CLIMATE CHANGE IN WESTERN IRELAND DURING THE HOLOCENE AS INDICATED BY STABLE ISOTOPE RATIOS OF CARBON AND OXYGEN IN LACUSTRINE SEDIMENTS

JUSTIN DODD
Beloit College, Beloit, WI
Sponsor: Carl Mendelson, Beloit College

INTRODUCTION

Global climate change and the effect of increased amounts of "greenhouse" gases in the atmosphere have generated a great amount of scientific and public concern in recent years. Houghton et al. (1996) predict that over the next 50 years, global climate will warm as much as 4.5 °C in response to anthropogenic doubling of atmospheric CO_2. However, other studies indicate that the "natural" climate throughout the Holocene has been relatively unstable (O'Brien et al., 1995). Therefore, a more complete understanding of Holocene climate variability is necessary to accurately assess potential future climate change.

The purpose of this research was to develop a high-resolution record of climate change in western Ireland over the past 1000 to 2000 years, by using stable isotope ratios of carbon and oxygen in lacustrine sediment as proxies for climate change. This record can then be correlated with modern climatic data from meteorological stations to assess the sensitivity with which sediment responds to climate. Sediment data are also compared to variations in the circumpolar vortex (CPV) and North Atlantic Oscillation (NAO) indices, in order to develop greater understanding of the global forces and cycles that are responsible for Holocene climatic variability in western Ireland. This will, in turn, lead to a greater understanding of how and why climate change will occur in the future.

Background

Kirby et al. (2002) found a strong correlation between the winter position of the CPV and the $\delta^{18}O_{calcite}$ values of the lacustrine sediments in eastern North America. The CPV refers to the polar front jet stream which causes a westerly circulation in the northern and southern hemispheres. Like the CPV, the NAO exerts a strong influence on North Atlantic climate as standing low- and high-pressure cells shift position (similar to El Niño in the Pacific). According to Lamb (1995), the position of the CPV plays a significant role in weather patterns over northern Europe. Therefore, the climatological data recorded by sediment in western Ireland are strongly dependent on the phase of the NAO. Ireland and much of northwestern Europe also have well-documented historical and meteorological records that offer yet another means of correlation.

METHODS

Core Sampling

Sediment samples were collected from Lough Carra in western Ireland (Figure 1). This study focuses on two cores, LCAPC-03 (0.50 m) and LCA-01 (2.05 m), which display continuous marl sequences up to the present depositional surface of the lake.

Laboratory Analysis

The cores were sampled at 2-mm intervals in LCAPC-03 and at 2-cm intervals in LCA-01. In order to measure the $\delta^{13}C$ and $\delta^{18}O$ values of the sediments, samples were roasted *in*

vacuo at 200 ºC to remove all volatile organic matter

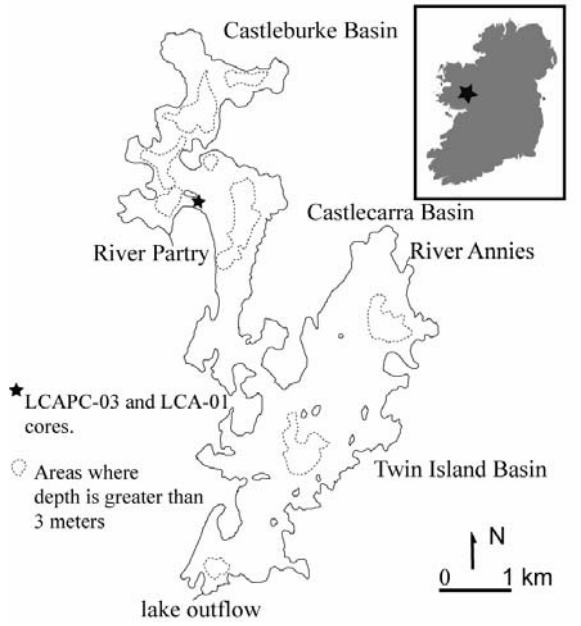

Figure 1. Lough Carra is a shallow, medium-sized marl lake in southwest county Mayo near the town of Partry. Lough Carra lies just to the northeast of the larger Lough Mask and Lough Corrib, and is underlain by Carboniferous limestone (adapted from King and Champ, 2000).

and water. The samples were then individually reacted in a Kiel-III carbonate preparation device directly attached to a Thermo Finnigan MAT 253 stable isotope ratio mass spectrometer in the University of Saskatchewan Isotope Laboratory, and values were corrected for acid fractionation and ^{17}O contribution. Isotopic data are reported relative to the Vienna Peedee belemnite (VPDB), and data are calibrated using NBS-18 and NBS-19 carbonate standards. Precision for both carbon and oxygen is better than ±0.1‰.

Cores were sampled for ^{137}Cs and ^{210}Pb to place age constraints on the sediment. Atmospheric ^{137}Cs is a by-product of the testing of nuclear weapons, and a "spike" in ^{137}Cs concentration can accurately locate 1963 (the peak year of aboveground testing) in the sediment column (e.g. Huang and O'Connell, 2000). ^{210}Pb chronology models, which make use of constant rate of supply and constant initial concentration, also place further age constraints on the core sediments (Appleby and Oldfield, 1978). Marl accumulation rates from other lakes in western Ireland provided general temporal constraints for the Lough Carra cores (Diefendorf, unpublished data; O'Connell et al., 1999).

RESULTS

Both LCAPC-03 (Figure 2a) and LCA-01 (Figure 2b) represent continuous marl records up to the present. In LCA-01, 108 samples were analyzed. Seventy-eight samples from LCAPC-03 were analyzed at a resolution of 2 to 3 mm. The carbon and oxygen isotopic values for the cores display significant variability, indicating that minimal sediment mixing has occurred.

Carbon isotope values are characterized by shifts of about 1‰ every 0.01 to 0.02 meters punctuated by larger excursions of greater than 1‰. In LCAPC-03, $\delta^{13}C_{calcite}$ values range from -2.9‰ to -0.0‰, with an average value of -0.9‰ for the core. In the longer LCA-01 core, $\delta^{13}C_{calcite}$ values range from -2.2‰ to 2.2‰ and have an average value of 0.2‰. In both cores, the $\delta^{13}C_{calcite}$ values become more negative from bottom to top, indicating that the sediments are becoming more enriched in ^{12}C in the more recent sediments. A prominent excursion of -2.9‰ occurs in $\delta^{13}C_{calcite}$ values at 0.114 meters in LCAPC-03. The sediment above this point yields a distinctive shift of about -1‰ in the average $\delta^{13}C_{calcite}$ values from -0.6‰ to -1.6‰.

The oxygen isotopes display trends similar to the $\delta^{13}C_{calcite}$. LCAPC-03 has an average $\delta^{18}O_{calcite}$ value of -3.8‰, with a range from -5.4‰ to -2.6‰. LCA-01 has an average $\delta^{18}O_{calcite}$ value of -3.9‰ and ranges from 4.8‰ to -2.7‰.

DISCUSSION

Stratigraphic age correlation was developed for lacustrine cores taken from four sites in western Ireland from loss on ignition analysis and accelerator mass spectrometry (AMS) radiocarbon dating (Diefendorf, unpublished data; O'Connell et al., 1999). From these

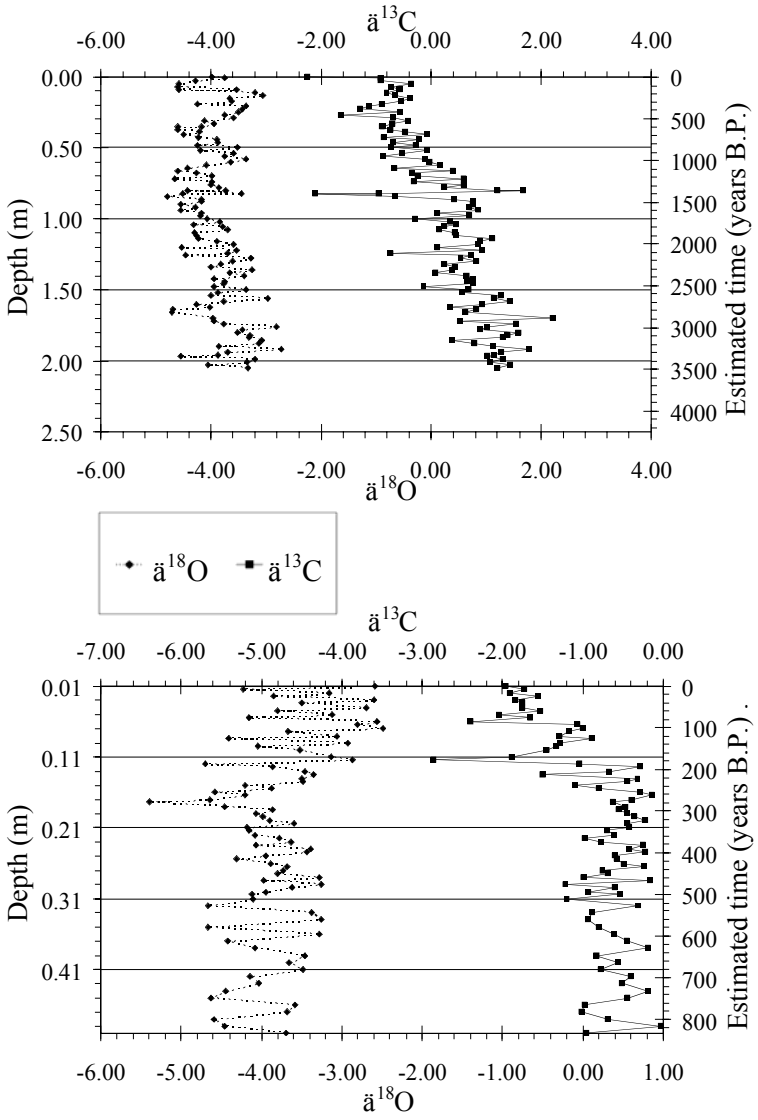

Figure 2a. Carbon and oxygen isotopic data LCAPC-03. Age estimates are based on an accumulation rate of 17.0 years per centimeter of marl. The Suess effect can be seen in $ä^{13}C_{calcite}$ in the upper portion of the core.

Figure 2b. Carbon and oxygen isotope values for LCA-01. $ä^{13}C_{calcite}$ values become more negative toward the top of the core, while $ä^{18}O_{calcite}$ values have a more consistent average with greater periodicity in excursions.

data, an age correlation of 16.0 to 17.5 years per centimeter of marl was obtained. Though the lake systems used in these analyses differ from the Lough Carra setting in size and geographic setting, an application of these accumulation rates to the Lough Carra samples presents some interesting possibilities.

Assuming an accumulation rate of 17 years per centimeter (0.59 cm/year) for the Lough Carra marl, some historical and climatological correlations can be made with the isotopic record represented in the cores. In the higher resolution LCAPC-03 core, there is a large, negative $\delta^{13}C_{calcite}$ excursion at about 177 years B.P., or 1825AD. O'Connell et al. (1999) describe a dramatic increase in intensive arable farming beginning in the early 1800s, which causes greater runoff and erosion. Large amounts of limestone were burned to produce lime, which was then used as fertilizer. The additional calcium load from the slaked lime could have increased the carbonate precipitation rate, while the soil disturbance supplied dissolved inorganic carbon with lower values to the lake basin. Another intriguing result is a corresponding negative excursion in $\delta^{18}O_{calcite}$ values at about 187 years B.P., which could also indicate increased vegetation removal and drainage associated with increases in population and arable farming. At 85 years B.P., or about 1917, a shift of -1‰ in $\delta^{13}C_{calcite}$ values begins. This is consistent with a negative shift in

$\delta^{13}C_{calcite}$ values between about 1900AD and the present called the Suess effect. This occurs as a result of increased atmospheric ^{12}C due to burning of fossil fuels, which are considerably enriched in ^{12}C (e.g. Andres et al., 2000). At about the same time, Ireland experienced significant expansion in arable farming, which meant more removal of trees and other vegetation, and therefore greater evaporation. The resulting increase in ^{18}O would cause a positive shift in $\delta^{18}O_{calcite}$ values as seen in the Lough Carra cores.

In both the carbon and the oxygen isotopic records there appears to be periodic excursions of about 1‰ throughout the core. Though there is obvious overprinting of multiple isotopic variables and climatic forces, this periodicity may reflect oscillations in the CPV as suggested by Kirby et al. (2002) for eastern North American lake sediments.

Meteorological data from the National Centers for Environmental Prediction and the National Center for Atmospheric Research (NCEP/ NCAR) Reanalysis Project also indicate a very strong correlation between the position of the CPV and weather conditions in western Ireland. An accurate correlation of climatic forces and the isotopic variability observed in the Lough Carra cores will be established by placing further age constraints on the sediments. This proved difficult, because the main form of organic material present in the cores was roots or stems that crosscut multiple sampling layers; there was insufficient *in situ* material to yield dates by AMS ^{14}C dating. Data from other radiometric methods that were sampled for, ^{137}Cs and ^{210}Pb, were not available at the time of this publication.

CONCLUSIONS

Isotopic variability in the Lough Carra cores is most likely a product of multiple climatic forcings that are complexly interwoven. NCEP/NCAR data indicate the CPV, and probably more significantly the NAO indices, are likely forces behind periodic 1‰ shifts in the $\delta^{13}C$ and $\delta^{18}O$ values observed in these cores. More accurate dating methods will allow correlations between climatic and isotopic data to be more rigorously constrained.

REFERENCES CITED

Andres, R.J., Marland, G., Boden, T., and Bischof, S., 2000, Carbon dioxide emissions from fossil fuel consumption and cement manufacture, 1751 -1991, and an estimate of their isotopic composition and latitudinal distribution, *in* Wigley, T.M.L., and Schimel, D.S., eds., The carbon cycle: Cambridge, Cambridge University Press, p. 53-62.

Appleby, P.G., and Oldfield, F., 1978, The calculation of ^{210}Pb dates assuming a constant rate of supply of unsupported ^{210}Pb to the sediments: Catena, v. 5, p. 1-8.

Houghton, J.T., Meira Filho, L.G., Callendar, B.A., Harris, N., Kattenbureg, A., and Maskell, K. eds., 1996, Climate Change 1995; the science of climate change. Contribution of Working Group 1 to the second assessment report of the Intergovernmental Panel on Climate Change: Cambridge, Cambridge University Press, 572 p.

Huang, C.C., and O'Connell, M., 2000, Recent land-use and soil-erosion history within a small catchment in Connemara, western Ireland: evidence from lake sediments and documentary sources: Catena, v. 41, p. 293-335.

King, J.J., and Champ, W. S. T., 2000, Baseline water quality investigations on Lough Carra, western Ireland, with reference to water chemistry, phytoplankton and aquatic plants: Proceedings of the Royal Irish Academy: Biology and Environment, v. 100B, no. 1, p. 13-25.

Kirby, M. E., Mullins, H. T., Patterson, W. P., and Burnett, A.W., 2002, Late glacial –Holocene atmospheric circulation and precipitation in the northeast United States inferred from modern calibrated stable oxygen and carbon isotopes: Geological Society of America Bulletin, v.114, p. 1326 -1340.

Lamb, H.H., 1995, Climate, history, and the modern world (2d ed.): New York, Routledge, 433 p.

O'Brien, S.R, Mayweski, P.A., Meeker, L.D., Meese, D. A., Twikler, T.S., and Whitlow, S. I., 1995, Complexity of Holocene climate as reconstructed from Greenland ice cores: Science, v. 270, p. 1962-1964.

O'Connell, M., Huang C.C., and Eicher, U., 1999, Multidisciplinary investigations, including stable-isotope studies, of thick Late-glacial sediments from Tory Hill, Co. Limerick, western Ireland: Palaeogeography, Palaeolimatology, Palaeoecology, v. 147, p. 169-208.