tibbitt to Contowyto Winter Road (TCWR) in the central Northwest Territories (Canada). Increased precision of age-depth models and increased sampling resolution of proxy data from lake sediment cores have permitted higher resolution characterization paleoclimate patterns (e.g. Galloway et al., 2010; Macumber et al., 2012; Upiter et al., 2014).

2. Regional setting

Lakes investigated in this study are located in the central Northwest Territories (Fig. 1) in an area underlain by a portion of the Canadian Shield known as the Slave Craton. This section of Archean crust is characterized by a depositional and volcanic history that has been overprinted by multiple phases of deformation and intruded by granitoid plutons (Bleeker, 2002). Major rock units include basement gneisses and metavolcanics, metasedimentary rocks, and widespread gneissic–granitoid plutons (Padgham and Fyson, 1992; Helmstaedt, 2009). This bedrock geology lacks carbon-rich rocks such as limestones or marl, and is unlikely to be a source of '^{14}C dead' carbon, which can cause radiocarbon dates to appear anomalously old.

The Slave Craton has been isostatically uplifting since the retreat of the Laurentide Glacier about 10,000–9000 years ago (Dyke and Prest, 1987; Dyke et al., 2003). Glacial-erosional processes have shaped the terrain, which is characterized by a gentle relief of only a few tens of meters (Rampton, 2000). Where bedrock is not exposed, it lies beneath deposits of till and glaciofluvial sediment of varying thickness. The action of glacial erosion and subglacial meltwater

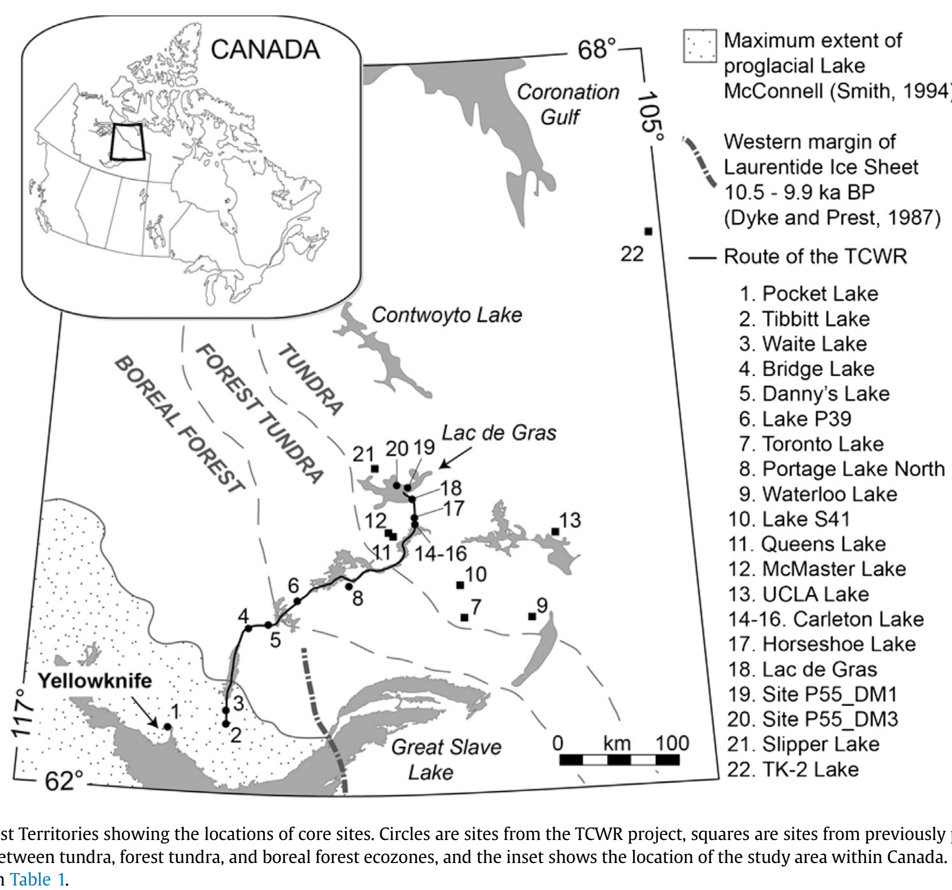

Fig. 1. Map of the Northwest Territories showing the locations of core sites. Circles are sites from the TCWR project, squares are sites from previously published work, dashed lines show current boundaries between tundra, forest tundra, and boreal forest ecozones, and the inset shows the location of the study area within Canada. References for the previously published sites are given in Table 1.