Bering Sea Surface Water Conditions during Marine Isotope Stages 12 to 10 at Navarin Canyon (IODP Site U1345)

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

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1 Methods

1.1 Study Area and Sampling

Site U1345 was drilled five times during Exp. 323 and cores from four of these holes were described onboard the JOIDES Resolution. This study focuses on a splice of 3 holes that were correlated onboard the ship, so that core gaps in one hole are covered by core material in other holes. In addition to the original analyses presented here, we refer to the shipboard core descriptions and physical properties data (Takahashi et al., 2011) in our interpretations. Depths are reported in CCSF-A, a correlated depth scale that allows for direct comparison between drill holes. Units are meters below sea floor (mbsf). A small syringe was used to collect approximately 1 cc of sediment periodically between 112.96 m and 136.40 mbsf. Sampling resolution varied for each analysis. Hyalochaete *Chaetoceros* resting spores were counted on average every 20 cm (~600 yr resolution), full diatom counts were carried out every 36 cm (~1000 yr resolution), calcareous nannofossils were counted every 40 cm (~1200 yr resolution), grain size was analyzed every 23 cm (670 yr resolution), and geochemistry was analyzed every 30 cm (800 yr resolution).

1.2 Diatom Analysis

In order to quantify the number of diatom valves deposited per gram of sediment, diatom slides were prepared according to the method described in Scherer (1994). This method allows for a direct comparison of diatom accumulation in the sediments between samples. Cover slips were mounted on cleaned microscope slides using hyrax in toulene (refractive index: 1.7135). At least 300 diatom valves were identified in at least three random transects across the slide using a light microscope at magnifications from 1000x to 1250x (see Armand et al., 2005; Sancetta, 1979; Sancetta and Silvestri, 1986; Scherer, 1994). The portion of the slide that was examined was measured using a stage micrometer. Partial valves were counted according to the methods of Schrader and Gersonde (1978). All diatoms were identified to the species level when possible following published taxonomic descriptions and images (Hasle and Heimdal, 1968; Koizumi, 1973;

Lundholm and Hasle, 2008, 2010; Medlin and Hasle, 1990; Medlin and Priddle, 1990; Onodera and Takahashi, 2007; Sancetta, 1982, 1987; Syvertsen, 1979; Tomas, 1996; Witkowski et al., 2000). Diatom counts were transformed into relative percent abundances. Absolute abundances (diatoms per gram sediment) were calculated following the methods of Scherer (1994). Diatom taxa were then grouped according to ecological niche (Table 3) based on biological observations (Aizawa et al., 2005; Fryxell and Hasle, 1972; Håkansson, 2002; Horner, 1985; Saito and Taniguchi, 1978; Schandelmeier and Alexander, 1981; von Quillfeldt, 2001; von Quillfeldt et al., 2003) and statistical associations (Barron et al., 2009; Caissie et al., 2010; Hay et al., 2007; Katsuki and Takahashi, 2005; Lopes et al., 2006; McQuoid and Hobson, 2001; Sancetta, 1982, 1981; Sancetta and Robinson, 1983; Sancetta and Silvestri, 1986; Shiga and Koizumi, 2000). In cases where a diatom species was reported to fit into more than one environmental niche, it was grouped into the niche where it was most commonly recognized in the literature.

1.3 Calcareous Nannofossils

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

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

1.4 Grain Size

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

1.5 Clay Mineralogy

Ten samples processed (Eberl, 2003) in order to determine what minerals comprised the clay and silt size sediment fractions. in a manner similar to the one described by Eberl in the RockJock user manual (2003). Between .5 and 1.0 grams of sediment were mixed with 0.250 g of a corundum standard. The mixture was then ground in a Shatterbox grinder with 4 mL of ethanol for 2 minutes, 30 seconds. This produced an average grain size of between 10 and 12 microns. The slurry was then allowed to dry under the fume hood, placed in a vial, and then mixed with 0.5 mL of hexane for every 1 gram of sample. The sample was shaken using a Vortex Genie and allowed to dry in a 50° C oven overnight. The sediment was mixed once again, and loaded into X-Ray Diffraction holders. A razor blade was used to pack the sample, and scrape of the excess. Samples were analyzed using a Siemens D-5000 Diffractometer using CuK-α radiation from 5-65° 2 Θ using 0.02° steps and a count time of 2 seconds per step. The results were analyzed using RockJock (Eberl, 2003).

1.6 Geochemistry

Sediment samples were freeze-dried then ground. An aliquot of homogenized sediment was treated to remove carbonates using pH 5 buffered acetic acid. The carbon (from the acidified sediment) and nitrogen (from the unacidified sediment) isotopic and elemental composition of organic matter was determined by Dumas combustion using a Carlo Erba 1108 elemental analyzer coupled to a Thermo-Finnigan Delta Plus XP isotope ratio mass

spectrometer at the University of California Santa Cruz Stable Isotope Laboratory. Isotope results are reported in per mille units using δ notation where

$$\delta\ (‰) = (R_{sample} / R_{standard} - 1) * 1000$$

In this equation, δ (‰) is $\delta^{13}C$ or $\delta^{15}N$ and R is the ratio of $^{13}C/^{12}C$ or $^{15}N/^{14}N$ in the sample or standard. $\delta^{13}C$ values are reported relative to the Vienna Pee Dee Belemnite (VPDB) and $\delta^{15}N$ values are reported relative to atmospheric N_2. The 1-sigma precision of stable isotope measurements and elemental composition of carbon are 0.2‰ and 0.03%, respectively, and for nitrogen are 0.2‰ and 0.002%, respectively. Percent $CaCO_3$ was calculated according to Schubert and Calvert (2001).

2 References

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Sample	Depth (CCSF-A, mbsf)	AGE (ka)	Mean (µm)	Sorting	Mean	Sorting
U1345A 12H-4 66 cm	112.97	368.82	20.1	2.9	Coarse Silt	Poorly Sorted
U1345A 12H-4 85 cm	113.16	369.24	17.8	3.0	Coarse Silt	Poorly Sorted
U1345A 12H-4 126 cm	113.57	370.15	14.0	2.8	Medium Silt	Poorly Sorted
U1345A 12H-5 8 cm	113.83	370.72	18.7	2.8	Coarse Silt	Poorly Sorted
U1345A 12H-5 34 cm	114.09	371.30	18.4	2.6	Coarse Silt	Poorly Sorted
U1345A 12H-5 86 cm	114.61	371.88	17.2	2.8	Coarse Silt	Poorly Sorted
U1345A 12H-5 60 cm	114.35	372.45	17.1	2.7	Coarse Silt	Poorly Sorted
U1345A 12H-5 112 cm	114.87	373.03	19.1	2.9	Coarse Silt	Poorly Sorted
U1345A 12H-5 138 cm	115.13	373.61	16.0	2.9	Coarse Silt	Poorly Sorted
U1345A 12H-6 14 cm	115.39	374.03	11.9	2.5	Medium Silt	Poorly Sorted
U1345A 12H-6 40 cm	115.65	374.87	15.7	3.1	Coarse Silt	Poorly Sorted
U1345A 12H-6 66 cm	115.91	375.65	12.9	2.8	Medium Silt	Poorly Sorted
U1345A 12H-6 85 cm	116.10	376.24	13.5	2.9	Medium Silt	Poorly Sorted
U1345A 12H-6 105 cm	116.30	376.86	19.9	3.3	Coarse Silt	Poorly Sorted
U1345A 12H-6 126 cm	116.51	377.51	14.8	2.9	Medium Silt	Poorly Sorted
U1345A 12H-6 146 cm	116.71	378.13	17.2	2.9	Coarse Silt	Poorly Sorted
U1345A 12H-7 35 cm	117.10	379.34	17.7	2.8	Coarse Silt	Poorly Sorted
U1345A 12H-7 55 cm	117.30	379.96	15.0	2.8	Medium Silt	Poorly Sorted
U1345A 12H-7 73 cm	117.48	380.51	16.5	2.7	Coarse Silt	Poorly Sorted
U1345A 12H-7 90 cm	117.61	381.04	16.3	2.8	Coarse Silt	Poorly Sorted
U1345A 12H-CC 25 cm	117.87	381.82	22.8	3.1	Coarse Silt	Poorly Sorted
U1345C 12H-5 4 cm	118.07	382.44	23.2	4.3	Coarse Silt	Very Poorly Sorted
U1345C 12H-5 24 cm	118.27	383.06	22.0	3.1	Coarse Silt	Poorly Sorted
U1345C 12H-5 44 cm	118.47	383.68	17.5	2.7	Coarse Silt	Poorly Sorted
U1345C 12H-5 64 cm	118.67	384.30	20.2	2.9	Coarse Silt	Poorly Sorted
U1345C 12H-5 84 cm	118.87	384.92	19.8	3.1	Coarse Silt	Poorly Sorted
U1345C 12H-5 104 cm	119.07	385.54	16.8	2.9	Coarse Silt	Poorly Sorted
U1345C 12H-5 124 cm	119.27	386.16	12.7	2.7	Medium Silt	Poorly Sorted
U1345C 12H-5 144 cm	119.47	386.78	13.7	3.1	Medium Silt	Poorly Sorted
U1345C 12H-6 16 cm	119.67	387.40	13.8	2.9	Medium Silt	Poorly Sorted
U1345C 12H-6 36 cm	119.87	388.02	15.4	2.8	Medium Silt	Poorly Sorted
U1345C 12H-6 56 cm	120.07	388.64	20.2	3.0	Coarse Silt	Poorly Sorted
U1345C 12H-6 76 cm	120.27	389.26	19.4	2.9	Coarse Silt	Poorly Sorted
U1345A 13H-1 55 cm	120.65	390.42	18.9	2.8	Coarse Silt	Poorly Sorted
U1345A 13H-1 75 cm	120.85	391.04	16.9	2.9	Coarse Silt	Poorly Sorted
U1345A 13H-2 5 cm	121.05	391.63	16.6	2.9	Coarse Silt	Poorly Sorted
U1345A 13H-2 22 cm	121.22	392.16	16.2	3.1	Coarse Silt	Poorly Sorted
U1345A 13H-2 42 cm	121.42	392.78	17.4	3.3	Coarse Silt	Poorly Sorted
U1345A 13H-2 62 cm	121.62	393.40	11.6	2.9	Medium Silt	Poorly Sorted
U1345A 13H-2 82 cm	121.82	394.02	17.5	3.0	Coarse Silt	Poorly Sorted
U1345A 13H-2 102 cm	122.02	394.64	18.0	3.2	Coarse Silt	Poorly Sorted
U1345A 13H-2 122 cm	122.22	395.26	21.4	3.1	Coarse Silt	Poorly Sorted
U1345A 13H-2 142 cm	122.42	395.88	23.2	3.3	Coarse Silt	Poorly Sorted
U1345A 13H-3 12 cm	122.62	396.50	18.0	3.2	Coarse Silt	Poorly Sorted
U1345A 13H-3 32 cm	122.82	397.12	17.3	3.1	Coarse Silt	Poorly Sorted
U1345A 13H-3 52 cm	123.02	397.74	16.9	2.9	Coarse Silt	Poorly Sorted

Sample	Depth (CCSF-A, mbsf)	AGE (ka)	Mean (µm)	Sorting	Mean	Sorting
U1345A 13H-3 72 cm	123.22	399.02	15.9	2.9	Coarse Silt	Poorly Sorted
U1345A 13H-3 96 cm	123.46	399.85	17.1	3.1	Coarse Silt	Poorly Sorted
U1345A 13H-3 112 cm	123.62	400.40	20.1	2.9	Coarse Silt	Poorly Sorted
U1345A 13H-3 132 cm	123.82	401.09	27.3	3.2	Coarse Silt	Poorly Sorted
U1345A 13H-4 6 cm	124.06	401.92	28.5	3.2	Coarse Silt	Poorly Sorted
U1345A 13H-4 22 cm	124.22	402.47	30.3	3.3	Coarse Silt	Poorly Sorted
U1345A 13H-4 42 cm	124.42	403.16	48.9	3.3	Very Coarse Silt	Poorly Sorted
U1345A 13H-4 62 cm	124.62	403.85	69.6	2.9	Very Fine Sand	Poorly Sorted
U1345A 13H-4 82 cm	124.82	404.54	58.4	2.8	Very Coarse Silt	Poorly Sorted
U1345A 13H-4 102 cm	125.02	405.23	34.3	2.9	Very Coarse Silt	Poorly Sorted
U1345A 13H-4 122 cm	125.22	405.92	26.3	2.9	Coarse Silt	Poorly Sorted
U1345A 13H-4 142 cm	125.42	406.61	45.9	2.9	Very Coarse Silt	Poorly Sorted
U1345A 13H-5 12 cm	125.62	407.20	25.1	2.7	Coarse Silt	Poorly Sorted
U1345A 13H-5 32 cm	125.82	407.89	21.4	2.8	Coarse Silt	Poorly Sorted
U1345A 13H-5 52 cm	126.02	408.58	20.3	2.8	Coarse Silt	Poorly Sorted
U1345A 13H-5 72 cm	126.22	409.27	19.4	2.8	Coarse Silt	Poorly Sorted
U1345A 13H-5 92 cm	126.42	409.96	22.1	2.8	Coarse Silt	Poorly Sorted
U1345A 13H-5 112 cm	126.62	410.65	21.6	2.8	Coarse Silt	Poorly Sorted
U1345A 13H-5 132 cm	126.82	411.34	17.3	2.8	Coarse Silt	Poorly Sorted
U1345A 13H-6 2 cm	127.02	412.03	21.0	3.0	Coarse Silt	Poorly Sorted
U1345A 13H-6 22 cm	127.22	412.72	22.7	3.0	Coarse Silt	Poorly Sorted
U1345A 13H-6 42 cm	127.42	413.41	20.5	2.7	Coarse Silt	Poorly Sorted
U1345A 13H-6 62 cm	127.62	414.10	20.7	2.8	Coarse Silt	Poorly Sorted
U1345A 13H-6 82 cm	127.82	414.79	17.3	2.8	Coarse Silt	Poorly Sorted
U1345A 13H-6 102 cm	128.02	415.48	17.3	2.8	Coarse Silt	Poorly Sorted
U1345A 13H-6 122 cm	128.22	416.17	19.7	3.0	Coarse Silt	Poorly Sorted
U1345A 13H-6 142 cm	128.42	416.86	16.8	2.8	Coarse Silt	Poorly Sorted
U1345A 13H-7 12 cm	128.62	417.55	21.1	2.9	Coarse Silt	Poorly Sorted
U1345A 13H-7 32 cm	128.82	418.24	20.5	2.9	Coarse Silt	Poorly Sorted
U1345A 13H-7 52 cm	129.02	418.93	20.3	2.9	Coarse Silt	Poorly Sorted
U1345A 13H-7 72 cm	129.22	419.62	21.8	3.0	Coarse Silt	Poorly Sorted
U1345A 13H-7 92 cm	129.42	420.31	24.8	3.0	Coarse Silt	Poorly Sorted
U1345A 13H-7 112 cm	129.62	421.00	22.7	3.0	Coarse Silt	Poorly Sorted
U1345A 13H-7 132 cm	129.82	421.69	19.1	2.9	Coarse Silt	Poorly Sorted
U1345A 13H-CC 2 cm	129.92	421.90	23.2	2.9	Coarse Silt	Poorly Sorted
U1345A 13H-CC 13 cm	130.03	422.28	25.2	2.9	Coarse Silt	Poorly Sorted
U1345D 13H-4 100 cm	130.17	423.05	24.3	2.8	Coarse Silt	Poorly Sorted
U1345D 13H-4 115 cm	130.32	423.56	22.3	2.7	Coarse Silt	Poorly Sorted
U1345D 13H-4 145 cm	130.62	423.61	23.8	2.8	Coarse Silt	Poorly Sorted
U1345D 13H-5 10 cm	130.77	424.05	19.9	2.7	Coarse Silt	Poorly Sorted
U1345D 13H-4 130 cm	130.47	424.08	19.3	2.7	Coarse Silt	Poorly Sorted
U1345A 14H-1 12 cm	130.92	424.51	14.1	2.7	Medium Silt	Poorly Sorted
U1345A 14H-1 32 cm	131.12	425.10	15.4	2.8	Medium Silt	Poorly Sorted
U1345A 14H-1 49 cm	131.29	425.61	14.2	2.7	Medium Silt	Poorly Sorted
U1345A 14H-2 6 cm	131.37	425.79	13.1	2.6	Medium Silt	Poorly Sorted
U1345A 14H-2 22 cm	131.53	426.27	14.6	2.8	Medium Silt	Poorly Sorted

Sample	Depth (CCSF-A, mbsf)	AGE (ka)	Mean (µm)	Sorting	Mean	Sorting
U1345A 14H-2 42 cm	131.73	426.86	13.8	2.4	Medium Silt	Poorly Sorted
U1345A 14H-2 62 cm	131.93	427.46	15.2	2.7	Medium Silt	Poorly Sorted
U1345A 14H-2 82 cm	132.13	428.05	16.0	3.0	Coarse Silt	Poorly Sorted
U1345A 14H-2 99 cm	132.30	428.56	16.7	2.9	Coarse Silt	Poorly Sorted
U1345A 14H-2 130 cm	132.61	429.48	13.3	2.3	Medium Silt	Poorly Sorted
U1345A 14H-3 15 cm	132.92	430.41	13.5	2.4	Medium Silt	Poorly Sorted
U1345A 14H-3 40 cm	133.17	431.15	11.7	2.5	Medium Silt	Poorly Sorted
U1345A 14H-3 66 cm	133.43	431.93	10.9	2.8	Medium Silt	Poorly Sorted
U1345A 14H-3 95 cm	133.72	432.79	13.4	2.8	Medium Silt	Poorly Sorted
U1345A 14H-3 135 cm	134.12	433.98	13.9	2.8	Medium Silt	Poorly Sorted
U1345A 14H-4 10 cm	134.37	434.73	17.6	2.9	Coarse Silt	Poorly Sorted
U1345A 14H-4 36 cm	134.63	435.50	12.8	2.9	Medium Silt	Poorly Sorted
U1345A 14H-4 65 cm	134.92	436.37	17.2	3.0	Coarse Silt	Poorly Sorted
U1345A 14H-4 96 cm	135.23	437.29	11.5	2.5	Medium Silt	Poorly Sorted
U1345A 14H-4 145 cm	135.72	438.75	13.3	2.9	Medium Silt	Poorly Sorted
U1345A 14H-5 29 cm	136.06	439.76	19.4	3.0	Coarse Silt	Poorly Sorted
U1345A 14H-5 63 cm	136.40	440.78	10.1	3.5	Medium Silt	Poorly Sorted

Table S1. Grain size analysis using the Folk and Ward method (Blott and Pye, 2001) for calculating mean grain size and sorting both in quantitative and descriptive terms.