Bering Sea surface water conditions during Marine Isotope Stages 12 to 10 at Navarin Canyon (IODP Site U1345)

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Abstract

Records of past warm periods are essential for understanding interglacial climate system dynamics. Marine Isotope Stage 11 occurred 425-394 ka when global ice volume was the lowest, sea level was the highest and terrestrial temperatures were the warmest of the last 500 kyrs. Because of its extreme character, this interval has been considered an analog for the next century of climate change. The Bering Sea is ideally situated to record how opening or closing of the Pacific-Arctic Ocean gateway (Bering Strait) impacted primary productivity, sea ice, and sediment transport in the past; however, little is known about this region prior to 125 ka. IODP Expedition 323 to the Bering Sea offered the unparalleled opportunity to look in detail at time periods older than had been previously retrieved using gravity and piston cores. Here we present a multi-proxy record for Marine Isotope Stages 12-10 from Site U1345 located near the continental shelf-slope break. MIS 11 is bracketed by highly productive laminated intervals that may have been triggered by flooding of the Beringian shelf. Although sea ice is reduced during the early MIS 11 laminations, it remains present at the site throughout both glacials and MIS 11.

High summer insolation is associated with higher productivity, but colder SSTs, which implies that productivity was likely driven by increased upwelling. Multiple examples of Pacific-Atlantic teleconnections are presented including laminations deposited at the end of MIS 11 in sync hrony with brief expansions in sea ice in the Bering Sea and stadial events seen in the North Atlantic. When global eustatic sea level was at its peak, ~~an~~ series of anomalous conditions are seen at U1345. We examine whether this is evidence for a reversal of Bering Strait Through Flow, an advance of Beringian tidewater glaciers, or a turbidite.

a synchrony

1 Introduction

Predictions and modeling of future climate change require a detailed understanding of how the climate system works. Reconstructions of previous warm intervals shed light on interhemispheric teleconnections. The most recent interglacial period with orbital conditions similar to today was approximately 400 ka, during the extremely long interglacial known as Marine Isotope Stage (MIS) 11. CO_2 concentration averaged approximately 275 ppm, which is similar to pre-industrial levels (EPICA Community Members, 2004). The transition from MIS 12 into MIS 11 has been compared to the last deglaciation (Dickson et al., 2009) and extreme warmth during MIS 11 has been considered an analog for future warmth (Droxler et al., 2003; Loutre and Berger, 2003), although the natural course of interglacial warmth today has been disrupted by anthropogenic forcing (IPCC, 2013).

Despite the work done to characterize the warmth of MIS 11 in the terrestrial realm (Candy et al., 2014; Melles et al., 2012; Prokopenko et al., 2010), as well as the North Atlantic (Bauch et al., 2000; Chaisson et al., 2002; Dickson et al., 2009; Milker et al., 2013; Poli et al., 2010), little is known about this interval from the North Pacific and Bering Sea region (Candy et al., 2014). Modeling studies describe several mechanisms for linking the Atlantic and Pacific through oceanic heat transport on glacial-interglacial time scales (DeBoer and Nof, 2004; Hu et al., 2010), however, there have been no tests of these modeling studies using proxy data older than 30 ka. Furthermore, the location of the Bering Sea marginal sea ice zone advanced and retreated hundreds of kilometers during the past three glacial-interglacial cycles (Caissie et al., 2010; Katsuki and Takahashi, 2005; Sancetta and Robinson, 1983); however, sea surface and intermediate water variability before MIS 5 is unknown.

This investigation of terrestrial-marine coupling at the shelf-slope break from MIS 12 to 10 is the first study of this interval in the subarctic Pacific (Fig. 1). We use a multi-proxy approach to examine orbital- and millennial-scale changes in productivity and sea ice extent. We demonstrate that insolation plays a major role in these changes, but that sea ice also shows rapid, millennial-scale variability. Finally, we test the hypotheses that 1) in Beringia, tidewater glaciers advanced while sea level was high and 2) Bering Strait Through Flow reversed shortly after the MIS 12 glacial termination (Termination V). We find inconclusive evidence of a glacial advance, but no evidence of Bering Strait reversal.

2 Background

2.1 Global and Beringian Sea Level during MIS 11

The maximum height of sea level during MIS 11 is an open question with estimates ranging from 6 to 13 m above present sea level (apsl) (Dutton et al., 2015) to 0 m apsl (Rohling et al., 2010; Rohling et al., 2014). The discrepancy may stem from large differences between global eustatic (Bowen, 2010) or ice-volume averages (McManus et al., 2003) and regional geomorphological or micropaleontological evidence (van Hengstum et al., 2009). Regional isostatic adjustment due to glacial loading and unloading are now known to be significant and regional highstands may record higher than expected sea levels if glacial isostasy and dynamic topography have not been accounted for, even in places that were never glaciated (PAGES et al., 2016; Raymo and Mitrovica, 2012; Raymo et al., 2011). For example, Raymo and Mitrovica (2012) suggest eustatic sea level during MIS 11 was 6-13 m apsl globally and near 5 m apsl locally in Beringia, yet MIS 11 shorelines are at +22 m today in northwest Alaska (Kaufman and Brigham-Grette, 1993) due to this complex geophysics.

Regardless of the ultimate height of sea level, the transition from MIS 12 to MIS 11 records the greatest change in sea level of the last 500 ka (Rohling et al., 2014); sea level

something missing (e.g. history)
Because "sea level" cannot be complex

rose from perhaps -140 m to its present level or higher (Bowen, 2010)(Dutton et al., 2015). Sea level during MIS 11 may have been complex (Kindler and Hearty, 2000), but most records agree that sea level during this exceptionally long interglacial (30 kyrs) was highest from 410 to 401 ka, coincident with a second peak in June insolation at 65°N. This long highstand most likely requires partial or complete collapse of the Greenland ice sheet (up to 6 m) (de Vernal and Hillaire-Marcel, 2008; Reyes et al., 2014) and/or the West Antarctic Ice Sheet (Scherer et al., 1998), but not the East Antarctic Ice Sheet (Berger et al., 2015; Dutton et al., 2015; Raymo and Mitrovica, 2012). It has frequently been hypothesized that the West Antarctic Ice Sheet collapsed during MIS 11 and modeling studies confirm this (Pollard and DeConto, 2009), however unconformities in the record prevent confirmation of a collapse (McKay et al., 2012). Yet, Teitler (2015) show that IRD during MIS 11 dropped as low as it was during MIS 31, when it is clear that the West Antarctic Ice Sheet had collapsed (Naish et al., 2009). With uncertainties, East Antarctica ice was stable; however, small changes in either sector of the Antarctic ice sheet may have contributed up to 5 m of sea level rise (Berger et al., 2015; EPICA Community Members, 2004).

The sea level history of Beringia defines Arctic communication between the Pacific and the Atlantic oceans during the Plio-Pleistocene. As a region, Beringia consists of both the terrestrial and marine regions north of the Aleutian Islands that stretch to the shelf-slope break in the Bering, East Siberian, Chukchi, and Beaufort seas (Fig. 1). On land, Beringia extends from the Lena River in Siberia to the Mackenzie River in Canada. Large portions of the Beringian shelf were exposed when sea level dropped below -50 m (Hopkins, 1959) and this subaerial expanse stretches more than 1000 km from north to south during most glacial periods (Fig. 2). In contrast, as sea level rises at glacial terminations the expansive continental shelf is flooded, rapidly once sea level reaches -60 mapsl (Keigwin et al., 2006). This introduces fresh organic matter and nutrients into the southern Bering Sea (i.e. Bertrand et al., 2000; Shiga and Koizumi, 2000; Ternois et al., 2001), re-establishing at -50 mapsl the connection between the Pacific and Atlantic oceans through Bering Strait (Keigwin et al., 2006). The late Cenozoic history of the depth of the Bering Strait sill is poorly known, hence current oceanographic reconstructions (e.g., Knudson and Ravelo, 2015) assume that a sill depth of -50 mapsl was temporally stable, which is

Margalef, Simpson, and Shannon indices (Maurer and McGill, 2011) which all show similar down-core profiles (Fig. 5). The Margalef index is a measure of species richness. It shows a decrease in the number of taxa during four out of five laminated intervals that are sufficiently well sampled. Between laminated intervals, there is also a noted decrease in taxa at 388 ka. The Simpson index measures the evenness of the sample. Values close to 1 indicate that all taxa contain an equal number of individuals, while values close to 0 indicate that one species dominates the assemblage. In general, the Simpson index is close to 1 throughout the core; however, during the Termination V Laminations and the most recent two laminations, the Simpson index decreases reflecting the dominance by *Chaetoceros* RS during these intervals (Fig. 5). The Simpson index never approaches 0, which would likely indicate a strong dissolution signal. The Shannon diversity index measures both species richness and evenness. Correspondingly, it is low during three of the laminated intervals, high during MIS 12 and peaks at 397 ka (Fig. 5).

Absolute diatom abundances vary between 10^6 and 10^8 diatoms deposited per gram of sediment with values an order of magnitude higher during most laminated intervals than during massive intervals (Fig. 5). The diatom assemblage is dominated by *Chaetoceros* and *Thalassiosira antarctica* resting spores (RS), with lesser contributions from *Fragilariopsis oceanica, F~~ragilariopsis~~ cylindrus, Fossula arctica, Shionodiscus trifultus* (=*T~~halassiosira~~ trifulta), T~~halassiosira~~ binata,* small (<10 µm in diameter) *~~Thalassiosira~~* species, *Paralia sulcata, Lindavia* cf. *ocellata*, *Neodenticula seminae,* and *Thalassionema nitzschioides* (Fig. 6).

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4.3.2 Qualitative Diatom Proxies

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Diatoms, like many organisms, thrive m under a specific range of environmental conditions or optima and these optima are different for each species. For this reason, diatom assemblages are excellent paleoceanographic indicators (Smol, 2002). We grouped diatoms with similar environmental niches together (Table 3) to interpret the paleoceanographic sea surface conditions at the Bering Sea shelf-slope break during MIS 12 to 10 (Caissie, 2012; Katsuki and Takahashi, 2005; Sancetta, 1982){Caissie and Nesterovich, In Prep} (Fig. 7).

interglacial in most marine records (Candy et al., 2014), rather MIS 5e is the warmest many places (PAGES et al., 2016). This is especially evident in the Nordic Seas where MIS 11 SSTs were lower than Holocene values (Bauch et al., 2000). However, MIS 11 is unique because it was much longer than MIS 5e in all records (PAGES et al., 2016). One exception to this is the Arctic Ocean, which was warm enough during MIS 11 to imply increased Pacific water input through Bering Strait (Cronin et al., 2013).

With elevated sea level, peak MIS 11c was very humid in many places. In the Bering Sea, modeling studies estimate up to 50 mm more precipitation than today at 410 ka (Kleinen et al., 2014). The most humid, least continental period recorded in the sediments at Lake Baikal occurs from 420-405 ka (Prokopenko et al., 2010), and extremely high precipitation is recorded at Lake El'gygytgyn on the nearby Chukotka Peninsula from 420-400 ka (Melles et al., 2012).

5.2.2 Millennial-Scale Laminations and Changes in Sea Ice

Globally, late MIS 11 is characterized as a series of warm and cold cycles (Candy et al., 2014; Voelker et al., 2010), though there is no agreement on the timing of these cycles. At Site U1345, laminations are deposited intermittently between 394 and 392 ka and again after 375 ka (Fig. 4) as the climate transitioned into MIS 10. These laminations are quite different from the Termination V Laminations due to their shorter duration and lack of obvious shift in terrigenous vs. marine carbon source. In addition, these Type II laminations have higher diatom abundances and $CaCO_3$, but lack increased upwelling indicators. Primary production during these laminations is likely not driven by nutrient upwelling along the shelf-slope break. Instead, most of these laminations show an increase in sea ice diatoms and roughly correspond with millennial scale stadial events that occurred during late MIS 11 in the North Atlantic (Fig. 9) (Voelker et al., 2010) as well as carbonate peaks at Blake Ridge (Chaisson et al., 2002). This suggests teleconnections between the Bering Sea and the North Atlantic at this time and places an indirect constraint on the depth of the Bering Strait sill.

It is ~~tantalizing to note~~ possible that the laminations occur at a time when global sea level was fluctuating near the sill depth of Bering Strait (-50 m apsl) (Rohling et al., 2010) (see

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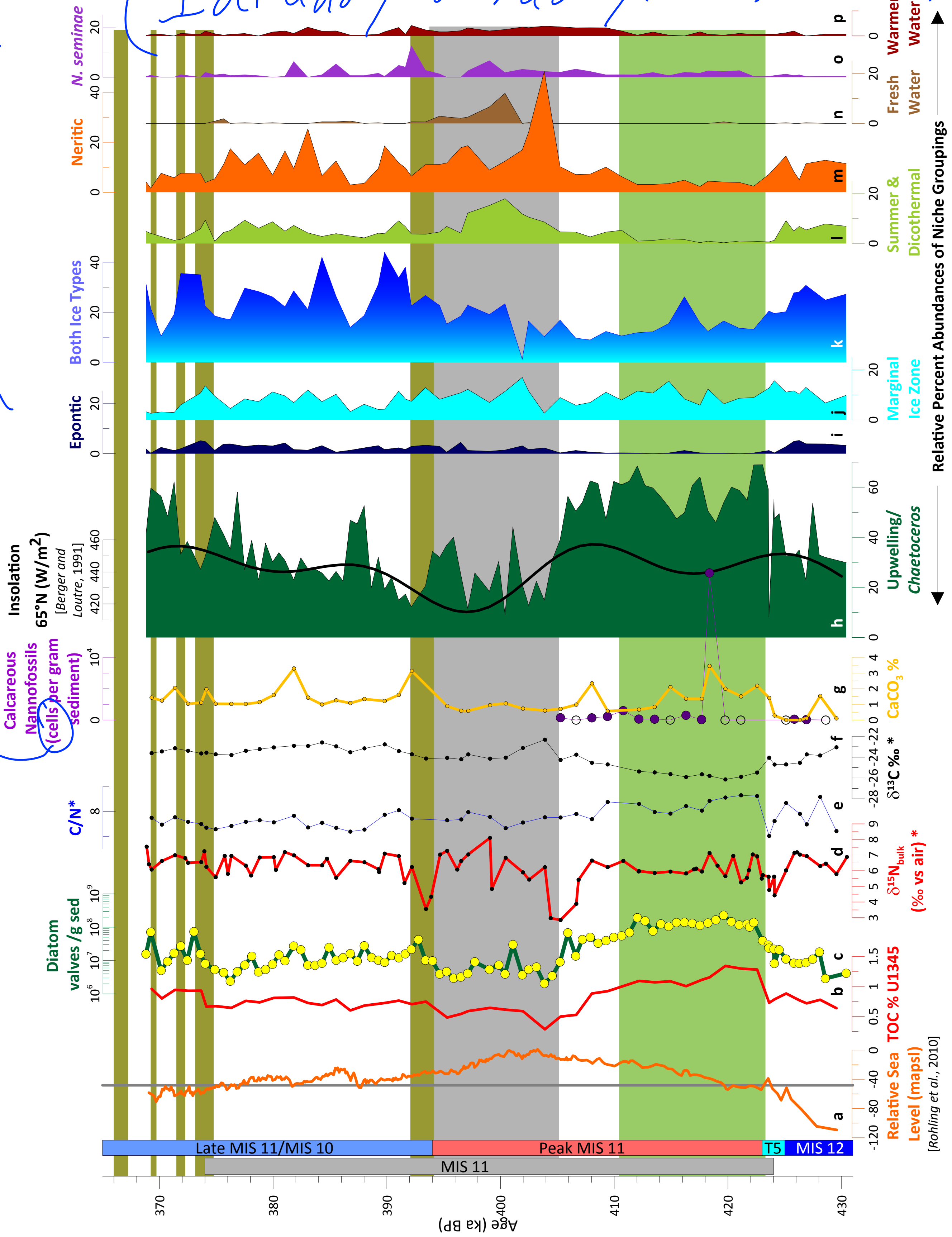

Figure 7.