CHANGES IN PRECIPITATION OVER HOLOCENE WESTERN IRELAND: EVIDENCE FROM CARBON ISOTOPE ANALYSIS OF PEAT

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INTRODUCTION

The idea that climate variability is caused by Milankovitch cycle forcings on the order of 20-100 kyr is now widely accepted. However, causes of climate changes on shorter time scales are still debatable. Understanding the nature and causes of short-term climate variability is important as we try to predict the future climate. In order to discover these causes, many records of climate variability over the Holocene have been produced (e.g. Bianchi and McCave, 1999; McDermott et al. 2001). These records all show short-term climate fluctuations, however, the timing and magnitude of these fluctuations vary. Even so, there seems to be some consensus that short-term climate fluctuations occur at a ~ 1500 (± 500) yr frequency (e.g. McDermott et al., 2001). The purpose of this study is to reconstruct short-term precipitation variations (centennial to millennial) in western Ireland during the Holocene.

This reconstruction is made by the analysis of carbon isotopes in moss from a peat-bog core. For mosses, variations in $\delta^{13}C$ are due to changes in the amount of moisture on the plants and the concentration and $\delta^{13}C$ of CO_2 in the atmosphere (Ménot and Burns, 2001). Of these variables, moisture affects the $\delta^{13}C$ of moss the most; thus it has been possible to create a 9500 yr record of moisture changes for western Ireland over the Holocene.

Methods

This study examines Corrib Core 2A collected from a peat bog on the southeastern bank of Lough Corrib, north of Galway City, County Galway. Corrib core 2A is a 7 m long core that was extracted using a Livingstone corer during July 2002.

The peat at the top of this core was sub-sampled at 5 cm increments. The samples were freeze-dried and, with the use of a binocular microscope, moss of the genus Sphagnum was collected. These moss samples (~ 1mg) were then combusted in an elemental analyzer and the resulting CO_2 was analyzed with a VG SIRA 10 mass spectrometer. The resulting carbon isotope ratios are reported as $\delta^{13}C$ values which are defined as

$$\delta^{13}C = \left(\frac{{}^{13}C/{}^{12}C_{sample}}{{}^{13}C/{}^{12}C_{standard}} - 1 \right) 1000$$

where the standard is Vienna Pee-Dee Belemnite (VPDB).

Two AMS radiocarbon ages were calculated for this study, one at a depth of 80 cm and the other at 160 cm, beneath the core surface. These AMS dates were obtained by: Beta Analytic Inc (Miami, Fl.). O'Connell et al. (1999) report a 580 yr BP age for the southeastern bank of the Lough Corrib region, including the core site in this study. This age, being older than the present, is due to the anthropogenic cutting of the peat that had accumulated there after 580 yrs BP.

RESULTS

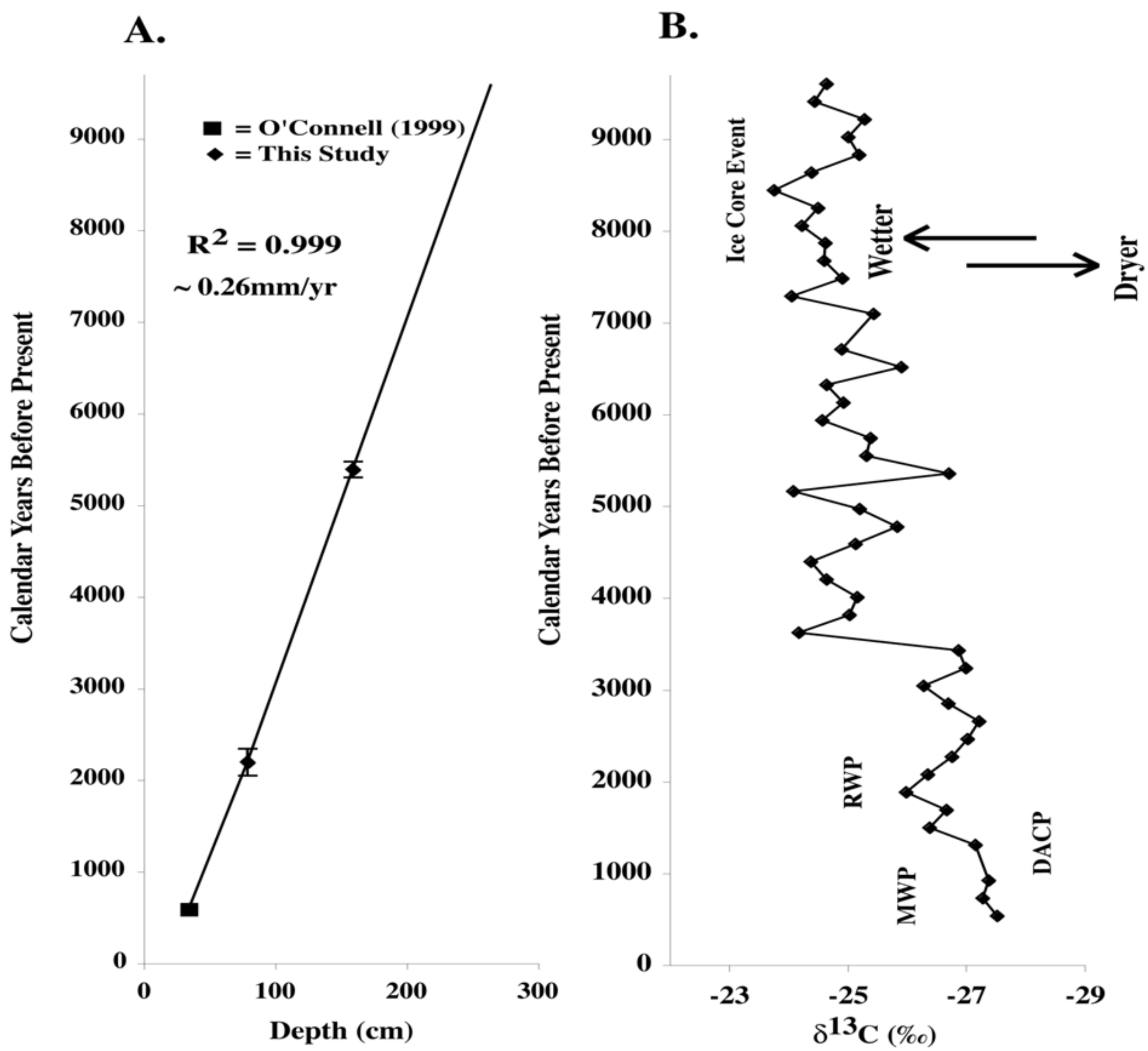

Figure 1. A: Age model showing a relatively constant accumulation rate of ~0.26mm/yr. The surface has been dated to be 580 years BP by O'Connell et al. (1999); the other two data points are radiocarbon dates from this study. B: Carbon isotope values for the core relative to VPDB. RWP= Roman Warm Period; DACP= Dark Ages Cold Period; MWP= Medieval Warm Period (Bianchi and McCave, 1999). Ice Core Event= cooling event recorded in both GISP2 and GRIP ice cores (McDermott et al., 2001).

The radiocarbon dates are 2185 (± 135) yrs BP for the younger age and 5380 (± 80) yrs BP for the older age at a 2σ probability interval. These ages, and the surface dated by O'Connell et al. (1999), indicate that the accumulation rate of peat was relatively constant at ~ 0.26mm/yr (Figure 1A). From this accumulation rate, ages have been interpolated along the depth of the core. The $\delta^{13}C$ values of the sampled moss range from –27.5‰ to –23.8‰ with a mean of –25.7‰ (Figure 1B). More generally, the trend of the data indicates decreasing $\delta^{13}C$ values from the lowest (oldest) part of the core to the present with a pronounced shift at ~ 3500 yrs BP to more negative values.

DISCUSSION

The $\delta^{13}C$ values of moss in this study are potentially affected by many variables as carbon is incorporated into the plant during photosynthesis. Therefore, in order to interpret the data correctly, it is necessary to discuss the physiology and chemical properties of Sphagnum moss.

The physiology of moss has been studied extensively (e.g. Rice and Giles, 1996). Unlike vascular plants, moss plants do not possess stomata or an epidermis with an impermeable cuticle and therefore are unable to regulate the uptake of atmospheric CO_2. In moss, CO_2 diffuses passively from the atmosphere through the cell walls and into the chloroplast, where photosynthesis occurs. However, when a water film coats a moss plant the CO_2 must first diffuse through it in order to get to the chloroplast. Given that the diffusivity of CO_2 is four orders of magnitude slower in water than in air, water films present a barrier for CO_2, in turn effecting the fractionation of carbon coming into the plant (Rice and Giles, 1996). Thus, moisture in the air that manifests itself as a water film on the plant greatly influences the $\delta^{13}C$ of the moss.

The degree to which water films on moss plants affect observed $\delta^{13}C$ has been investigated in the laboratory (Rice and Giles, 1996). It has been observed that, with no water film, diffusion of CO_2 into the plant discriminates against ^{13}C (Δ = 2.9‰; Rice and Giles, 1996). This is because ^{12}C is lighter and thus diffuses faster than ^{13}C. Water films enhance this effect because, when a water film is present, the CO_2 must diffuse through it. This process also results in a slight discrimination against ^{13}C (Δ = 0.7‰; Farquhar et al., 1989). However, more important than the extent to which diffusional processes fractionate carbon isotopes is the fact that these processes limit the total amount of CO_2 that reaches the chloroplast. This, in effect, forces the photosynthetic enzyme, Rubisco, to be less discriminating and use more ^{13}C than it otherwise would (Δ = 30‰ with an infinite pool of CO_2, Rice and Giles, 1996). The overall effect of these processes is that low $\delta^{13}C$ values correspond to dryer conditions and higher $\delta^{13}C$ values correspond to wetter conditions.

In addition to atmospheric moisture conditions, the concentration and $\delta^{13}C$ of CO_2 in the atmosphere can affect the $\delta^{13}C$ recorded in plants. Lab based investigations indicate that increased CO_2 concentrations results in lower $\delta^{13}C$ values (Ménot and Burns, 2001 and references therein). In order to quantify the magnitude of this effect, Ménot and Burns (2001) investigated $\delta^{13}C$ variations in moss plants as a function of varying CO_2 concentrations, along an altitudinal transect. Their results suggest that $\delta^{13}C$ increased by 0.9 - 1.1‰ per km of elevation gained. This translates to a $\delta^{13}C$ decrease of ~ 1‰ per 36.5ppmv increase in atmospheric CO_2.

Atmospheric CO_2 concentrations have fluctuated throughout the Holocene from a low of ~ 260ppmv at 8200 yrs BP to a pre-industrial high of ~ 285ppmv (Indermühle et al., 1999). With this information, this study has quantified the change in $\delta^{13}C$ that is expected, theoretically, in Sphagnum plants that have been subject to Holocene atmospheric CO_2 conditions. The result of this is that a 0.68‰ increase in $\delta^{13}C$ should be observed in the $\delta^{13}C$ values from 8200 yrs BP to present. It is worth noting that this should theoretically account for < 15% of the observed variation in the $\delta^{13}C$ reported here.

Indermühle et al. (1999) has also observed that the $\delta^{13}C$ of CO_2 in the atmosphere has fluctuated over the time period in question. This will also affect the $\delta^{13}C$ recorded in the moss. However, this effect is small because the $\delta^{13}C$ of atmospheric CO_2 has varied minimally (± 0.3‰; Indermühle et al. 1999) over the Holocene and therefore accounts for less than 6% of the overall variation observed in Figure 1B.

Given the minimal influence of the concentration and $\delta^{13}C$ of atmospheric CO_2 on the $\delta^{13}C$ of moss. Variability in the $\delta^{13}C$ of the moss in this study must be influenced most heavily by the amount of water on the plants. Which, in turn, is related to the amount of precipitation at the time. Interpreting the data in this manner indicates a general drying trend from ~ 9500 yrs BP to the present punctuated by a rapid drying event at ~ 3200 yrs BP.

Several generally accepted intervals of climatic variability have occurred within the last 2000 years. These are the Medieval Warm Period (~ 750-1050 yrs BP), Dark Ages Cold Period (~ 950-1450 yrs BP), and Roman Warm Period (~ 2000 yrs BP) (Bianchi and McCave, 1999). The isotope data presented in this study does relate with these episodes

(Figure 1B). According to this relation, the warm episodes relate to wetter weather resulting in less negative $\delta^{13}C$ values in the moss. Likewise, cold periods correlate with dryer episodes, which result in more negative $\delta^{13}C$ values. It is also interesting to note that the largest $\delta^{13}C$ values in this study occur at ~ 8400 yrs BP (Figure 1B). This coincides with the only major Holocene event recorded by both the GRIP and GISP2 ice cores (McDermott et al., 2001). The event has been interpreted as recording cooler temperatures in the northern hemisphere. This study proposes that, in western Ireland, this event increased precipitation. Drawing additional correlations with existing palaeoclimate work is difficult due to a lack of consensus about the timing and magnitude of Holocene climate events.

Several concerns regarding the use of moss $\delta^{13}C$ to infer past climate conditions have been raised (Price et al., 1997; Rice and Giles 1996; Williams and Flanagan, 1996). First, different species of Sphagnum differ in the ease in which CO_2 can diffuse into them. This is attributed to differing leaf morphologies in which photosynthetic cells are surrounded by larger hyaline cells (Rice and Giles, 1996). The density of the clustering of the surrounding hyaline cells dictates the ease to which CO_2 can diffuse through and into the photosynthetic cells. Thus, different species of Sphagnum will give different $\delta^{13}C$ values even when exposed to the same environmental conditions. Another concern is that Sphagnum plants might be much more sensitive to their microhabitat (on hummocks or hollows) in the bog and would record this positioning instead of the regional precipitation regime.

Another potential source of error in this study comes from difficulty distinguishing moss from the other organic matter in the core. This is further complicated by the fact that the core site is near the bank of a large lake, making the ecological situation more of a wetland swamp than a bog where Sphagnum is less abundant (Mooney and O'Connell, 1990).

CONCLUSIONS

A 9500-year record of changes in precipitation has been observed for western Ireland. This record indicates a general drying trend over the sample interval and also correlates to known climatic episodes from the last 2000 years (Medieval Warm Period, Dark Ages Cold Period, and Roman Warm Period) and the only climatic event recorded by both Greenland ice cores. However, these results show no evidence of a pervasive periodicity in short-term Holocene climate fluctuations as has been previously suggested (e.g. McDermott et al., 2001).

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