

SUPPLEMENTARY MATERIALS

S1. Age model

We developed an age model for core U1357B based on ^{87}C analyses on bulk organic carbon (Fig. S1). In the standard IODP CSF-A depth scale, recovery often exceeds 100% and to correct for this, the standard IODP procedure is to apply a linear compression algorithm which is based on the assumption that expansion is uniform in the core. However, in U1357B, expansion due to biogenic gas was particularly high and resulted in discrete sections of core being pushed apart creating voids in the depth scale that did not represent real gaps in the stratigraphy. To account for this, the voids are numerically removed and depth scale adjusted prior to linear compression being applied (if recovery still exceeds 100%).

The model was calibrated with a reservoir age correction of 1200 ± 100 years and depth to age conversions achieved by using BACON. This is a Bayesian iteration scheme that invokes memory from dates above any given horizon, and produces a weighted mean and median age-depth curve

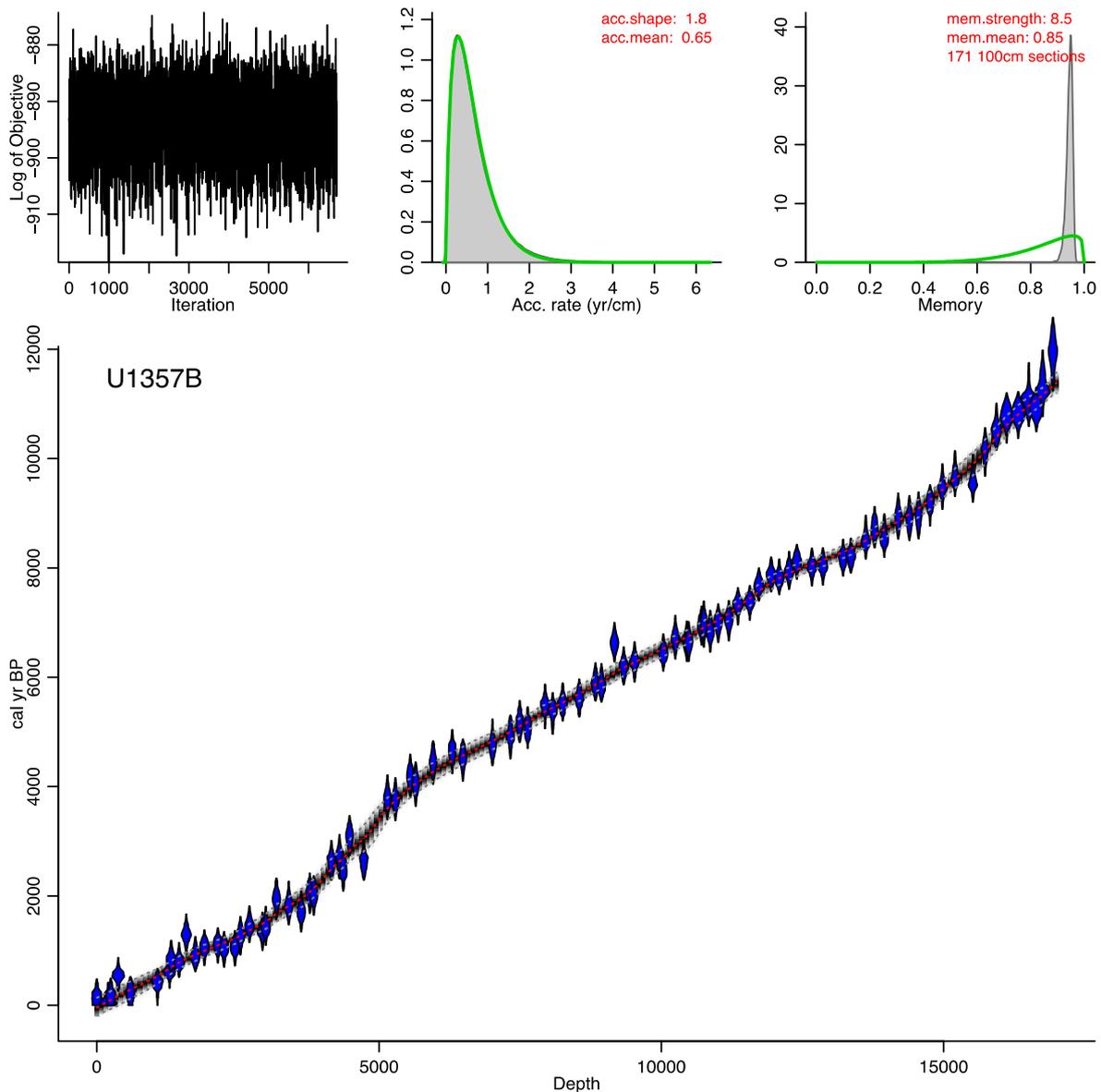


Figure S1. Age-depth plot of U1357B, using the default outputs from the BACON software. Upper panels show (from left to right): a stationary distribution of the Markov Chain Monte Carlo iterations; prior (green curve) and posterior (grey curve) distribution for the accumulation rate; prior (green curve) and posterior (grey curve) distribution for memory. Bottom panel shows the calibrated ^{14}C dates (blue) and age depth model with 95% confidence intervals.

(Blaauw and Christeny, 2011). The top depth of 3 m is consistent with the reservoir age in the Southern Ocean (Hall et al., 2010). Bulk organic carbon ages in the Antarctic are commonly compromised by reworking of older carbon in the sediment column (Andrews et al., 1999), which is compounded by extreme sediment starvation of post-LGM sequences in the Antarctic. However, due

to extremely high input of autochthonous carbon associated with the Adélie Drift deposit, which is a predominately seasonally deposited

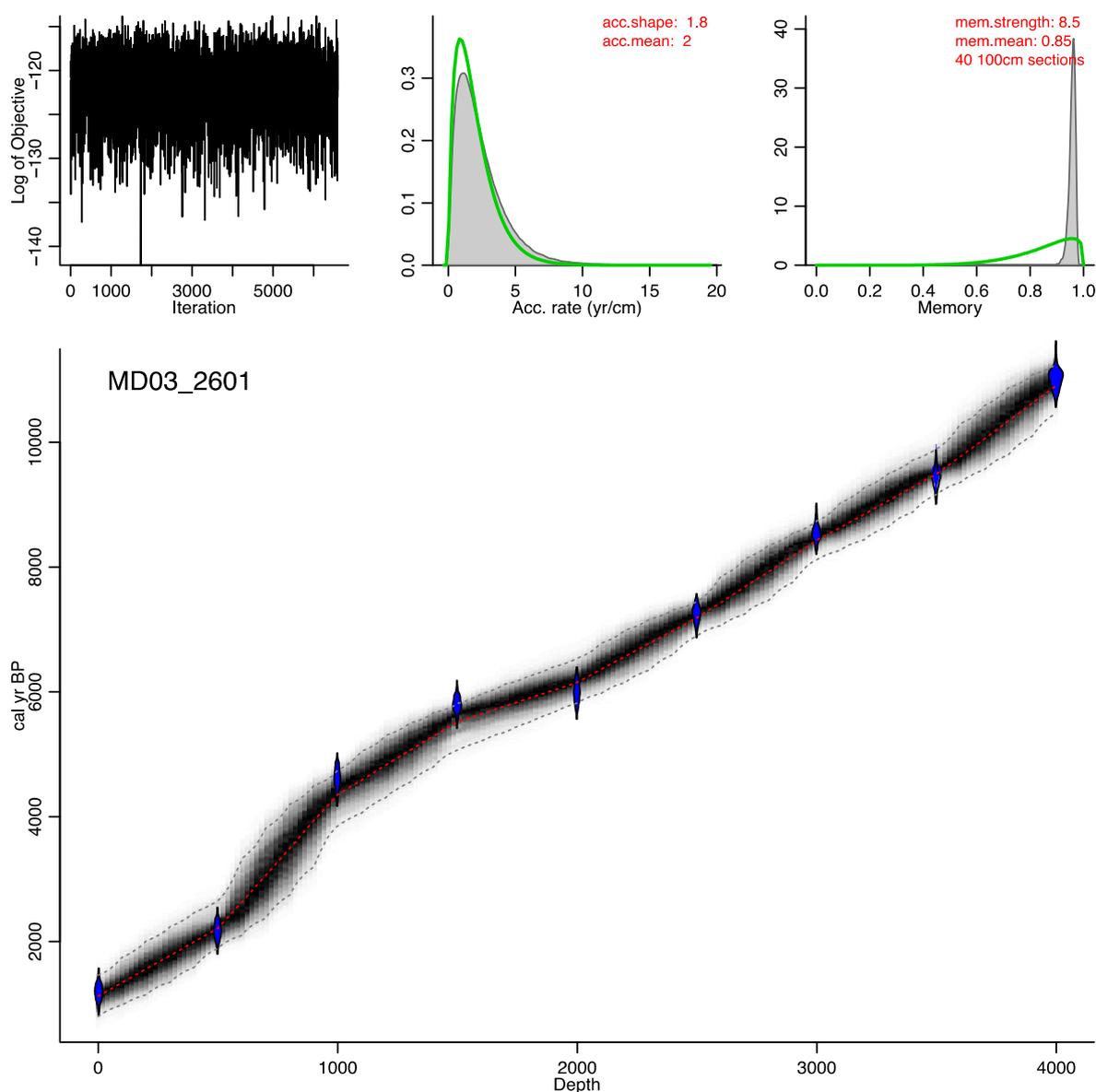


Figure S2. Age-depth plot of MD03-2601, using the default outputs from the BACON software. Upper panels show (from left to right): a stationary distribution of the Markov Chain Monte Carlo iterations; prior (green curve) and posterior (grey curve) distribution for the accumulation rate; prior (green curve) and posterior (grey curve) distribution for memory. Bottom panel shows the calibrated ^{14}C dates (blue) and age depth model with 95% confidence intervals.

diatom bloom, this reworking is expected to be minimal at the U1357 site, and is only a potential issue at the base of the core (Unit II), due to increased proximity to glacial influences from the Adélie Land coast during the deglaciation (e.g. > 11.4 ka). This is supported by the radiocarbon ages,

maintaining a strong stratigraphic order (within error), relatively consistent sedimentation rates throughout the deposited interval, and core top ages that are consistent with the expected reservoir age.

We also recalibrated the age-model for MD03-2601 applying the BACON methodology using the ^{14}C dates presented in (Crosta et al., 2008) (Fig. S2). This age model differs from that of (Denis et al., 2009a), who discarded two ^{14}C ages bracketing the mid-Holocene (4.4 and 5.6 cal ka BP), on the basis of an inferred meteorite impact at ca. 15 m and correlated this to an event at 4 ka BP. We note that this impact correlation does not provide a unique absolute age constraint, with our revised age model instead indicating an age of 5.4 cal ka BP for this impact event. Critically, comparison between the age model for U1357B and the revised age model for MD03-2601 now indicates a strong similarity regarding changes in the sedimentation rates at ca. 4.5 ka and ca. 2 ka BP, indicating that both sites are influenced by similar depositional processes.

S2. Further details on interpretation of proxy data

S2.1 Ba/Ti ratio excess as a primary productivity proxy

Ba-based proxies (e.g., Ba/Ti or equivalent Ba/Al) in the Wilkes Land margin sediments have been commonly related to marine productivity (Presti et al., 2011), although studies in other pelagic environments indicate that they can also be sensitive to bottom current intensity (Bahr et al., 2014), meltwater (Plewa et al., 2006), and other processes (Griffith and Paytan, 2012). FESEM analysis and images at Site U1357 indicate the presence of biogenic barite (Fig. S3a), recognized by the elliptical morphologies and sizes between 1 to 3 μm (Paytan et al., 2002). Titanium is found associated with small heavy minerals (ilmenite) with angular and low sphericity shapes.

Along the entire record, Ba/Ti ratios show persistent periodic fluctuations with values between 0.1 and 2.7. Nevertheless, a marked enrichment can be observed at 4.5 ka reaching Ba/Ti ratio values

over 36.1 (Fig. 2). Pore water analysis indicates that the carbon dioxide (methanic) reduction zone (CRZ) is reached just few cm near sea floor and the upper 20 m already contain sulfate-free interstitial waters (Escutia et al., 2011). Observed geochemical conditions indicate that some Barite dissolution could be expected, but there is no diagenetic barite that could justify the obtained enrichment. In addition, at the enriched interval we did not observe any lithological change or enrichment in other elements (e.g., Si). The influence of aeolian dust or fluvial input on Ba input can also be discarded in the glaciated Wilkes Land margin. In the same way, Ba concentration in sea-ice is considered null because on an annual cycle, sea ice does not constitute a net source or sink of these species to the underlying seawater (Thomas, 2011).

Furthermore, FESEM imaging detected biogenic barite during intervals where the Ba/Ti excess occurs (Fig. S3) pointing to an increase in productivity. This may be driven by water column stratification

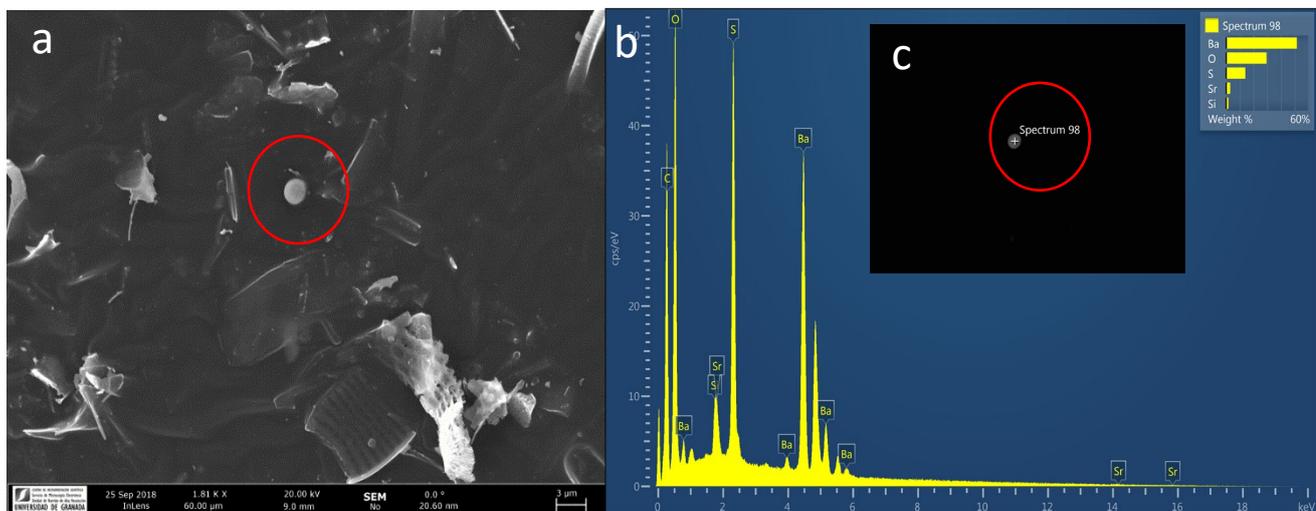


Figure S3. Authigenic marine barite (red circle, size > 300nm) observed in Ba/Ti enriched interval (sample U1357B-8H-2A 141-143; age: 4,430 cal yr) a) SEM image obtained with secondary electrons with Inlens detector at 20 kV b) SEM-EDX spectrum (analyzed spot marked with a white cross in image c)) showing barite composition (BaSO_4) c) Same barite shown in a backscattered electron (BSE) mode by AsB detector at 20 kV.

or greater nutrient availability. This interpretation is coherent with other paleoproductivity reconstructions in this area, in particular peaks in ^{230}Th -normalized fluxes of biogenic silica (BSi) and organic carbon content recorded in nearby core MD03-2601 (Denis et al., 2009b) (when using the recalibrated age-model – see S2).

S2.2 Grain size

Grainsize analysis was conducted on paired samples with lipid biomarker samples in Unit I. Unit I represents the onset of the modern deposition at Site U1357, and the underlying stratigraphy is discussed in the main text. Between ca. 11.4 and 8 ka, U1357B has a relatively high terrigenous component (i.e. high Natural Gamma Radiation (NGR) content and low BSi%; Fig 4). The grain size distribution contains coarse tails of fine (125-250 μm) to medium sands (250-500 μm), but only one sample contains coarse sands (>500 μm) that may represent ice-berg rafted debris (IBRD). However, terrigenous content and IBRD is more common in the underlying Unit II, which is interpreted to represent a true “calving bay environment” (Escutia et al., 2011). Shipboard description of the core faces found the presence of small isolated faceted and striated pebbles (lonestones) in Unit II (Escutia et al., 2011), which is supportive of an iceberg component to sediment supply, but these are largely absent in Unit I. The fine grained sands and muds have a distribution with similar modes to overlying intervals, albeit with an increase in the size of the coarse silt and very fine sand modes. The subtle increased sorting up core between ca. 11.4 and ca.8 ka (from very poorly to poorly sorted, Fig. 4) is consistent with an increasingly more distal setting, with less potential for a glacial grounding line sediment supply (Powell and Domack, 1995; McKay et al., 2009). This interval is interpreted to reflect the final post-LGM retreat of local EAIS outlet glacier grounding lines from a proximal (less sorted, more IBRD) to more distal setting (better sorted, less IBRD) from the site, although we note a much larger shift occurs at the Unit I/II boundary at 170.25 mbsf (ca.11.4 ka) (Escutia et al., 2011) and dominant sediment supply from local outlet glaciers probably ceased at this earlier time. It is likely this distal setting was close to the modern day grounding line, as the Dumont d’Urville Trough is overdeepened between Site U1357 and the modern day grounding line, and this bathymetry configuration is inherently unstable for marine-based ice sheets (Thomas and Bentley, 1978; Bentley et al., 2014).

Today, Adélie Land glaciers are inferred to have relatively clean basal layers due to the solid bedrock (Kleinschmidt and Talarico, 2000), and distal polar glacimarine settings are usually sediment starved and provide very low inputs of terrigenous sediments (Powell and Domack, 1995; McKay et al., 2009).

There are also no large proglacial fans evident at the mouths of these glaciers (Beaman et al., 2011) and consequently, direct sediment discharge from the Mertz and Ninnis Glaciers is unlikely to be of significant quantity to sustain dense overflows delivering sediment over the Adélie Bank and into the Dumont d'Urville Trough. Therefore, the release of terrigenous material through glacial melting is low (to absent) when glacier activity is steady and distal from the site, but is anticipated to increase with increased proximity to the glacier front or with enhanced dynamic ice discharge (which may occur either during a retreat or advance), which would be associated with an increase in IBRD from local outlet glaciers. We note evidence for proglacial fan deposition and IBRD is lacking throughout Unit I (post 11.4 ka).

Between 9 and 4.5 ka, mass accumulation rates (MARs) (both biogenic and terrigenous; Fig. S4) are relatively high, albeit with millennial scale variability. However, the mean grain size and sorting of the terrigenous material is relatively stable throughout the entire interval, and as with the rest of Unit I there is an almost complete lack of IBRD. This suggests that sediment input from grounding line processes were also minimal through this time. Based on the drift morphology (Fig S4), and the prevailing easterly flow of the Antarctic Coastal Current, this interval is interpreted to be the result of sediment advection to the site from the east as residual ice retreated from the bathymetric highs in the region. Diatom frustules and sponge spicules are mainly in the 16 to 63 μm range, much of which is maintained in suspension by weak currents (a few cm s^{-1}) (Dunbar et al., 1985). The greater area of open water for primary production during the summer, combined with an open pathway for

advection of biogenic matter from the MGP (Fig. 1) can thus explain the significant rise in linear sedimentation and mass accumulation rates for both biogenic and terrigenous material. Most of the terrigenous material after ~8 ka is proposed to have been primarily eroded off the Adélie Bank by westward flowing currents into the Adélie drift where sediment would have settled out from suspension. Terrigenous sediment younger than 8 ka in this drift is almost entirely finer than 125 μm , while Dunbar et al. (1985) revealed that surface sediments on shallow banks have a grain size distribution that generally exceeds 125 μm . This supports our interpretation that the majority of the terrigenous material in U1357B is winnowed from these banks by bottom currents. The size of the material winnowed implies that maximum current velocities in the region are greater than 18-20 cm s^{-2} , the minimum velocity required to transport fine sand by intermittent suspension and suspension in poorly sorted glacial marine settings (Singer and Anderson, 1984; McCave and Hall, 2006).

The complete lack of medium to coarse sand in the grain size distributions of Unit I (<11.4 ka), and from visual observation of the core face, that may represent IBRD may be the consequence that icebergs calved from large ice shelves and ice tongues, such as the RIS and Mertz Glacier Tongue, are advected into the region via the Antarctic Coastal Current but usually lack basal debris. While the lack of IBRD could in part be explained as the consequence of the widespread development of the RIS in the Holocene (McKay et al., 2016), it could also be due to the Adélie and Mertz Banks (and Mertz Glacier Tongue) acting to shield Site U1357 from large icebergs passing over the site, as icebergs would have become grounded on the bathymetric highs and deflected north (Massom et al., 2001; Beaman et al., 2011). Notably, this lack of IBRD further supports a lack of shifting glacial dynamics and calving of sediment-laden icebergs from the smaller local Astrolabe and Zélée outlet glaciers through this time.

There is a rapid increase in mud content at 4.5 ka coincident with a reduction in both the biogenic and terrigenous MARs, although the terrigenous MAR curve shows higher

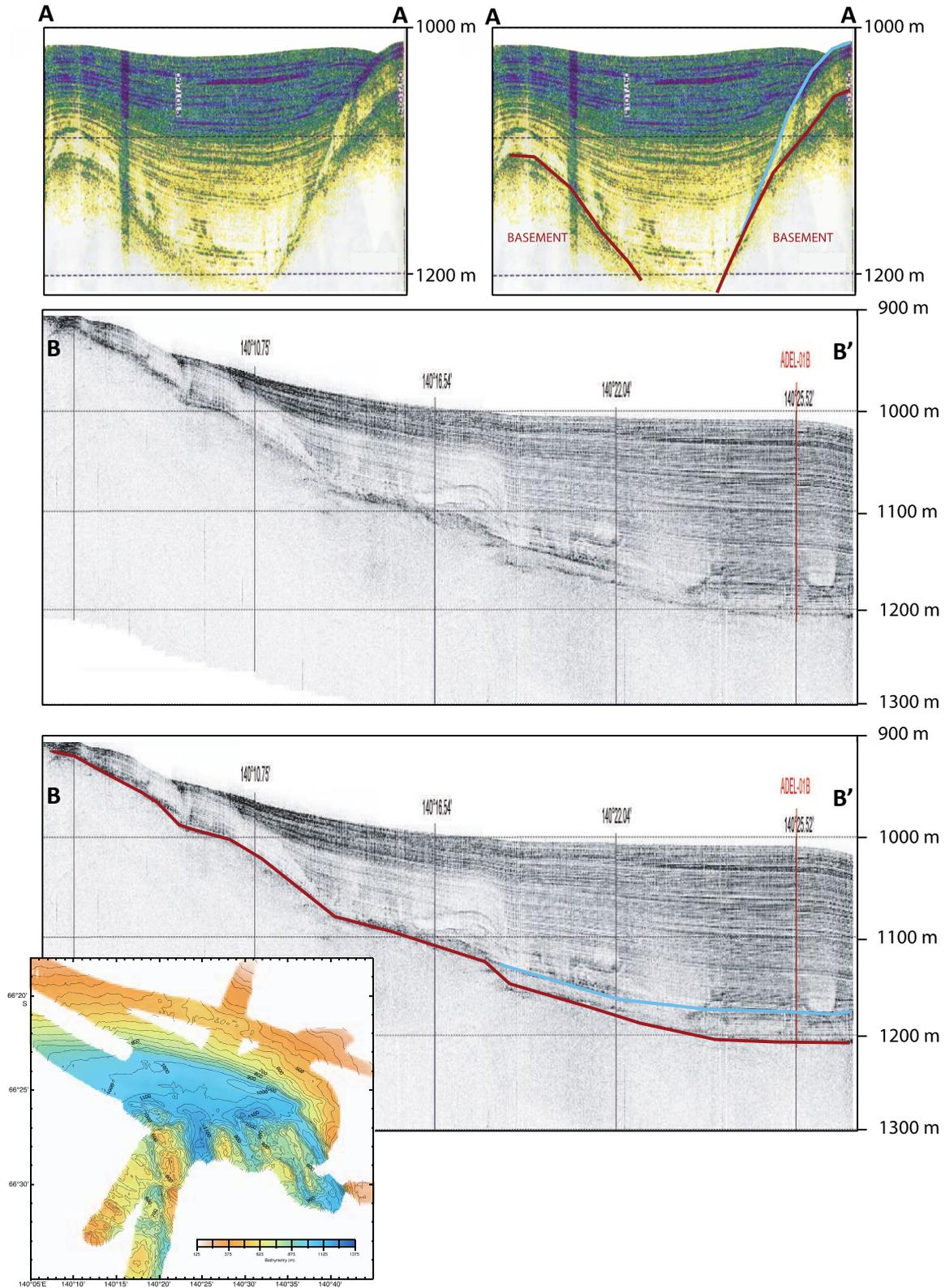


Figure S4 3.5 kHz seismic profile of the Adélie drift. Top: South (A) to north (A') profile, showing early Holocene (inferred to be ~11-8.2 ka) strata downlapping on top the basement highs (blue reflector and below). This is overlain by onlapping strata (blue reflector and above). Middle and Bottom: West (B) to East (B') profile, showing that in the depocentre of the basin, the pre-8.2 strata has a different geometry to overlying strata (onlapping onto the northern bank of the Dumont D'Urville Trough), suggesting a supply from the south, while overlying strata form a drift deposit that is thickest on the northern flank of the trough, and infers a drift deposit morphology that is aligned with the flow of easterly Antarctic Coastal Current.

accumulation rates than the biogenic MAR curve (Fig. 4). Hence, less material is being advected to the site, and the maximum current strength acting to winnow and advect material from the Adélie Bank into the Dumont d'Urville Trough is reduced. A reduction in maximum current strength could potentially be explained by more extensive sea ice over the site, which would act to reduce wind stress on the ocean surface and thus the maximum strength of the easterly flow, despite enhanced zonal easterly winds that are predicted with a cooler Antarctic climate (Shin et al., 2003; DeConto et al., 2007).

A final consideration is that aeolian contribution of terrigenous material is known to be of importance in Antarctic coastal areas affected by katabatic winds (Atkins and Dunbar, 2009; Chewings et al., 2014). However, windblown sediment is usually well-sorted, and combined with the lack of exposed sediment in Wilkes Land, and the distance of the core site from the coast, input of aeolian sediment into the ocean from melting sea ice is likely to be a relatively minor component of the sediment population relative to the suspended sediment load derived from the local banks and pelagic processes.

S2.3. Highly-branched isoprenoids (HBI)

Several recent studies have highlighted the strong potential of the HBI biomarkers along the Antarctic coast as a robust proxy of sea ice extent. Indeed, it has been shown that the di-unsaturated HBI lipid (i.e. diene II or C_{25:2} alkene) is only synthesized in the modern Antarctic waters by sea ice-associated diatoms (Belt et al., 2016; Massé et al., 2011; Smik et al., 2016). The tri-unsaturated HBI lipid (i.e. triene III or C_{25:3}) is in contrast strictly produced by open water diatom species, which have been found to be in highest abundance in the marginal ice zone (Smik et al., 2016). Thus, the calculated diene/triene ratio is a reliable tracer to qualitatively estimate the sea ice extent (sea ice vs open water conditions). As previously applied in various Antarctic coastal sediments during different period of time (Etourneau et al., 2013; Collins et al., 2012; Barbara et al., 2010), the diene/triene

ratio was successfully used to reconstruct the past sea ice history around Antarctica. In particular, it has been shown that the HBIs were not significantly affected by (i) changes in sources (glacial ice vs sea ice), as the diatoms producing the HBIs strictly grow in relation with sea ice (under or at the edge) (ii) bacterial degradation (Robson and Rowland, 1988) or (iii) rapid sulfurization under anoxic conditions (Sinninghe Damsté et al., 2007). Absolute concentrations of the HBI diene and triene compounds are shown in Fig. S5.

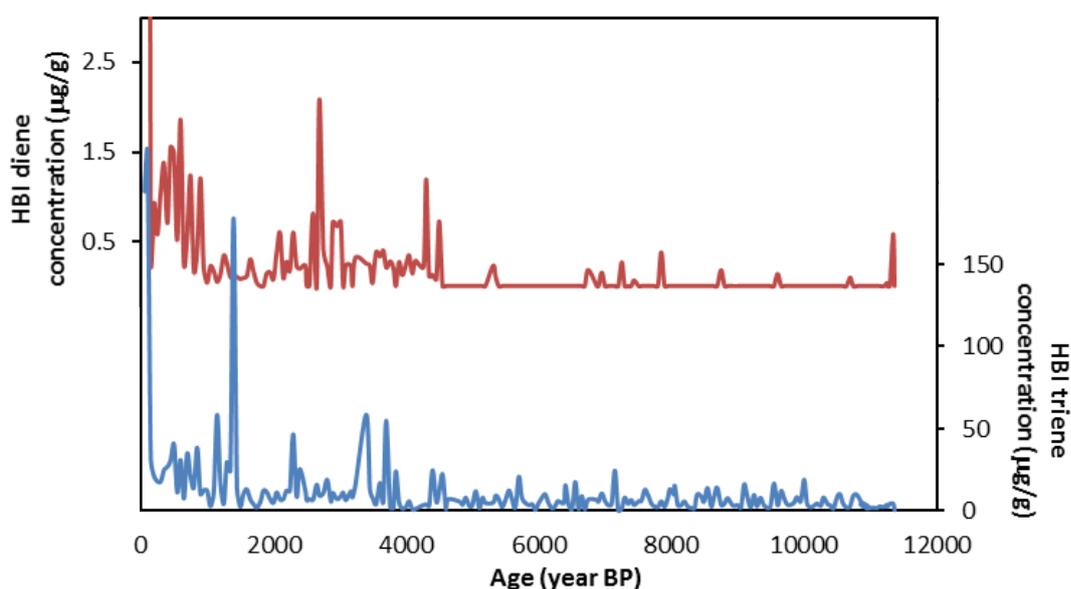


Figure S5 Absolute concentrations of highly branched isoprenoids (HBIs) measured in U1357B.

S3. Data-Model mismatch

Comparison of sea ice data from the Adélie region (presented in this study), with model output for sea ice thickness and extent from TraCE-21k simulations, indicates a clear mismatch between the observational data and model output over the Holocene (Fig. 6). The rapid mid-Holocene increase in sea ice, recorded at Site U1357 and other sites in the Antarctic coastal zone (Fig. 6c, d), is not seen in the model simulations, which instead indicate a sharp decline in sea ice extent and thickness around the Antarctic and in the Adélie region after ca. 5 ka (Fig. 6a, b). The Community Climate System Model (CCSM3) used in the simulations lacks a dynamic ice sheet, instead using a constant prescribed meltwater flux of 1.12 m ka^{-1} from the Antarctic which finishes at 5 ka, which can likely explain the simulated sea-ice decline at ca. 5 ka. Furthermore, it does not incorporate ice-ocean coupling or ice shelf cavities. We have shown that these processes have an important role on sea ice production and thus are required within models to capture the coupled response between ice sheets and the ocean. We note that some models, such as LOVECLIM (Renssen et al., 2010), do simulate a gradual sea-ice increase and cooling trend in the late Holocene, however the timing (gradual) and magnitude (subtle) of sea-ice trends do not match the abrupt and large changes seen in the proxy data.

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