



Note:
WC = word choice
SP = spelling

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

4
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12

13 **Abstract**

14 Records of past warm periods are essential for understanding interglacial climate system
15 dynamics. Marine Isotope Stage 11 occurred ~410 ka when global ice volume was the
16 lowest, sea level was the highest and terrestrial temperatures were the warmest of the last
17 500 kyrs. This interval with its extreme character has been considered an analog for the
18 near future. The Bering Sea is ideally situated to record how opening or closing of
19 Pacific-Arctic Ocean gateway (Bering Strait) impacted primary productivity, sea ice, and
20 sediment transport in the past; however, little is known about this region prior to 125 ka.
21 IODP Expedition 323 to the Bering Sea offered the unparalleled opportunity to look in
22 detail at time periods older than had been previously retrieved using gravity and piston
23 cores. Here we present a multi-proxy record for Marine Isotope Stages 12-10 from Site
24 U1345 located near the shelf-slope break. MIS 11 is bracketed by highly productive
25 laminated intervals that may have been triggered by flooding of the Beringian shelf. Low
26 insolation is associated with higher productivity, which was likely driven by increased
27 upwelling. During the majority of MIS 11 however, high stratification appears to have

Vague (WC)
Try AD 2100
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Continental

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28 led to lowered productivity in both the northern Atlantic and the northern Pacific. U1345,
29 located near the marginal ice zone, experienced seasonal sea ice throughout both the
30 glacial and interglacial stages. When global eustatic sea level was at its peak, Beringian
31 tidewater glaciers advanced, driven by decreasing insolation, reduced seasonality, and
32 high humidity due to high sea level and ice-free summers. Multiple examples of Pacific-
33 Atlantic teleconnections are presented including laminations deposited at the end of MIS
34 11 in sync with millennial scale stadial events seen in the North Atlantic.

35

36 1 Introduction

37 Predictions and modeling of future climate change require a detailed understanding of
38 how the climate system works. Reconstructions of previous warm intervals shed light on
39 interhemispheric teleconnections. The most recent interglacial period ^{with} when orbital
40 conditions ~~were~~ similar to today was approximately 400 ka ⁵ during the extremely long
41 interglacial known as marine isotope stage (MIS) 11. Eccentricity was low, obliquity was
42 high and the amplitude of precessional changes was low (Loutre and Berger, 2003). In
43 addition, CO₂ concentration averaged approximately 275 ppm, which is similar to pre-
44 industrial levels (EPICA community members, 2004). The transition from MIS 12 into
45 MIS 11 has been compared to the last deglaciation (Dickson et al., 2009) and extreme
46 warmth during MIS 11 has been considered an analog for future warmth (Droxler et al.,
47 2003; Loutre and Berger, 2003), although the natural course of interglacial warmth today
48 has been disrupted by anthropogenic forcing (IPCC, 2013).

Consistency

49 Globally, MIS 11 is easily recognizable in the sediment record by an abrupt and distinct
50 transition from high to low $\delta^{18}\text{O}$ values at the MIS 12/11 boundary and subsequent
51 prolonged low values of $\delta^{18}\text{O}$ during MIS 11 (Lisiecki and Raymo, 2005). Furthermore,
52 MIS 11 was unique in the polar regions. Antarctica experienced temperatures 2° C
53 warmer than pre-industrial temperatures (Jouzel et al., 2007), and boreal forest extended
54 across Greenland, which may have been largely ice free (de Vernal and Hillaire-Marcel,
55 2008). Large lakes in Siberia were anomalously productive and record warmer air and
56 lake temperatures than today. Lake Baikal was 2° C warmer (Prokopenko et al., 2010)
57 and Lake El'gygytyn was 4° C warmer (Lozhkin and Anderson, 2013; Vogel et al.,



58 2013). MIS 11 is also unique in Beringia because coastal glaciers advanced midway
59 through the long interglacial cycle while sea level was still high (Brigham-Grette et al.,
60 2001; Huston et al., 1990; Kaufman et al., 2001; Pushkar et al., 1999). This implies that
61 parts of Beringia were glaciated rapidly as high latitude insolation fell in the northern
62 hemisphere, but before global sea level dropped in response to the buildup of large ice
63 sheets reaching lower latitudes. [MIS 11 ice (i.e., leading to the Nome River Glaciation in
64 MIS 10) is widely believed to be the last of the most extensive glaciations in central
65 Beringia (Brigham-Grette et al., 2001; Gualtieri and Brigham-Grette, 2001; Kaufman et
66 al., 1991; Manley et al., 2001).] *Hmm.*

67 Despite the work done to characterize the warmth of MIS 11 in the terrestrial realm
68 (Candy et al., 2014; Melles et al., 2012; Prokopenko et al., 2010), as well as the North
69 Atlantic (Bauch et al., 2000; Chaisson et al., 2002; Dickson et al., 2009; Milker et al.,
70 2013; Poli et al., 2010), little is known about this interval from the Pacific region (Candy
71 et al., 2014). Modeling studies describe several mechanisms for linking the Atlantic and
72 Pacific through oceanic heat transport on glacial-interglacial ^{time} scales (DeBoer and Nof,
73 2004; Hu et al., 2010), however, there have been no tests of these modeling studies using
74 proxy data older than 30 ka. Furthermore, the location of the Bering Sea marginal ice
75 zone advanced and retreated hundreds of kilometers during the past three glacial-
76 interglacial cycles (Caissie et al., 2010; Katsuki and Takahashi, 2005; Sancetta and
77 Robinson, 1983); however, sea surface and intermediate water variability before MIS 5 is
78 unknown.

79 This investigation of terrestrial-marine coupling at the shelf-slope break from MIS 12 to
80 10 is the first study of this interval in the subarctic Pacific (Fig. 1). We use
81 sedimentology, diatom assemblages, geochemistry, and calcareous nannofossil
82 abundances as proxies for sea ice, sea surface conditions, and shelf to basin transport.
83 These proxy records show changes in sea ice and glacial ice that are in sync with
84 insolation changes at high northern latitudes. An interval of productivity occurs at the
85 glacial termination (Termination V) that is both short-lived and intense. This is followed
86 by evidence of glacial advance in Beringia during peak MIS 11 when sea level is high.
87 We put these changes seen in the Bering Sea in the context of global records of MIS 11.



88

89 2 Background

90 2.1 Global Sea Level during MIS 11

91 The maximum height of sea level during MIS 11 is an open question with estimates
92 ranging from more than 20 m above present sea level (apsl) (Kindler and Hearty, 2000) to
93 0 m apsl (Rohling et al., 2010). The discrepancy may stem from large differences
94 between global eustatic (Bowen, 2010) or ice-volume averages (McManus et al., 2003)
95 and regional geomorphological or micropaleontological evidence (van Hengstum et al.,
96 2009). Regional isostatic adjustment due to glacial loading and unloading is also perhaps
97 not as insignificant as previously assumed and regional highstands may record higher
98 than expected sea levels if glacial isostasy and dynamic topography have not been
99 accounted for, even in places that were never glaciated (Raymo and Mitrovica, 2012;
100 Raymo et al., 2011). Work by Raymo and Mitrovica suggests that eustatic sea level
101 during MIS 11 was 6-13 m apsl globally and near 5 m apsl locally in Beringia (Raymo
102 and Mitrovica, 2012).

103 Regardless of the ultimate height of sea level, the transition from MIS 12 to MIS 11 was
104 the greatest change in sea level of the last 500 ka (Rohling et al., 1998); sea level rose
105 from -140 m to its present level or higher (Bowen, 2010). Up to three highstands
106 occurred during MIS 11 (Kindler and Hearty, 2000), the highest at the second June
107 insolation peak at 65°N. This highstand is referred to as MIS 11.3 and occurs 406 ka
108 (Bassinot et al., 1994). Sea levels above modern require partial or complete collapse of
109 the Greenland ice sheet (up to 6 m) (de Vernal and Hillaire-Marcel, 2008) and/or the
110 West Antarctic Ice Sheet (Scherer et al., 1998), but not the East Antarctic Ice Sheet
111 (Berger et al., 2015; Raymo and Mitrovica, 2012). It has frequently been hypothesized
112 that the West Antarctic Ice Sheet collapsed during MIS 11 and modeling studies confirm
113 this (Pollard and DeConto, 2009), [however drilling in Antarctica was not able to confirm
114 a collapse (Naish et al., 2009)] East Antarctica appears stable; however, small changes in
115 either Antarctic ice sheet may have contributed up to 5 m of sea level rise (Berger et al.,
116 2015; EPICA community members, 2004).

117

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118 2.2 Sea Level Variation in Beringia

119 Beringia refers to both the terrestrial and marine regions north of the Aleutian Islands that
120 stretch to the shelf-slope break in the East Siberian, Chukchi, and Beaufort seas (Fig. 1).
121 On land, Beringia extends from the Lena River in Siberia to the Mackenzie River in
122 Canada. Large portions of the Beringian shelf are exposed when sea level drops below -
123 50 m (Hopkins, 1959) and this subaerial expanse stretches more than 1000 km from north
124 to south during glacial periods (Fig. 2). In contrast, as sea level rises at glacial
125 terminations the expansive continental shelf is flooded, introducing fresh organic matter
126 and nutrients into the southern Bering Sea (i.e. Bertrand et al., 2000; Ternois et al., 2001)
127 and re-establishing the connection between the Pacific and Atlantic oceans through
128 Bering Strait.

129

130 2.3 Beringian Hydrography

→ worth adding Fig. 1 aerology?

131 Today, water circulates cyclonically in the deep basins of the Bering Sea (Fig. 1). Site
132 U1345 is influenced by the northwest flowing Bering Slope Current, which is derived
133 from the Alaskan Stream. South of the Aleutians Islands, the Alaskan Stream flows
134 westward and enters the Bering Sea through deep channels in the western Aleutian
135 Islands. Once north of the Aleutian Islands, this water mass ^{becomes} ~~is called~~ the Aleutian North
136 Slope Current, and flows eastward until it reaches the Bering Sea shelf. Interactions with
137 the shelf turn this current to the northwest where it becomes the Bering Slope Current
138 (Stabeno et al., 1999). Tidal forces and eddies in the Bering Slope Current drive
139 upwelling through Navarin Canyon and other interfluves along the shelf-slope break
140 (Kowalik, 1999). The resulting cold water and nutrients brought to the sea surface,
141 coupled with the presence of seasonal sea ice, drive the high productivity found today in
142 the so called “Green Belt” (Springer et al., 1996) along the shelf-slope break. North of the
143 site, low salinity, high nutrient shelf waters (Cooper et al., 1997) primarily flow north
144 through the Bering Strait to the Arctic Basin (Schumacher and Stabeno, 1998).

145 Major changes in circulation may have occurred throughout MIS 12 to 10 due to sea level
146 rise and fall, the strength of North Atlantic Deep Water (NADW) formation, and the
147 intensity of winds originating in the Southern Ocean (e.g. DeBoer and Nof, 2004; Hu et



148 al., 2010). Specifically, as sea level rose after MIS 12, the connection between the Pacific
149 and the Atlantic was reestablished. De Boer and Nof (2004) suggest that under high sea
150 level conditions, if freshwater is suddenly released into the North Atlantic, the Bering
151 Strait might act as an “exhaust valve” allowing fresh water from the North Atlantic to
152 flow into the Arctic Ocean and then flow south through the Bering Strait, thus preventing
153 a shut-down in thermohaline circulation (DeBoer and Nof, 2004). Hu et al. (2010)
154 suggest that when sea level is fluctuating near the sill depth of Bering Strait (~ -50 m aspl
155 today), this gateway can modulate widespread climate changes. When Bering Strait is
156 open and North Pacific water is transported to the North Atlantic, the less saline Pacific
157 water can freshen the North Atlantic and slow meridional overturning, subsequently
158 cooling the North Atlantic, but warming the North Pacific. This North Atlantic cooling
159 can result in the buildup of ice sheets and global sea level drops, closing Bering Strait. A
160 closed Bering Strait concentrates fresher waters in the North Pacific and more saline
161 waters in the North Atlantic. A more saline Atlantic means that stratification is low and
162 meridional overturning is increased. This increases oceanic heat transport to the North
163 Atlantic, triggers warming in the North Atlantic and ultimately ice sheets retreat and sea
164 level rises reconnecting the Pacific with the Atlantic (Hu et al., 2010).

Good
summary,
but reads
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concise.

165

166 3 Methods

167 3.1 Study Area and Sampling

168 The Integrated Ocean Drilling Program’s (IODP) Expedition 323, Site U1345, is located
169 on an interfluvial ridge near the shelf-slope break in the Bering Sea (Fig. 1). Navarin
170 Canyon, one of the largest submarine canyons in the world (Normack and Carlson, 2003)
171 is located just to the northwest of the site. Sediments were retrieved from ~1008 m of
172 water, placing the site within the center of the modern day oxygen minimum zone
173 (Takahashi et al., 2011). We focus on this site because of its proximity to the modern
174 marginal ice zone in the Bering Sea and observed high sedimentation rates.

175 Site U1345 was drilled five times during Exp. 323 and cores from four of these holes
176 were described onboard the JOIDES Resolution. This study focuses on a splice of 3 holes
177 that were correlated onboard the ship, so that core gaps in one hole are covered by core



178 material in other holes. In addition to the original analyses presented here, we refer to the
179 shipboard core descriptions and physical properties data (Takahashi et al., 2011) in our
180 interpretations. Depths are reported in CCSF-A, a correlated depth scale that allows for
181 direct comparison between drill holes. Units are meters below sea floor (mbsf). A small
182 syringe was used to collect approximately 1 cc of sediment periodically between 112.96
183 m and 136.40 mbsf. Sampling resolution varied for each analysis. Hyalochaete
184 *Chaetoceros* resting spores were counted on average every 20 cm (~600 yr resolution),
185 full diatom counts were carried out every 36 cm (~1000 yr resolution), calcareous
186 nannofossils were counted every 40 cm (~1200 yr resolution), grain size was analyzed
187 every 23 cm (670 yr resolution), and geochemistry was analyzed every 30 cm (800 yr
188 resolution).

189

190 3.2 Age Model

191 The age model (Fig. 3) is derived from the shipboard age model, which was developed
192 using magnetostratigraphy and biostratigraphy. First and last appearance datums for
193 diatoms and radiolarians make up the majority of the biostratigraphic markers used to
194 place the record in the correct general stratigraphic position (Takahashi et al., 2011).
195 Oxygen isotope measurements taken on the benthic foraminifera, *Uvigerina peregrina*,
196 *Nonionella labradorica*, and *Globobulimina affinis* (Cook et al., In Press) were then used
197 to tune site U1345 to the global marine benthic foraminiferal isotope stack (LR04)
198 (Lisiecki and Raymo, 2005) (Fig. 3). Based on this combined age model, MIS 11 spans
199 from 115.3 to 130.6 mbsf (Cook et al., In Press); however, the characteristic interglacial
200 isotopic depletion was not found in U1345 which means that the exact timing of peak
201 interglacial conditions is unknown.

202 The nearby core, IODP Exp 323, Site U1343 (Fig. 1) has an excellent oxygen isotopic
203 record during MIS 11 (Kim et al., 2014). We compared the two isotopic records and their
204 magnetic susceptibilities (Fig. 3) and found that even with only two tie points, there was
205 good correlation between the timing of the onset of laminated intervals and also the
206 interglacial increase in magnetic susceptibility (Fig. 3). We added one additional tie point
207 to connect the inflection points in magnetic susceptibility. In U1343, this point occurred

MS correlations look good; maybe some compression/expansion visible?
5180 looks okay, but error is acknowledged
~~is not; needs more data~~

this is odd.....



208 at 398.50 ka. U1345 was shifted 1.5 ka younger in order to align with U1343. The
209 addition of this point allows us to have more confidence in the timing of peak interglacial
210 conditions in U1345. However, given the oxygen isotope sampling resolution, as well as
211 the stated error in the LR04 dataset (4 kyr), we estimate the error of the age model could
212 be up to 5 kyr. [Therefore, we urge caution when interpreting millennial scale changes at
213 the site or comparing our record to others that examine MIS 11 at millennial scale
214 resolution or finer.]

[Good acknowledgement of error!

215 Sedimentation rates during the study interval range from 29 cm/kyrs to 45 cm/kyr with
216 the highest sedimentation rates occurring during glacial periods.

217

218 3.3 Diatom Analysis

219 In order to quantify the number of diatom valves deposited per gram of sediment, diatom
220 slides were prepared according to the method described in Scherer (1994). This method
221 allows for a direct comparison of diatom accumulation in the sediments between samples,

222 [though not diatom flux] Cover slips were mounted on cleaned microscope slides using
223 hyrax in toluene (refractive index: 1.7135). At least 300 diatom valves were identified in
224 at least three random transects across the slide using a light microscope at magnifications
225 from 1000x to 1250x (see Armand et al., 2005; Sancetta, 1979; Sancetta and Silvestri,
226 1986; Scherer, 1994). The portion of the slide that was examined was measured using a
227 stage micrometer. Partial valves were counted according to the methods of Schrader and
228 Gersonde (1978). All diatoms were identified to the species level when possible
229 following published taxonomic descriptions and images (Hasle and Heimdal, 1968;
230 Koizumi, 1973; Lundholm and Hasle, 2008, 2010; Medlin and Hasle, 1990; Medlin and
231 Priddle, 1990; Onodera and Takahashi, 2007; Sancetta, 1982, 1987; Syvertsen, 1979;
232 Tomas, 1996; Witkowski et al., 2000). Diatom counts were transformed into relative
233 percent abundances. Absolute abundances (diatoms per gram sediment) were calculated
234 following the methods of Scherer (1994). Diatom taxa were then grouped according to
235 ecological niche (Table 1) based on biological observations (Aizawa et al., 2005; Fryxell
236 and Hasle, 1972; Håkansson, 2002; Horner, 1985; Saito and Taniguchi, 1978;
237 Schandelmeier and Alexander, 1981; von Quillfeldt, 2001; von Quillfeldt et al., 2003)

*Huh?
You mean
flux rate
right?*



238 and statistical associations (Barron et al., 2009; Caissie et al., 2010; Hay et al., 2007;
239 Katsuki and Takahashi, 2005; Lopes et al., 2006; McQuoid and Hobson, 2001; Sancetta,
240 1982, 1981; Sancetta and Robinson, 1983; Sancetta and Silvestri, 1986; Shiga and
241 Koizumi, 2000). In cases where a diatom species was reported to fit into more than one
242 environmental niche, it was grouped into the niche where it was most commonly
243 recognized in the literature.

244

245 **3.4 Calcareous Nannofossils**

246 In order to quantify calcareous nannofossils per gram of sediment, a total of 18 samples
247 were prepared following the methodology of Flores and Sierro (1997). A known mass of
248 dried sediment was diluted in a known volume of buffered water. A small fraction was
249 extracted with a micropipette and dropped onto a petri dish previously filled with
250 buffered water and with a cover slip in its bottom. After settling overnight, the excess
251 water was removed and the slide was left to dry and then mounted using Canada balsam.

252 Observations were made using a Zeiss polarized light microscope at 1000x
253 magnification. Samples were considered barren if no coccoliths were found in at least
254 165 randomly selected fields of view. All taxa were identified to the species or variety
255 level, following Flores et al. (1999) and Young et al. (2003).

256

257 **3.5 Grain Size**

258 Volume percent of grains in 109 size bins ranging from 0.01 μm to 3500 μm was
259 measured using a Malvern Mastersizer 3000 with the Hydro MV automated wet
260 dispersion unit. Samples were prepared by adding 200 μl of the deflocculant, sodium
261 hexametaphosphate, to 0.2 mg dry sediment. In this way, we were able to quantify all
262 sediment types including biogenic and terrigenous grains.

263



264 **3.6 Geochemistry**

265 Sediment samples were freeze-dried then ground. An aliquot of homogenized sediment
266 was treated to remove carbonates using pH 5 buffered acetic acid. The carbon (from the
267 acidified sediment) and nitrogen (from the unacidified sediment) isotopic and elemental
268 composition of organic matter was determined by Dumas combustion using a Carlo Erba
269 1108 elemental analyzer coupled to a Thermo-Finnigan Delta Plus XP isotope ratio mass
270 spectrometer at the University of California Santa Cruz Stable Isotope Laboratory. The 1-
271 sigma precision of stable isotope measurements and elemental composition of carbon are
272 0.2‰ and 0.03‰, respectively, and for nitrogen are 0.2‰ and 0.002‰, respectively.
273 Percent CaCO₃ was calculated according to Schubert and Calvert (2001).

274
275 **4 Results**

276 **4.1 Sedimentology**

277 In general the sediments at Site U1345 are massive with centimeter-scale dark or coarse-
278 grained mottles. The sediments are mainly composed of clay and silt with varying
279 amounts of diatoms, sand, and tephra throughout. Laminated intervals bracket MIS 11
280 (Fig. 4). The proportion of diatoms relative to terrigenous or volcanogenic grains is
281 highest during laminated intervals and lowest immediately preceding Termination V
282 (~425 ka). Vesiculated tephra shards were seen in every diatom slide analyzed. Several
283 thin (< 1 cm) sand layers and shell fragments were visible on the split cores, especially
284 during MIS 12. However, high-resolution grain size analyses show that the median grain
285 size was lowest during MIS 12, increasing from approximately 14 μm to 21 μm at the
286 start of Termination V at 424.5 ka (130.92 mbsf). [Median grain size peaks at 84 μm
287 between 401 and 407 ka (125.42-123.62 mbsf). This interval is also the location of an
288 obvious sandy layer in the core.] After this interval, median grain size remains steady at
289 about 17 μm. Subrounded to rounded clasts (granule to pebble) commonly occur on the
290 split surface of the cores. We combined clast and sand layer data from all Holes at Site
291 U1345 when examining their distribution (Fig. 4).

*Isotope standards?
(Please include "standard" isotope details,
e.g., referenced to which int. standards,
‰ notation, etc.)*

*Is this a turbidite?
If so, then "continuous" diagnosis problematic
→ low diatom abundance
→ low δ¹⁵N
→ high P.
→ sulcata?*

Transported



292 A 3.5 m thick laminated interval, estimated to span 12 kyrs (see Table 2 for depths and
293 ages) is deposited beginning during Termination V. Although the termination is short
294 lived and the laminated interval quite long, we refer to it as the Termination V
295 Laminations for the sake of clarity throughout this manuscript. The next laminated
296 interval occurs at about 394 ka and lasts approximately 1100 years. During the transition
297 from late MIS 11 to MIS 10, a series of four thin laminated intervals are observed. Each
298 interval lasts between 0.34 and 1.25 ka (Table 2). In general, the upper and lower
299 boundaries of laminated intervals are gradational; however the boundaries between
300 individual lamina are sharp (Takahashi et al., 2011). There are two types of laminations.
301 The Termination V Laminations are Type I laminations: millimeter-scale alternations of
302 black, olive gray, and light brown triplets. In addition to containing a high proportion of
303 diatoms, this laminated interval also contains high relative proportions of calcareous
304 nannofossils and foraminifera (Takahashi et al., 2011). The majority of laminations are
305 parallel; however, a 7 cm interval during the Termination V Laminations is highly
306 disturbed in Hole A, showing recumbent folds in the laminations (Takahashi et al., 2011).
307 This interval was not sampled. Type II laminations occur throughout the remainder of
308 MIS 11. These laminations have fewer diatoms and tend to be couplets of siliciclastic
309 sediments with <40% diatoms (Takahashi et al., 2011). Percent CaCO₃ also increases
310 during these laminations though foraminifera and calcareous nannofossils are very rarely
311 seen. None of these later laminated intervals contain any evidence of disturbance.

Is this
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312

313 4.2 Diatoms

314 4.2.1 Diatom Assemblages

I like the diversity indices!

315 A total of 97 different diatom taxa were identified. Individual samples include between
316 26 and 46 taxa each with an average of 37 taxa. Both types of laminated intervals contain
317 fewer taxa than bioturbated intervals do. This decrease in diversity is confirmed using the
318 Margalef, Simpson, and Shannon indices which all show similar down-core profiles (Fig.
319 5). The Margalef index is a measure of species richness (Maurer and McGill, 2011). It
320 shows a decrease in the number of taxa during four out of five laminated intervals that are
321 sufficiently well sampled. Between laminated intervals, there is a noted decrease in taxa

⊕ probably
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to cite one
in subsection
since all tests
are derived
from this text.

Species
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322 at 388 ka. Instead of species richness, the Simpson index measures the evenness of the
323 sample. Values close to 1 indicate that all taxa contain an equal number of individuals,
324 while values close to 0 indicate that one species dominates the assemblage (Maurer and
325 McGill, 2011). In general, the Simpson index is close to 1 throughout the core indicating
326 a rather even distribution of diatom valves across all taxa; however, during the
327 Termination V Laminations and the most recent two laminations, the Simpson index
328 drops reflecting the dominance by *Chaetoceros* RS during these intervals (Fig. 5). [It does
329 not come close to 0, which would likely indicate a strong dissolution signal.] The Shannon
330 diversity index measures both species richness and evenness (Maurer and McGill, 2011).
331 Correspondingly, it is low during three of the laminated intervals, high during MIS 12
332 and peaks at 397 ka (Fig. 5).

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

Fig. 6
has label
as "T. trifulta"

341 Relative percent abundances of *Chaetoceros* RS are highest (up to 69%) during the
342 Termination V Laminations and, ^{follow} in general, mimic the pattern of both diatom
343 accumulation rate and insolation at 65° N (Berger and Loutre, 1991). When insolation is
344 low, *Chaetoceros* RS are also low (Fig. 7). *T. antarctica* RS, in contrast, are lowest
345 during the Termination V Laminations (as low at 1%) and higher during MIS 12 and after
346 406 ka (above 125.00 mbsf and 112.97 mbsf). This taxon peaks at 38% relative
347 abundance at 390 ka (120.45 mbsf; Fig. 6).

348 Relative percent abundances of the characteristic marginal ice zone species, *F. oceanica*
349 and *F. cylindrus* (Caissie et al., 2010; Saito and Taniguchi, 1978; Sancetta, 1982; von
350 Quillfeldt et al., 2003), oscillate between ~10% and less than 3% of the diatom
351 assemblage and are highest during MIS 12 and all laminated intervals. They are both at



352 their lowest between ~411 to ~400 ka (126.62 to 123.45 mbsf). The neritic species and
353 moving water indicator, *P. sulcata* is lowest during the laminated intervals. It reaches a
354 maximum (34% relative abundance) at 404 ka (124.61 mbsf). *P. sulcata* remains
355 moderately high (~10%) during non-laminated intervals. *L. cf. ocellata* is the dominant
356 taxa in the fresh water group and the variability in its abundances is discussed below. *S.*
357 *trifultus* follows a very similar distribution to the fresh water group and *L. cf. ocellata*. It
358 is relatively high (~4%) during MIS 12, is virtually absent from the sediments during the
359 Termination V Laminations, and then increases again until it peaks at 10% relative
360 abundance at 400 ka (123.22 mbsf). *Thalassiosira binata* and other small (<10 µm in
361 diameter) *Thalassiosira* species have similar distributions with low relative abundances
362 throughout the record (< 6%) except for a small peak between 397 and 386 ka (122.62
363 and 119.07 mbsf). The relative percent abundances of *N. seminae* are discussed below.
364 The largest peak in *N. seminae* is at 392 ka (121.2 mbsf) (Fig. 6).

365

366 4.2.2 Diatom Proxies

367 Diatoms, like many organisms, thrive under a specific range of environmental conditions
368 or optima and these optima are different for each species. For this reason, diatom
369 assemblages are excellent paleoceanographic indicators (Smol, 2002). Table 1 delineates
370 which species were grouped together into specific environmental niches. Our
371 interpretations of the paleoceanographic sea surface conditions at the Bering Sea shelf-
372 slope break during MIS 12 to 10 are based on changes in these 8 groups and the
373 variability of *Neodenticula seminae*, an indicator of the Alaskan Stream and North
374 Pacific water (Katsuki and Takahashi, 2005; Sancetta, 1982) (Fig. 7).

375

376 4.2.2.1 Sea Ice Species

377 Epontic diatoms are those that bloom attached to the underside of sea ice or within brine
378 channels in the ice. This initial bloom occurs below the ice as soon as enough light
379 penetrates to initiate photosynthesis in the Bering Sea, which can occur as early as March
380 (Alexander and Chapman, 1981). The centric diatom, *Melosira arctica*, and pennate

Huh?
Down slope
transport?

Not
on Fig. 6

On Fig. 6,
listed as
Cyclosetella



381 diatoms, *Nitzschia frigida* and *Navicula transitrans* are among the major components of
382 the eponitic diatom bloom (von Quillfeldt et al., 2003) and all are found in the sediments
383 at U1345A, although they tend to be quite rare.

384 A second ice-associated bloom occurs as sea ice begins to break up on the Bering Sea
385 shelf. This bloom is referred to as the marginal ice zone bloom and many of its members
386 are common species in the sediment assemblage including the pennate diatom,
387 *Staurosirella* cf. *pinnata* (= *Fragilaria* cf. *pinnata*), and the centric diatoms, *Bacterosira*
388 *bathyomphala* and several *Thalassiosira* species including *Thalassiosira antarctica*
389 (Schandelmeier and Alexander, 1981; Shiga and Koizumi, 2000; von Quillfeldt et al.,
390 2003). *T. antarctica* resting spores have been classified in various ways in the past and
391 their ecology is not well understood. However, *T. antarctica* is a member of the marginal
392 ice zone flora (von Quillfeldt et al., 2003) and was the only organism found in thick pack
393 ice (Horner, 1985). The resting spores are associated with coastal or ice-margin waters
394 that range from -1 to 4° C and have relatively low salinity (25–34‰) (Barron et al.,
395 2009; Shiga and Koizumi, 2000). In Antarctica, *T. antarctica* blooms in concert with
396 frazil and platelet ice growth in the fall (Pike et al., 2009). This same association has not
397 yet been observed in the Arctic, though it is a possibility. High abundances might indicate
398 that ice formed early enough in the fall that light and/or nutrients were high enough to
399 support *T. antarctica* growth then.

400 Several diatom species are present in both types of sea ice blooms, and so while they are
401 indicators of ice presence, they cannot be used to distinguish between types of sea ice.
402 These species are grouped under “both ice types” and include such common diatoms as
403 *Fragilariopsis oceanica*, *Fragilariopsis cylindrus*, *Fossula arctica*, and many Naviculoid
404 pennate diatoms (Saito and Taniguchi, 1978; Sancetta, 1981; Schandelmeier and
405 Alexander, 1981; von Quillfeldt, 2001; von Quillfeldt et al., 2003).

406 Eponitic species are present in low relative percent abundances ($< 5\%$) throughout much
407 of the record, but there is a marked absence of them during the laminated interval from
408 423 to 410 ka (129.96–126.45 mbsf). Marginal ice zone species fluctuate between 4% and
409 14% throughout the record and do not show any trends in abundance changes. The



410 grouping of species found both within the ice and in the water surrounding ice, however,
411 is also somewhat reduced during laminated intervals (Fig. 7).

412

413 4.2.2.2 Warmer Water Species

414 Diatoms associated with warmer water or classified as members of temperate to
415 subtropical assemblages are rare in this record; however, they are present. This group
416 includes *Azpeitia tabularis*, *Thalassiosira eccentrica*, *Shionodiscus oestrupii*
417 (= *Thalassiosira oestrupii*), and *Thalassiosira symmetrica*. (Fryxell and Hasle, 1972;
418 Lopes et al.; Sancetta; Sancetta and Silvestri, 1986).

419 Relative abundances of warmer water species are quite low throughout the record (<5%),
420 and are highest (3-4%) during mid to late MIS 11 approximately ~410 to 391 ka (126.74
421 to 116.50 mbsf) (Fig. 7).

422

423 4.2.2.3 Alaskan Stream Species

424 *Neodenticula seminae* is often used as a tracer of North Pacific water, in particular the
425 Alaskan Stream (e.g. Caissie et al., 2010; Katsuki and Takahashi, 2005). But its
426 distribution also varies on glacial-interglacial time scales within the Pacific Ocean
427 (Sancetta and Silvestri, 1984). It is adapted to the low productivity of the North Pacific
428 gyre and is heavily silicified which could lead to high proportions of *N. seminae*
429 reflecting simply dissolution of finely silicified diatoms (Sancetta, 1982, 1981). *N.*
430 *seminae* is used here as a tracer of Pacific water with the above caveats.

431 Absolute abundances of *N. seminae* began to increase at 422 ka as global eustatic sea
432 level rises above -50 mpsl. Abundance then decreases slowly over the course of the
433 Termination V Laminations and peaks again at 392 ka and 382 ka. As sea level drops
434 below -50 mpsl, *N. seminae* is no longer present at U1345. Relative percent abundances
435 remain stable at ~2% relative percent abundance between 422 and 400 ka (129.62-123.62
436 mbsf), then peaks at 13% at 392 ka (121.22 mbsf) (Fig. 6). Low proportions of *N.*
437 *seminae* during the Termination V Laminations are likely due to the overwhelming
438 proportion of *Chaetoceros* RS during this time.



439

440 4.2.2.4 High Productivity Species

441 *Chaetoceros* resting spores are the dominant taxa included in the high productivity group.
442 *Chaetoceros* RS have been used as indicators of high productivity (e.g. Caissie et al.,
443 2010) and are often found in locations influenced by intense upwelling (Lopes et al.,
444 2006; Sancetta, 1982). In addition, *Chaetoceros socialis* can be a common member of the
445 marginal ice zone bloom (von Quillfeldt, 2001) and a dominant member of the sub ice
446 bloom (Melnikov et al., 2002). *Chaetoceros furcellatus* is also associated with the
447 marginal ice zone bloom (von Quillfeldt, 2001). Unfortunately, the morphology of
448 *Chaetoceros* resting spores is quite variable, and they cannot be classified definitively
449 without the more labile vegetative cell also present (Tomas, 1996). *Odontella aurita*,
450 *Thalassionema nitzschioides* are also included in the high productivity group although
451 they are also associated with the marginal ice zone (von Quillfeldt et al., 2003), areas of
452 high productivity (Aizawa et al., 2005), and upwelling (Lopes et al., 2006; Sancetta,
453 1982). [It should be noted that we can not discern between high productivity due to
454 upwelling and high productivity due to other factors because the diatom proxies are not
455 sufficiently refined to distinguish between the two.] Yes! Right on!

456 It may be that the combination of upwelling and ice melt at the shelf slope break in the
457 Bering Sea is responsible for correlation between these two environmental niches. The
458 spring-blooming *Thalassiosira pacifica* and small (<10 μm) *Thalassiosira* species round
459 out the high productivity group due to their associations with high productivity and
460 upwelling specifically in the Bering Sea and North Pacific (Aizawa et al., 2005; Hay et
461 al., 2007; Katsuki and Takahashi, 2005; Lopes et al., 2006; McQuoid and Hobson, 2001;
462 Saito and Taniguchi, 1978).

463 Like *Chaetoceros* RS, high productivity species mimic the trend of the insolation curve
464 (Berger and Loutre, 1991) with highest relative abundances (60-70%) occurring during
465 high levels of insolation (Fig. 7). The lowest relative abundances (15-20%) of high
466 productivity species occur between 403 and 390 ka (124.21 to 120.07 mbsf) when both
467 obliquity and insolation are low. High productivity species are high during both the
468 Termination V Laminations and during the late MIS 11 laminations (Fig. 7).



469

470 4.2.2.5 Dicotermal Water Indicators and Late Summer Species

471 A cold layer of water found between seasonally warmer surface and warmer deep water
472 characterizes dicothermal water. It is stable because of its very low salinity. In the Sea of
473 Okhotsk and the Bering Sea, the dicothermal layer is often associated with melting sea
474 ice. The highest abundances of *Shionodiscus trifultus* are found associated with this
475 highly stratified, cold water in the Sea of Okhotsk today (Sancetta, 1981; Sancetta and
476 Silvestri, 1986).

477 *Actinocyclus curvatulus* has been observed living in water surrounding sea ice (von
478 Quillfeldt et al., 2003); however, it is neither a common member of the marginal ice zone
479 flora, nor is its spatial distribution in the Bering Sea consistent with the distribution of sea
480 ice (Sancetta, 1982). Its relative percent abundances are more closely associated with
481 those of *S. trifultus* (Sancetta, 1982), and so it was grouped with *S. trifultus* as an
482 indicator of dicothermal water.

483 Genera present in the Bering Sea during late summer (*Coscinodiscus*, *Leptocylindrus*,
484 and *Rhizosolenia*) (Aizawa et al., 2005; Lopes et al., 2006; von Quillfeldt et al., 2003)
485 tend to co-vary with the dicothermal water indicators, so the two groups were merged for
486 comparison with other diatom groups.

487 These two groups are highest (18% relative abundance) at ~401 ka (123.62 mbsf) as
488 insolation declines. This peak is coeval with the peak in fresh water species and an
489 intermediate peak in *N. seminae* and occurs immediately following a peak in neritic
490 species. Dicotermal water indicators and summer species are lowest (< 1%) during the
491 Termination V Laminations (~424-412 ka). Intermediate relative abundances (1% to 5%)
492 occur during MIS 12 and above 392 ka (121.04 mbsf) (Fig. 7).

493

494 4.2.2.6 Shelf to Basin Transport Indicators

495 Freshwater species are rare, but present in the record. They include the centric species
496 *Lindavia cf. ocellata* and *L. radiosa* (Håkansson, 2002). Additional freshwater diatoms
497 found in the record are species also found in sea ice (*S. cf. pinnata*) (von Quillfeldt et al.,

check
out

Ren et al
2014 (PPP)

As earlier,
Fig 6 has this
labelled as *Cyclotella*



498 2003) or in the neritic zone (*Cyclotella stolorum*) (Barron et al., 2009) and so these
499 species were placed in the marginal ice zone and neritic groups respectively.

500 The dominant species in the neritic group is *Paralia sulcata*, which is an interesting
501 species because it can be either planktic or benthic (Kariya et al., 2010) and is associated
502 both with river deltas and the species *Melosira sol* (Sancetta, 1982). It can be a member
503 of the marginal ice zone assemblage (von Quillfeldt et al., 2003) though Pushkar (1999)
504 asserts that *P. sulcata* indicates water shallower than 20 m. Its high abundances in Bering
505 Strait may mean that it is adapted to moving water (Sancetta, 1982). *P. sulcata* thrives in
506 water that is warmer than 3 degrees (Zong, 1997), with low light (Blasco et al., 1980) and
507 low salinity (Ryu et al., 2008).

508 The fresh water group is notably absent from much of the core, but prevalent between
509 401 and 392 ka (123.70 mbsf and 121.20 mbsf); it reaches its highest relative percent
510 abundance (12%) at 401 ka (123.62 mbsf). Neritic species, on the other hand maintain
511 ~10% relative abundance throughout the core. They are lowest during the Termination V
512 Laminations and increase dramatically around 404 ka (124.61 mbsf) to almost 50% of the
513 assemblage (Fig. 7).

514

515 4.3 Calcareous Nannofossils

516 Calcareous nannofossils were examined between 432-405 ka (133.4 to 125.0 mbsf); one
517 third of the samples were barren and only one sample (418 ka; 128.8 mbsf) had sufficient
518 individuals to estimate relative percent abundances (Fig. 7). This sample is located
519 midway through the Termination V Laminations when the diatom assemblage is
520 overwhelmingly dominated by *Chaetoceros* RS. Small *Gephyrocapsa* dominates (>50%)
521 the calcareous nannofossil assemblage. There are 35% medium *Gephyrocapsa*, 9%
522 *Coccolithus pelagicus*, and 1% *G. oceanica*.

523

Barron '09
classifies
P. sulcata
as "transported
in the GoAK"
⊕ see
complications
raised by
Ren '14



524 **4.4 Geochemistry**

~~Handwritten~~ → missing references to figures

525 **4.4.1 Organic and Inorganic Carbon Content**

526 Total organic carbon (TOC) roughly follows the trend of relative percent abundances of
527 *Chaetoceros* RS, with higher values during the Termination V Laminations. Mean TOC
528 value during MIS 12 is 0.76%, and during the Termination V Laminations, it is 1.11%.
529 TOC decreases [temporarily in sync] with depleted $\delta^{15}\text{N}$ values, before rising linearly from
530 404 ka (124.77 mbsf) to 374 ka (115.39 mbsf). TOC is again high during the late MIS
531 11/MIS 10 laminations.

532 In contrast, inorganic carbon, calculated as % CaCO_3 is less than 1% for most of the
533 record; however, it increases up to 3.5% during the laminated intervals and also at 382 ka
534 (117.87 mbsf), 392 ka (110.00 mbsf), and 408 ka (125.82 mbsf).

535

536 **4.4.2 Terrigenous Input Indicator (C/N)**

→ Molar or atomic?

537 The ratio, C/N is one of two proxies used as indicators of marine versus terrigenous
538 organic matter, with marine values typically ranging from 5-7 and terrigenous ratios over
539 20 (Meyers, 1994; Redfield et al., 1963).

540 Throughout the record, C/N indicates primarily a marine source for organic matter.
541 During MIS 12, C/N is highly variable, when sea level is below -50 m aspl. As sea level
542 rises during Termination V, C/N values increase from 6 to more than 9. The highest C/N
543 value occurs at the start of the Termination V Laminations. C/N decreases as sea level
544 rises until at 400 ka (123.62 mbsf) it stabilizes near 7 for the remainder of the record.

545

546 **4.4.3 Bulk Sedimentary Stable Isotopes**

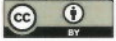
→ section too brief for those complex data!

547 **4.4.3.1 Carbon Isotopes**

548 Stable isotopes of carbon are also used as an indicator of marine vs. terrigenous organic
549 matter with $\delta^{13}\text{C}$ values near -27 indicating C3 plant-sourced organic matter; values
550 between -22 and -19 are typical for Arctic Ocean marine phytoplankton and -18.3 is
551 average for ice-related plankton (Schubert and Calvert, 2001). However, it has been

Need cross-plots of $\delta^{13}\text{C}$, N/C, + $\delta^{15}\text{N}$ for the OM source discussion

Both Meyers + Redfield use molar, but EA output is commonly atomic



Ref; see (at least) Rau et al. '89
+ Laws et al. '95

552 shown that $\delta^{17}\text{C}$ is sometimes related more to growth rate, cell size, and cell membrane
553 permeability, so it may reflect changing phytoplankton groups instead of simply marine
554 vs. C3 plant sources of organic matter in U1345.

Statistics?

555 Carbon isotopic values range between -22 ‰ and -26 ‰ and are generally anticorrelated
556 with C/N values. These values indicate a mix of marine phytoplankton and C3 plants as
557 the main contributors to organic matter at the site. At the onset of the Termination V
558 Laminations, $\delta^{13}\text{C}$ becomes more negative and then gradually increases to a maximum of
559 -22.33 at 404 ka (124.62). After 400 ka (123.5 mbsf), $\delta^{13}\text{C}$ is relatively stable around -
560 23.5‰.

561

562 4.4.3.2 Nitrogen Isotopes

563 Nitrogen, in the form of nitrate, is a key nutrient for phytoplankton growth. Diatoms
564 preferentially assimilate the lighter isotope, ^{14}N , which in turn enriches surface waters
565 with respect to ^{15}N (Barron et al., 2009; Shiga and Koizumi, 2000). Keeping in mind the
566 effects of nitrification of oxygen rich and poor sediments (Brunelle et al., 2007), the
567 efficiency of nitrogen utilization can be estimated by examining the $^{15}\text{N}/^{14}\text{N}$ ratio of
568 nitrogen in either bulk sedimentary organic matter, with enriched values of $\delta^{15}\text{N}$
569 indicating higher nutrient utilization. Sponge spicules (very low $\delta^{15}\text{N}$ values) and
570 radiolarians (highly variable $\delta^{15}\text{N}$ values) may contaminate the $\delta^{15}\text{N}$ of bulk organic
571 matter, however we looked for and found no correlation between spicule abundance and
572 $\delta^{15}\text{N}$ in our samples.

No $\delta^{15}\text{N}$
(or N!)
in this
at all!
Maybe you
mean

Addison '12?
in paleoceanography

573 Surprisingly, $\delta^{15}\text{N}$ is relatively stable throughout the study interval, fluctuating around an
574 average value of 6.4‰, though there are several notable excursions. Coeval with sea level
575 rise and increased relative percent *Chaetoceros* RS, $\delta^{15}\text{N}$ decreased 2.7‰ to 4.4‰ before
576 recovering to average values during the Termination V Laminations. Two other
577 depletions occur at 405 ka (124.77 mbsf) and 393 ka (121.62 mbsf), the first is the most
578 extreme and reaches 2.9‰.

579

This is fairly high, could there be an influence from denitrification?



580 5 Discussion

581 The study interval can be broken into five zones based on changes in diatom assemblages
582 and lithology (Fig. 7): MIS 12, Termination V, Peak MIS 11, Beringian Glacial Initiation,
583 and Late MIS 11. These zones reflect changing sea ice, glacial ice, sea level, and SST and
584 correspond to events recognized elsewhere in ice cores and marine and lake sediments.

585

586 5.1 Marine Isotope Stage 12 and Early Deglaciation (beginning of record to 587 425 ka)

588 The beginning of the record to 425 ka chronicles conditions at the end of MIS 12.
589 Although diatom accumulation rate is quite low, a relatively diverse assemblage
590 characterizes this period (Fig. 5) with moderate amounts of sea ice, high productivity, and
591 dicothermal species (Fig. 7), indicating seasonal sea ice with highly stratified waters
592 during the ice-melt season. Nitrogen isotopes indicate high nutrient utilization (Fig. 7)
593 consistent with nitrogen-limited productivity in stratified waters. Similarly, the North
594 Atlantic was also highly stratified with significantly reduced NADW production (Poli et
595 al., 2010). High stratification appears to have led to lowered productivity in both the
596 Atlantic and Pacific.

597 Sea level was low during this interval (Rohling et al., 2010), placing U1345 proximal to
598 the Beringian coast (Fig. 2). With the Beringian shelf exposed, the continent was
599 relatively cold and arid (Glushkova, 2001). In western Beringia, Lake El'gygytyn was
600 perennially covered with ice, summer air temperatures were warming from 4 to 12° C
601 and annual precipitation was low (200-400 mm) (Vogel et al., 2013).

602 Numerous shell fragments, two sand layers and the highest percentages of clay-sized
603 sediments in the record were deposited during MIS 12 (Figs 4 and 8) indicating input of
604 terrigenous material, however, both C/N and $\delta^{13}\text{C}$ indicate that the organic matter during
605 MIS 12 is of marine origin. Non-organic, terrigenous material could be transported to
606 U1345 by large glacial meltwater rivers, icebergs, or sea ice. It is unlikely that meltwater
607 rivers played a large role in sediment transport at this time because terrigenous organic
608 matter and fresh water diatoms are absent and there are only moderate amounts of

marked as '09 on Fig. 7

An important source you have neglected is the glacial Yukon River.

Please see
21 Van Lanningham, '09 in EPSL.



609 diatoms transported from shallow waters (Fig. 8). This may also reflect the reduced area
610 of submerged continental shelf. In addition, glacial ice was likely restricted to mountain-
611 valley glaciers, similar to the last glacial maximum (e.g. Glushkova, 2001). These small,
612 distant glaciers would not have produced large amounts of ice bergs though occasional
613 glacial ice rafted debris (IRD) may have come from the Koryak Mountains, Aleutians or
614 Beringia. Consistent with this, sediments typical of glacial IRD, such as dropstones, are
615 sparse. Terrigenous materials found in MIS12 sediments are most likely evidence of sea
616 ice rafting which tends to preferentially entrain clay and silt (Reimnitz et al., 1998) or of
617 minor downslope transport. In contrast, the North Atlantic is surrounded by ice sheets
618 readily calving ice bergs and MIS 12 is characterized as an intense glacial period with ice
619 rafted debris found as far south as Bermuda (Poli et al., 2000). Evidence for warming and
620 the reduction of IRD begins as early as 430 ka in the North Atlantic (Kandiano et al.,
621 2012) and the strength of the Gulf Stream increases in step with this glacial ice loss
622 (Chaisson et al., 2002).

623

624 **5.2 Early MIS 11: Termination V (425-423 ka)**

625 Termination V is the transition from MIS 12 to MIS 11. Worldwide, it is a rapid
626 deglaciation that is followed by a long (up to 30 kyrs) climate optimum (Milker et al.,
627 2013). At U1345, it can be broken into two stages, the first part from 425-423 ka, and the
628 second part from 423-410 ka, which is notably dominated by laminated sediments and is
629 discussed in the next section. The first part of Termination V corresponds with a local
630 maxima in insolation at 65°N (Schimmelmann et al., 1990) and increasing temperatures
631 in Antarctica (EPICA community members, 2004), the North Atlantic (Voelker et al.,
632 2010), and globally (Milker et al., 2013).

633 At U1345, the first part of Termination V is expressed as increasing absolute diatom
634 abundances and relative percent abundance of *Chaetoceros* RS while sea ice diatoms and
635 $\delta^{15}\text{N}$ values decrease (Fig. 7) indicating gradually increasing productivity coupled with
636 decreasing nutrient utilization and sea ice.

637 At the same time, episodic increases in productivity were occurring in places as distant as
638 Lake Baikal (Prokopenko et al., 2010) and the North Atlantic (Chaisson et al., 2002;

From your plots (Fig. 7), it
looks like there are only 2-3
data points in this time, and
gradational
w.r.t. MIS12.

Is this the evidence for upwelling? Are
there no
diatom upwelling
indicators other
than
Chaetoceros RS?



639 Dickson et al., 2009; Poli et al., 2010) and NADW formation was intensifying (Poli et al.,
640 2010). Ventilation of NADW generally continues to increase from 424 to 410 ka to its
641 strongest and then weakens over the course of the interglacial (Thunell et al., 2002). In
642 addition, the flux of terrigenous dust was decreasing near Antarctica reflecting perhaps a
643 decrease in the strength of Southern Ocean winds (Wolff et al., 2006). [Evidence for
644 higher productivity in the Bering Sea, possibly caused by intensified upwelling, suggests
645 teleconnections between NADW formation, the strength of the southern winds, upwelling
646 in the North Pacific, and northward flow through Bering Strait (e.g. DeBoer and Nof,
647 2004).

648 } This seems like a stretch for only
a hand full of data points.

649 5.2.1 Early MIS 11, part 2: Laminations (423-410 ka)

650 The most prominent expression of Termination V is a 3.5 m thick laminated interval
651 deposited beginning at 423 ka (Fig. 7) when insolation was high at 65°N (Berger and
652 Loutre, 1991). Its presence indicates that the bottom water at 1,000 m in the Bering Sea
653 was dysoxic for more than 11 kyrs. These laminations are characterized as Type I
654 laminations with a notably high diatom content (Fig. 4). Several lines of evidence point
655 towards high productivity among multiple phytoplankton groups as opposed to simply a
656 change in preservation. There is a two orders of magnitude increase in diatom
657 abundances since MIS 12, a low-diversity diatom assemblage dominated by *Chaetoceros*
658 RS, an abrupt increase in percent organic carbon, high percent CaCO₃ and abundant
659 calcareous nannofossils dominated by small *Gephyrocapsa*. Furthermore, enriched $\delta^{15}\text{N}$
660 values indicate increased nitrogen utilization that likely fed this increased productivity
661 (Fig. 7). Dysoxia could promote denitrification + elevated $\delta^{15}\text{N}$

662 Sea ice is reduced during this interval with almost no eponitic diatoms present and
663 reduced amounts of other sea ice diatoms (Fig. 7). The $\delta^{13}\text{C}$ pattern of depleted values at
664 the start of the laminated interval and increasingly enriched values until about 409 ka is
665 very similar to the C_{org}/N ^{data} story (Fig. 7) reflecting the highest contribution from C3 plant
666 organic matter at the onset of the laminated interval as the tundra-covered Bering Shelf is
667 flooded. However, the depletion in $\delta^{13}\text{C}$ during the Termination V Laminations occurs at



668 the same time that *Chaetoceros* RS overtake the assemblage (Fig. 7), so a species effect
669 cannot be ruled out.

670 The diatom record, on the other hand has the lowest contribution of neritic diatoms
671 during the laminated interval and virtually no fresh water diatoms (Fig. 7), suggesting
672 that although terrigenous organic matter was an important input at the site, coastal, river,
673 or swamp/tundra diatoms were not major constituents of this terrigenous organic matter.

674 The sum of this evidence of high productivity, reduced sea ice, and terrigenous input is
675 similar to changes in productivity in this region during Termination I (Brunelle et al.,
676 2007; Caissie et al., 2010). At the start of Termination I, productivity initially increased
677 while nitrogen utilization decreased, then an abrupt increase in productivity and nitrogen
678 utilization was recorded (Brunelle et al., 2007; Brunelle et al., 2010). It is plausible that
679 increased nitrogen availability drove higher primary productivity as floods scoured fresh
680 organic matter from the submerging continental shelf (Bertrand et al., 2000). Rapid input
681 of bioavailable nitrogen as the shelf was inundated has been suggested to explain
682 increasing productivity during the last deglaciation in the Sea of Okhotsk (Shiga and
683 Koizumi, 2000) and during MIS 11 in the North Atlantic (Poli et al., 2010) and also may
684 have contributed to dysoxia by ramping up nutrient recycling, bacterial respiration, and
685 decomposition of organic matter in the Bering Sea.

686 The brief nitrogen utilization decrease just prior to the laminations (Fig. 7), suggests that
687 productivity was limited by some other factor, such as light or micronutrients, and could
688 not increase proportional to the increase in available nitrogen. Lam (2013) suggests that
689 during the last deglaciation, a breakdown in stratification limited productivity by creating
690 a very deep mixed layer that extended below the photic zone. This seems possible during
691 Termination V, since diatom indicators for stratified waters (dicothermal species) and
692 epontic diatoms decline coeval with the increase in productivity indicators (Fig. 7),
693 though seasonal sea ice remains and likely provides a mechanism for maintaining
694 stratification to some extent. As the interglacial began however, we would expect this
695 light limitation to be removed when stratification was re-established. However, if
696 dicothermal diatoms are indicators for stratification, then stratification is not re-
697 established until long after $\delta^{15}\text{N}$ values increase (Fig. 7), suggesting that if there is a limit



698 on productivity during the early deglacial it is likely not light via a deep mixed layer
699 (Obata et al., 1996). In contrast, a nearby core (HLY 0202 JPC3) displayed laminated
700 sediments for only about 500 years during the last deglaciation (Cook et al., 2005),
701 suggesting that the two Terminations were very different.

702 There is a “Younger Dryas-like” temperature reversal seen midway through Termination
703 V in the North Atlantic (Voelker et al., 2010), Antarctica (EPICA community members,
704 2004) and at Lake El’gygytgyn (Vogel et al., 2013), however there is no evidence for
705 such an event in the Bering Sea.

706

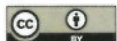
707 **5.3 Peak MIS 11 (423-394 ka)**

708 Globally, peak interglacial conditions (often referred to as MIS 11.3 or 11c) are centered
709 around 410 ka, though the exact interval of the temperature optimum varies and lasted
710 anywhere from 10 to 30 kyrs (Kandiano et al., 2012; Kariya et al., 2010; Milker et al.,
711 2013). At U1345, peak interglacial conditions begin during the Termination V
712 Laminations and continue until 394 ka.

713 Both decreasing C_{org}/N and increasing $\delta^{13}C$ indicate that input of terrigenous organic
714 matter decreases from the onset of the Termination V Laminations until mid MIS 11 (400
715 ka) at which time the organic matter remains solidly marine sourced for the remainder of
716 the record (Fig. 7). Sea level is high and the Pacific water indicator, *N. seminae*, is found
717 at the site beginning at 424 ka.

718 Throughout MIS 11, *Chaetoceros* RS, a species indicative of high productivity, is
719 generally higher when insolation is higher and lower when insolation is lower (390-404
720 ka; Fig. 7). However, although their fluctuations are small, warm water species show the
721 opposite trend, with higher proportions of warm water diatoms when insolation is low
722 (Fig. 7). If higher proportions of warm water diatoms indicate warmer water, then this
723 suggests that productivity is highest in colder waters but when insolation is high, and
724 lowest in warmer waters when insolation is low.

725 During MIS 11c, global ice volume was the lowest that it has been for the past 500 kyrs
726 (Lisiecki and Raymo, 2005), and generally continental temperatures were warmer than



727 today (D'Anjou et al., 2013; de Vernal and Hillaire-Marcel, 2008; Lozhkin and Anderson,
728 2013; Lyle et al., 2001; Melles et al., 2012; Pol, 2011; Prokopenko et al., 2010; Raynaud
729 et al., 2005; Tarasov et al., 2011; Tzedakis, 2010; Vogel et al., 2013) with a northward
730 expansion of boreal forests in Beringia (Kleinen et al., 2014). However, it was not warm
731 uniformly world-wide. At U1345, the relative percent warm water species suggest that
732 SSTs during MIS 11c were only slightly warmer than during MIS 12. Indeed, MIS 11 is
733 not the warmest interglacial in most marine records (Candy et al., 2014). This is
734 especially evident in the Nordic Seas where MIS 11 SSTs were lower than Holocene
735 values, although no IRD was deposited between 408 and 398 ka (Bauch et al., 2000).

736 However, MIS 11c was very humid in many places. In the Bering Sea, modeling studies
737 estimate up to 50 mm more precipitation than today at 410 ka (Kleinen et al., 2014). The
738 most humid, least continental period recorded in the sediments at Lake Baikal occurs
739 from 420-405 ka (Prokopenko et al., 2010), and extremely high precipitation are recorded
740 at Lake El'gygytgyn on the nearby Chukotka Peninsula from 420-400 ka (Melles et al.,
741 2012). Conditions in Africa during MIS 11c were similar to the Holocene African humid
742 period. In addition, pollen records from Western Europe also reflect humid environments
743 (Candy et al., 2014). A warmer, moister climate in Western Europe and Africa is
744 indicative of increased Atlantic Meridional Overturning Circulation (AMOC) (Bauch,
745 2013). AMOC appears to be stable over MIS 11 (Milker et al., 2013) as evidenced by
746 high carbonate in the North Atlantic (Chaisson et al., 2002; Poli et al., 2010).
747 Interestingly, small carbonate peaks in the Bering Sea are contemporaneous with those on
748 the Bermuda Rise, suggesting teleconnections between the two regions (Fig. 7). These
749 conditions are similar to a modern day negative North Atlantic Oscillation (NAO) which
750 is linked to wet conditions in N. Africa, weaker westerlies, more zonal storm tracks, a dry
751 Northern Europe, colder Nordic Seas and increased sea ice in the North Atlantic
752 (Kandiano et al., 2012).

753

754 5.3.1 Bering Strait Current Reversal (406-402 ka)

755 Between 405 and 394 ka, there is an unusual diatom assemblage and grain size
756 distribution at Site U1345. There are several possible explanations for deposition of



757 shallow water and fresh water species along with large changes in sediment grain size.
758 We will consider two possibilities in detail: Bering Strait current reversal and glacial
759 surge in Beringia. *→ Also mention your section 5.3.3 here too.*

760 On St. Lawrence Island in the Northern Bering Sea (Fig. 1), evidence for Arctic mollusks
761 entering the Gulf of Anadyr suggests that flow through Bering Strait was reversed at
762 some point during the Middle Pleistocene (Hopkins, 1972). Unfortunately, this event is
763 poorly dated. If Bering Strait flow were reversed due to a meltwater event (DeBoer and
764 Nof, 2004), we would expect a temporary reduction in NADW formation and an increase
765 in southerly winds from Antarctica (DeBoer and Nof, 2004). In the Bering Sea, we would
766 expect to see an increase in common Arctic or Bering Strait diatom species and a
767 decrease in North Pacific indicators. *[In addition, the clay minerals in the Arctic Ocean are*
768 *overwhelmingly dominated by illite (Ortiz et al., 2012), which is a clay mineral that tends*
769 *to adsorb large amounts of ammonium (Schubert and Calvert, 2001). So, if net flow were*
770 *to the south, one might also expect to find decreased C_{org}/N and $\delta^{15}N$ values resulting*
771 *from increased illite deposition.]*

772 A warm Arctic Ocean during MIS 11 suggests increased Pacific water input through
773 Bering Strait (Cronin et al., 2013). Proxy evidence for NADW ventilation (decreases in
774 $CaCO_3$ % and $\delta^{13}C$) indicates that between 412 and 392 ka, NADW formation decreased
775 for short periods (< 1 ka) (Poli et al., 2010). In contrast, AABW formation appears to
776 have drastically slowed around 404 ka, suggesting that winds derived from Antarctica
777 decreased as opposed to increased (Hall et al., 2001).

778 At U1345, C_{org}/N values began decreasing linearly starting at 409 ka, productivity
779 sharply decreases at 406 ka, $\delta^{15}N$ values are the most depleted at 405 ka, just 1 kyr before
780 a conspicuous peak in *P. sulcata*, a common diatom in the Bering Strait. Finally, diversity
781 is highest around 400 ka, due to the multiple contributions of Arctic species (fresh water,
782 shelf, coastal, sea ice) and common pelagic diatoms, while the North Pacific indicator, *N.*
783 *seminae* maintains low relative abundances throughout this interval. *[The sum of this*
784 *evidence ~~does point toward~~ ^{suggests} species migration from the Arctic Ocean southward.*
785 However, these changes occur in series over 4 kyrs or more and there is no synchronicity
786 between NADW formation and Antarctic winds. Therefore, there is no consensus in the

with

*Reference Müller, 1977
in GCA;
C/N = 1004
in illite
XRD!
(+ ISU
has one in
the office
of Biotech)*

*On Fig. 7,
it looks
the same
before & after
this period...*



787 evidence to support or reject the hypothesis of reversed flow through Bering Strait during
788 MIS 11.

789

790 5.3.2 Glacial Inception in Beringia (405-394 ka)

791 Regardless of whether flow through Bering Strait reversed during peak MIS 11, the
792 interval between 405 and 394 ka contains an unusual diatom assemblage and grain size
793 distribution. Diatom assemblages are similar to that found in sediments from the
794 Anvillian Transgression 800 km northeast of U1345 near Kotzebue (Fig. 1) (Pushkar et
795 al., 1999). In the Bering Sea, a large peak in neritic species occurs at 404 ka followed by
796 the highest relative percentages of fresh water species at the site and a slight increase in
797 sea ice diatoms from 400 to 394 ka (Fig. 7).

798 Despite the deposition of shallow and fresh water species, the proportion of marine to
799 terrestrial carbon was the highest in the entire interval. However, primary productivity
800 was quite low during this interval with high nitrogen utilization reflected in the $\delta^{15}\text{N}$
801 values. Two large depletions in $\delta^{15}\text{N}$ bracket this interval and occur as *Chaetoceros* RS
802 decrease in relative percent abundance, but only the older depletion is also associated
803 with a decrease in the number of diatom valves per gram of sediment (Fig. 8). [The older
804 depletion may reflect an environment that is limited by micronutrients such as iron as sea
805 level approaches its maximum.] *Just speculation!*

806 Detailed grain size analysis shows a trend of increasing clay sized grains as well as a
807 broad increase in sand sized grains and in particular grains greater than 250 μm (Fig. 8).
808 All samples are poorly to very poorly sorted (See Supplemental Material). In addition,
809 shipboard data shows an increase in the presence of large, isolated clasts > 1 cm in
810 diameter, a cluster of sand layers (Fig. 8), and a thick interval of silty sand (Takahashi et
811 al., 2011) around 411 ka (Fig. 4).

812 The sum of this evidence leads us to propose that the interval highlighted in grey on
813 Figure 8, reflects a glacial advance that may be the onset of the Nome River Glaciation at
814 ~404 ka. This advance is short-lived in the Bering Sea and is followed by a period when
815 intensified winds blew fresh water diatoms more than 1000 km off shore to Site U1345.



816 Glacial ice is effective at carrying terrigenous and near shore particles far from land.
817 Previous work has suggested that sediments deposited by icebergs should be poorly
818 sorted and skew towards coarser sediments (Nürnberg et al., 1994). Sediments greater
819 than 150 µm are likely glacially ice rafted (St. John, 2008), however it is not possible to
820 distinguish sediments deposited by glacial versus sea ice on grain size alone (St. John,
821 2008). Both types of ice commonly carry sand-sized or larger sediments (Nürnberg et al.,
822 1994). Sea ice diatoms should not be found in glacial ice, instead, we would expect
823 glacial ice to be either barren, or to carry fresh water diatoms from ice-scoured lake and
824 pond sediments.

825 The Nome River Glaciation is the most extensive glaciation in central Beringia and is
826 dated to Middle Pleistocene. Although it has not been precisely dated, it is likely
827 correlative with MIS 11 (Kaufman et al., 1991; Miller et al., 2009). Nome River
828 glaciomarine sediments are found in places such as St. Lawrence Island (Gualtieri and
829 Brigham-Grette, 2001; Hopkins, 1972), the Pribilof Islands (Hopkins, 1966), the Alaska
830 Arctic coastal plain (Kaufman and Brigham-Grette, 1993), Kotzebue (Huston et al.,
831 1990), Nome (Kaufman, 1992), and Bristol Bay (Kaufman et al., 2001) (Fig. 1). Mollusks
832 and pollen in these sediments reflect a tundra environment with temperatures similar to
833 today (Hopkins, 1972; Kaufman and Brigham-Grette, 1993) or warmer than today
834 (Pushkar et al., 1999) with significantly reduced or absent sea ice (Kaufman and
835 Brigham-Grette, 1993; Pushkar et al., 1999). These sites all contain evidence that glaciers
836 in Beringia advanced, in some cases more than 200 km, and reached tidewater while
837 eustatic sea level was high (Huston et al., 1990).

838 Although global sea level was near its maximum, and much of the world was
839 experiencing peak MIS 11 conditions (Candy et al., 2014), there is evidence that the high
840 latitudes were already cooling. At 410 ka, insolation at 65° N began to decline (Berger
841 and Loutre, 1991), cooling began at 407 ka in Antarctica, expressed both isotopically and
842 as an expansion of sea ice (Pol, 2011). Millennial scale cooling events are recorded at
843 Lake Baikal (Prokopenko et al., 2010). By 405 ka, there is some evidence globally for ice
844 sheet growth (Milker et al., 2013) as Lake Baikal begins to shift towards a dryer, more
845 continental climate (Prokopenko et al., 2010) and productivity declines at Lake
846 El'gygytyn (Melles et al., 2012). Around 400 ka, SSTs decrease temporarily by 2° C in

Whoa! Needs
Transition
since preceding
is all about
warmth & then
followed by
glacial advance
(= cold &
and/or precip)



847 the Arctic Ocean (Medeleev Ridge) (Cronin et al., 2013) and permanently at Lake
848 El'gygytgyn (D'Anjou et al., 2013). Precipitation also decreases at Lake El'gygytgyn
849 (Melles et al., 2012). Modelling results show that by 400 ka, the Bering Sea is expected
850 to have temperatures cooler than today with increased sea ice (Kleinen et al., 2014).

851 We suggest that Beringian glaciation during MIS 11 was initiated ~404 ka by decreasing
852 insolation when eccentricity was high and perihelion coincided with the equinox
853 (Schimmelmann et al., 1990). Solar forcing coupled with a proximal moisture source, the
854 flooded Beringian shelf, to drive snow buildup (Huston et al., 1990; Pushkar et al., 1999)
855 and glacial advance. Precipitation at Lake El'gygytgyn, just west of the Bering Strait, was
856 two to three times higher than today (Melles et al., 2012). A similar "snow gun"
857 hypothesis has been invoked for other high latitude glaciations (Miller and De Vernal,
858 1992); however, Beringia is uniquely situated. Once sea level began to drop, Beringia
859 became more continental and arid (Prokopenko et al., 2010) and the moisture source for
860 these glaciers was quickly cut off.

861 In central Beringia, glaciers from coastal mountains on chukotka advanced to St.
862 Lawrence Island and glaciers from the western Brooks Range advanced into Kotzebue
863 Sound as global eustatic sea level dropped coincident with decreased insolation during
864 Northern Hemisphere summers (Berger and Loutre, 1991), Lake El'gygytgyn returned to
865 glacial conditions by 398 ka, and globally MIS 11.3 ended (Milker et al., 2013; Poli et al.,
866 2010; Voelker et al., 2010).

Make 2
sentences

867

868 5.3.3 Alternative Explanations

869 There are several other explanations for how these sediments could have been carried
870 more than 300 km from the coast out over the shelf-slope break and deposited in 1000 m
871 of water: turbidites or strong density currents on the shelf, sediment reworking and
872 winnowing, sea ice transport, and eolian deposition

873 The location of Site U1345 on a high interfluvium minimizes the likelihood that sediments
874 will have been transported and deposited here by turbidites or other down-slope currents.
875 Sancetta and Robinson (1983) argue that benthic pennate species were transported out of



876 shallow water by rivers and turbidity currents during glacial periods. They do not
877 consider ice as a transport mechanism (Sancetta and Robinson, 1983). If turbidites were
878 present, we would expect fining up sequences in the detailed grain size analysis,
879 slumping or distorted sedimentation in the core and clear erosive surfaces. But there is no
880 evidence of turbidite deposition (Takahashi et al., 2011). If winnowing were a dominant
881 transport mechanism, the sediments should be well sorted. Instead, the presence of
882 multiple terrigenous grain sizes indicates that the sediments are relatively poorly sorted
883 and the Folk and Ward method (Blott and Pye, 2001) classifies all samples as either
884 poorly sorted or very poorly sorted (See supplemental material).

885 Sea ice could bring neritic (though probably not freshwater) diatoms out to deeper waters
886 as it preferentially entrains silt and clay size particles (Reimnitz et al., 1998). However, if
887 there was an increase in sea ice, we would expect to see a significant increase in sea ice
888 diatoms during this interval. Instead we see only a small increase in sea ice related
889 species, primarily eponitic species. Additionally, during this time, the marginal ice zone
890 assemblage is dominated by *T. antarctica* RS which is a taxon primarily found in coastal,
891 low salinity areas (Barron et al., 2009; Shiga and Koizumi, 2000), so its presence may be
892 further support for increased shelf to basin transport.

P. sulcata
is also
thought to
indicate
greater
shelf-to-basin
transport, too.

893 Eolian deposition of diatoms is a common event in Antarctica where strong katabatic
894 winds transport mainly small (up to 50 μm in diameter), non-marine diatoms (McKay et
895 al., 2008). The freshwater diatoms that are abundant between 409 and 405 ka are
896 dominated by species that tend to be quite small. *Lindavia* cf. *ocellata* ranges from 8-20
897 μm and *Lindavia radiosa* from 7-35 μm . Wind-driven deposition of these species is the
898 most probably explanation for their transport more than 800 km from shore, therefore,
899 this interval may represent a period of time when northerly winds intensified over
900 Beringia.

901

902 **5.4 Late MIS 11 (younger than 394 ka)**

Diatom or geochem?

903 After 394 ka, upwelling indicators are the lowest in the record and linearly increase to the
904 top of the record. This is in contrast to a slight increase in diatom abundance, which
905 increases at 393 ka and then remains relatively stable to the top of the record. Sea ice



906 indicators also remain relatively high from 392 to the top of the record and dicothermal
907 species reflect moderately stratified waters. Warm water species decrease from 390 ka to
908 the top of the record (Fig. 7). The sum of this evidence indicates that at the end of MIS
909 11, summers were warm and sea ice occurred seasonally, perhaps lasting a bit longer than
910 at other times in the record. Modelling results indicate that at 394 ka, temperatures were
911 below modern by 0° to 2° C, and precipitation in Beringia was relatively low, like today
912 (Kleinen et al., 2014). These patterns reflect general cooling worldwide (de Abreu et al.,
913 2005; Prokopenko et al., 2010; Raynaud et al., 2005). IRD is again deposited in the North
914 Atlantic beginning around 390 ka.

915 Eustatic sea level decreased beginning about 402 ka (Rohling et al., 2010), but sea level
916 was high enough ~~though~~ to allow *N. seminae* to reach the shelf slope break until about
917 380 ka (Fig. 7). As sea level dropped, significant parts of the Beringian continental shelf
918 were exposed, cutting off the moisture supply for the Nome River Glaciation (Pushkar et
919 al., 1999). Subaerial and glaciofluvial deposits above the Nome River tills and correlative
920 glaciations indicate that Beringian ice retreated, while climate remained cold or grew
921 colder. Ice wedges and evidence of permafrost are common (Huston et al., 1990; Pushkar
922 et al., 1999) above Nome River glaciation deposits.

923 Laminations are again prominent in the sediment record and deposited intermittently
924 between 394 and 392 ka and again after 375 ka (Fig. 4) as the climate transitioned into
925 MIS 10. These laminations are quite different from the Termination V Laminations due
926 to their shorter duration and lack of obvious shift in terrigenous vs. marine carbon source.
927 In addition, these Type II laminations have increased diatom abundances and CaCO₃, but
928 not necessarily increased upwelling indicators reflecting increased primary production
929 that is perhaps not linked to nutrient upwelling along the shelf-slope break.

930 Most of these laminations show an increase in sea ice diatoms and a decrease in
931 productivity indicators. These roughly correspond with millennial scale stadial events
932 that occurred during MIS 11a in the North Atlantic (Fig. 7) (Voelker et al., 2010). Late
933 MIS 11 is characterized as a series of warm and cold cycles (Candy et al., 2014; Voelker
934 et al., 2010), though there is not agreement on the timing of these cycles.



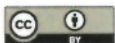
935 It is tantalizing to note that the laminations occur at a time when global sea level was
936 fluctuating around -50 mpsl (Rohling et al., 2010) (see grey line at -50 m on Fig. 7).
937 Increased productivity and repeating laminated sediments could be related to shelf to
938 basin nutrient dynamics as rising sea levels carry fresh organic matter from the shelf out
939 over the southern Bering Sea (e.g. Bertrand et al., 2000). In addition to the
940 correspondence between laminations and North Atlantic stadials, carbonate peaks in the
941 Bering Sea also occur coeval with carbonate peaks at Blake Ridge (Chaisson et al., 2002)
942 suggesting teleconnections between productivity in the Bering Sea and the North Atlantic
943 at this time. This suggests that sea level fluctuation driven by the closure of Bering Strait
944 may also be occurring at the end of MIS 11 as well as during the last glacial maximum
945 (Hu et al., 2010), though this hypothesis requires further testing ~~and rethinking~~
946 dynamic topography in the Bering Strait region over time.

947

948 **6 Conclusions**

949 The interval between glacial MIS 12 and MIS 10 is marked by large changes in
950 productivity but minor changes in sea ice extent at the shelf slope break in the Bering
951 Sea. There is inconclusive evidence for a reversal of the Bering Strait current at 405 ka,
952 but evidence for teleconnections between the Atlantic and the North Pacific is strong
953 when eustatic sea level fluctuated near the Bering Strait sill depth at the end of MIS 11.
954 Tidewater glaciers advanced in Beringia when eustatic sea level was high, insolation was
955 declining in the Arctic, and other high latitude regions saw decreasing SSTs.

956 During MIS 12, productivity and nitrogen utilization was low. At Termination V, an 11
957 kyr long laminated interval began. This interval was highly productive for multiple
958 phytoplankton groups and diatom productivity increased by two orders of magnitude
959 while nitrogen utilization decreased. The surface waters were relatively warm and
960 unstratified with reduced sea ice duration. This period is marked by the highest
961 terrigenous organic matter input of the record possibly due to scouring of the continental
962 shelf as sea level rose. Throughout much of MIS 11, productivity changed in concert with
963 changes in insolation and water temperature. During warmer periods, high stratification



964 appears to have led to lowered productivity in both the Atlantic and the North Pacific
965 Oceans.

966 During MIS 12, seasonal sea ice dominated the western Bering Sea with highly stratified
967 waters during the ice-melt season. Sea ice was at a minimum from 423 to 410 ka when
968 the Termination V Laminations were deposited. After this, although summers appear to
969 have been warm, seasonal sea ice lasted longer. And at the end of MIS 11, sea ice
970 increased and cooling continued in sync with declining sea level.

971 While decreased NADW formation and species transport from the Arctic Ocean
972 southward support a reversal of the Bering Strait current at 405 ka, there is no evidence
973 for transport of Arctic Ocean clay minerals or an increase in winds in Antarctica. In
974 addition, oceanographic changes indicative of a shift in Bering Strait through flow occur
975 in series over 4 kyrs or more and there is no synchronicity with Bering Sea changes,
976 NADW formation and Antarctic winds. Therefore, there is inconclusive evidence for a
977 reversal of the Bering Strait current during MIS 11.

Capitalize?

978 When global sea level was at its maximum, insolation dropped slightly and coastal
979 Beringia began to cool in sync with other polar regions. Tidewater glaciers brought
980 neritic species far off shore and are attributed to humid conditions in Beringia that
981 allowed glacial growth. Evidence of glaciation is short lived in the western Bering Sea
982 and followed by an intensification of northerly winds that brought freshwater diatoms out
983 over the open ocean.

984 Laminations at end MIS 11 correspond with millennial scale stadials seen in the N
985 Atlantic. These deposits represent further possible evidence of teleconnections between
986 the Atlantic and the Pacific as eustatic sea level fluctuated near the Bering Strait sill
987 depth.

988 This study supports hypotheses that the region responds to insolation changes at 65° N
989 and that Bering Strait modulates climate in both the North Atlantic and Pacific regions.
990 Future work should focus on leads and lags between changes in the North Atlantic, North
991 Pacific and Antarctic regions to determine how upwelling, deep water formation, and
992 climate are related.

This is
a very
strong
statement

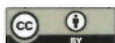


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995

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Note: I did not check references, except Schubert

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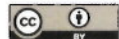
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1419 Table 1: Bering Sea diatom species grouped by environmental niche. In cases where a species appears in more than one niche, the
 1420 grouping used in this study is highlighted in bold.

| <i>Modern Seasonal Succession</i> | | | |
|-----------------------------------|--|--|----------------------------------|
| Epontic | Marginal Ice Zone (MIZ) | Both Epontic and MIZ | Summer Bloom |
| <i>Navicula transitrans</i> | <i>Bacterosira bathyomphala</i> | <i>Actinocyclus curvatulus</i> | <i>Coscinodiscus</i> spp. |
| <i>Nitzschia frigida</i> | <i>Chaetoceros furcellatus</i> | <i>Fossula arctica</i> | <i>Leptocylindrus</i> sp. |
| | <i>Chaetoceros socialis</i> | <i>Fragilariopsis cylindrus</i> | <i>Rhizosolenia</i> spp. |
| | <i>Leptocylindrus</i> sp. | <i>Fragilariopsis oceanica</i> | |
| | <i>Odontella aurita</i> | <i>Navicula pelagica</i> | |
| | <i>Paralia sulcata</i> | Naviculoid pennates | |
| | <i>Porosira glacialis</i> | <i>Nitzschia</i> spp. | |
| | <i>Staurosirella</i> cf. <i>pinnata</i> | <i>Pinnularia quadratarea</i> | |
| | <i>Thalassionema nitzschioides</i> | <i>Thalassiosira antarctica</i> | |
| | <i>Thalassiosira angulata</i> | <i>Thalassiosira gravida</i> | |
| | <i>Thalassiosira baltica</i> | | |
| | <i>Thalassiosira decipiens</i> | | |
| | <i>Thalassiosira hyalina</i> | | |
| | <i>Thalassiosira hyperborea</i> | | |
| | <i>Thalassiosira nordenskiöldii</i> | | |
| | <i>Thalassiosira pacifica</i> | | |

1421

1422 Continued on next page



1423

Table 1 continued

| <i>Water Mass Tracers</i> | | | <i>Shelf to Basin Transport</i> | | |
|--------------------------------|------------------------------------|-----------------------------|------------------------------------|---------------------------------|---|
| Dicothermal | High Productivity | Alaska Stream | Warmer Water | Neritic | Fresh Water |
| <i>Actinocyclus curvatulus</i> | <i>Chaetoceros</i> spp. | <i>Neodenticula seminae</i> | <i>Azpeitia tabularis</i> | <i>Actinoptychus senarius</i> | <i>Lindavia</i> cf. <i>ocellata</i> |
| <i>Thalassiosira trifulta</i> | <i>Odontella aurita</i> | | <i>Stellarimia stellaris</i> | <i>Amphora</i> sp. | <i>Lindavia stylorum</i> |
| | <i>Thalassionema nitzschioides</i> | | <i>Thalassionema nitzschioides</i> | <i>Lindavia stylorum</i> | <i>Staurosirella</i> cf. <i>pinnata</i> |
| | <i>Thalassiosira pacifica</i> | | <i>Thalassiosira eccentrica</i> | <i>Delphineis</i> spp. | <i>Lindavia radiosa</i> |
| | <i>Thalassiosira</i> spp. small | | <i>Thalassiosira oestrupii</i> | <i>Dentonula confervacea</i> | |
| | <i>Thalassiothrix longissima</i> | | <i>Thalassiosira symmetrica</i> | <i>Diploneis smithii</i> | |
| | | | | Naviculoid pennates | |
| | | | | <i>Odontella aurita</i> | |
| | | | | <i>Paralia sulcata</i> | |
| | | | | <i>Rhaphoneis amphiceros</i> | |
| | | | | <i>Stephanopyxis turris</i> | |
| | | | | <i>Thalassiosira angulata</i> | |
| | | | | <i>Thalassiosira decipiens</i> | |
| | | | | <i>Thalassiosira eccentrica</i> | |



1424 Table 2: Distribution of Laminated Intervals during MIS 11. Note that the depth and age
 1425 of laminated intervals encompasses all holes drilled, but the average duration is
 1426 calculated using each of the holes that it is present in.

| Lamination | Type | Depth (mbsf) | Age (ka) | Average Duration (kyrs) | Found in Holes |
|---------------|------|---------------|-------------|-------------------------|----------------|
| MIS 11.5 | II | 112.02-111.47 | 367.2-366.0 | 0.50 | C |
| MIS 11.4 | II | 113.14-112.94 | 369.7-369.3 | 0.34 | CD |
| MIS 11.3 | II | 114.28-113.95 | 372.3-371.5 | 0.73 | D |
| MIS 11.2 | II | 115.59-114.69 | 374.8-373.2 | 1.25 | ACE |
| MIS 11.1 | II | 121.84-121.18 | 394.1-392.1 | 1.10 | ED |
| Termination V | I | 130.00-126.52 | 423.3-410.4 | 12.14 | ACDE |

1437

Odd unit. Why "average"?
 Median better perhaps?
 And, how do Lamination
 MIS 11.5 + 11.3 which
 have only 1 hole representation
 have different "avg durations"
 than the noted age interval?

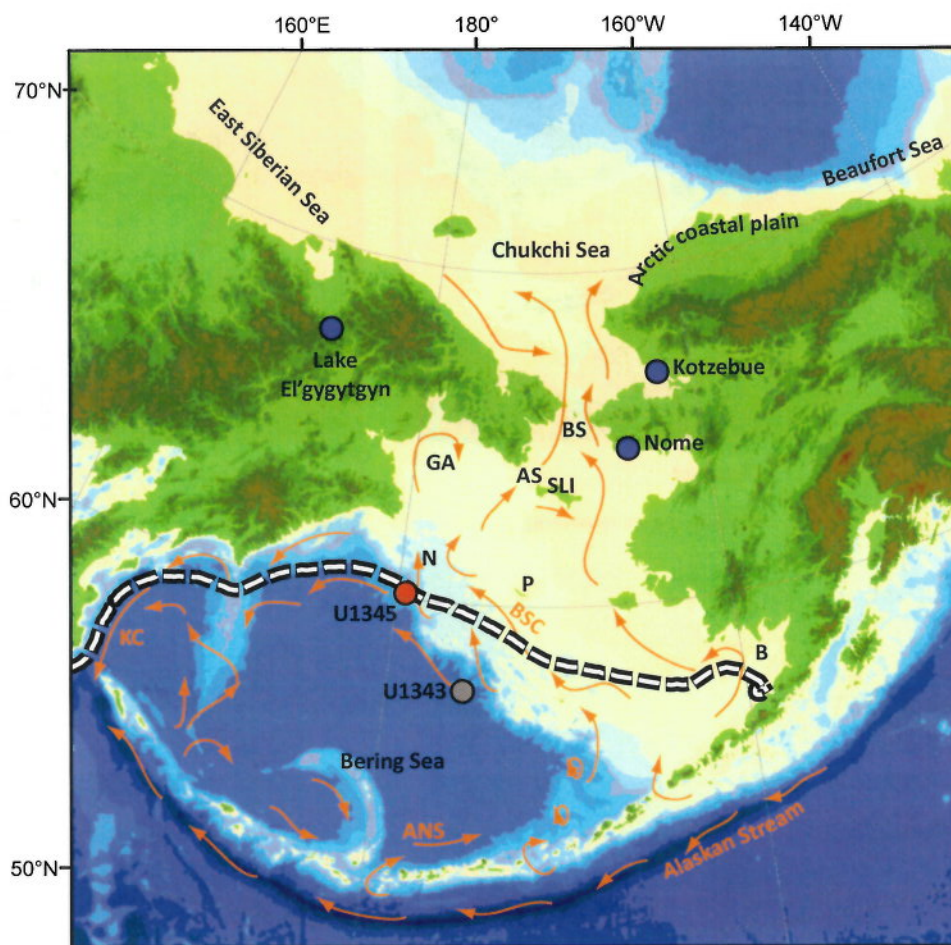


Figure 1. Map of Beringia. Locations of place names from the text are labeled: Aleutian North Slope Current (ANS), Anadyr Strait (AS), Bristol Bay (B), Bering Strait (BS), Bering Slope Current (BSC), Gulf of Anadyr (GA), Kamchatka Current (KC), Navarin Canyon (N), Pribilof Islands (P), St. Lawrence Island (SLI). The white and black dashed line is the modern, median maximum extent of sea ice (Cavaliere et al., 1996). Currents are in orange and are modified from Stabeno (Stabeno et al., 1999). Base map is modified from Manley (Manley, 2002).

mouthful!⁵⁷
maybe add time-range over w/this is "median-ed"

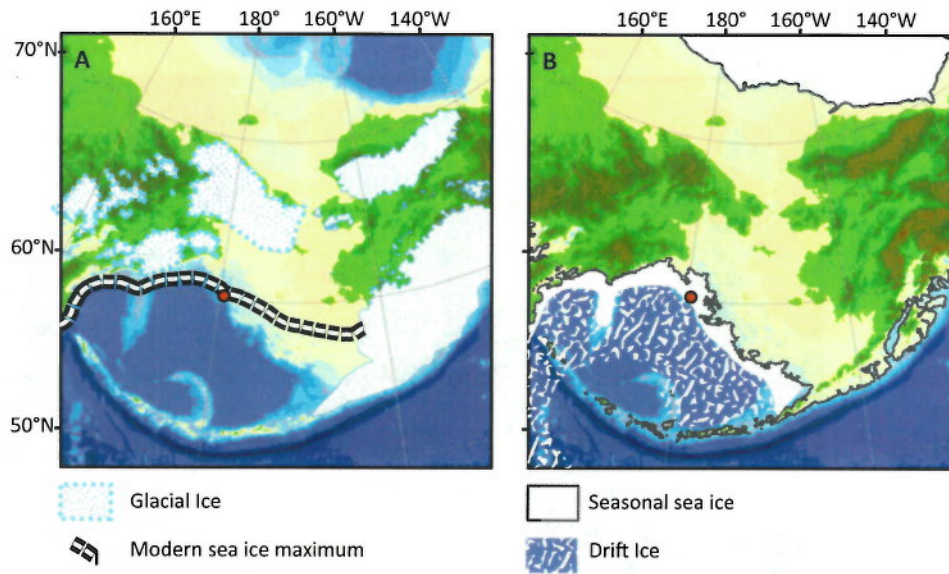
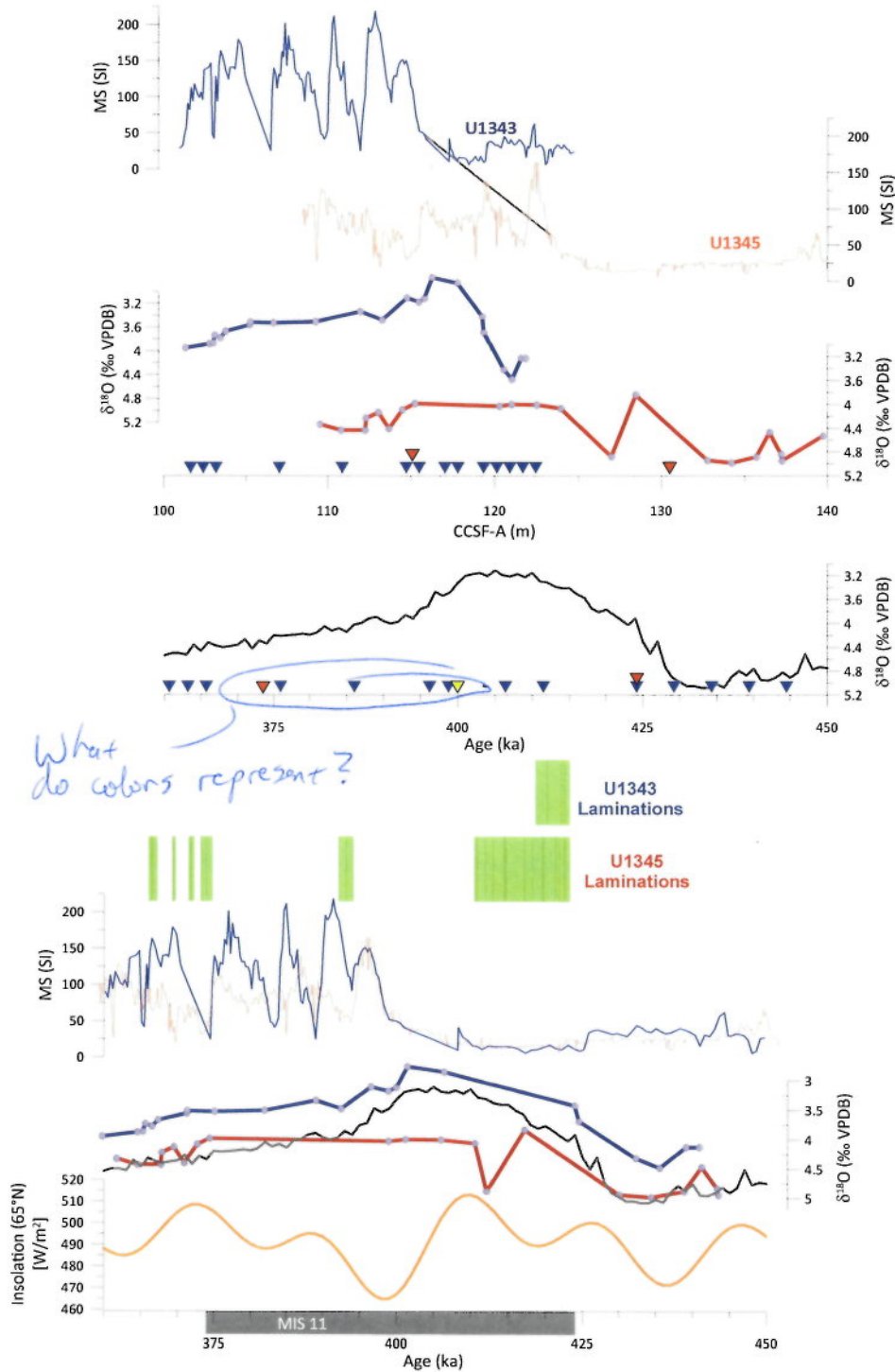


Figure 2. Maximum glacial and sea ice extents in Beringia. A. depicts the maximum glacial ice in Beringia as inferred from terminal and lateral moraines. This is not intended to show the maximum extent during a particular glaciation, but rather the maximum possible extent of glacial ice. These moraines are likely from several different major glaciations. The white and black dashed line is the modern, median maximum extent of sea ice (Cavaliere et al., 1996). B. depicts the approximate pattern of sea ice during glacial stages (Katsuki and Takahashi, 2005). The dark grey contour is -140 m, the approximate sea level during MIS 12 (Rohling et al., 2010). Base map is modified from Manley (Manley, 2002).

↳ Since using Manley's GIS layers, you should also import the certainty⁵⁸ polyline layer!





1438 Figure 3. Age model. Blue plots depict data from Site U1343, red plots are from U1345.
1439 Magnetic susceptibility and benthic foraminiferal $\delta^{18}\text{O}$ are plotted by depth for each Site
1440 in the top half of the figure. The grey line joining the magnetic susceptibility plots
1441 indicates the tie point that was added in this study. Inverted triangles indicate locations of
1442 tie points between Bering Sea $\delta^{18}\text{O}$ (Cook et al., In Press; Kim et al., 2014) and the global
1443 marine stack (Lisiecki and Raymo, 2005), which is plotted in grey. Green bars indicate
1444 laminated intervals in U1343 and U1345 plotted by age. The bottom half of the figure
1445 depicts the same data (magnetic susceptibility and $\delta^{18}\text{O}$) plotted by age with the global
1446 marine stack (grey) and insolation at 65°N (orange for reference).
1447
1448

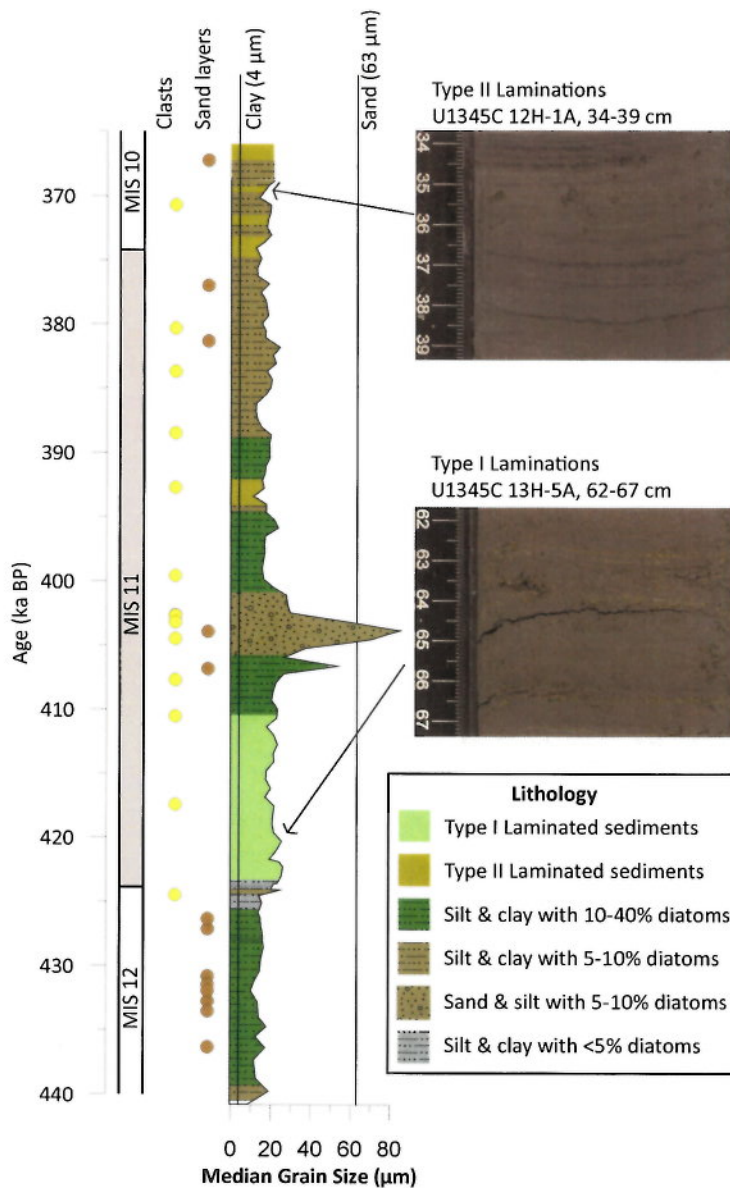


Figure 4. Lithostratigraphic column for U1345A. Marine Isotope Stage 11 is depicted as a grey bar. Ice rafted debris (yellow dots) and sand layers (maroon dots) are a compilation of these features in all four holes at U1345. The width of the lithologic column varies according to median grain size. Vertical lines indicate the cut off for clay and sand sized particles. Silt lies between the two lines. Colors depict varying amounts of diatoms relative to terrigenous grains in the sediment. Type I Laminations are depicted as pale green bars and Type II laminations are depicted as olive green bars. An example of each of the lamination types is shown in the images to the right.

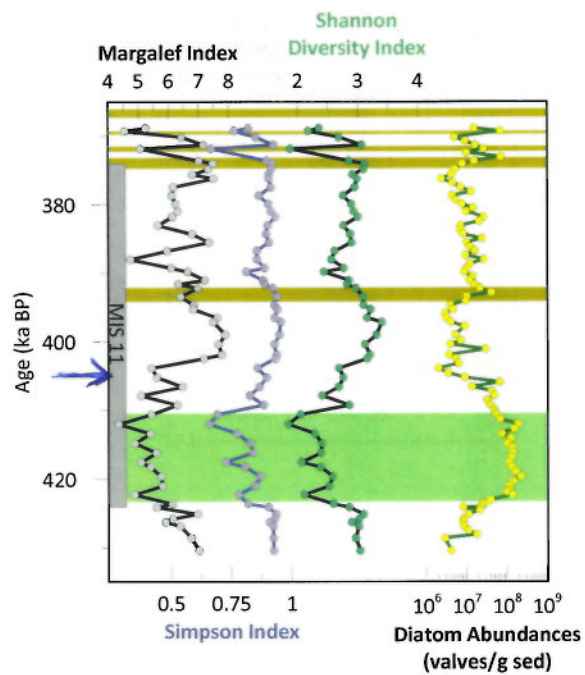


Figure 5. The Margalef, Simpson, and Shannon diversity indices plotted with diatom abundances. Type I Laminations are depicted as pale green bars and Type II laminations are depicted as olive green bars.

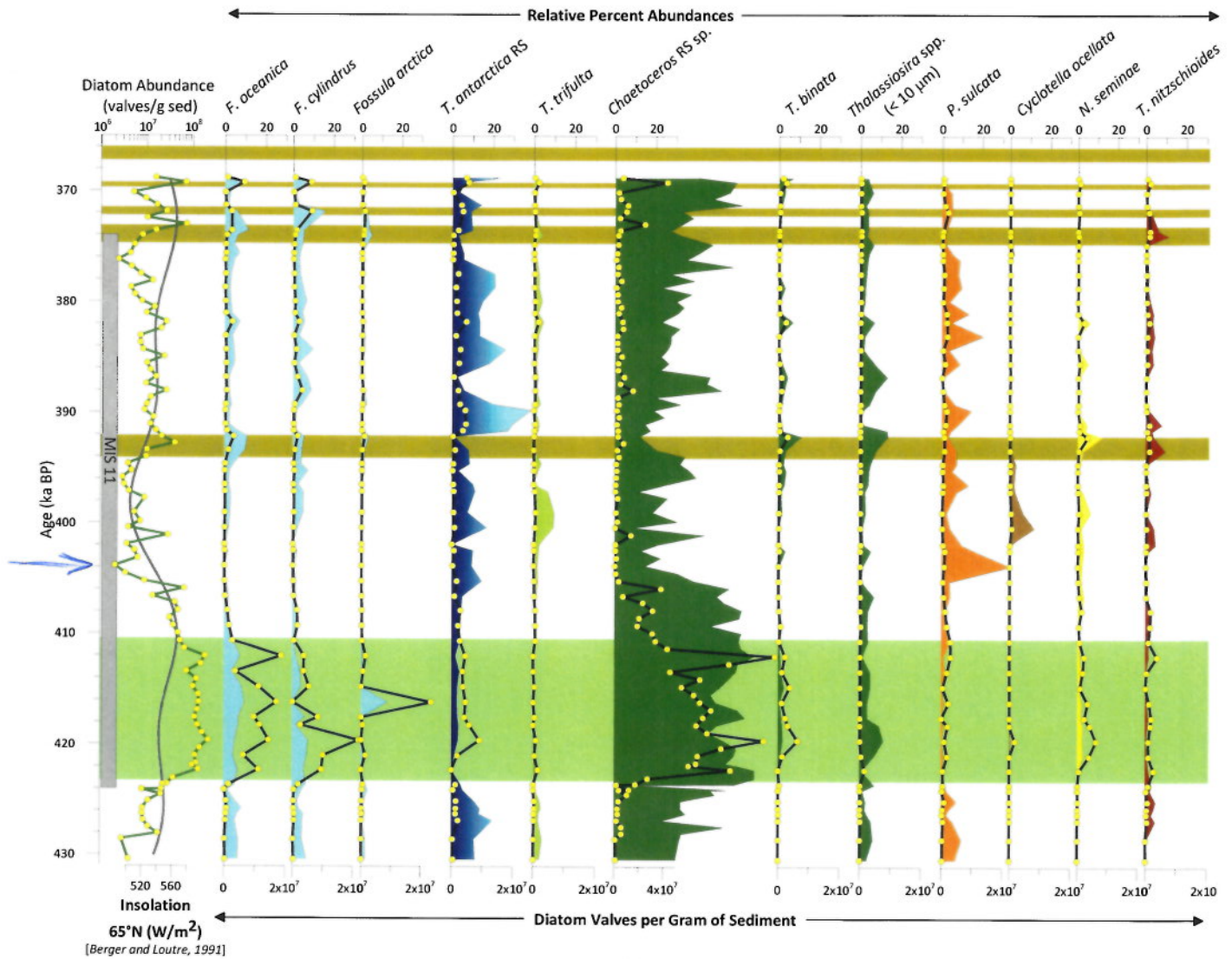
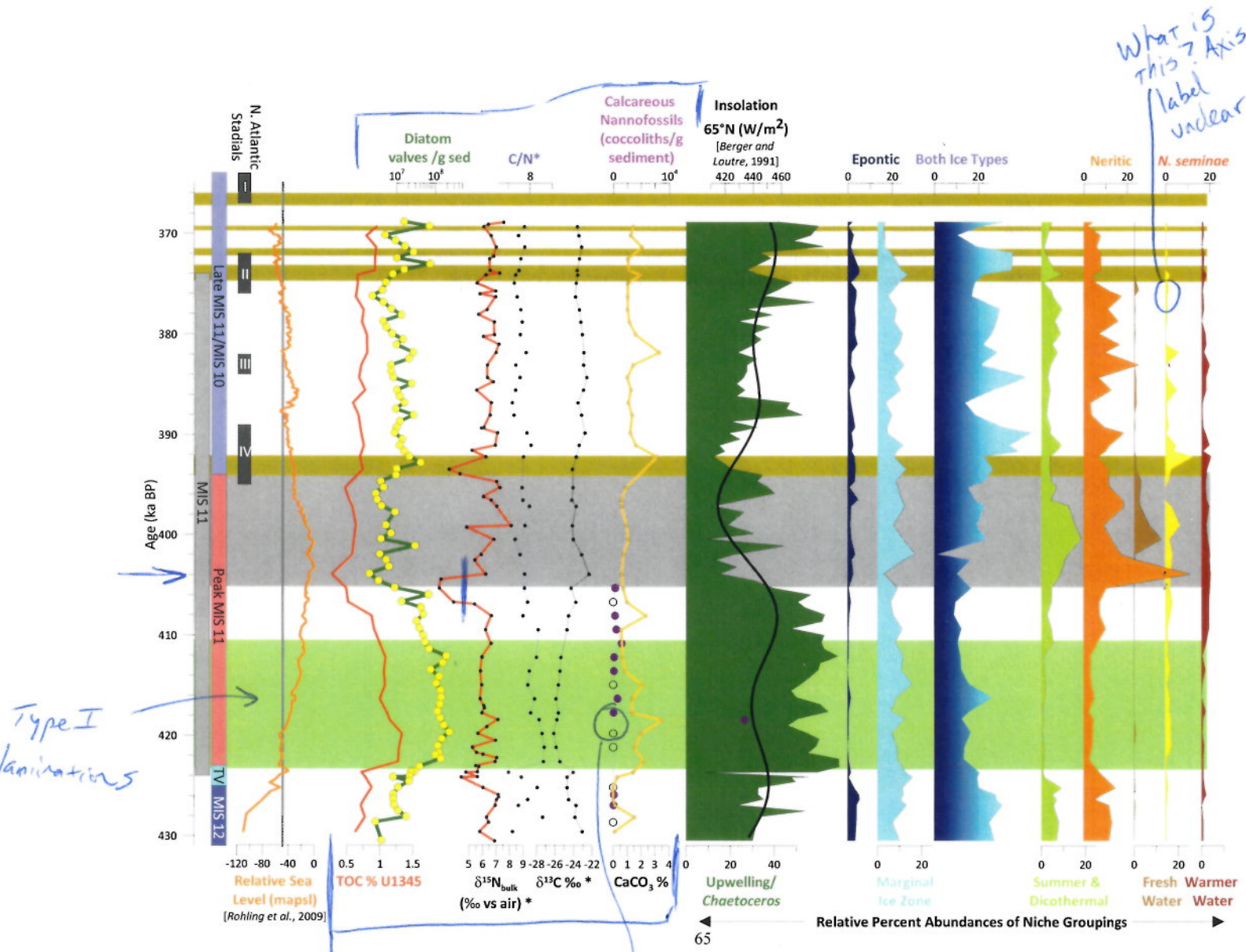
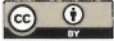


Fig 6



1449 Figure 6. Absolute and relative percent abundances of all diatoms that occur in
1450 abundances greater than 10% of any assemblage. Line plots depict absolute abundance
1451 and area plots depict relative percent abundance. Species are color coded according to the
1452 niche that they are grouped into: marginal ice zone (light blue), both ice types (dark blue
1453 to light blue), dicothermal (light green), high productivity (green), neritic (orange),
1454 freshwater (brown), North Pacific (yellow), and warm water (red). Insolation 65° N (light
1455 grey line) is also shown. Type I Laminations are depicted as pale green bars and Type II
1456 laminations are depicted as olive green bars.



Hard to tell which axis refers to what line; perhaps color code axis + text to same color as line + points? Plus some values outside of axes + try offsetting axes to help w/ space

filled vs open circles?

Fig. 7



1457 Figure 7. Summary of geochemistry and biological proxies. The grey vertical bar depicts
1458 the duration of MIS 11, colored vertical bars refer to the sections in the text, and dark
1459 grey bars show the timing of North Atlantic stadials (I-IV) (Voelker et al., 2010). Global
1460 eustatic sea level (orange) is plotted for reference. The sill depth of Bering Straight (-50
1461 m amsl) is shown as a vertical grey line. Total organic carbon (red) is plotted with the
1462 total diatom abundance (green line, yellow dots). Geochemical data is plotted as $\delta^{15}\text{N}$
1463 (red), C/N (blue), $\delta^{13}\text{C}$ (black), and % CaCO_3 (yellow). Biological proxies include
1464 absolute abundance of calcareous nannofossils (purple), and relative percent abundances
1465 of diatoms grouped by environmental niche (see color coding in Fig. 6). Insolation at 65°
1466 N (black) is overlain on *Chaetoceros* RS relative percent abundances. Type I
1467 Laminations are depicted as pale green bars and Type II laminations are depicted as olive
1468 green bars. A grey bar indicates the Beringian glacial advance.

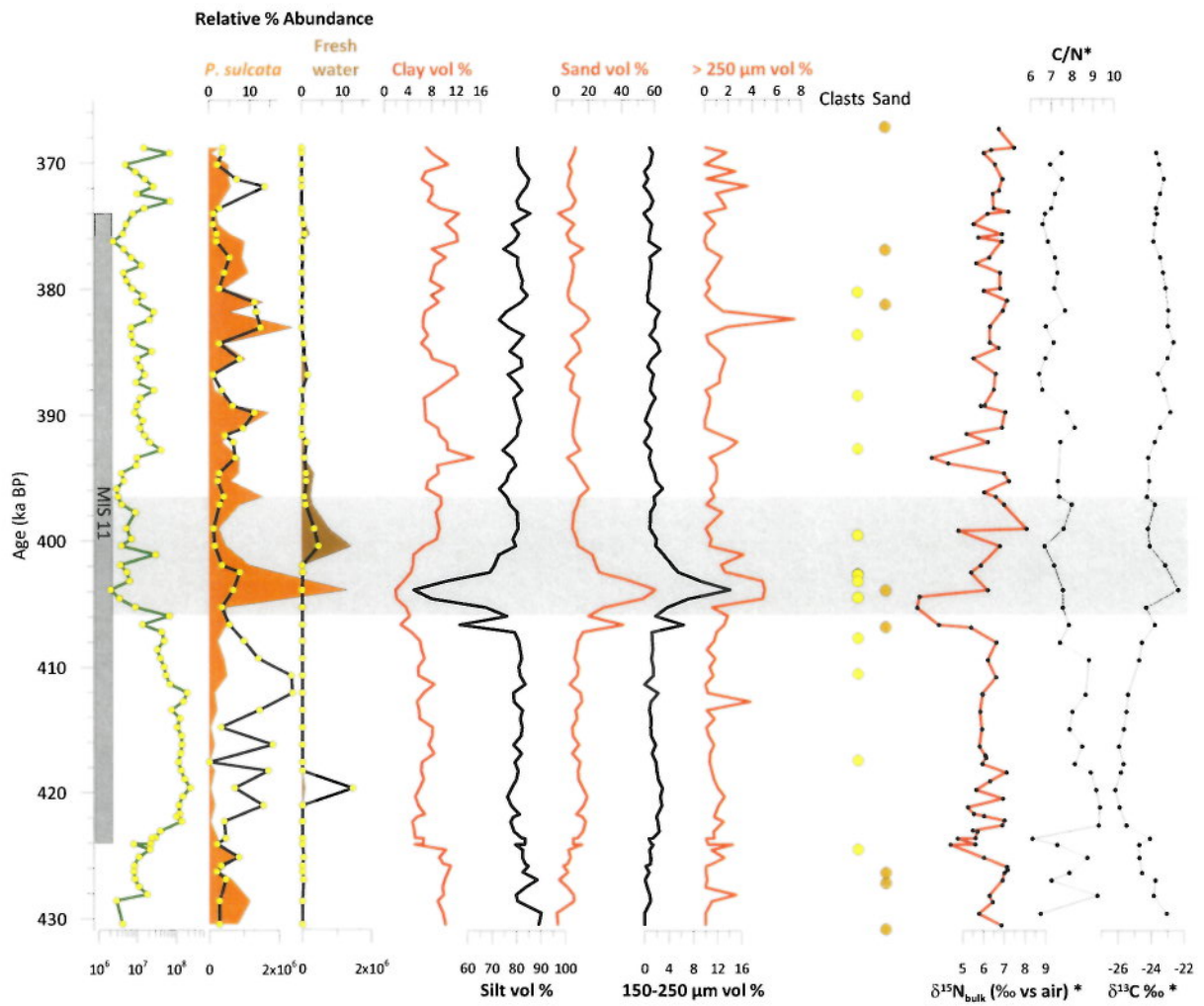


Fig. 8



1469 Figure 8. Proxy indicators of shelf to basin transport. Total diatom absolute abundances
1470 are plotted next to absolute (line plots) and relative percent abundance of *P. sulcata*
1471 (orange area plot) and fresh water species (brown area plot). High-resolution grain size
1472 includes % clay, sand, and greater than 250 μm (red lines) and % silt and 150-250 μm
1473 (black lines). Yellow circles indicate isolated clasts (IRD), maroon circles indicate sand
1474 layers for all holes at U1345. Geochemical data is plotted as $\delta^{15}\text{N}$ (red), C/N (black), and
1475 $\delta^{13}\text{C}$ (black). The grey bar spans 406-396 ka, the interval of increased shelf to basin
1476 transport in Beringia.

1477