Declining moisture availability on the Antarctic Peninsula during the Late Eocene

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Abstract
Paleobotanical data have indicated that the Antarctic landscape shifted from a beech (Nothofagus)-dominated forest to a more sparsely vegetated taiga-like woodland and tundra during the Late Eocene, coincident with progressive cooling and glacial growth. Reduced moisture availability may have contributed to this vegetation change, but there is limited evidence for assessing the Late Eocene hydrologic regime. We evaluated the relationship between Nothofagus δ13C and moisture availability by determining δ13C of modern Nothofagus pollen, sporopollenin, and leaves and comparing these results to precipitation data. To assess plant moisture availability and vegetation composition just prior to the Eocene–Oligocene boundary, we measured δ13C of fossil Nothofagus sporopollenin (Nothofagidites) from the SHALDRIL 3C cores (which date to ~35.9 My) and evaluated these results in the context of temporal variation in pollen assemblages from the same sediments. Values of carbon isotope discrimination (Δ) for modern Nothofagus sporopollenin range between 18.1 and 22.4‰. These values are positively correlated with precipitation amount, as well as pollen and leaf Δ, which suggests that fossil sporopollenin Δ records the level of plant moisture availability. Δ values obtained from Nothofagidites sporopollenin from the SHALDRIL 3C sediments range between 17.9 and 20.2‰, and generally decline through time. These results suggest a decrease in plant moisture availability on the Antarctic Peninsula during the Late Eocene, perhaps as a result of declining precipitation and/or soil moisture. Therefore, moisture stress experienced by Nothofagus likely contributed to the shift to a more sparsely vegetated Late Eocene landscape. Our results show that carbon isotopic analysis of pollen from C3 plants may aid understanding how variations in moisture availability contribute to shifts in plant community composition in the paleorecord.

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1. Introduction
During the Early and Middle Eocene, Antarctica was relatively warm, with mild, frost-free winters and moisture availability (> 1000 mm/yr) sufficient to support tropical and temperate rainforests (e.g. Poole et al., 2005; Francis et al., 2008; Pross et al., 2012). Starting ~2 My before the onset of continental-scale glaciation at the Eocene/Oligocene (E/O) boundary (~33.7 My; Peters et al., 2010; Dallai and Burgess, 2011), glaciers began to wax and wane, and the landscape underwent a shift from a lush, Nothofagus-dominated woodland to a more sparsely vegetated taiga-like woodland and tundra (e.g. Askin, 2000; Anderson et al., 2011; Warny and Askin, 2011). These large-scale changes in vegetation composition, along with a low diversity and high abundance of dinoflagellate cysts in nearshore marine sediments, suggest decreased temperatures during the Late Eocene (Warny and Askin, 2011). Shifts in moisture availability may have also influenced these vegetation changes, as modern studies document significant Nothofagus mortality during periods of drought (Hosking and Kershaw, 1985; Hosking and Hutcheson, 1988; Suarez et al., 2004). However, although the nature of temperature change and extent of glaciation are reasonably well constrained for the Late Eocene in Antarctica (e.g. Zachos et al., 2001, 2008; Pagani et al., 2011; Pearson et al., 2009;Kirshner and Anderson, 2011), there remains uncertainty with regard to the influence of hydrologic variation on Late Eocene vegetation changes.
There are contrasting estimates of the Antarctic hydrologic regime during the Eocene. For East Antarctica, inferences from paleobotanical data (MacPhail and Truswell, 2004) and bulk major element geochemistry (Passchier et al., in press) suggest annual rainfall during the Late Eocene of 1200–2500 mm/yr and 1000–1250 mm/yr, respectively. Similarly, Francis et al. (2008) estimate that mean annual precipitation (MAP) on Seymour Island (Antarctic Peninsula) was around 1534 mm/yr. In contrast, climate models for the land area of Antarctica suggest that conditions were drier, with MAP of ~500 mm/yr before the E/O boundary (Thorn and DeConto, 2006). This discrepancy may be the result of maritime locations in Antarctica (e.g. the Antarctic Peninsula, Prydz Bay, and Seymour Island) having generally wetter conditions than the interior of the continent and/or the uncertainty associated with using the nearest living relative approach to estimate climate parameters (e.g. Wolfe, 1995) in the Paleogene. Regardless, a better understanding
of the relationships among temperature, moisture, and plant communities is important for constraining the impact of climate on shifts in plant community composition during the Late Eocene in Antarctica. Pollen from C$_3$ plants is relatively well preserved and abundant in Antarctic sediment cores, and stable carbon isotope analysis of the pollen provides a unique approach for reconstructing past hydrologic variability (e.g. Loader and Hemming, 2001, 2004; Jahren, 2004; Descalos-Gros and Schönzel, 2007; Nelson, 2012). The basis of this approach is that carbon isotope discrimination ($\Delta$) during photosynthesis is influenced by the ratio of intercellular to atmospheric CO$_2$ (C$i$/C$_a$), which is controlled by the proportion of net photosynthetic assimilation and stomatal conductance (Farquhar et al., 1982, 1989). In leaves of C$_3$ plants, $\Delta$ often declines with decreased water availability (e.g. Ehleringer and Cooper, 1988; Dawson et al., 2002; Kohn, 2010), and a similar relationship appears to occur in pollen of C$_3$ plants. For example, Nelson (2012) analyzed $\delta^{13}$C of small quantities (10–30 grains) of pollen and sporopollenin from herbarium specimens of the C$_3$ plants Ambrosia and Artemisia and found strong relationships between values of $\Delta$ and historic records of moisture availability.

We conducted $\delta^{13}$C analysis on modern Nothofagus pollen, sporopollenin, and leaves, as well as fossil Nothofagus sporopollenin (Nothofagidites) from the Late Eocene SHALDRIL 3C sediment cores. Our objectives were to (1) assess the relationship between $\Delta$ values of modern species of Nothofagus and water availability; (2) infer shifts in plant water availability during the Late Eocene on the Antarctic Peninsula; and (3) decipher how variations in plant community composition were influenced by changes in water availability.

2. Materials and methods

2.1. Modern samples

Nothofagus (the genus of Southern beech) is extant in the Southern Hemisphere. Leaves and pollen were obtained from ten herbarium specimens of Nothofagus that were collected from locations within or near the range of MAP thought to have occurred during the Late Eocene in Antarctica (~500–2500 mm/yr) near the Antarctic Peninsula (Table S1). The specimens came from the Harvard University Herbarium and the Herbarium at the Museum of New Zealand (Table S1). The specimens represent eight different species of each of the four subgenera of Nothofagus (Hill and Read, 1991). All species analyzed are monoeccious and flower in the Austral spring, with the exception of N. discoides, which flowers in the New Caledonian wet season from January to April (van Steenis, 1971; Donoso, 1974; Ogden et al., 1996). Years of collection span the period 1911–1984 (Table S1).

2.2. SHALDRIL samples

The sediment samples came from the SHALDRIL NBP-06-02A 3C cores obtained in 2006 from the James Ross Basin in the Weddell Sea near the Antarctic Peninsula. Diatom and dinoflagellate biostratigraphy indicate an age between 37 and 33.7 My for the cores (Bohaty et al., 2011). This range is confirmed by a more precise age estimate of 35.9 ± 1.1 My from a single strontium date (Bohaty et al., 2011). Seismic stratigraphy of the site indicates that the cores represent a short period of time, likely no more than 200 kyr based on typical accumulation rates for these types of sediments (J.B. Anderson, per. comm.). The cores thus represent a ≤200 kyr period that occurred approximately 1.1–3.3 My before the E/O boundary (Bohaty et al., 2011). Although dating uncertainties prevent precise correlation with records of atmospheric CO$_2$ concentrations (e.g. Pagani et al., 2011) and marine $\delta^{18}$O (e.g. Zachos et al., 2008), CO$_2$ concentrations ranged from 600 to 980 ppm (Zachos et al., 2008) and $\delta^{18}$O generally increased (e.g. Zachos et al., 2008) within the 1.1–3.3 My period before the E/O boundary (Fig. 3).

Ten samples from the SHALDRIL 3C cores were used in the present study; the samples are numbered 1 to 10 from youngest to oldest (Table S2). A previous study on the same SHALDRIL 3C cores (Warny and Askin, 2011) indicates that the palynomorphs in samples 3–10 are thought to be in situ. Some reworking likely occurred in the shallower sections of the cores (samples 1–2), which is addressed in further detail in the discussion. We observed a few Nothofagidites palynomorphs that showed obvious signs of reworking (e.g. fragmentation and/or discoloration), these grains were avoided when selecting grains for isotopic analysis.

2.3. Pollen isolation and isotopic analysis

$\delta^{13}$C analysis was performed on untreated pollen from each herbarium specimen and the remaining pollen (if available) was treated to isolate the chemically resistant sporopollenin exine. Treatment of the pollen from the herbarium specimens followed standard pollen preparation techniques modified to exclude carbon-containing chemicals (Nelson et al., 2006, 2007, 2008), but without treatment with HF or HCl since they have been shown to have little influence on pollen $\delta^{13}$C (Jahren, 2004) and because the pollen was not being extracted from sediments. Pollen from ten sediment samples (10–20 g) spaced throughout the SHALDRIL 3C cores was extracted in the same manner, except that HF and HCl were used.

For comparison with pollen and sporopollenin $\delta^{13}$C data from the herbarium specimens, leaves from each specimen were also analyzed for $\delta^{13}$C. Approximately 0.5 g of leaf material from each specimen was homogenized and placed in a tin capsule. Each capsule was combusted in a Carlo Erba NC2500 elemental analyzer and the evolved CO$_2$ sent to a Thermo Delta V+ isotope ratio mass spectrometer. The analytical precision for leaf $\delta^{13}$C measurements was 0.12‰.

Isolation and $\delta^{13}$C analysis of pollen followed Nelson (2012), as summarized below. All pollen grains were isolated using a micromanipulator and rinsed in nano-pure water at 200× magnification on a microscope slide. The grains were then transferred to a 0.5 μl drop of nano-pure water. Each drop was applied to a spooling-wire microcombustion device interfaced with a Delta V+ isotope ratio mass spectrometer (SWiM-IRMS; moving wire; Sessions et al., 2005; Eek et al., 2007). Blanks (nano-pure water to which pollen grains were added and then removed) were analyzed concomitantly with each sample. A threshold of 0.8 nmol of carbon was set so that the accuracy and precision of the obtained pollen $\delta^{13}$C data were no worse than ±1‰. The use of, on average, 13 grains of untreated modern Nothofagus pollen (range: 10–30 grains), 21 grains of modern Nothofagus sporopollenin (range: 15–30 grains), and 49 grains of Eocene Nothofagidites sporopollenin (range: 40–75 grains) in each analysis produced yields sufficient to exceed this threshold; samples below this threshold were excluded from data analysis. Larger numbers of grains of Eocene than modern sporopollenin were needed to produce sufficient yields because the Eocene grains were of smaller size than the modern grains (on average 25 vs. 33 μm in diameter, respectively). Sample data were normalized to VPDB (Vienna Pee Dee Belemnite) using a two-point normalization curve with in-house standards calibrated to USGS40 and USGS41.

2.4. Data processing and analysis

To correct our $\delta^{13}$C data for variation in $\delta^{13}$CCO$_2$ within the modern record and between the modern record and the Eocene, all obtained $\delta^{13}$C values were converted to values of carbon isotope discrimination ($\Delta$), using the equation:

$$\Delta(\%) = \left(\delta_i - \delta_p\right) / \left(1 + \delta_p\right)$$

where $\delta_i$ is the approximate $\delta^{13}$C of atmospheric CO$_2$ ($\delta^{13}$CCO$_2$) at the time the plant was growing and $\delta_p$ is the $\delta^{13}$C value of the sample
(Farquhar et al., 1989; Read and Farquhar, 1991). $\delta^{13}\text{CO}_2$ values associated with each herbarium specimen were determined using plant collection dates and ice-core records of $\delta^{13}\text{C}$ (Francey et al., 1999), with the exception of two specimens for which there was no collection date (Table S1). For these two specimens, the average $\delta^{13}\text{CO}_2$ from the collection years of all herbarium samples (1911–1984) was used. $\delta^{13}\text{C}$, of $-6.1\%$ was used for calculation of $\Delta$ for the Late Eocene samples (Tipple et al., 2010).

To assess the relationship between moisture availability and *Nothofagus* $\Delta$, we compared $\Delta$ from modern specimens with precipitation records. Monthly precipitation data were obtained from the BIOCLIM database (Hijmans et al., 2005) for the location and year represented by each herbarium specimen. MAP and growing season precipitation (defined here as the austral spring, October–November) were calculated for each specimen. The range of total MAP represented by the specimens was 174 to 1721 mm/yr. Relationships among pollen, sporopollenin, and leaves were assessed using reduced major-axis regression (Smith, 2009). Relationships among precipitation and pollen, sporopollenin and leaf $\Delta$ values, respectively, were assessed using ordinary least squares regression (Smith, 2009). Regressions were performed using the PAST software package (Hammer et al., 2001).

### 3. Results and discussion

#### 3.1. Validation of carbon isotope discrimination of *Nothofagus* pollen as an indicator of water availability

A total of 81 $\delta^{13}\text{C}$ measurements were made of modern *Nothofagus* pollen and sporopollenin from the ten herbaria specimens. $\delta^{13}\text{C}$ values range from $–28.0$ to $–23.1\%$ for untreated pollen, $–30.6$ to $–24.6\%$ for sporopollenin, and $–28.6$ to $–23.7\%$ for leaves. The average $\delta^{13}\text{C}$ values of sporopollenin are lower than those of untreated pollen (Table S1). The average difference between $\delta^{13}\text{C}$ values of sporopollenin and untreated pollen is $1.7\%$ (range: $0.9$ to $3.6\%$), which is similar to the value of $1.5\%$ reported for *Ambrosia* and *Artemisia* (Nelson, 2012). There is a positive correlation between $\Delta$ of untreated pollen and sporopollenin ($r^2 = 0.64$, $p < 0.03$, $n = 7$; Fig. 1a) and thus we refer primarily to sporopollenin in the discussion. Leaf $\Delta$ values are positively correlated with those of sporopollenin ($r^2 = 0.63$, $p < 0.04$, $n = 7$; Fig. 1b) and untreated pollen ($r^2 = 0.54$, $p < 0.02$, $n = 10$; Fig. 1c). Pollen, sporopollenin, and leaf $\Delta$ each exhibit significant positive correlations with MAP and growing season precipitation (Fig. 2).

Our results from *Nothofagus* herbaria specimens are consistent with those of Nelson (2012) who found a significant relationship between sporopollenin $\Delta$ and moisture for the C₃ herbaceous taxa *Ambrosia* and *Artemisia*. Together, these results provide confidence for using $\Delta$ of sporopollenin as an indicator of community-level moisture availability in the paleorecord. King et al. (2012) found that inter-flower variation in $\delta^{13}\text{C}$ of pollen from individual *Hibiscus* plants ranged from 0.4 to 3.2\% (average of 1.6\%), and they suggested that this variation may hinder the use of pollen $\delta^{13}\text{C}$ data for paleoenvironmental reconstruction. However, our results suggest that such variation does not impede *Nothofagus* $\Delta$ from indicating moisture availability, as the observed relationships between sporopollenin $\Delta$ and precipitation are

![Fig. 1. Reduced major axis regression relationships among mean $\Delta$ (with 1σ error bars, which represent the standard deviation of multiple analyzes of individual samples) of untreated pollen, sporopollenin, and leaves of modern *Nothofagus* species. The dashed lines indicate 1:1 relationships. The solid lines represent linear regressions through the data.](image-url)
significant (Fig. 2). Furthermore, fossil pollen assemblages integrate pollen from multiple flowers and plants, which would likely minimize intra-plant variation in sporopollenin Δ in the paleorecord.

3.2. Late Eocene water availability inferred from carbon isotope discrimination of sporopollenin

Values of Δ for Nothofagidites sporopollenin (Table S2) exhibit a range of 17.9–20.2‰ and an overall decreasing trend (Fig. 3). There is a decline in Δ of 1.0‰ between samples 10 and 9. Values of Δ show small (<0.3‰) variations around a mean of 19.2‰ between samples 9 and 5 and further decline by 1.4‰ between samples 5 and 3. They then vary around a mean of 18.0‰ above sample 3. The most significant decline in Δ occurred between samples 5 and 3.

We consider several potential explanations, besides changes in moisture availability, for the declining trend in Δ of Nothofagidites sporopollenin in the SHALDRIL 3C cores. Variation in diagenetic alteration of sporopollenin is unlikely for several reasons. First, there was lack of
evidence of diagenetic alteration of sporopollenin $\delta^{13}C$ in a previous surface-sediment calibration study (Nelson et al., 2008). Second, sporopollenin is highly resistant to degradation (van Bergen et al., 1993). Finally, the Nothofagidites sporopollenin that we analyzed showed no signs of strong diagenetic alteration (Warny and Askin, 2011).

Varying pCO$_2$ during the Late Eocene (Fig. 3) may have altered plant C$_4$/C$_3$ and thus plant $\delta^{13}C$ of C$_4$ plants (e.g. Arens et al., 2000), a more recent study found that pCO$_2$ does affect plant fractionation of carbon isotopes and that this effect is most pronounced at low pCO$_2$ (Schubert and Jahren, 2012). We corrected our data for pCO$_2$ using equation 5 in Schubert and Jahren (2012):

$$S = \left[\frac{(0.21)(28.26)^2}{28.26 + 0.21(pCO_2 + 25)}\right]^2$$

where S is the increase in $\Delta$ per unit increase in pCO$_2$. For this correction, we used Eocene pCO$_2$ values from Pagani et al. (2011) and modern pCO$_2$ values from Franck et al. (1999). These corrections had little effect on Eocene Nothofagidites $\Delta$ (average of $-0.3\%$ difference) or modern Nothofagus $\Delta$ (average difference of $<0.4\%$ for pollen and $<0.3\%$ for sporopollenin), and correcting our data for these differences did not significantly influence the relationships between MAP and pollen $\Delta$ values or MAP and sporopollenin $\Delta$ values (i.e. the $r^2$ values in Fig. 2 changed by $<0.05$ and p-values remained significant). Finally, average C$_4$/C$_3$ ratios calculated from modern Nothofagus and Eocene Nothofagidites sporopollenin $\Delta$ (using the equation $\Delta = a + (b - a)(C_4 / C_3)$, where $a = 4.4^\%$ and $b = 27^\%$, e.g. Farquhar et al., 1989; Ehleringer and Cerling, 1995) remain relatively stable (average modern Nothofagus C$_4$/C$_3 = -0.64$). Thus shifts in pCO$_2$ between the Eocene and historic period did not significantly change plant C$_4$/C$_3$, which supports the hypothesis that C$_4$/C$_3$ ratios remain relatively constant through time (e.g. Ehleringer and Cerling, 1995; Gerhart et al., 2011).

We note that the inclusion of older, reworked fossil Nothofagidites sporopollenin from the Cretaceous, Paleocene, and/or Early–Middle Eocene in our samples could have affected our results. Reworked material in the older sections of the SHALDRIL core discussed in this paper (samples 3–10) comprised, on average only 3% (and no more than 8%) of the overall total pollen abundance (Warny and Askin, 2011). Reworking is of greater concern in the younger sections of core (samples 1 and 2) where an average of 22% (and up to 35%) of the palynomorphs shows signs of reworking (Warny and Askin, 2011). However, reworked pollen grains are notably darker and more fragmented, and care was taken to avoid selecting these grains for isotopic analysis. Furthermore, inclusion of reworked grains in our youngest samples (1 and 2) would have likely skewed inferences of moisture based on $\Delta$ values toward wetter conditions, as previous studies suggest that the Cretaceous, Paleocene, and Early–Middle Eocene were generally wetter than the Late Eocene in Antarctica (e.g. Poole et al., 2005; Francis et al., 2008; Pross et al., 2012).

Our results indicate that decreased moisture availability during the Late Eocene on the Antarctic Peninsula was the primary driver of the shift toward lower values of $\Delta$ for Nothofagidites sporopollenin. This interpretation of hydrologic variation is independently supported by decreased smectite and kaolinite concentrations in the SHALDRIL 3C cores (Wellner et al., 2011), which suggest reduced chemical erosion, potentially as a result of reduced precipitation (e.g. Robert and Kennett, 1997). Other studies also indicate a major change in the Antarctic weathering regime near the E/O Boundary, from chemical weathering in a warm, humid climate to physical weathering under
cooler and drier conditions as a result of increased glaciation (Ehrmann and Mackensen, 1992).

There are several potential explanations for the observed trend toward decreased plant moisture availability during the Late Eocene in Antarctica. The first is a decrease in precipitation amount. Precipitation in Antarctica was generally greater during the Early than Middle Eocene (Pross et al., 2012), and the Miocene was generally drier than the Eocene (e.g. Warmy et al., 2009; Passchier et al., in press), except for short intervals of increased precipitation during the middle Miocene Climatic Optimum (Lewis et al., 2006; Warmy et al., 2009; Feakins et al., 2012). Thus, the decrease in moisture availability evidenced by our data may indicate the continuation of an overall trend of decreasing precipitation between the Early Eocene and Miocene. Another possible explanation is that a decline in soil water content decreased moisture availability independent of precipitation amount. For example, as glaciers became more established on the Antarctic Peninsula during the latest Eocene (Kirshner and Anderson, 2011; Warmy and Askin, 2011), production of meltwater may have decreased during the spring and summer months, thus reducing moisture available to plants. These changes in moisture availability could be caused by factors such as pCO2-driven continental runoff (e.g. Betts et al., 2007; Steinhorsdottir et al., 2012), shifts in atmospheric circulation patterns (Passchier et al., in press), or orbital forcing, but the age uncertainty of SHALDRIL 3C prevents detailed comparison of our Δ data with other records (e.g. of pCO2).

Regardless of their cause, the observed shifts in water availability are notable since the Antarctic Peninsula, with its more maritime conditions, would have presumably been wetter than the interior of the continent. Moreover, the Eocene Nothofagidites sporopollenin Δ values fall on the drier end of the global range of Δ values for C3 plants (e.g. Diefendorf et al., 2010; Kohn, 2010) and of Δ values from modern Nothofagus sporopollenin (Fig. 2). Thus, our results suggest that plants in Antarctica experienced generally dry conditions and a reduction in water availability leading up to the E/O boundary.

3.3. Influence of plant moisture stress on Late Eocene vegetation dynamics

The declines in moisture availability inferred from Nothofagus Δ values coincide with, or slightly precede, declines in the relative abundance of Nothofagidites pollen from the same sediments (Fig. 3). For example, between samples 10 and 5, Nothofagidites Δ values remain > 19.1‰ and the relative abundance of Nothofagidites pollen was relatively high (1249–1409 cbmsf, centimeters below sea floor; Warmy and Askin, 2011). A decrease in Nothofagidites Δ by ~1.4‰ between 1151 and 800 cbmsf (samples 5 and 3) suggests increased aridity before the decline in the relative abundance of Nothofagidites pollen at 388 cbmsf (Warmy and Askin, 2011). This offset may suggest that Nothofagus tolerated changes in water availability up to a point, beyond which conditions likely became too dry or were perhaps coupled with other factors (e.g. decreasing temperatures) that ultimately led to the significant decline in Nothofagus relative abundance from 76% at 763 cbmsf to 45% at 431 cbmsf (Fig. 3). The species of Nothofagus that survived in Antarctica during the Late Eocene (N. fusca group) are similar to extant New Zealand species of Nothofagus (e.g. N. fusca, N. truncata, N. solandri) that are cold tolerant (Sakai and Wardle, 1978; Sakai et al., 1981; Read and Brown, 1996) and can form stands on supraglacial debris and in-transit moraines (Veblen et al., 1989), which suggests that colder conditions were not the only driver of the shift to a more sparsely vegetated Late Eocene landscape. Aridity-induced mortality likely also contributed to decreased abundance of Nothofagus on the Antarctic Peninsula during the Late Eocene. The successive period of decreased moisture availability followed by changes in plant community composition suggests that changes in fossil plant Δ may provide forewarning of vegetation changes induced by changes in plant moisture availability in the paleorecord.

Our results complement recent studies that have provided insights into the relationships between temperature and moisture availability in Antarctica during the Cenozoic, including the effect of variation in water availability on vegetation change. For example, Pross et al. (2012) used palynology and organic geochemical approaches to infer that a transition to cooler and drier conditions during the Middle Eocene led to a shift from wet tropical, to drier temperature, rainforest taxa. Feakins et al. (2012) used leaf-wax δ13C data to show that short periods of increased summer temperatures and precipitation coincided with increased plant productivity during the Middle Miocene in the Ross Sea region. Our results, in conjunction with existing inferences of temperature and terrestrial vegetation composition from the SHALDRIL sediments (Warmy and Askin, 2011), suggest similar climate–vegetation relationships during the Late Eocene on the Antarctic Peninsula such that a shift from warmer/wetter to cooler/drier conditions led to a shift from Nothofagus-dominated forests to more sparsely vegetated woodland and tundra plant communities.

4. Conclusions

Recent advances in organic geochemistry provide new opportunities to infer paleohydrologic change in Antarctica (Feakins et al., 2012). Here, we used δ13C of sporopollenin to assess changes in the availability of moisture to Nothofagus on the Antarctic Peninsula during the Late Eocene. Our results suggest that declining moisture availability contributed to the shift from Nothofagus woodland to a more sparsely vegetated woodland and tundra on the Antarctic Peninsula around 35.9 ± 1.1 My. Elucidating such changes in moisture availability is fundamental for parameterizing and assessing the accuracy of climate models used to project effects of environmental change. Overall, our results illustrate how pollen δ13C and assemblage data can provide an improved understanding of the nature of past hydroclimatic changes and their impact on vegetation.

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