

Supplementary Materials for
Arctic marine sediments reveal massive coastal permafrost erosion during the
Bølling-Allerød warm period

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This Supplementary Material file includes:

Supplementary methods
Figs. S1 to S7
Tables S1 to S2

Supplementary text

Subsampling and sample handling

HH11-09 gravity core (GC) was subsampled at 2-cm resolution at the University Centre in Svalbard (UNIS). Humid samples were packaged in isolated plastic bags and shipped via courier to the laboratories of the Institute of Polar Sciences in Bologna, Italy. Since the shipment took longer than expected, after arrival 5 random intervals were selected to check for potential degradation and/or contamination during the shipment. Their analyses were compared to the same 5 intervals shipped via passenger flights (less than 2-day travel), revealing no loss of organic content or degradation took place.

Calculation of indexes

$$CPI = \frac{1}{2} \left(\frac{C25 + C27 + C29 + C31}{C24 + C26 + C28 + C30} + \frac{C25 + C27 + C29 + C31}{C26 + C28 + C30 + C32} \right)$$

$$ACL = \frac{\sum_{n=15}^{35} Cn * n}{\sum_{n=15}^{35} Cn}$$

$$\%MeC37:4 = 100 * \frac{MeC37:4}{MeC37:2 + MeC37:3 + MeC37:4}$$

$$\%MeC38:4 = 100 * \frac{MeC38:4}{MeC38:2 + MeC38:3 + MeC38:4}$$

Compound specific radiocarbon ages processing

The method proposed in Schefuß *et al.*¹ and Winterfeld *et al.*² was used to extrapolate pre-depositional ages of FAME compound. $\Delta^{14}C$ values measured and reported in Supplementary Table 2 were used to calculate the $\Delta^{14}C$ at the time of deposition ($\Delta^{14}C_{initial}$):

$$\Delta^{14}C_{initial} = \left[\left(\frac{\Delta^{14}C}{1000} + 1 \right) * e^{\lambda t} - 1 \right] * 1000$$

Where $\lambda=1/8267 \text{ y}^{-1}$ and t is the time of deposition of the sediment interval from the age-depth model.

Pre-depositional ^{14}C ages were calculated with the formula:

$$age = -8033 * \ln \left(\frac{1 + \frac{\Delta^{14}\text{C}_{\text{initial}}}{1000}}{1 + \frac{\Delta^{14}\text{C}_{\text{atm}}}{1000}} \right)$$

Where $\Delta^{14}\text{C}_{\text{atm}}$ is the atmospheric $\Delta^{14}\text{C}$ at the time of deposition estimated from the IntCal20 dataset³ and from direct measurement⁴ for the top (modern) sample. Gaussian error propagation (<http://www.julianibus.de/>) was used to estimate the uncertainty on the derived pre-depositional ages from the initial errors on $\Delta^{14}\text{C}$, time of deposition (from the age-depth model) and $\Delta^{14}\text{C}_{\text{atm}}$. Out of the initial 24 radiocarbon datings obtained on individual FAMEs, 5 results were too close to the radiocarbon dating limit (approximately 50000 years) and with too large uncertainties to calculate pre-depositional ages.

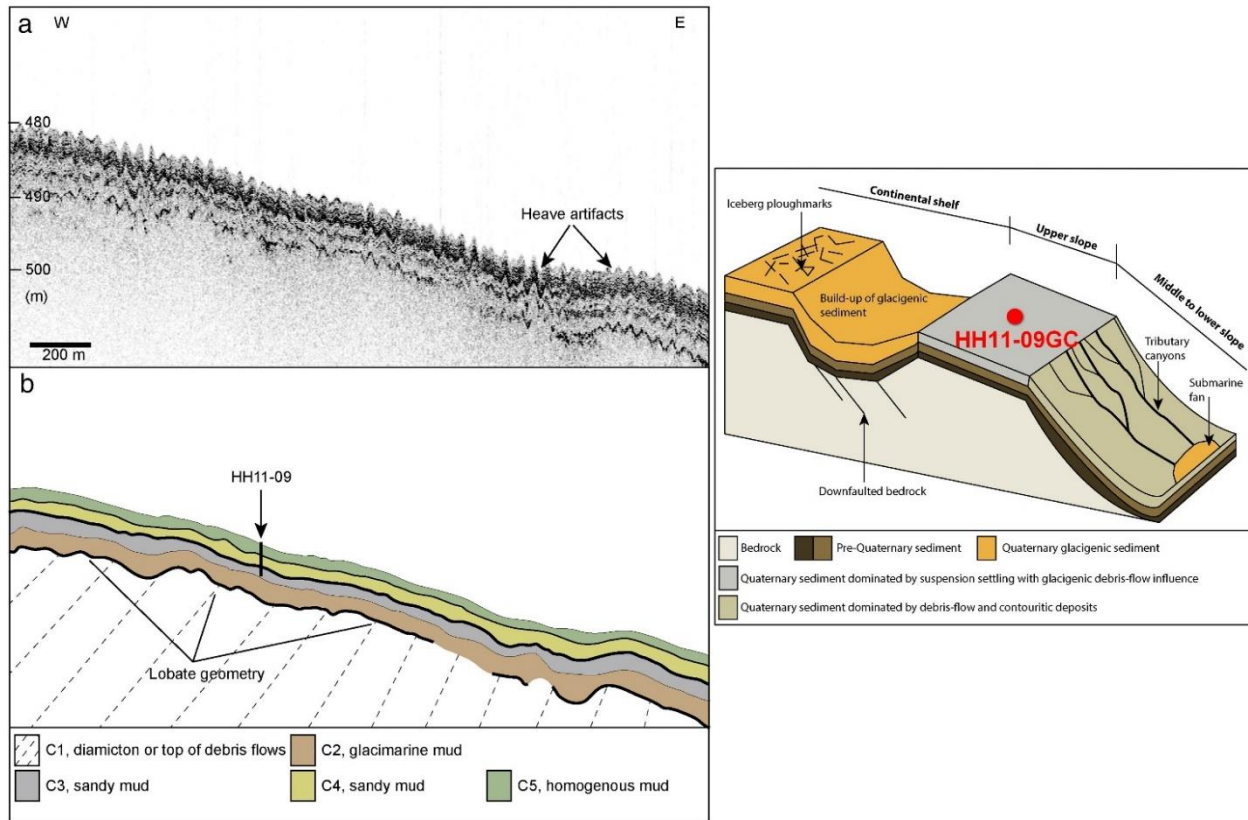


Fig. S1. Sub-bottom profile of the core location. (a) Chirp profile along the upper slope of Albertini trough with (b) interpreted sub-parallel reflectors, showing the location and approximate penetration of HH11-09GC sediment core⁵. (c) Illustrated sketch of distal continental shelf and slope in front of Albertini trough, showing the approximate position of the core. The presence of down-faulted bedrock before the upper slope is thought to be the primary reason of the absence of a trough mouth fan and of important glacial-related deposits for most of the last glacial period and deglaciation on the upper slope. Images slightly modified from Fransner *et al.*⁶.

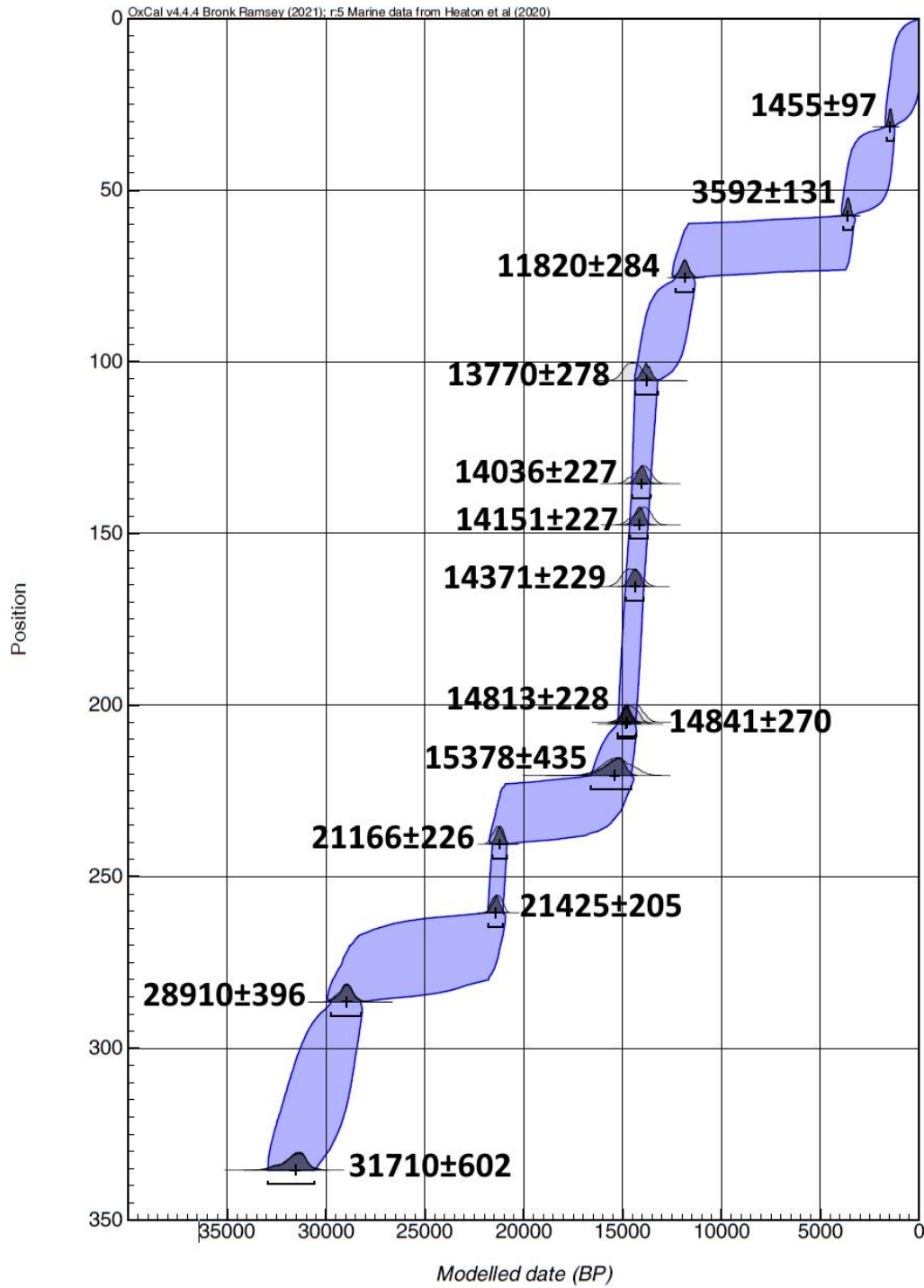


Fig. S2. Age-depth model. Graphical representation of the Bayesian age-depth model realized with OxCal 4.4.4⁷. The median of the 14 modelled datings used to build the model are reported, with 1σ uncertainty, beside their plotted statistical distribution.

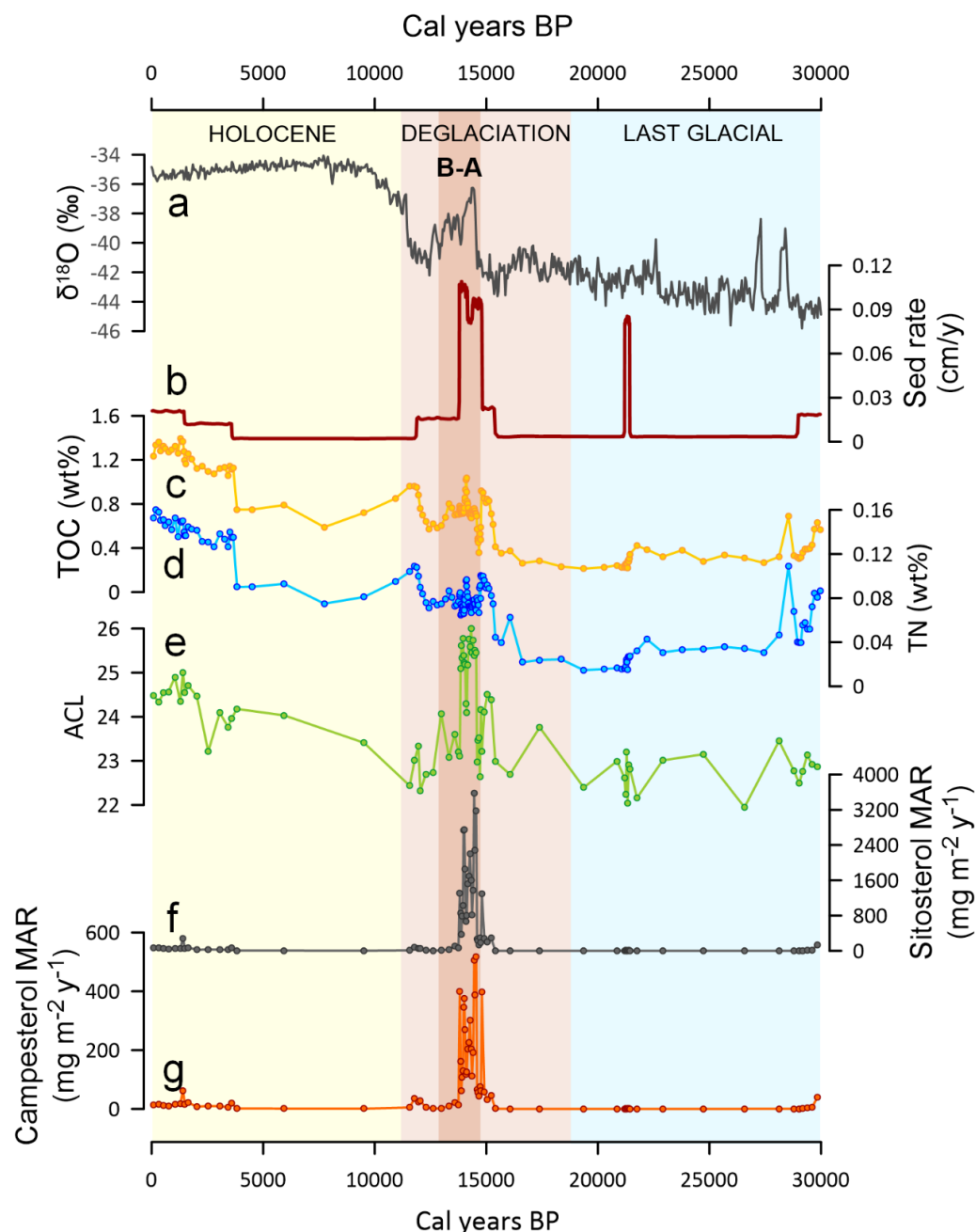


Fig. S3. Additional sedimentological and geochemical data. (a) Oxygen isotopes ($\delta^{18}\text{O}$) from Greenland ice cores⁸ (black line); (b) Modelled sedimentation rate in the core location derived from the age-depth model calculation on OxCal (red line); (c) Total organic carbon (TOC, yellow line and dots) and (d) nitrogen (TN, blue line and dots); (e) Average Chain Length (ACL, green line and dots) of *n*-alkanes; (f) Sitosterol (grey line and dots) and (g) campesterol (orange line and dots) mass accumulation rates (MAR). Vertical coloured regions display the major climatic periods, with the B-A highlighted by the darker red colour.

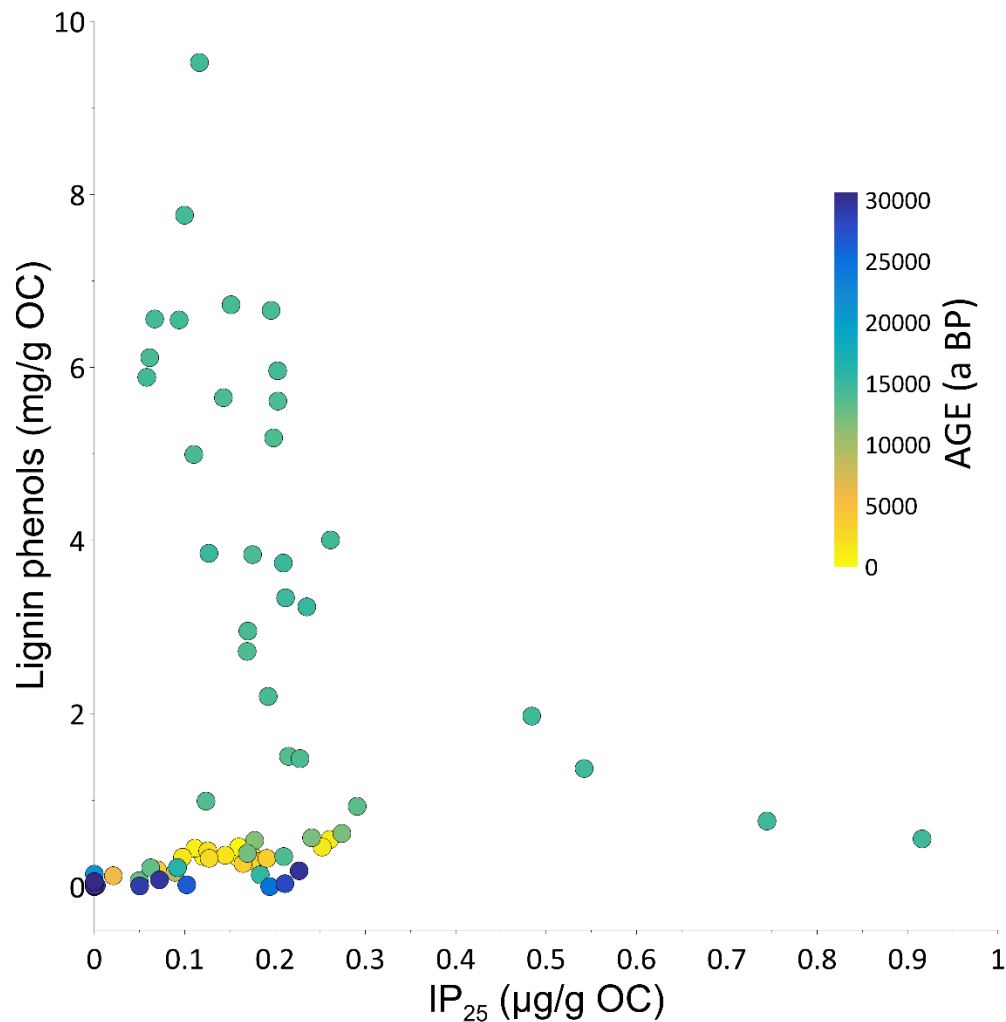


Fig. S4. Correlation between sea ice proxy and terrestrial biomarkers. Horizontal axis represents the concentration of the sea ice proxy IP_{25} and the vertical axis represents the concentration of lignin phenols, both normalized for the OC content. The color of the circles changes with the age of sedimentation.

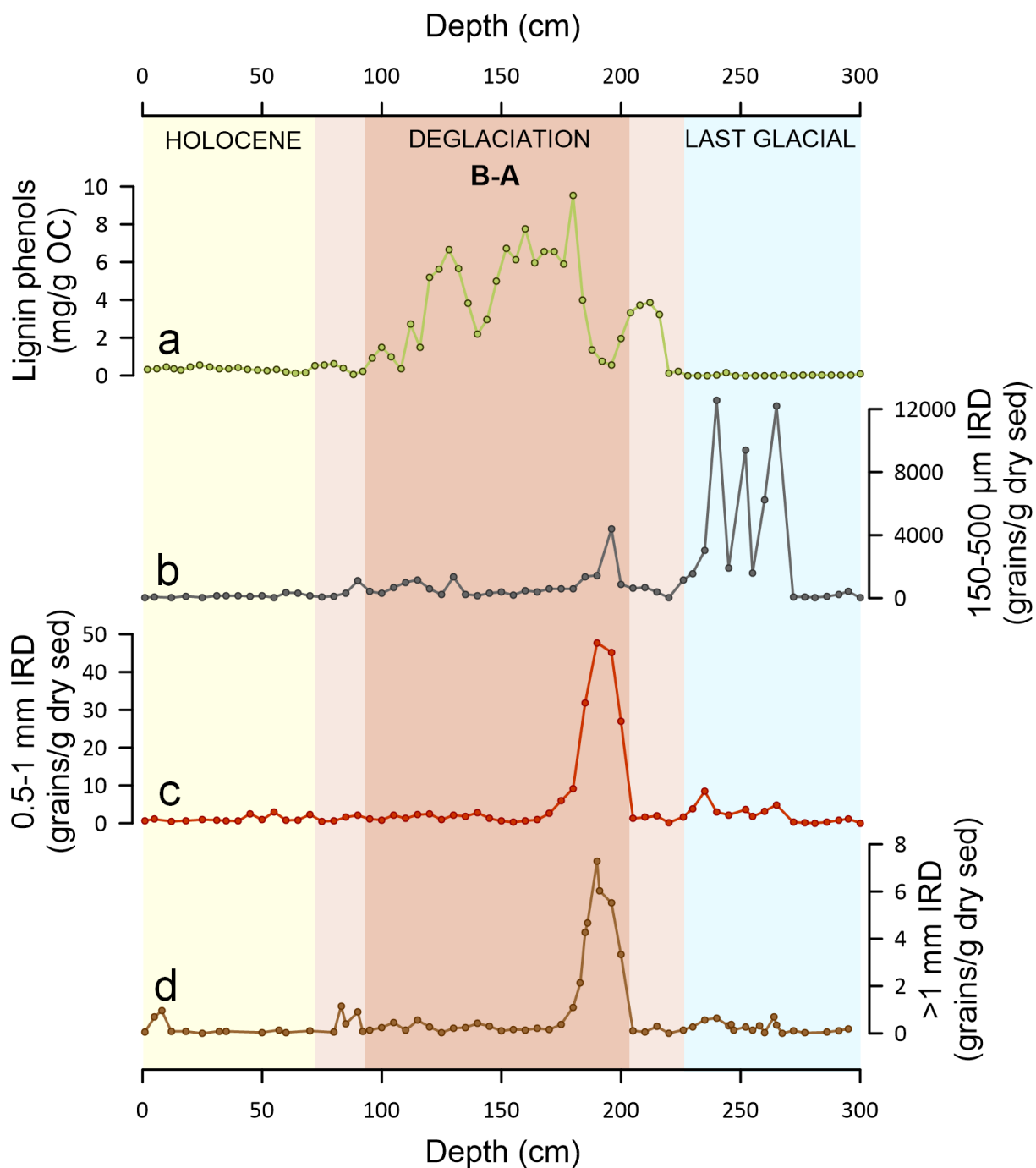


Fig. S5. Additional sedimentological data. (a) Lignin phenols (green line and dots) concentration (OC-normalized); (b) 150-500µm (grey line and dots), (c) 0.5-1mm (red line and dots) and (d) >1mm (brown line and dots) ice rafted debris (IRD) distribution. IRD data from Chauhan *et al.*⁹.

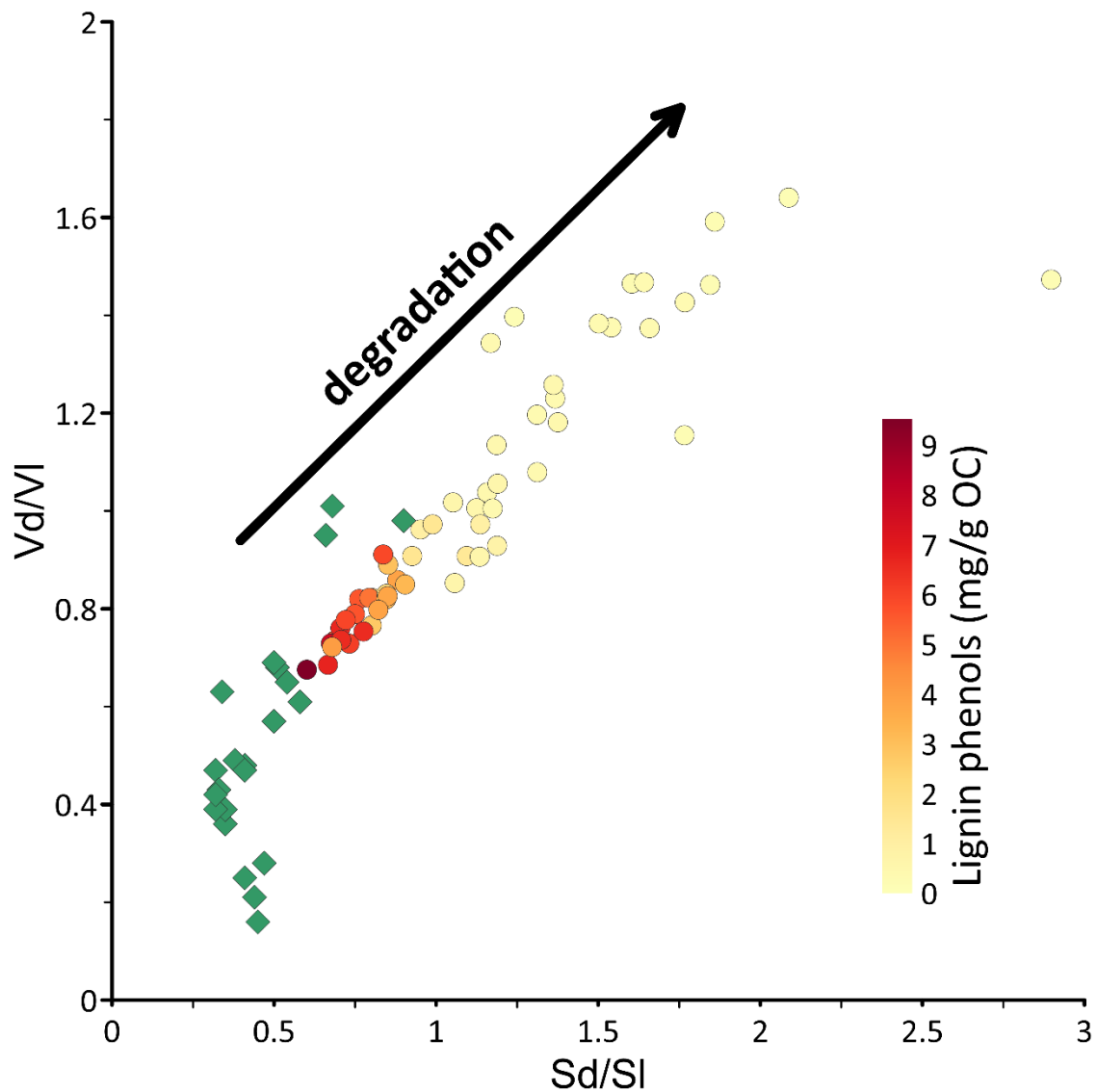


Fig. S6. Lignin degradation proxies. The graph shows the relation between acid to aldehyde ratio of syringyl (Sd/SI) and vanillyl (Vd/Vl) phenols. Filled circles represent samples from core HH11-09GC, with filling color depending on the total lignin phenols concentration. For comparison, data from ice complex deposits (Yedoma)¹⁰ are represented as green diamonds.

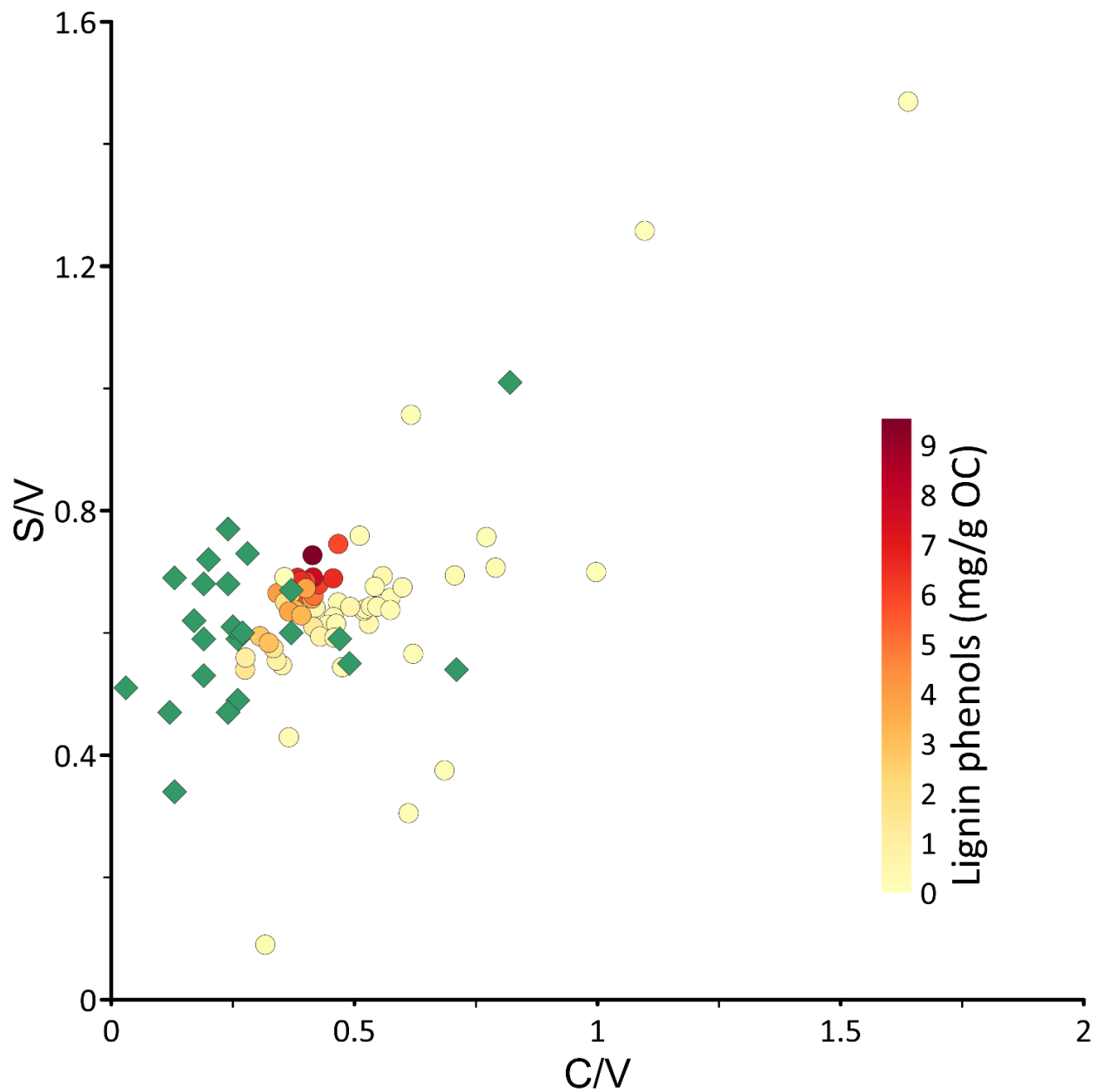


Fig. S7. Lignin source proxies. The graph shows the relation between cinnamyl over vanillyl (C/V) and syringyl over vanillyl (S/V) phenols ratio. Filled circles represent samples from core HH11-09GC, with filling color depending on the total lignin phenols concentration. For comparison, data from ice complex deposits (Yedoma)¹⁰ are represented as green diamonds.

Facility	ID	Depth (cm)	Sample type	AMS ^{14}C age (yr)	σ ^{14}C age (yr)	ΔR (yr)	σ ΔR (yr)	$\Delta\text{R}_{\text{ref}}$	Modelled age (yr BP)	σ modelled age (yr)
Lund Radiocarbon Dating Laboratory	LuS10822	31	Mixed planthic foraminifera	2010	45	-55	35	7	1455	97
Lund Radiocarbon Dating Laboratory	LuS10823	57	Mixed planthic foraminifera	3770	65	-55	35	7	3592	131
Lund Radiocarbon Dating Laboratory	LuS10824	75	Mixed benthic foraminifera	10610	70	-80	95	8	11820	284
AWI-MICADAS	8336.1.1	105	Mixed benthic foraminifera	13094	124	230	250	8	13770	278
AWI-MICADAS	8337.1.1	135	Mixed benthic foraminifera	12616	127	110	260	8	14036	227
AWI-MICADAS	8338.1.1	147	Mixed benthic foraminifera	12564	128	70	260	8	14151	227
Lund Radiocarbon Dating Laboratory	LuS10825	165	Mixed benthic foraminifera	13270	70	358	285	8	14371	229
AWI-MICADAS	8339.1.1	205	Mixed benthic foraminifera	12972	128	132	260	8	14813	228
NOSAMS	OS-163812	206	Mixed benthic foraminifera	13350	100	420	200	8	14841	270
Ångström Radiocarbon Laboratory	Ua-46353	220	Bivalve	14382	488	970	125	8	15378	435
Lund Radiocarbon Dating Laboratory	LuS10826	240	<i>N. pachyderma</i>	18565	85	170	100	8	21166	226
Lund Radiocarbon Dating Laboratory	LuS10827	260	<i>N. pachyderma</i>	18545	85	170	100	8	21425	205
Lund Radiocarbon Dating Laboratory	LuS10828	286	Mixed benthic foraminifera	25800	300	170	100	8	28910	396
Lund Radiocarbon Dating Laboratory	LuS10830	335	<i>N. pachyderma</i>	28350	500	170	100	8	31710	602

Table S1. List of radiocarbon datings used in the realization of the age-depth model with their respective $\Delta\text{R}^{11,12}$.

Depth (cm)	Individual FAME	AMS ^{14}C AGE (yr)	σ AMS ^{14}C AGE (yr)	$\Delta^{14}\text{C}$ (‰)	$\sigma \Delta^{14}\text{C}$ (‰)	Sedimentation age (yr BP)	σ sedimentation age (yr)	$\Delta^{14}\text{C}_{\text{initial}}$ (‰)	$\sigma \Delta^{14}\text{C}_{\text{initial}}$ (‰)	Pre-depositional ^{14}C age (yr)	σ pre-depositional ^{14}C age (yr)
1	C _{24:0}	5586	271	-496.8	17.3	-59	156	-500.4	19.6	5931.4	314.6
1	C _{26:0}	4635	209	-433.6	14.9	-59	156	-437.6	18.2	4980.6	260.3
40	C _{24:0}	8524	311	-651.0	13.8	1965	670	-557.3	39.9	6444.0	724.2
40	C _{26:0}	7551	228	-606.0	11.3	1965	670	-500.3	43.0	5470.9	690.9
40	C _{28:0}	12294	895	-781.7	25.7	1965	670	-723.1	39.6	10214.2	1149.1
78.5	C _{24:0}	20696	1096	-923.3	11.2	11958	410	-674.1	50.3	10351.0	1240.5
78.5	C _{26:0}	20948	1163	-925.7	11.6	11958	410	-684.2	51.6	10603.3	1313.1
78.5	C _{28:0}	22059	2178	-935.3	20.2	11958	410	-725.0	86.7	11714.4	2533.8
127.5	C _{24:0}	31037	1377	-978.8	4.0	13973	253	-885.2	21.7	18966.0	1522.0
127.5	C _{26:0}	33433	1753	-984.3	3.8	13973	253	-914.8	20.9	21362.2	1974.2
127.5	C _{28:0}	45833	6627	-996.6	4.3	13973	253	/	/	/	/
139	C _{24:0}	32009	1620	-981.2	4.2	14073	232	-897.1	23.2	20274.4	1809.5
139	C _{26:0}	39745	3864	-992.8	4.4	14073	232	-960.7	24.3	28010.4	4966.7
139	C _{28:0}	43951	6172	-995.8	4.9	14073	232	/	/	/	/
160	C _{24:0}	33003	1586	-983.4	3.6	14309	237	-906.4	20.6	20581.8	1769.7
160	C _{26:0}	35455	2289	-987.8	4.0	14309	237	-931.0	22.8	23034.1	2659.0
160	C _{28:0}	42360	4999	-994.8	4.5	14309	237	-971.3	24.8	30076.5	6939.0
180	C _{24:0}	48679	8305	-997.6	4.3	14536	242	/	/	/	/
180	C _{26:0}	36090	2314	-988.7	3.8	14536	242	-934.5	22.0	23582.6	2692.6
180	C _{28:0}	61491	19062	-999.5	4.6	14536	242	/	/	/	/
180	C _{30:0}	47527	8553	-997.3	5.2	14536	242	/	/	/	/
212	C _{24:0}	34660	2348	-986.5	4.6	15027	429	-917.0	28.5	21977.4	2758.9
212	C _{26:0}	31958	1613	-981.1	4.2	15027	429	-883.8	26.5	19275.5	1834.8
212	C _{28:0}	38010	3499	-991.1	4.9	15027	429	-945.3	30.0	25327.8	4405.4

Table S2. List of compound specific radiocarbon datings (CSRA). No pre-depositional ages are shown for 5 samples which are too close to the limit of radiocarbon dating ($\Delta^{14}\text{C} < -995\text{‰}$).

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