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Late Holocene moisture balance variability in the southwest Yukon Territory, Canada

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Abstract

Analyses of sediment cores from Marcella Lake, a small, hydrologically closed lake in the semi-arid southwest Yukon, provides effective moisture information for the last ~4500 years at century-scale resolution. Water chemistry and oxygen isotope analyses from lakes and precipitation in the region indicate that Marcella Lake is currently enriched in ^{18}O by summer evaporation. Past lake water values are inferred from oxygen isotope analyses of sedimentary endogenic carbonate in the form of algal Charophyte stem encrustations. A record of the $\delta^{18}O$ composition of mean annual precipitation at Jellybean Lake, a nearby evaporation-insensitive system, provides data of simultaneous $\delta^{18}O$ variations related to decade-to-century scale shifts in Aleutian Low intensity/position. The difference between the two isotope records, $\Delta\delta$, represents ^{18}O-enrichment in Marcella Lake water caused by summer effective moisture conditions. Results indicate increased effective moisture between ~3000 and 1200 cal BP and two marked shifts toward increased aridity at ~1200 and between 300 and 200 cal BP. These prominent late Holocene changes in effective moisture occurred simultaneously with changes in Aleutian Low circulation patterns over the Gulf of Alaska indicated by Jellybean Lake. The reconstructed climate patterns are consistent with the topographically controlled climatic heterogeneity observed in the coastal mountains and interior valleys of the region today.

1. Introduction

Air masses that influence the southwest Yukon Territory originate in the Bering Sea, the Gulf of Alaska and the Arctic Ocean. Trajectories of these air mass systems are strongly controlled by variations in the intensity and position of the semi-permanent Aleutian Low (AL) located over the Gulf of Alaska (Fig. 1; Trenberth and Hurrell, 1994; Mock et al., 1998). A major regional topographic feature is the ~3000-m high St. Elias massif and Coast Mountains of southeastern Alaska. Varying atmospheric circulation patterns superimposed on the regional topography produce notably different climates on the coast and the interior (Wahl et al., 1987). Relatively warm/wet Gulf of Alaska airmasses delivered by AL circulation result in high precipitation on the coastal side of the mountains (>6000 mm/yr) and a strong rain shadow in the southwest Yukon (<260 mm precipitation/year), approximately 200 km inland from the coast (Wahl et al., 1987).

Previous paleoclimatic studies suggest that variations in AL intensity and/or position were an important control on Northwest Pacific Holocene climate (e.g., Heusser et al., 1985; Mann and Hamilton, 1995; Edwards et al., 2001; Spooner et al., 2003). Oxygen isotope variations in endogenic carbonate at Jellybean Lake, an evaporation-insensitive system, located in the southwest Yukon, provides a detailed record of AL variability for the last ~7500 years at decade-to-century time scales (Anderson et al., 2005a). Abrupt oxygen isotope shifts at Jellybean Lake at ~1200 and 300 cal BP are verified by corresponding oxygen isotope shifts at the summit of Mt. Logan and interpreted to represent rapid AL intensification and/or eastward shifts (Fisher et al., in press). In contrast,

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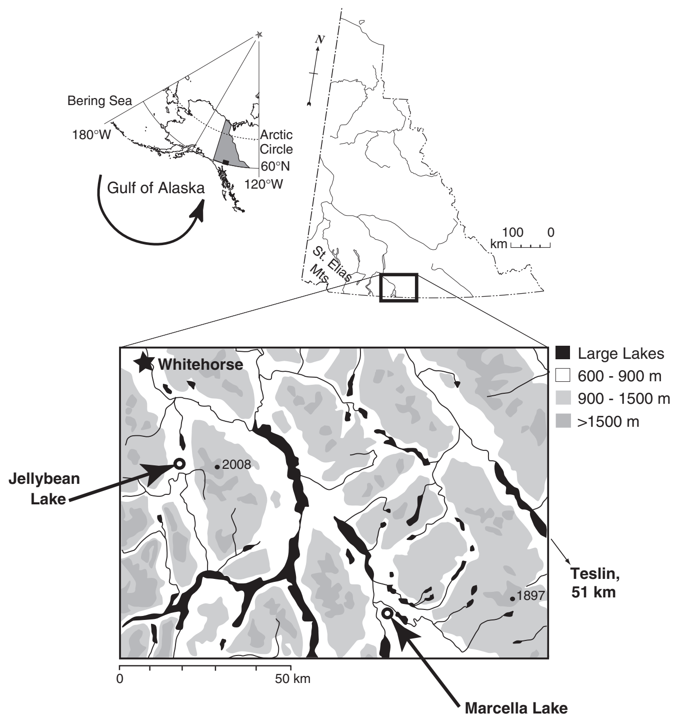

Fig. 1. Location map of the study area in the southwest Yukon Territory. The circular arrow indicates the general atmospheric circulation around the Aleutian Low in the Gulf of Alaska oriented towards the northeast to southwest trending St. Elias Mountains. The shaded relief map of the area surrounding Jellybean and Marcella Lakes shows the large lakes in the region (black areas), the locations of Whitehorse and Teslin, local topography and high elevations in each lake's watershed. Bathymetric maps of Marcella and Jellybean Lake including coring locations are in Anderson et al. (2005a, b).

hydrologically closed lakes located in the rain shadow of the southwest Yukon are sensitive to changes in moisture balance (precipitation minus evaporation). Evaporation-sensitive lakes that accumulate endogenic carbonate at relatively high rates (0.3–1.0 mm/yr) present the opportunity to investigate the relationship between interior moisture balance and AL circulation variations at decade-to-century time scales.

Previous studies in the southwest Yukon provide information regarding moisture balance variability on millennial- to century-scales (Cwynar, 1988; Pienitz et al., 2000; Anderson et al., 2005b). Conditions prior to 10,000 cal BP were dry. Effective moisture increased during the early Holocene. Conditions were wetter-than-modern by ~3000 cal BP but subsequently increasingly arid to present. Tree-ring studies in semi-arid central Alaska highlight the ecological impacts of inter-decadal changes in effective moisture during the last century (Barber et al., 2000). However, relatively little is known about sub-millennial scale moisture balance variability during the Holocene or about the relative importance of temperature and precipitation in controlling effective moisture.

We analyzed oxygen and carbon isotopes of endogenic carbonate in the form of Characean algae (*Chara* sp.) calcite encrustations at Marcella Lake to provide more detailed information on the moisture balance history of the southwest Yukon. Marcella Lake is small and hydrologically closed. Water loss is primarily by evaporation and oxygen isotope ratios of preserved *Chara* encrustations document changes in the oxygen isotope ratios of lake water caused by evaporation. The sampling resolution and analytical precision of the geochemical data are of sufficient quality to document changes at 50- to 200- year resolution back to ~4500 cal BP

2. Paleoclimatic application of Marcella Lake Oxygen Isotopes

Marcella Lake is a terminal hydrologically closed lake with a well-defined watershed that is small relative to the lake's surface area. In terminal lakes, the preferential evaporation of light ^{16}O-water leaves remaining lake water ^{18}O-enriched (Craig and Gordon, 1965; Gonfiantini, 1986). However, lake-water oxygen isotope ratios may also be affected by changes in isotopic composition of input water, including catchment runoff, groundwater and precipitation falling directly into the lake (Kendall and Caldwell, 1998). These effects are relatively small for evaporation-sensitive lakes, but they may be the dominant influence on lake-water $\delta^{18}O$ in hydrologically open lakes with large catchment-to-surface-area ratios. In such systems, evaporation processes are typically less significant because lake-water residence times are shorter (e.g., von Grafenstein et al., 2001; Anderson et al., 2005a). Although Marcella Lake water is dominantly controlled by evaporation, longer-term oxygen isotope variations of input waters could be important. We can account for these effects by utilizing our reconstruction of regional mean annual precipitation, $\delta^{18}O_p$, from endogenic carbonate (bulk marl) in Jellybean Lake, located ~75 km northwest of Marcella Lake (Fig. 1; Anderson et al., 2005a). The two records have comparable age control and temporal resolution and it is likely that $\delta^{18}O_p$ has been similar at both lakes.

The moisture balance history of evaporation sensitive lakes can be determined from oxygen isotope ratios of endogenic carbonate (e.g., Talbot, 1990; Hammerlund et al., 2003; Anderson and Leng, 2004). This study is based on analyses of calcite encrustations on *Chara* stems. *Chara* provide a locus and kinetic advantage for calcite precipitation as a 1:1 byproduct of photosynthesis (e.g., bio-induced calcification; McConnaughey et al., 1994). McConnaughey (1991) showed that calcite encrustation is beneficial (by providing structural support and facilitating proton and CO_2 generation), but not essential for *Chara* photosynthesis. *Chara* calcite records the oxygen isotope composition of lake water provided there is isotopic equilibrium. Previous studies of modern endogenic carbonate show that *Chara* oxygen isotope values can be ~1.5‰ more negative than estimated equilibrium values in eutrophic lakes undergoing rapid photosynthesis (Huon and Mojon, 1994; Fronval et al., 1995; Andrews et al., 2004). This is