LAKES OF WESTERN IRELAND: AN ARCHIVE FOR HOLOCENE OCEANOGRAPHIC AND CLIMATIC VARIABILITY

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INTRODUCTION

Recent predictions suggest that global climates will likely warm as much as 1.5 to 4.5°C in the next 50 years in response to an anthropogenic doubling of atmospheric CO_2 (Houghton *et al*. 1990). In order to evaluate and model potential future warming, as well as oceanic and atmospheric circulation feedbacks, it is imperative to have a more comprehensive understanding of natural climate variability, particularly over the Holocene.

The Holocene (last ~10,000 years) has previously been viewed as a period of extreme climatic stability (Dansgaard *et al.* 1993). This perception stems in large part from the study of Greenland ice cores that depict numerous comparatively large amplitude $\delta^{18}O$ variations (a proxy for temperature) preceding the Holocene over the past 250 ky (Dansgaard *et al*. 1993). However, more recent detailed analysis of Holocene ice core $\delta^{18}O$ values indicates significant, albeit lower amplitude, variation. Ice core analysis from both the Renland site in Greenland (Larsen *et al*. 1995) and the Peruvian Andes (Thompson *et al*. 1995) reveal a broad warming trend from ≈9 ka to ≈4 ka (the Holocene Hypsithermal) followed by gradual global cooling over the past 4 ky. In addition, instrumental and tree ring records indicate climatic changes during the past 1,000 years, such as the Little Ice Age and Medieval Warm Period (*e.g.* Mann *et al*. 1995; Keigwin, 1996). A more complete understanding of the climate changes of the Holocene is of particular importance today as we strive to assess the potential impact of anthropogenic forcing by the introduction of greenhouse gases.

In a study of New York lakes, a high-resolution examination of the $\delta^{18}O_{(H_2O)}$ values were determined to be controlled by winter precipitation (Kirby *et al.* 2001; Kirby *et al.* 2002a&b; Patterson et. al., 2003). A strong relationship between $\delta^{18}O_{(CaCO_3)}$ values and the position of the circumpolar vortex allowed for development of a transfer function that in turn permits calculation of the relative position of the circumpolar vortex through the Holocene. Variability in the position of the circumpolar vortex over western Ireland can be used to develop circulation models over much larger areas.

Our interpretation of $\delta^{18}O_{(CaCO_3)}$ and $\delta^{13}C_{(CaCO_3)}$ values will involve evaluation of all possible mechanisms for variation in isotope values. By combining the atmospheric circulation information derived from $\delta^{18}O_{(CaCO_3)}$ values with season-specific precipitation amounts derived from $\delta^{13}C_{(CaCO_3)}$ values we can generate a more realistic and complete record of climate variability over the northern Atlantic region through the Holocene.

Our previous research in North America and our current work in Ireland suggests that $\delta^{18}O$ and $\delta^{13}C$ values of fine-grained calcite in Irish lakes can be a sensitive indicator of past surface water chemistry, temperature, and productivity/humidity. Following up on research in the eastern United States, we are establishing similar relationships between stable isotope values of marl from Ireland and the position of the circumpolar vortex. By linking the long-term circumpolar vortex records between North America and Western Europe, we will significantly increase the longitudinal extent of our current circumpolar vortex reconstructions, one of our primary goals in this proposed research. Because atmospheric circulation is linked to ocean circulation, our study may in turn provide evidence of variation in thermohaline circulation as well. In phase II of our project, we will subsample molluscs to develop for the first time a series of climate snapshots with weekly resolution during intervals of exceptional warmth and cold as well as during rapid excursions.

GEOLOGIC SETTING

The Carboniferous limestone of western Ireland (Figure 1) contains a large number of lakes that produce sediment consisting of up to 60-95 wt % $CaCO_3$ (Coxon, 1987). In preliminary fieldwork by Co-PI Patterson, cores were recovered from several lakes with an abundance of bio-induced fine-grained calcite precipitate (marl) and numerous ostracods, gastropods, bivalves and oogonia (reproductive cysts of the aquatic macrophyte *Chara sp.*). The sediment also contains macroscopic terrestrial organic debris (wood, seeds, leaves, etc.) that provides material for radiocarbon dating without complications from reservoir effects.

Methods

Field Work and Sample Processing

Students worked in teams and alone to develop separate records for each lake sampled at Dr. Michael O'Connell's laboratory in the Palaeoenvironmental Research Unit, National University of Ireland, Galway. Keck Consortium scholars split, described, and photographed the cores under the supervision of the PIs. One half of each core was archived for later study, the other being subsampled for analysis. Field analysis in Ireland included total organic carbon (TOC) and total inorganic carbon (TIC) using standard loss-on-ignition (LOI) techniques. Samples were wet-sieved for terrestrial organic matter (wood, leaves, seeds) with selected samples being separated for later AMS radiocarbon analysis. Samples were also wet-sieved for skeletal remains that were identified using a binocular microscope. Absolute abundance of ostracods, gastropods, bivalves, and oogonia will be determined and normalized to 5g dry sediment weight. Selected core intervals were squeezed for pore water sampling with both alkalinity and pH being determined in the field.

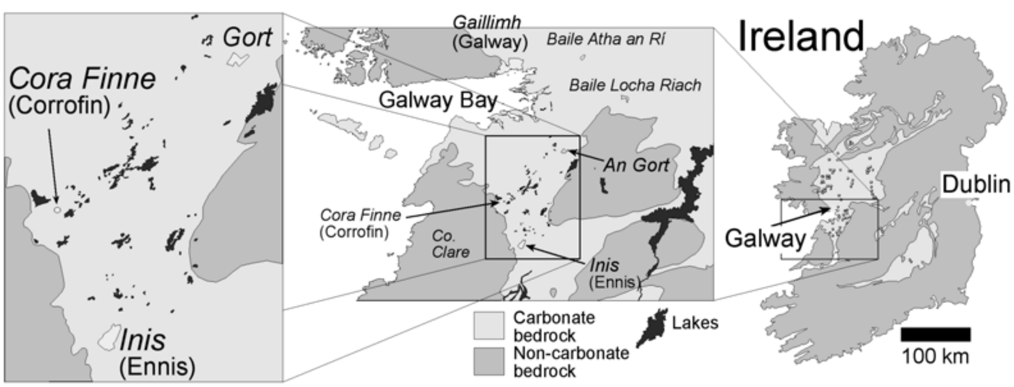

Figure 1: Map of Ireland showing the distribution of permanent lakes in central west Ireland. Most are concentrated on outcropping Carbonifereous Limestone shown as unshaded regions. Marl lakes are most common in the central western region of the island in counties Clare, Mayo and Galway. We will concentrate our sampling efforts in Co. Clare between Cora Finne, An Gort, and Inis. Galway will serve as our base of laboratory research. Map is based on the work of Coxon (1987), Rialtas na hÉireann, (1998) and Hallissy (1928).

Laboratory Analysis

Keck institutions determined sediment components, by magnetic susceptibility and elemental analysis (Roger Huang, Amherst College), trace metal analysis (Chris Garvin, Williams College) and grain size analysis (Adam Myers Pomona College). All stable isotope analyses (approximately 1,500) were conducted in the Saskatchewan Isotope Laboratory. These analyses were performed at the University of Saskatchewan, Saskatoon by Keck graduate student Aaron Diefendorf and Keck scholars (Justin Dodd, Jessica Conroy and Lindsey Able) working under the direction of Dr. Patterson. Isotope data was provided to Amalia Doebbert who cut and labeled her carbonate samples in the field.

SUMMARY

This study uses a range of chemical and isotopic records in order to test a series of hypotheses based on variation in flora and fauna observed in lacustrine sediment from western Ireland. Specifically, we are producing:

1) a continuous high-resolution (centennial, decadal, and seasonal) record of changes in atmospheric and hydrographic conditions associated with specific and documented events, such as the mid-Holocene peaks in warmth, the 8.2 cal ka and 10.3 ka cold events as well as the Younger and Older Dryas (e.g. Kirby *et al.* 2002; and Patterson *et al.* 2003),

2) a record of the changes in seasonality and in annual temperature variability for key intervals of the last 10,000 yrs in order to evaluate North Atlantic Oscillation (NAO)-like changes and NAO evolution during the Holocene, and

3) combined lacustrine isotope records from Ireland with our North American data to produce a record of variability in the circumpolar vortex (also known as the polar front jet stream) for the entire Atlantic region through the Holocene.

In addition, each of our Keck scholars have been working on senior thesis projects based on field work from last summer. In brief,

Lindsey Able characterized changes in ostracod assemblages at Smith College with Co-PI Tibert and determined stable isotope values of select samples in Co-PI Patterson's lab at the University of Saskatchewan

Jessica Conroy has characterized changes in molluscan assemblages at Wooster and micromilled select specimens that she analyzed in Co-PI Patterson's lab at the University of Saskatchewan

Amailia Doebbert prepared high-resolution carbonate samples from the Younger Dryas period of the core for isotope analyses in Co-PI Patterson's lab at the University of Saskatchewan

Justin Dodd prepared high-resolution samples from a lake push core that he analyzed in Co-PI Patterson's lab at the University of Saskatchewan

Christopher Garvin is conducting minor and trace elemental analyses of sediment samples from the LINC core at Williams College.

Roger Huang characterized the chemistry of surface and pore waters at Co-PI Martini's lab at Amherst College to calculate the effects of groundwater on the long-term isotopic record in these marl cores. Specifically, he is looking at whether there is significant mass transfer of calcium carbonate via dissolution/re-precipitation reactions to alter the isotopic signal.

Adam Myers is conducting grain-size analyses on the LINC core at Pomona College.

Alex MacPherson prepared peat samples for stable isotope analyses at Colorado College and in Co-PI Patterson's lab at the University of Saskatchewan.

Aaron Diefendorf is developing his MS thesis with Patterson at the University of Saskatchewan working up the stable isotope and other proxy data from the many cores sampled.

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