LATE GLACIAL TO MID-HOLOCENE CLIMATE CHANGE IN WESTERN IRELAND: EVIDENCE FROM HIGH-RESOLUTION STABLE ISOTOPE RECORD OF LACUSTRINE MARL

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INTRODUCTION

Global climates have been predicted to warm by as much as 1.5 to 4.5°C in the next 50 years as a result of anthropogenic doubling of atmospheric CO^2 (Houghton et al., 1990). To date however, models predict temperatures that are higher than those observed, suggesting that models may be poorly calibrated. Therefore, modeling of future climate change requires a better understanding of natural climate variability over the Holocene. The Holocene has previously been characterized as a period of climatic stability relative to the most recent period of glaciation during which proxy records demonstrate that climate variability was high (Alley et al. 1997). However, further analysis of multiple proxy records, such as tree rings, lacustrine carbonates, and ice cores suggest significant changes in temperature and precipitation over the Holocene (Dansgaard et al. 1993). Ice core analyses suggest a warming trend from ~9ka until about ~4 ka when global temperatures began to cool (Larsen et al. 1995, Thompson et al. 1995). Several major excursions occurred over this period, including the 8,200 year event, the Little Ice Age and the Medieval Warm Period (Mann et al. 1995; Keigwin, 1996). Nonetheless, the Holocene paleoclimate record is incomplete and remains poorly understood. A better understanding of Holocene climate is critical if future climate change is to be accurately predicted. To better constrain global climate models requires a complete Holocene high-resolution climate record.

This research project is significant because it will be the first lacustrine paleoclimate record in Ireland of such high-resolution (decadal). Isotope analyses of carbon and oxygen will provide valuable information on Holocene climate variability. Western Ireland is of particular interest due to minimal continental climate influence on the record and because of the abundance of marl lakes. Marls in western Ireland are biologically-mediated during the warmest period each year (thus reflecting summer months).

METHODS

Cores were collected at Lough Inchiquin in County Clare using standard square rod piston coring equipment. Cores were analyzed for organic matter and carbonate content via loss on ignition (LOI) at 550ºC and 1000ºC respectively. Stable isotope analyses of the carbonate were conducted at the Saskatchewan Isotope Lab at the University of Saskatchewan. Cores were subsampled for stable isotope analyses at 2mm resolution (n=3500) and fine grain carbonate was selectively isolated from gastropods and ostracods. Prior to stable isotope analyses carbonate was roasted in vacuo at 200°C to remove volatile organics and water. Carbonate was analyzed using a Thermo Finnigan Kiel III carbonate preparation device directly coupled to a Thermo Finnigan MAT 253 mass spectrometer. Samples were reacted at 70°C with 103% phosphoric acid and were corrected for acid/water fractionation, ^{17}O contribution, and temperature fractionation. All samples are reported in standard delta notation relative to VPDB (Vienna Peedee belemnite) by standards NBS-19, NBS-18 and internal standards. Precision is better than ±0.1‰ for carbon and oxygen. Primary age control will use ^{137}Cs, ^{210}Pb, AMS radiocarbon dating and correlation with pollen in cores to other previously dated cores (preliminary dating by isotopic correlation with O'Connell et al, 1999 in absence of dates).

RESULTS

LOI reveals that total carbonate and organic matter (Fig. 1) are inversely correlated (r^2=0.99) above 6.3m. However, below 6.3m total carbonate and inorganic material are inversely correlated (r^2=0.99). The upper 2m of core displays considerable variation in carbonate and organic content related to shifts in peat/marl content. A significant shift in carbonate and inorganic matter occurs at 6.5 correlating with a clay layer in the core.

Stable oxygen isotope results are shown in Figure 2. These values are characterized by high-frequency variations throughout the profile. $\delta^{18}O_{(CaCO3)}$ values range from -8.8‰ to -4.0‰ (n=484) with an average value of -5.8‰. A large decrease occurs above 6.6m that abruptly stops at the clay layer and abruptly increases above. A notable decrease occurs between 4.5m and 4.3m.

Stable carbon isotope results (Fig. 2) range from 2.8‰ to -8.3‰ (n=484) with an average value of -4.1‰. Two large negative shifts occur between 7.5m and 5.5m. Above 5.5m, $\delta^{13}C_{(CaCO3)}$ values are characterized by low amplitude variability.

DISCUSSION

Late Glacial to Younger Dryas

Stable oxygen isotope values at the end of the Pleniglacial (~15 ka) in western Ireland record the transition from glacial to non-glacial conditions. This is evident in a >3‰ increase in $\delta^{18}O_{(CaCO3)}$ which can be attributed to release of meltwater (depleted in ^{18}O) from receding glaciers. As the meltwater decreases, a return to more positive $\delta^{18}O_{(CaCO3)}$ values (consistent with a relatively cold and dry climate). This is followed by a negative trend in oxygen interpreted as an amelioration of the climate correlating with the Bølling warming period. A negative shift occurs around 14 ka that most likely correlates with the Older Dryas and the isotopic composition is reflecting precipitation depleted in ^{18}O. The Older Dryas persisted for several centuries when there was an advancement/stalling of glaciers to the far north. The Allerød period followed and $\delta^{18}O_{(CaCO3)}$ values appear to remain variable indicating a combination of precipitation and temperature variations. A positive shift occurs at 12.5 ka that is probably due to a cold and dry climate with increased evaporation resulting in increased ^{18}O. This is followed by an abrupt decrease in $^{18}O_{(CaCO3)}$ of 4.5‰ coinciding with the start of the Younger Dryas where there is a return to glacial conditions. A large shift may be explained by an expansion of the circumpolar vortex (CPV) causing precipitation to be derived from colder water and air temperatures above the ocean.

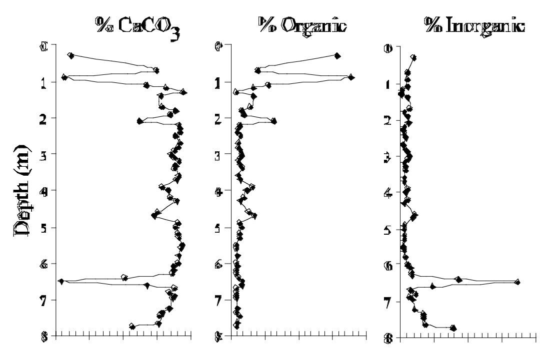

Figure 1. Sedimentology from Lough Inchiquin, County Clare Ireland.

Post-Younger Dryas to Early Holocene

The transition from the Younger Dryas to the Early Holocene was an abrupt event that has been documented in multiple proxies in the northern hemisphere (Mullins, 1998) and occurs at Lough Inchiquin where there is a rapid increase in $\delta^{18}O_{(CaCO3)}$ values and carbonate content. This shift at the end of the Younger Dryas (~11.6ka) is similar to the end of the Pleniglacial and is explained by the same mechanism. A positive spike in $\delta^{18}O_{(CaCO3)}$ at 6.4m may coincide with the Preboreal oscillation (11.3 ka) event that lasted for ~200 years (Fisher, et al. 2002), attributed to cold weather and increased evaporation. Following the Preboreal oscillation, $\delta^{18}O_{(CaCO3)}$ becomes more negative influenced by warmer temperatures that persist until about 6m. A shift at 6m may be explained by a change in precipitation controlled by a contraction of the CPV resulting in heavier values.

Early Holocene to Mid-Holocene

Climate during this period was generally variable with a base line trend that suggests

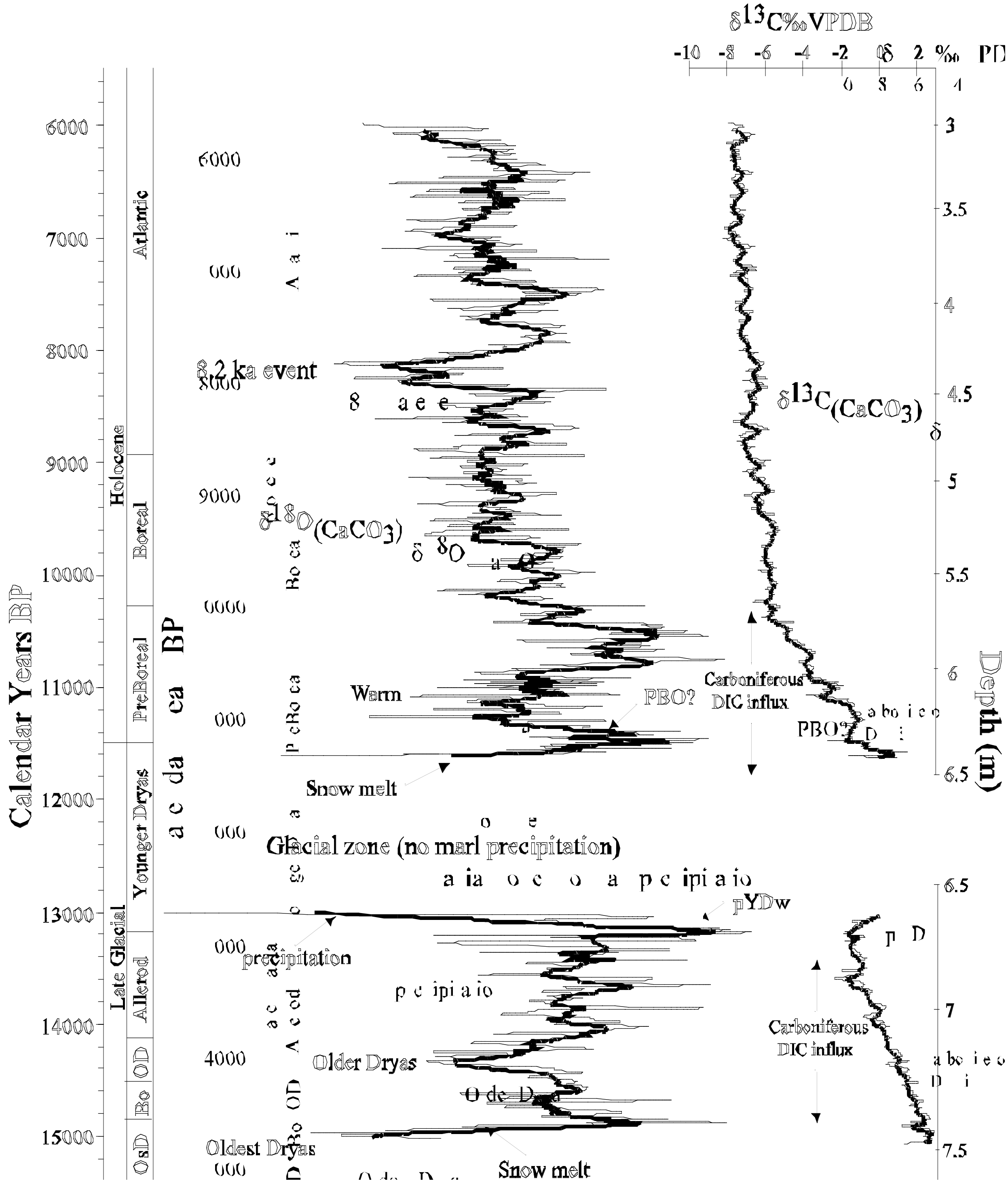

Figure 2. Late Glacial to mid-Holocene $\delta^{18}O_{(CaCO3)}$ and $\delta^{13}C_{(CaCO3)}$ data for Lough Inchiquin, County Clare Ireland. Climate events of interest are labeled: Younger Dryas, preYounger Dryas warming (pYDw), Bølling (Bo), Allerød, Older Dryas (OD), Oldest Dryas (OsD), 8.2 ka cold event, preBoreal Oscillation (PBO). Initial dates (cal. years BP) shown with dashed line determined from isotopic and lithological comparison from O'Connell, et al (1999). Thin line represents raw data and thick line represents five point moving average.

moderate warming evidenced by increasing $\delta^{18}O_{(CaCO3)}$ values. Starting at ~4.5m, a negative shift in $\delta^{18}O_{(CaCO3)}$ occurs. Again, explained by precipitation derived from cooler water and air. Based on the magnitude of this event, it is likely to coincide with the 8.2 ka cold event. At about 8.2ka, a meltwater pulse released freshwater into the North Atlantic, shutting down thermohaline circulation, decreasing thermal transport, and resulting in a cold climate that persisted for several decades (Baldini et al, 2002).

Carbon Isotopes and DIC

$\delta^{13}C_{(CaCO3)}$ values at the end of the Pleniglacial and Younger Dryas are significantly higher for over 1m in each occurrence. This large shift cannot be attributed to flora changes and rather represents an influx of dissolved inorganic carbon (DIC) sourced from Carboniferous limestone that has characteristically high $\delta^{13}C_{(CaCO3)}$ values. During glacial retreat, limestone was eroded and transported to the lacustrine basin and incorporated into the calcite precipitating in the lake reflecting enriched isotopic composition. As much of this ground limestone is sequestered, the carbon isotope values of DIC gradually decrease (reflecting the proportional increase in the dominance of the isotope values of surrounding terrestrial vegetation).

CONCLUSION

This study uses high-resolution stable isotope records from lacustrine marl to define climate variability through the Late Glacial to mid-Holocene. Climate during this period was highly variable with several periods of cooling reflected by changes in precipitation, temperature, and changes in the CPV. Continued research on the more recent portion of the core will be compared to historical data in order to develop a transfer function for calculating the position the circumpolar vortex over the past ~15ka. Subsequently, this work will be linked to data from the Northeastern United States (e.g. Kirby et al. 2002) in order to characterize variation in atmospheric circulation from ~100°W to ~15°E longitude.

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