Supplemental Information for

'Persistent intermediate water warming during cold stadials in the SE Nordic seas during the last 65 kyr'

By

Mohamed M. Ezat, Tine L. Rasmussen, Jeroen Groeneveld

Table DR1. Tephra layers in JM11-F1-19PC.

Tephra horizons	Depth (cm) in JM11-FI-19PC	NGRIP Age (b2k) Svensson et al. (2008)
Saksunarvatn tephra	**83**	**10.347**
Vedde ash	**130**	**12.171**
Faroe Marine Ash Zone (FMAZ) II	**305**	**26.740**
FMAZ III	**440**	**38.122**
FMAZ IV*	**540**	
North Atlantic Ash Zone (NAAZ) II**	**~620**	**55.380**

***** Located in the lower part of interstadial 12 (Wastegård and Rasmussen, 2014). It has not yet been located in the ice cores.
** Because of no distinct peak (Fig. DR1) it has not been included in the final age model.

Table DR2. Calibrated radiocarbon dates using the Calib7.01 and Marine13 programs (Reimer et al., 2013). The reservoir corrections of the Calib7.01 program were used.

Depth (cm) in JM11-FI-19PC	Conventional Radiocarbon ages (kyr)	Calibrated Ages (kyr)	calibrated Ages ±1σ (b2k)	Laboratory code	Species
15	2.229 ± 0.03	1.822	1.822 ±0.07	UBA-21487	*N. pachyderma s*
40	4.570 ± 0.03	4.774	4.774 ±0.09	UBA-21488	*N. pachyderma s*
70	8.083 ± 0.04	8.534	8.534 ±0.08	UBA-21489	*N. pachyderma s*
130	10.905 ± 0.05	12.418	12.418 ±0.17	UBA-21490	*N. pachyderma s*
150	12.186 ± 0.05	13.632	13.632 ±0.12	UBA-21594	*N. pachyderma s*
195	13.493 ± 0.06	15.663	15.663 ±0.19	UBA-21595	*N. pachyderma s*
230	15.786 ± 0.08	18.653	18.653 ±0.13	UBA-21492	*N. pachyderma s*
305	23.962 ± 0.17	27.709	27.709 ±0.17	UBA-21493	*N. pachyderma s*
350	27.459 ± 0.2	31.103	31.103 ±0.18	UBA-21494	*N. pachyderma s*
430	33.614 ± 0.41	37.41	37.41 ±0.89	UBA-21495	*N. pachyderma s*
555	46.045 ± 2.02	48.162	48.162 ±1.89	UBA-21496	*N. pachyderma s*

Table DR3. Tie points of JM11-F1-19PC to NGRIP used in the construction of the age model. The final age model is based on a radiocarbon date from a core-top sample (15 cm, Table DR1), 4 tephra layers and 15 MS-K/Ti based tie points (see Fig. DR1). The ice core ages are taken from Svensson et al. (2008 and references therein).

Tie Points	Depth (cm) in JM11-FI-19PC	NGRIP Age (b2k) Svensson et al. (2008)
Saksunarvatn tephra	83	10.347
Vedde ash	130	12.171
IS 1 onset	190	14.692
IS 2 onset	260	23.340
FMAZ II	305	26.740
IS 3 onset	313	27.780
IS 4 onset	323	28.900
IS 5 onset	348	32.500
IS 6 onset	362	33.740
IS 7 onset	387	35.480
FMAZ III	440	38.122
IS 10 onset	486	41.460
IS 11 onset	513	43.340
IS 12 onset	545	46.860
IS 13 onset	567	49.280
IS 14 onset	590	54.220
IS 15 onset	625	55.800
IS 16 onset	638	58.280
IS 17 onset	670	59.440

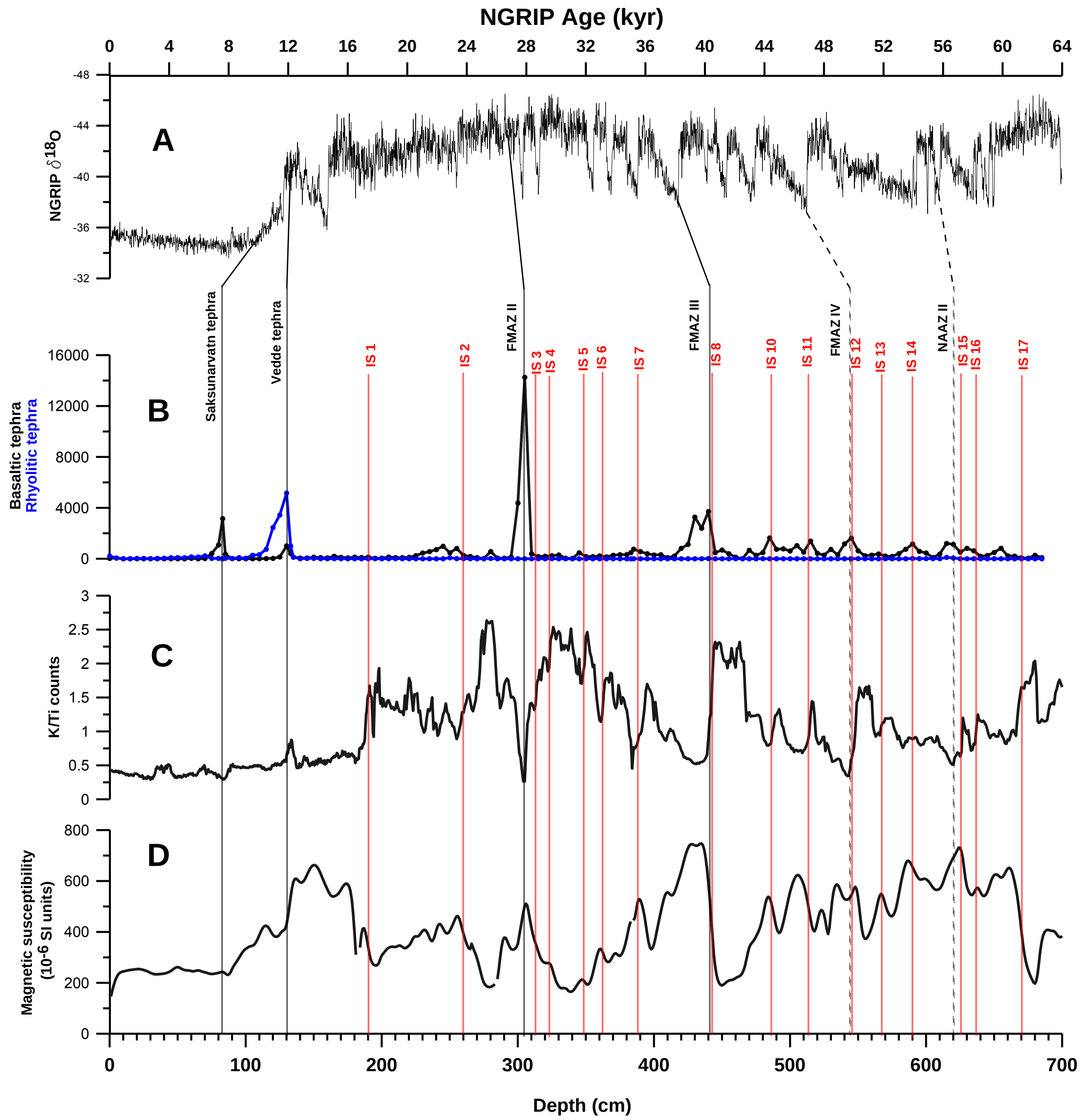

Figure DR1. Correlation of core JM11-F1-19PC to NGRIP based on location of tephra layers, magnetic susceptibility (MS) and XRF-K/Ti ratios. MS and K/Ti counts vary oppositely; high (low) MS correlates with low (high) K/Ti ratios during interstadials (stadials) (Rasmussen et al., 1996; Richter et al., 2006). Black and red lines mark the depths of the tephra and start of interstadials, respectively. Faroe Marine Ash Zone (FMAZ) IV and NAAZ II (North Atlantic Ash Zone) (dashed black lines) are used only as supporting tie points. Abbreviations: FMAZ (Faroe Marine Ash Zone), NAAZ (North Atlantic Ash Zone). NGRIP data are from Svensson et al. (2008).

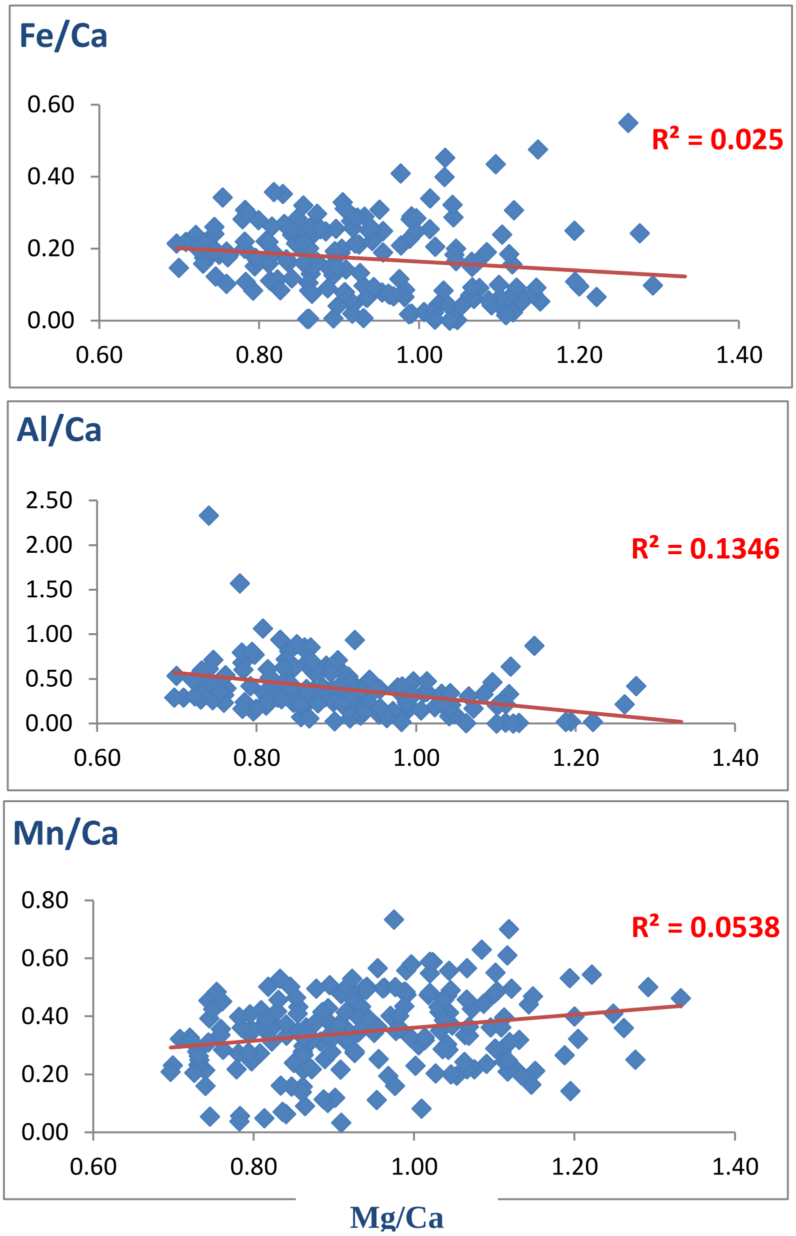

Figure DR2. Plots of Mg/Ca versus Fe/Ca, Al/Ca and Mn/Ca ratios for both *M. barleeanus* and *C. neoteretis* showing the absence of contamination by clay minerals and/or Mn-Fe-carbonates and oxyhydroxides (Boyle 1983; Barker et al 2003); for 13% of the samples the concentration of Fe, Al, and/or Mn was below the detection limit. All units are in mmol/mol.

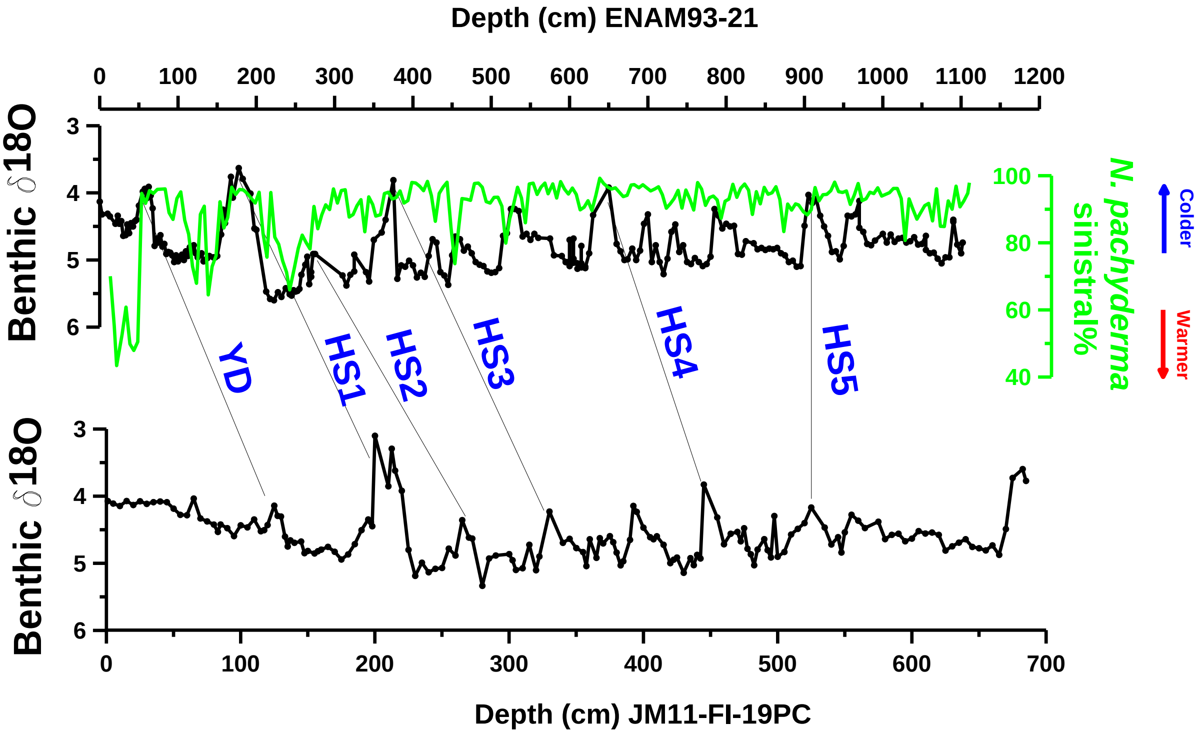

Figure DR3. Correlation between benthic δ^{18}O records measured on ***Melonis barleeanus*** of JM11-F1-19PC and nearby core ENAM93-21 from 1020 m water depth (Rasmussen et al., 1996). The two records are very similar and with similar values. The magnetic susceptibility and XRF-K/Ti ratios for ENAM93-21 (Richter et al., 2006) are the same as in JM11-FI-19PC (Fig. DR. 1). The percentage of planktic species *N. pachyderma* sinistral for ENAM93-21 (green line) indicates relatively warmer surface/subsurface temperatures during the interstadials than in the stadials.

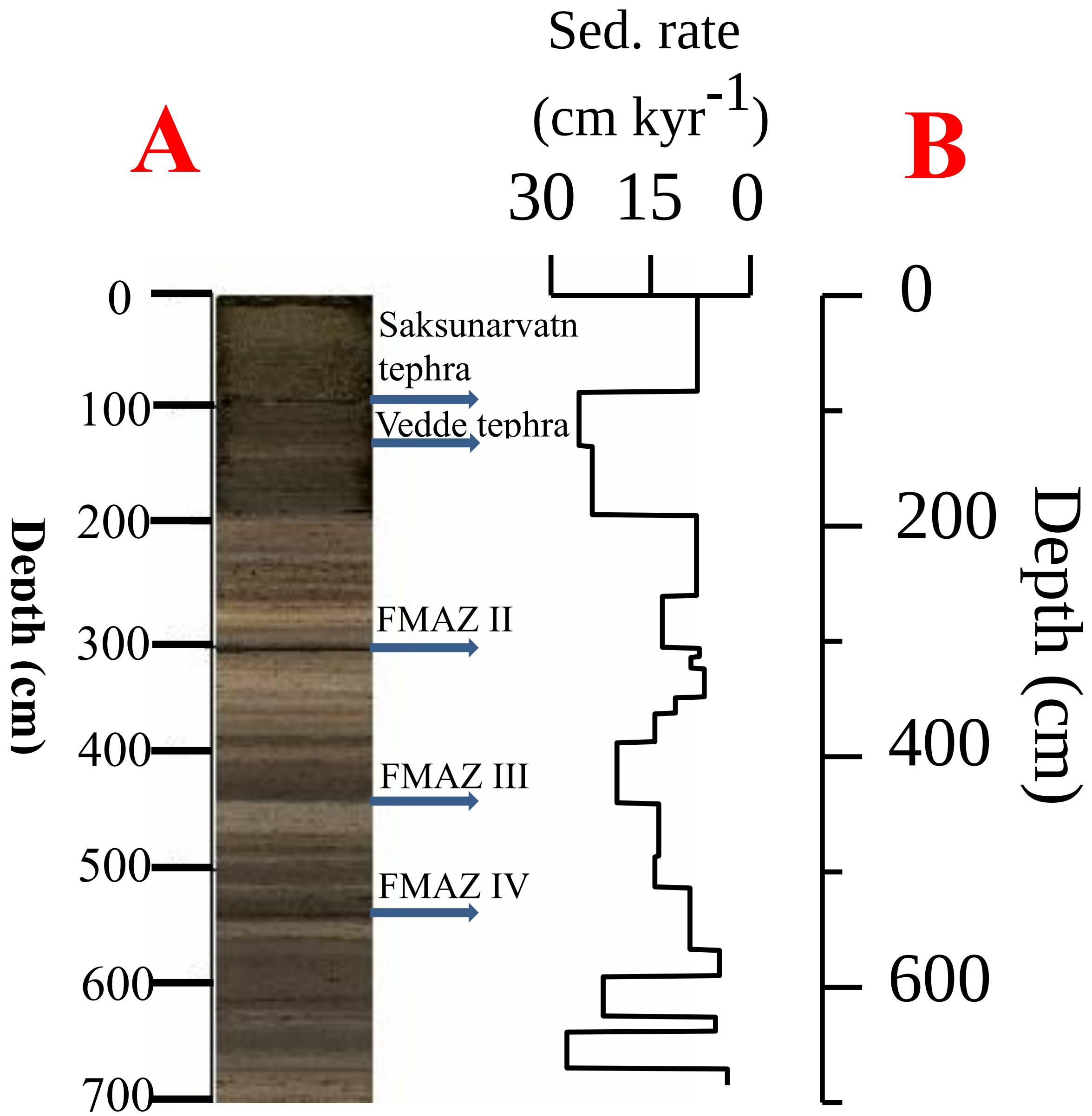

Figure DR4. A. XRF-scanner image of the upper 7 m of JM11-FI-19PC. The dark layers correlate with interstadials, while the light layers represent stadials/Heinrich events and the LGM. The same was recorded in ENAM93-21 (Rasmussen et al., 1998). Blue arrows refer to the tephra layers (see Table DR. 1). FMAZ: Faroe Marine Ash Zone. **B. Sedimentation rate of JM11-FI-19PC based on the tuned age model.**

Atlantic species

Benthic foraminiferal species linked to warm bottom water were grouped as ‘Atlantic Species’ (Rasmussen et al., 1996) and comprised predominantly specimens of *Epistominella decorata*, *Cibicidoides pachyderma* (=*C. aff C. floridanus*), *Gyroidina umbonata*, *Miliolinella irregularis*, *Sigmoilopsis schlumbergeri*, *Valvulineria sp.*, *Anomalinoides minimus*, *Eggerella bradyi*, *Bulimina costata*, and *Sagrina subspinescens*. The ecological preferences and systematics of those species assemblages are treated in detail in Rasmussen et al. (2003) and Rasmussen (2005). They are subtropical–boreal species adapted to low food supply. They do not occur in the Nordic seas today except two of them (*Gyroidina neosoldani*i and *Sigmoilopsis schlumbergeri*) that can be found on the shelf of western Norway in bottom water with a temperature >4 °C (Sejrup et al., 2004).

Table DR 4. Mg/Ca data for core JM11-F1-19PC.

Depth (cm)	Age (kyr)	Mg/Ca (mmol/mol)	BWT (°C)	Species
1	0.085	0.78	0.3	*M. barleeanus*
5	0.581	0.81	0.6	*M. barleeanus*
5	0.581	0.91	0.6	*C. neoteretis*
10	1.200	0.75	-0.1	*M. barleeanus*
15	1.822	0.78	0.3	*M. barleeanus*
20	2.448	0.84	0.9	*M. barleeanus*
25	3.075	0.84	0.8	*M. barleeanus*
30	3.702	0.82	0.8	*M. barleeanus*
30	3.702	0.89	1.4	*M. barleeanus*
35	4.329	0.81	0.7	*M. barleeanus*
35	4.329	0.86	1.1	*M. barleeanus*
40	4.956	0.90	1.5	*M. barleeanus*
45	5.583	0.89	1.3	*M. barleeanus*
50	6.209	0.86	1.1	*M. barleeanus*
55	6.836	0.85	1.0	*M. barleeanus*
60	7.463	0.86	1.1	*M. barleeanus*
65	8.090	0.86	1.1	*M. barleeanus*
65	8.090	0.83	0.8	*M. barleeanus*
70	8.717	0.87	1.2	*M. barleeanus*
75	9.344	0.86	1.1	*M. barleeanus*
80	9.971	0.91	1.5	*M. barleeanus*

83	10.347	0.85	1.0	*M. barleeanus*
85	10.425	0.80	0.4	*M. barleeanus*
90	10.619	0.78	0.3	*M. barleeanus*
95	10.813	0.73	-0.3	*M. barleeanus*
100	11.007	0.74	-0.2	*M. barleeanus*
105	11.201	0.73	-0.3	*M. barleeanus*
110	11.395	0.87	1.2	*M. barleeanus*
110	11.395	0.81	0.6	*M. barleeanus*
115	11.589	0.70	-0.7	*M. barleeanus*
117.5	11.686	0.74	-0.2	*M. barleeanus*
120	11.783	0.81	0.6	*M. barleeanus*
125	11.977	0.79	0.4	*M. barleeanus*
127.5	12.074	0.78	0.2	*M. barleeanus*
130	12.171	0.95	1.9	*M. barleeanus*
133	12.289	1.01	2.4	*M. barleeanus*
135	12.368	0.84	0.8	*M. barleeanus*
137	12.447	0.86	1.1	*M. barleeanus*
140	12.565	0.73	-0.3	*M. barleeanus*
142.5	12.663	0.86	1.1	*M. barleeanus*
145	12.762	0.76	0.1	*M. barleeanus*
147.5	12.860	0.88	1.3	*M. barleeanus*
150	12.959	0.84	0.9	*M. barleeanus*
152.5	13.057	0.86	1.1	*M. barleeanus*
152.5	13.057	0.96	1.2	*C. neoteretis*

155	13.156	0.81	0.6	*M. barleeanus*
157.5	13.254	0.90	1.5	*M. barleeanus*
160	13.353	0.76	0.0	*M. barleeanus*
162.5	13.451	0.82	0.7	*M. barleeanus*
165	13.550	0.74	-0.2	*M. barleeanus*
167.5	13.648	0.76	0.0	*M. barleeanus*
170	13.747	0.81	0.6	*M. barleeanus*
172.5	13.845	0.79	0.4	*M. barleeanus*
175	13.944	0.75	-0.1	*M. barleeanus*
177.5	14.042	0.81	0.6	*M. barleeanus*
180	14.141	0.75	-0.1	*M. barleeanus*
185	14.337	0.76	0.0	*M. barleeanus*
190	14.692	0.82	0.7	*M. barleeanus*
192.5	15.001	0.88	1.3	*M. barleeanus*
195	15.310	0.90	1.4	*M. barleeanus*
195	15.310	1.11	3.0	*C. neoteretis*
196	15.433	0.89	1.4	*M. barleeanus*
197	15.557	0.93	1.7	*M. barleeanus*
198	15.680	1.05	2.8	*M. barleeanus*
198	15.680	1.06	2.5	*C. neoteretis*
199	15.804	1.33	5.3	*C. neoteretis*
200	15.927	1.29	4.9	*C. neoteretis*
205	16.545	1.20	4.0	*C. neoteretis*
210	17.163	1.25	4.5	*C. neoteretis*

210	17.163	1.37	5.6	*C. neoteretis*
210	17.163	0.94	1.8	*M. barleeanus*
212.5	17.472	1.21	4.1	*C. neoteretis*
212.5	17.472	1.07	2.9	*M. barleeanus*
215	17.781	1.13	3.3	*C. neoteretis*
220	18.398	1.15	3.5	*C. neoteretis*
225	19.016	1.09	2.8	*C. neoteretis*
225	19.016	1.07	2.9	*M. barleeanus*
230	19.634	1.15	3.5	*M. barleeanus*
230	19.634	1.11	3.1	*C. neoteretis*
235	20.251	1.12	3.2	*C. neoteretis*
240	20.869	1.11	3.1	*C. neoteretis*
245	21.487	1.13	3.3	*C. neoteretis*
247.5	21.796	1.12	3.1	*C. neoteretis*
250	22.105	1.08	2.7	*C. neoteretis*
252.5	22.413	1.13	3.3	*C. neoteretis*
255	22.722	1.04	2.2	*C. neoteretis*
255	22.722	1.07	2.9	*M. barleeanus*
260	23.340	1.12	3.1	*C. neoteretis*
265	23.718	1.10	3.0	*C. neoteretis*
270	24.096	1.12	3.2	*C. neoteretis*
272.5	24.284	1.07	2.6	*C. neoteretis*
277.5	24.662	0.89	1.6	*C. neoteretis*
280	24.851	0.98	2.4	*C. neoteretis*

285	25.229	1.05	0.6	*C. neoteretis*
290	25.607	0.91	1.5	*C. neoteretis*
295	25.984	0.98	2.9	*C. neoteretis*
300	26.362	1.1	2.0	*C. neoteretis*
300	26.362	1.02	2.1	*M. barleeanus*
302.5	26.551	1.03	2.2	*C. neoteretis*
305	26.740	1.04	2.3	*C. neoteretis*
307.5	27.065	1.02	2.0	*C. neoteretis*
310	27.390	1.09	3.0	*M. barleeanus*
312.5	27.715	1.02	2.0	*C. neoteretis*
312.5	27.715	1.10	3.2	*M. barleeanus*
317.5	28.284	0.99	2.3	*M. barleeanus*
317.5	28.284	1.07	2.6	*C. neoteretis*
320	28.564	1.12	3.3	*M. barleeanus*
322.5	28.844	1.02	2.5	*M. barleeanus*
322.5	28.844	1.04	2.2	*C. neoteretis*
325	29.188	1.12	3.3	*M. barleeanus*
327.5	29.548	1.04	2.7	*M. barleeanus*
327.5	29.548	1.04	2.2	*C. neoteretis*
330	29.908	1.19	4.0	*C. neoteretis*
332.5	30.268	1.00	1.8	*C. neoteretis*
332.5	30.268	1.04	2.7	*M. barleeanus*
335	30.628	1.11	3.2	*M. barleeanus*
335	30.628	0.97	1.4	*C. neoteretis*

337.5	30.988	1.03	2.1	*C. neoteretis*
340	31.348	1.07	2.6	*C. neoteretis*
342.5	31.708	1.06	2.5	*C. neoteretis*
342.5	31.708	1.05	2.7	*M. barleeanus*
345	32.068	1.10	3.2	*M. barleeanus*
347.5	32.428	0.97	2.1	*M. barleeanus*
347.5	32.428	1.09	2.8	*C. neoteretis*
350	32.677	1.05	2.7	*M. barleeanus*
352.5	32.899	0.91	1.5	*M. barleeanus*
355	33.120	1.07	2.9	*M. barleeanus*
357.5	33.341	1.07	2.9	*M. barleeanus*
360	33.563	0.85	0.9	*M. barleeanus*
362.5	33.775	0.99	2.2	*M. barleeanus*
365	33.949	0.99	2.3	*M. barleeanus*
367.5	34.123	0.96	2.0	*M. barleeanus*
370	34.297	0.96	2.0	*M. barleeanus*
372.5	34.471	0.96	2.0	*M. barleeanus*
375	34.645	0.93	1.7	*M. barleeanus*
377.5	34.819	0.92	1.6	*M. barleeanus*
380	34.993	0.99	2.3	*M. barleeanus*
383	35.202	0.89	1.4	*M. barleeanus*
385	35.341	0.83	0.8	*M. barleeanus*
387.5	35.505	0.93	1.8	*M. barleeanus*
390	35.630	0.94	1.8	*M. barleeanus*

392.5	35.754	1.04	2.7	*M. barleeanus*
395	35.879	0.94	1.8	*M. barleeanus*
397.5	36.003	0.86	1.0	*M. barleeanus*
400	36.128	0.80	0.4	*M. barleeanus*
402	36.228	0.92	1.6	*M. barleeanus*
405	36.377	0.86	1.0	*M. barleeanus*
407.5	36.502	0.91	1.6	*M. barleeanus*
410	36.627	0.85	1.0	*M. barleeanus*
412.5	36.751	0.83	0.7	*M. barleeanus*
415	36.876	0.83	0.8	*M. barleeanus*
417.5	37.000	0.92	1.6	*M. barleeanus*
420	37.125	0.93	1.7	*M. barleeanus*
422.5	37.250	0.94	1.8	*M. barleeanus*
425	37.374	0.98	2.1	*M. barleeanus*
427.5	37.499	0.92	1.6	*M. barleeanus*
430	37.624	0.84	0.9	*M. barleeanus*
432.5	37.748	0.10	2.3	*M. barleeanus*
435	37.873	0.92	1.6	*M. barleeanus*
437.5	37.997	0.93	0.9	*C. neoteretis*
440	38.122	0.94	1.8	*M. barleeanus*
440	38.122	0.98	1.5	*C. neoteretis*
442.5	38.303	1.22	4.2	*C. neoteretis*
445	38.485	1.07	2.6	*C. neoteretis*
447.5	38.666	1.14	3.4	*C. neoteretis*

452.5	39.029	1.19	3.9	*C. neoteretis*
452.5	39.029	1.00	2.4	*M. barleeanus*
455	39.210	1.11	3.2	*M. barleeanus*
457.5	39.392	1.04	2.7	*M. barleeanus*
457.5	39.392	1.11	3.0	*C. neoteretis*
460	39.573	0.94	1.1	*C. neoteretis*
462.5	39.755	0.91	1.5	*M. barleeanus*
465	39.936	0.99	2.2	*M. barleeanus*
467.5	40.118	0.91	1.5	*M. barleeanus*
472.5	40.480	0.89	1.3	*M. barleeanus*
475	40.662	0.81	0.6	*M. barleeanus*
477.5	40.843	0.87	1.1	*M. barleeanus*
480	41.025	0.92	1.7	*M. barleeanus*
482.5	41.206	1.01	2.4	*M. barleeanus*
482.5	41.206	0.99	2.3	*M. barleeanus*
485	41.387	0.83	0.8	*M. barleeanus*
487.5	41.564	0.93	1.7	*M. barleeanus*
490	41.739	1.03	2.6	*M. barleeanus*
495	42.087	0.98	2.2	*M. barleeanus*
497.5	42.261	0.90	1.4	*M. barleeanus*
500	42.435	0.86	1.1	*M. barleeanus*
505	42.783	1.01	2.5	*M. barleeanus*
507.5	42.957	0.94	1.8	*M. barleeanus*
510	43.131	0.10	2.3	*M. barleeanus*

512.5	43.305	0.98	2.2	*M. barleeanus*
515	43.560	0.92	1.6	*M. barleeanus*
520	44.110	1.28	4.4	*M. barleeanus*
525	44.660	1.04	2.7	*M. barleeanus*
530	45.210	0.73	-0.4	*M. barleeanus*
532	45.43	0.78	0.3	*M. barleeanus*
535	45.760	0.87	1.2	*M. barleeanus*
537	45.98	0.85	1.0	*M. barleeanus*
541	46.42	0.85	1.0	*M. barleeanus*
545	46.860	1.10	3.1	*M. barleeanus*
547.5	47.135	0.87	1.2	*M. barleeanus*
550	47.410	1.15	3.5	*M. barleeanus*
555	47.960	0.95	1.9	*M. barleeanus*
560	48.510	0.86	1.1	*M. barleeanus*
565	49.060	1.01	2.5	*M. barleeanus*
570	49.924	0.71	-0.6	*M. barleeanus*
575	50.998	0.72	-0.4	*M. barleeanus*
580	52.072	0.73	-0.3	*M. barleeanus*
585	53.146	0.74	-0.2	*M. barleeanus*
590	54.220	0.70	-0.7	*M. barleeanus*
595	54.446	1.04	2.7	*M. barleeanus*
600	54.671	0.90	1.4	*M. barleeanus*
605	54.897	0.86	1.0	*M. barleeanus*
610	55.123	0.75	-0.0	*M. barleeanus*

615	55.349	0.80	0.5	*M. barleeanus*
620	55.574	1.03	2.6	*M. barleeanus*
625	55.800	0.90	1.5	*M. barleeanus*
630	56.754	0.91	1.5	*M. barleeanus*
635	57.708	0.82	0.7	*M. barleeanus*
640	58.353	0.72	-0.4	*M. barleeanus*
645	58.534	0.88	1.2	*M. barleeanus*
650	58.715	1.05	2.3	*C. neoteretis*
655	58.896	0.79	0.3	*M. barleeanus*
660	59.078	0.78	0.3	*M. barleeanus*
660	59.078	0.90	0.5	*C. neoteretis*
665	59.259	0.82	0.6	*M. barleeanus*
670	59.440	0.96	2.0	*M. barleeanus*
670	59.440	1.02	2.0	*C. neoteretis*
675	60.893	0.93	0.8	*C. neoteretis*
677.5	61.620	1.26	4.6	*C. neoteretis*
682.5	63.073	1.15	3.5	*C. neoteretis*
685	63.800	1.20	4.0	*C. neoteretis*

References

Barker, S., Greaves, M., and Elderfield, H., 2003, A study of cleaning procedures used for foraminiferal Mg/Ca paleothermometry: Geochemistry Geophysics Geosystems**,** v. 4, no. 8407, doi: 10.1029/2003GC000559.

Boyle, E.A., 1983, Manganese carbonate overgrowths on foraminifera tests: Geochimica et Cosmochimica Acta**,** v. 47, p. 1815– 1819.

Rasmussen, T.L., 2005, Systematic paleontology and ecology of benthic foraminifera from the Plio-Pleistocene Kalithea Bay Section, Rhodes (Greece): Cushman Foundation for Foraminiferal Research Special Publication Series, v. 39, p. 53-157.

Rasmussen, T.L., and Thomsen, E., 2004, The role of the North Atlantic Drift in the millennial timescale glacial climate fluctuations: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 210, p. 101–116, doi:10.1016/j.palaeo.2004.04.005.

Rasmussen, T.L., Thomsen, E., Kuijpers, A., Troelstra, S.R., Prins, M., 2003, Millennial-scale glacial variability versus Holocene stability: changes in planktic and benthic foraminifera faunas and ocean circulation in the North Atlantic during the last 60,000 years: Marine Micropaleontology, v. 47, p. 143–176.

Rasmussen, T.L., Thomsen, E., Van Weering, T.C.E., 1998, Cyclic changes in sedimentation on the Faeroe Drift 53-9 kyr BP related to climate variations: Geological Society Special Publication, v. 129. P. 255–267.

Rasmussen, T.L., Thomsen E., Labeyrie L., and van Weering T.C.E., 1996, Circulation changes in the Faeroe-Shetland Channel correlating with cold events during the last glacial period (58–10 ka): Geology, v. 24, p. 937– 940.

Reimer, P.J., and 29 others, 2013, IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP: Radiocarbon, v. 55, p. 1869–1887, doi:10.2458/azu_js_rc.55.16947.

Richter, T.O., et al., 2006, The Avaatech XRF Core Scanner: technical description and applications to NE Atlantic sediments. New Techniques in Sediment Core Analysis. Geol. Soc. London, Spec. publ., v. 267, p. 39–50 (2006).

Sejrup, H.P., Birks, H.J.B., Klitgaard Kristensen, D., Madsen, H., 2004, Benthonic foraminiferal distributions and quantitative transfer functions for the northwest European continental margin: Marine Micropaleontology, v. 53, p. 197–226.

Svensson, A., et al., 2008, A 60 000 year Greenland stratigraphic ice core chronology: Climate of the Past, v. 4, p. 47–57.

Wastegård, S., and Rasmussen, T.L., 2014, Faroe Marine Ash Zone IV – a new MIS 3 ash zone on the Faroe Islands margin. Geol. Soc. London, Spec. publ. in press.