Supplementary Information

Synchronous vegetation response to the last glacial-interglacial transition in northwest Europe

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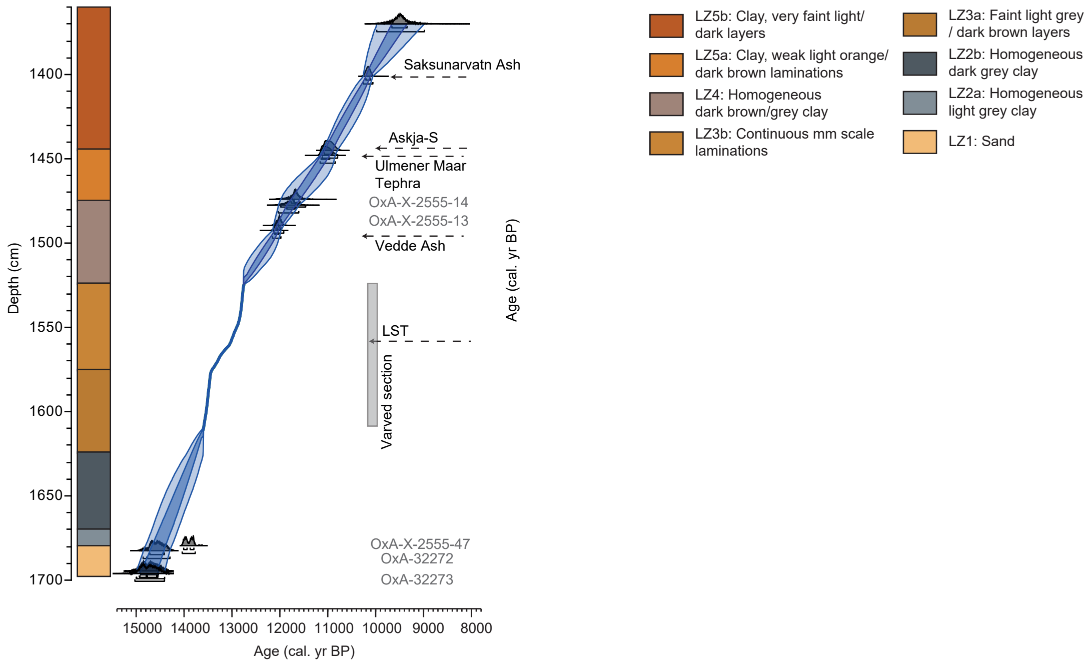
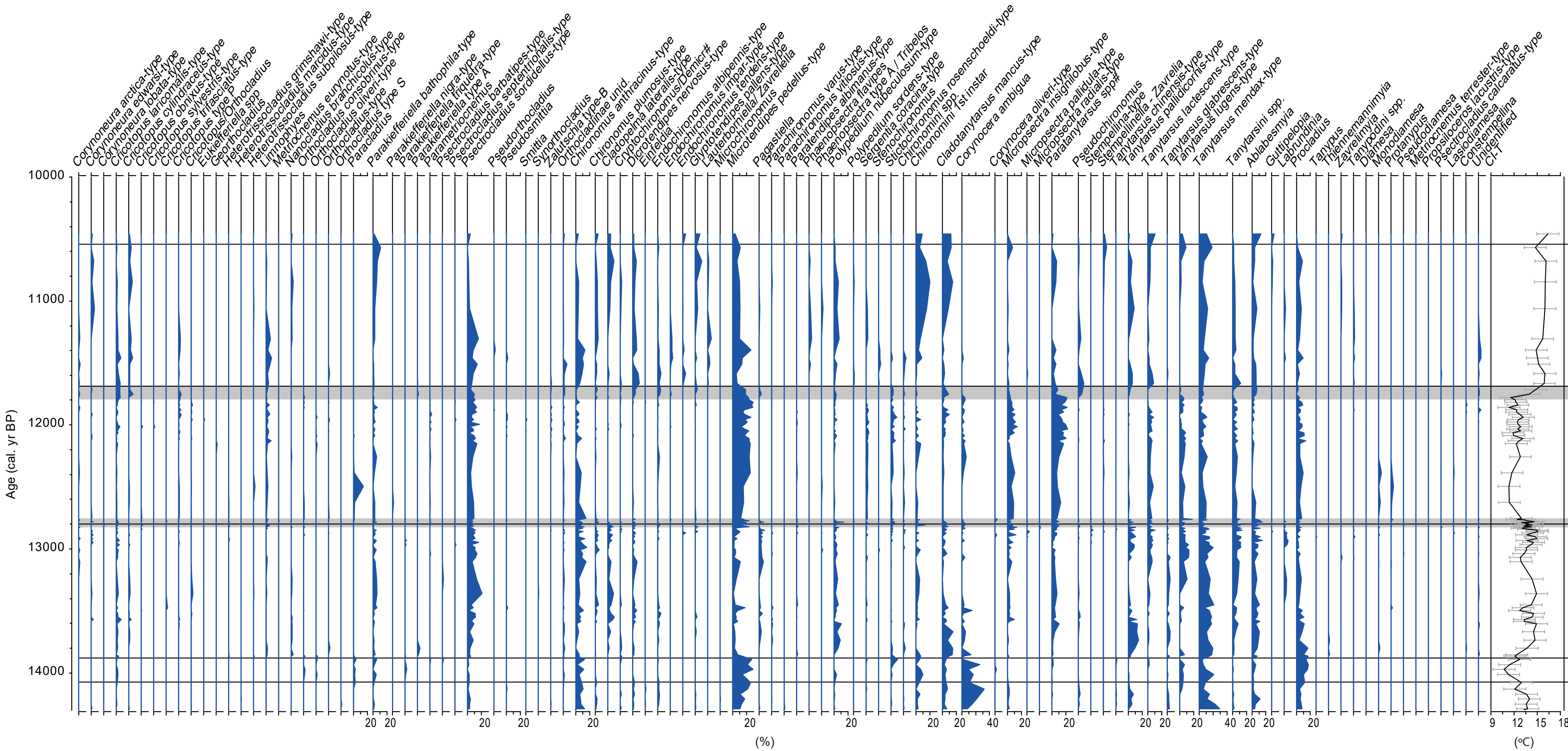
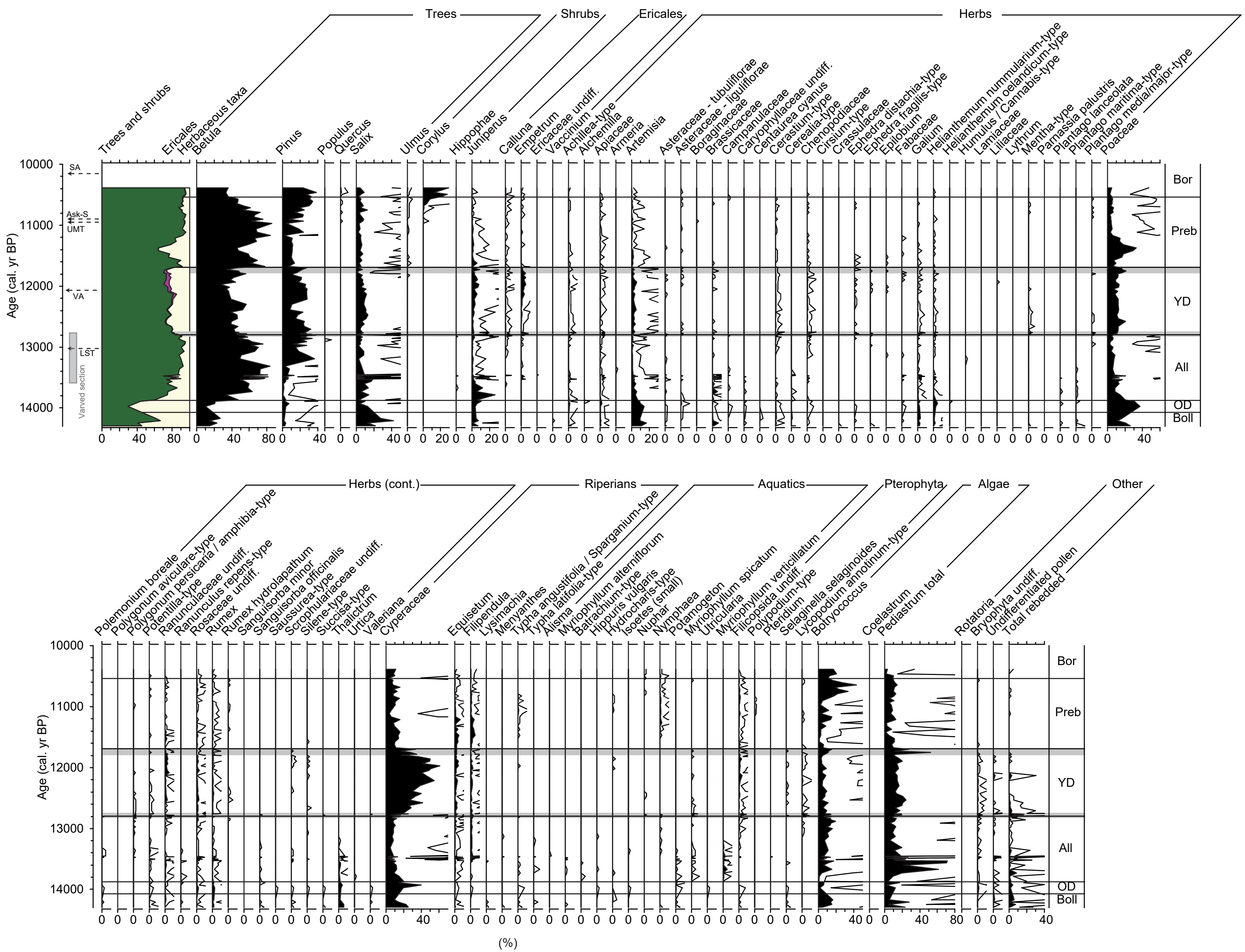


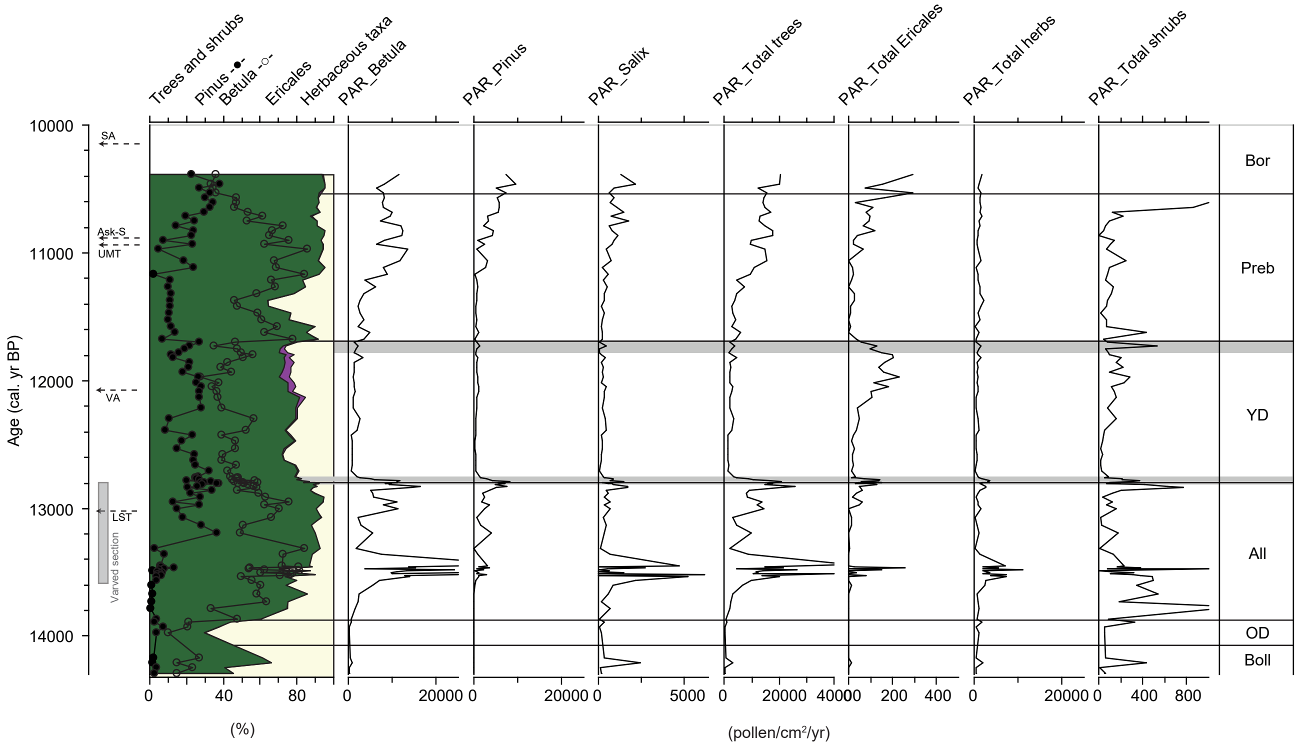
Supplementary Figure 1: Age/depth model (HaemChron21) for the lake Hämelsee record, indicating decadal-scale uncertainties for key intervals of the age depth model. Posterior likelihoods (68.3% and 95.4%) shown by dark and light blue, respectively. Positions of geochemically identified tephra horizons (Supplementary Table 1) identified by arrows; positions of radiocarbon dates indicated by grey text, and grey block indicates depth of varve-counted section of the sequence. A simplified lithological column is plotted to the left.



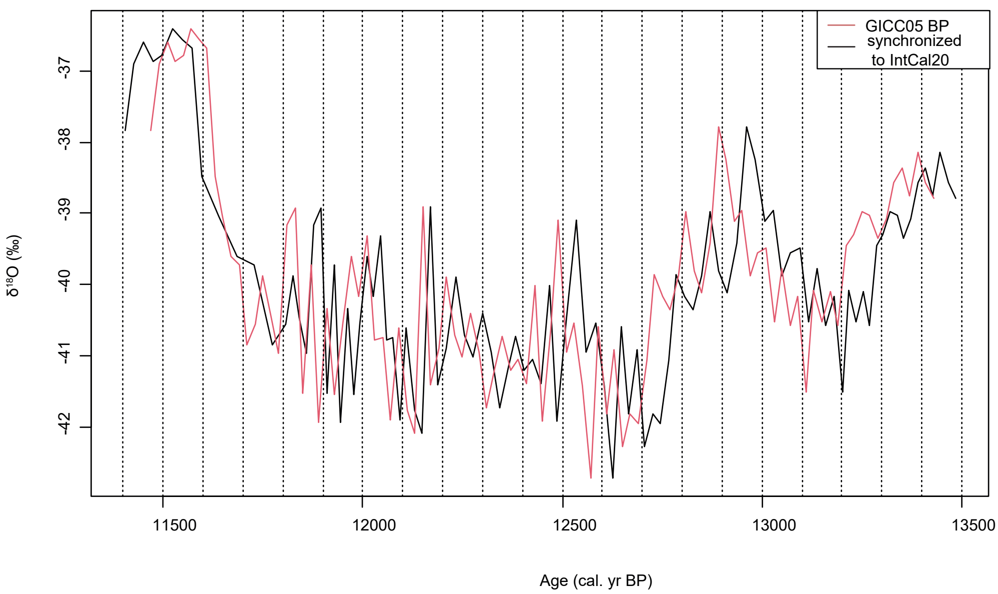
Supplementary Figure 2: Chironomid percentage-abundance diagram for lake Hämelsee, with all identified taxa shown as percent-abundances and with a chironomid-inferred July air temperature curve plotted on the right (ºC). Zonation on the right follows the Late-Glacial zonation scheme by Hoek (2001)[1]: Boll = Bølling, OD = Older Dryas, All = Allerød, YD = Younger Dryas, Preb = Preboreal, Bor = Boreal. Horizontal black lines demarcate zonal boundaries, except for at the onset and end of the YD, where the grey zones indicate the interval from the earliest changes observed in the pollen assemblages (YD_{early} and Hol_{early}, respectively) to the end of the transition (YD_{eq}, Hol_{eq}) with the black line indicating the location of the transitions sensu stricto (YD_{SS} and Hol_{SS}; see main text for more information).



Supplementary Figure 3: Complete pollen diagram for lake Hämelsee, with all identified taxa shown as percent-abundances relative to the pollen sum, which includes trees, shrubs, ericaceae and Herbaceous taxa. Zonation on the right follows the Late-Glacial zonation scheme by Hoek (2001)[1]: Boll = Bølling, OD = Older Dryas, All = Allerød, YD = Younger Dryas, Preb = Preboreal, Bor = Boreal. Horizontal black lines demarcate zonal boundaries, except for at the onset and end of the YD, where the grey zones indicate the interval from the earliest changes observed in the pollen assemblages (YD_{early} and Hol_{early}, respectively) to the end of the transition (YD_{eq}, Hol_{eq}) with the black line indicating the location of the transitions sensu stricto (YD_{SS} and Hol_{SS}; see main text for more information). Occurrences of tephra horizons and varved sediment interval indicated to the left.



Supplementary Figure 4: Pollen Accummulation Rate (PAR) curves of selected pollen taxa and groups for lake Hämelsee, with curves shown as pollen/cm^2/year. Main percentage diagram on the left, zonation on the right following the late-glacial zonation scheme by Hoek (2001)[1]: Boll = Bølling, OD = Older Dryas, All = Allerød, YD = Younger Dryas, Preb = Preboreal, Bor = Boreal. Horizontal black lines demarcate zonal boundaries, except for at the onset and end of the YD, where the grey zones indicate the interval from the earliest changes observed in the pollen assemblages (YD_{early} and Hol_{early}, respectively) to the end of the transition (YD_{eq}, Hol_{eq}) with the black line indicating the location of the transitions sensu stricto (YD_{ss} and Hol_{ss}; see main text for more information). Occurrences of tephra horizons and varved sediment interval indicated to the left.



Supplementary Figure 5: NGRIP δ[18]O plotted on the original GICC05 timescale[2] (Rasmussen et al., 2006) and on IntCal20[3] (Reimer et al. 2020) using the Bayesian wiggle matching approach[4,5]. See Methods section for more details.

Supplementary Table 1: Chronological data used to construct the age-depth model for the lake Hämelsee record (HaemChron21). a: AMS ^{14}C ages of dated macroremains ((±1-sigma). b: Identified tephra horizons[6] and their age estimates in cal. years BP (±1-sigma; see Supplementary Methods 1). c: Varved sediment interval as used in the age-depth model with uncertainty estimates derived from replicate counts by two independent examiners.

1a: Radiocarbon dates

	Segment depth	Sediment depth (cm)	Dated material	Lab ID	^{14}C age (BP)	Error estimate
1	HAEM13-2E2 65-66cm	1477-1478	Betula seeds	OxA-X-2555-14	10,310	130
2	HAEM13-2E2 77-78cm	1489-1490	Betula seeds	OxA-X-2555-13	10,550	160
3	HAEM13-1F2 79-80cm	1679-1680	Salix bud scales	OxA-X-2551-47	11,975	50
4	HAEM13-1F2 82-83cm	1682-1683	Twigs	OxA-32272	12,475	60
5	HAEM13-1F2 94-96cm	1694-1696	Twig	OxA-32273	12,450	65

1b: Tephra horizons

	Segment depth	Sediment depth (cm)	Tephra horizon	Date used in model (cal. yr BP)	Reference
1	HAEM13-1E2 85-86cm	1400-1402	Saksunarvatn Ash (SA)	10,178 ±45	Lohne et al. (2014)[7]
2	HAEM13-1E3 35-36cm	1444.6-1445.5	Askja-S (Ask-S)	10,865 ±99	Kearney et al. (2018)[8]
3	HAEM13-1E3 41-42cm	1450-1451	Ulmener Maar Tephra (UMT)	10,941 ±109	Modelled combined ^{14}C ages (this study)
4	HAEM13-2E2 80-81cm	1492-1493	Vedde Ash (VA)	12,044 ±53	Lohne et al. (2014)[7]
5	HAEM13-2E3 45-46cm	1557-1558	Laacher See Tephra (LST)	13,006 ±5	Reinig et al. (2021)[9]

1c: Varve interval

	Segment depth	Sediment depth (cm)	Varves (yr)	Error estimate	Reference
1	HAEM13-2E3 12.5-98cm	1525-1610	825	± 4 varve yr	This study

Supplementary Table 2. Palynological definitions of the onset of (a) the Younger Dryas and (b) the Holocene. (a) shows YD_{early} = earliest changes in pollen spectra that are interpreted to have resulted from LGIT cooling; YD_{SS} = midpoint of change in pollen spectra from the woodland assemblages of the Allerød to the (sub-)arctic assemblages of the YD biozone; YD_{eq} = point where new equilibrium is reached. (b) shows HOL_{early}, HOL_{SS} and HOL_{eq} which represent similar points across the YD/Holocene transition. Dates are provided both in original format as well as rounded to the nearest multiple of 5 yrs (as used in the manuscript).

Supplementary Table 2a

Site	**Event**	**Depth (cm)**	**Date (95.4%)**		**Date rounded (95.4%)**		**Criterion**	**Reference**
Kråkenes	Event	Depth (cm)	Age (cal. yr BP)		Age (cal. yr BP)		Criterion	Age/depth: Lohne et al. (2013)[11]
	YD_{eq}	911	12,641 (12,545-12,733)		12,640 (12,545-12,735)		Establishment YD vegetation (e.g. NAP)	Birks et al. (2000)[10]
	YD_{SS}	924.5	12,765 (12,700-12,840)		12,765 (12,700-12,840)		Lithostratigraphy and increase PAR	Birks et al. (2000)[10]
	YD_{early}	925.4	12,795 (12,721-12,888)		12,795 (12,720-12,890)		Increase Salix	Lohne et al. (2013)[11]; this study
Hässeldala	Event	Depth (cm)	Age (cal. yr BP)		Age (cal. yr BP)		Criterion	Age/depth: Wohlfarth et al. (2017)[12]
	YD_{eq}	338.7	12,623 (12,517-12,683)		12,625 (12,515-12,685)		Increase Juniperus	Wohlfarth et al. (2017)[12]; this study
	YD_{SS}	341.6	12,716 (12,623-12,772)		12,715 (12,625-12,770)		Increase in Artemisia, decrease in Empetrum	Wohlfarth et al. (2017)[12]
	YD_{early}	344	12,863 (12,791-12,913)		12,865 (12,790-12,915)		Start decrease Empetrum	Wohlfarth et al. (2017)[12]; this study
Hämelsee	Event	Depth (cm)	Age (cal. yr BP)	Years post-LST (yr)	Age (cal. yr BP)	Years post-LST (yr)	Criterion	Age/depth: this study
	YD_{eq}	1523.5	12,730 (12,691-12,757)	276	12,730 (12,690-12,760)	275	End decrease Salix, Pinus PAR	This study
	YD_{SS}	1537	12,799 (12,789-12,809)	207	12,800 (12,790-12,810)	205	Increase Poaceae	This study
	YD_{early}	1541.5	12,821 (12,811-12,831)	185	12,820 (12,810-12,830)	185	Onset decrease PAR (Salix, Juniperus)	This study
Meerfelder Maar	Event	Depth (cm)	Varve Age (yr BP)	Years post-LST (yr)	Varve Age (yr BP)	Years post-LST (yr)	Criterion	Varve age: Brauer et al. (1999)[13] Date LST: Reinig et al. (2021)[9]
	YD_{eq}	174.3	12,619 (+/- 40)	260	12,620 (12,580-12,660)	260	Increase Salix, Artemisia	This study
	YD_{SS}	179.8	12,674 (+/- 40)	205	12,675 (12,760-12,840)	205	Strongest decrease Betula	Engels et al. (2016)[14]; this study
	YD_{early}	182.5	12,726 (+/- 40)	155	12,725 (12,685-12,765)	155	Decrease Betula and Pine PAR	Engels et al. (2016)[14]; this study

Supplementary Table 2b

Site	Event	Depth (cm)	Date (95.4%)		Date rounded (95.4%)		Criterion	Reference
Kråkenes	Event	Depth (cm)	Age (cal. yr BP)		Age (cal. yr BP)		Criterion	Age/depth: Lohne et al. (2013)[11]
	HOL_{eq}	701.5	10,845 (10,746-10,945)		10,845 (10,745-10,945)		Arrival tree birch	Birks & Birks (2008)[15]
	HOL_{SS}	756.5	11,520 (11,410-11,631)		11,520 (11,410-11,630)		Sharp sedimentological change	Birks & Birks (2008)[15]
	HOL_{early}	762	11,556 (11,440-11,664)		11,555 (11,440-11,665)		Increase Salix	Birks & Birks (2008)[15]
Hässeldala	Event	Depth (cm)	Age (cal. yr BP)		Age (cal. yr BP)		Criterion	Age/depth: Wohlfarth et al. (2017)[12]
	HOL_{eq}	318.8	11,668 (11,588-11,744)		11,670 (11,590-11,745)		End increase Empetrum	This study
	HOL_{SS}	320.3	11,741 (11,659-11,819)		11,740 (11,660-11,820)		Decreasing Juniper & Artemisia; increasing Empetrum	Wohlfarth et al. (2017)[12]
	HOL_{early}	323.4	11,888 (11,803-11,970)		11,890 (11,805-11,970)		Start decrease Artemisia	Wohlfarth et al. (2017)[12]
Hämelsee	Event	Depth (cm)	Age (cal. yr BP)	Years post-LST (yr)	Age (cal. yr BP)	Years post-LST (yr)	Criterion	Age/depth: this study
	HOL_{eq}	1474	11,689 (11,472-11,978)	1317	11,690 (11,470-11,980)	1315	Abrupt increase Betula	This study
	HOL_{SS}	1474	11,689 (11,472-11,978)	1317	11,690 (11,470-11,980)	1315	Abrupt increase Betula	This study
	HOL_{early}	1477	11,788 (11,615-12,032)	1218	11,790 (11,615-12,030)	1215	Start decrease Empetrum-PAR	This study
Meerfelder Maar	Event	Depth (cm)	Years post- LST (yr)	Relative to LST (yr)	Varve Age (yr BP)	Years post-LST (yr)	Criterion	Varve age: Brauer et al. (1999)[13] Date LST: Reinig et al. (2021)[9]
	HOL_{eq}	72.5	11,590 (+/- 40)	1416	11,590 (11,550-11,630)	1415	Abrupt increase Betula	Litt & Stebich (1999)[16]
	HOL_{SS}	72.5	11,590 (+/- 40)	1416	11,590 (11,550-11,630)	1415	Abrupt increase Betula	Litt & Stebich (1999)[16]
	HOL_{early}	73.5	11,640 (+/- 40)	1366	11,640 (11,600-11,680)	1365	Start increase Juniperus	Litt & Stebich (1999)[16]

Supplementary Table 3. Comparison of dates for transitions as established visually (see Supplementary Table 2) and through piecewise linear regression (PLR). R code used to determine the PLR dates is provided in Supplementary Code 1. Note that ages for Kråkenes, Hässeldala and Hämelsee are in cal. yr BP, whereas those for Meerfelder Maar are in varve yr BP (cf. Brauer et al., 2008)[17].

Supplementary table 3a: Onset YD

Site	**Event**	**Depth (cm)**	**Visual date**	**PLR Date**	**Variable**	**Interval**
Kråkenes	**Event**	**Depth (cm)**	**Visual date**	**PLR Date**	**Variable**	**Interval**
	YD_{eq}	911	12,641	12,566	Salix-her (%)	12,100-12,750
	YD_{early}	925.4	12,795	12,832	Salix (%)	12,650-13,200
Hässeldala	**Event**	**Depth (cm)**	**Visual date**	**PLR Date**	**Variable**	**Interval**
	YD_{eq}	338.7	12,623	12,636	Juniperus (%)	12,500-12,800
	YD_{early}	344	12,863	12,936	Empetrum (%)	12,600-13,100
Hämelsee	**Event**	**Depth (cm)**	**Visual date**	**PLR Date**	**Variable**	**Interval**
	YD_{eq}	1523.5	12,730	12,733	Salix (PAR)	12,100-12,850
	YD_{early}	1541.5	12,821	12,826	Salix (PAR)	12,700-13,300
Meerfelder Maar	**Event**	**Depth (cm)**	**Visual date**	**PLR Date**	**Variable**	**Interval**
	YD_{eq}	174.3	12,619	12,627	Salix (%)	12,580-12,800
	YD_{early}	182.5	12,726	12,732	Pinus (PAR)	12,650-12,870

Supplementary table 3b: Onset Holocene

Site	**Event**	**Depth (cm)**	**Visual date**	**PLR Date**	**Variable**	**Interval**
Kråkenes	**Event**	**Depth (cm)**	**Visual date**	**PLR Date**	**Variable**	**Interval**
	HOL_{eq}	701.5	10,845	10,800	Arrival tree birch	10,400-11,200
	HOL_{early}	762	11,556	11,578	Salix (%)	11,530-11,800
Hässeldala	**Event**	**Depth (cm)**	**Visual date**	**PLR Date**	**Variable**	**Interval**
	HOL_{eq}	318.8	11,668	11,652	Empetrum (%)	11,300-12,300
	HOL_{early}	323.4	11,888	No breakpoint found	Artemisia (%)	11,300-12,300
Hämelsee	**Event**	**Depth (cm)**	**Visual date**	**PLR Date**	**Variable**	**Interval**
	HOL_{eq}	1474	11,689	11,651	Betula (%)	11,000-12,200
	HOL_{early}	1477	11,788	11,798	Empetrum (PAR)	11,000-12,200
Meerfelder Maar	**Event**	**Depth (cm)**	**Visual date**	**PLR Date**	**Variable**	**Interval**
	HOL_{eq}	72.5	11,590	No breakpoint found	Betula (%)	11,500-12,000
	HOL_{early}	73.5	11,640	11,640	Juniperus (%)	11,500-12,500

Supplementary Table 4. Re-evaluated YD_{SS} ages of selected palynological sites.
Re-evaluated age estimates for the Allerød/YD transition for sites across northwest Europe; note that only the age is re-evaluated, not the local definition of the onset of the YD (YD_{SS}). Due to the very high number of available sites (e.g. the Neotoma database (https://apps.neotomadb.org/explorer) shows ca. 224 pollen records that contain the Allerød/YD transition for NW Europe (search: 21/09/2021) the table below is not comprehensive. Instead, we focussed on those sites that one of the authors of this paper worked or published on, for which we know a reliable date or age/depth model exists, and for which the chronological data is available publicly. Recalibrated radiocarbon ages are given as a 95% interval and are rounded to the nearest multiple of 5 years.

Site	Reference	Original age	Re-evaluated age (95.4%)	Notes / lab no*
Achterberg	de Jong (unpubl.), Hoek (1997)[18]	10,960 ± 60 ^{14}C yr	13,065-12,755 cal yr BP	Recalibrated using IntCAL20/ GrN-17326
Arendonk Korhaan	Vanmontfort et al. (2010)[19]	11,000 ± 60 ^{14}C yr	13,080-12,770 cal yr BP	Recalibrated using IntCAL20/ Poz-28168
Bosscherheide I	Bohncke et al. (1993)[20], Hoek (1997)[18]	10,940 ± 60 ^{14}C yr	13,060-12,750 cal yr BP	Recalibrated using IntCAL20/ GrN 13379
Bosscherheide III	Bohncke et al. (1993)[20], Hoek (1997)[18]	10,880 ± 50 ^{14}C yr	12,895-12,735 cal yr BP	Recalibrated using IntCAL20/ GrN-11569
Groot Ammers Ia	RGD-602a: de Jong and Zagwijn (1977)[21], Hoek (1997)[18]	10,970 ± 90 ^{14}C yr	13,080-12,755 cal yr BP	Recalibrated using IntCAL20/ GrN-6444
Gulickshof GH-I	Hoek et al. (1999)[22]	10,800 ± 90 ^{14}C yr	12,960-12,620 cal yr BP	Recalibrated using IntCAL20/ GrA-4309
Milheeze Lake	Bos & Janssen (1996)[23], Bos et al. (2006)[24]	11,010 ± 190 ^{14}C yr	13,300-12,685 cal yr BP	Recalibrated using IntCAL20/ UtC-1980
Milheeze Shore	Bos & Janssen (1996)[23], Bos et al. (2006)[24]	10,940 ± 110 ^{14}C yr	13,085-12,740 cal yr BP	Recalibrated using IntCAL20/ UtC-1620
Notsel	Vandenberghe et al. (1987)[25], Hoek (1997)[18]	10,970 ± 50 ^{14}C yr	13,060-12,760 cal yr BP	Recalibrated using IntCAL20/ GrN-9595
Putbroek	Janssen and IJzermans-Lutgerhorst (1973)[26], Hoek (1997)[18]	10,890 ± 65 ^{14}C yr	12,985-12,730 cal yr BP	Recalibrated using IntCAL20/ GrN-6308
Rehwiese	Neugebauer et al. (2012)[27]	12,675 varve yr BP	12,801 cal yr BP	Floating varve chronology "re-anchored" using revised LST age
Reinders	Kasse et al. (2005)[28]	11,060 ± 50 ^{14}C yr	13,095-12,840 cal yr BP	Recalibrated using IntCAL20/ GrA-23740
Snellegem	Verbruggen (1979)[29], Hoek (1997)[18]	10,940 ± 60 ^{14}C yr	13,060-12,750 cal yr BP	Recalibrated using IntCAL20/ GrN-6063
Stegerveld I	Butter (1957)[30], Vogel and Waterbolk (1967)[31], Hoek (1997)[18]	11,000 ± 300 ^{14}C yr	13,580-12,100 cal yr BP	Recalibrated using IntCAL20/ GrN-437
Usselo A	van der Hammen (1951)[32], Lanting and Mook (1977)[33], Hoek (1997)[18]	10,880 ± 160 ^{14}C yr	13,155-12,500 cal yr BP	Recalibrated using IntCAL20/ Y 139/2
Veenlaag Hamert	Teunissen (1983)[34], Hoek (1997)[18]	10,870 ± 100 ^{14}C yr	13,065-12,710 cal yr BP	Recalibrated using IntCAL20/ GrN-4786
Westrhauderfehn II	Behre (1966)[35], Hoek (1997)[18]	10,890 ± 210 ^{14}C yr	13,300-12,200 cal yr BP	Recalibrated using IntCAL20/ Hv-736-ML

* where applicable

Supplementary Table 5. Site information.

Table 5a: Site names, coordinates, chronological information, reference.

Site	Coordinates	Chronology	Updates applied	Reference
Kråkenes (W Norway)	N: 62°02' E: 5°00'	118 ^{14}C AMS dates	Remodelled using IntCal20	Birks et al. (2000)[10] Lohne et al. (2013; 2014)[7,11]
Hässeldala Port (S Sweden)	N: 56°16' E: 15°01'	49 ^{14}C AMS dates	Remodelled using IntCal20	Muschitiello et al. (2015)[36] Wohlfarth et al. (2017)[12]
Hämelsee (N Germany)	N: 52°46' E: 9°19'	Varve counting 5 ^{14}C AMS dates 5 Tephra ages	This study	This study
Meerfelder Maar (Central Germany)	N: 50°06' E: 6°45'	Varve counting 69 ^{14}C AMS dates	Presented relative to LST following Reinig et al. (2021)	Brauer et al. (1999; 2008)[13,17]
NGRIP	N: 75°06' W: 42°19'	Layer counting	Transposed to IntCal20	Rasmussen et al. (2006; 2014)[37]

Table 5b: Site names, depth and age range of the pollen record; number of pollen samples and average sampling density for pollen data; data and publication reference.

Site	Depth range pollen record (cm)	Age range pollen record (cal kyr BP)	Number of pollen samples	Average year/sample – entire record	Average year/sample – 13000-12500 (onset YD)	Data reference	Publication reference
Kråkenes (W Norway)	600-962	13.8-9.2	80	58yr	42yr**	n/a	Birks et al. (2000)[10] Lohne et al. (2013; 2014)[7,11]
Hässeldala Port (S Sweden)	330.5-379.5	13.0-11.3	45	38yr	36yr	n/a	Wohlfarth et al. (2017)[12]
Hämelsee (N Germany)	1413.5-1674.5	14.2-10.4	105	36yr	20yr	Pangaea – Dataset ID PDI-29595	This study; https://doi.org/10.1594/PANGAEA.939693
Meerfelder Maar (Central Germany)	670-805.5 160.5-204.6*	12.5-11.8 13.2-12.5 Total: 13.2-11.5	69 94 Total: 163	27yr 7yr Total: 15yr	8yr	European Pollen database – Dataset ID 42510 European Pollen database – Dataset ID 48664	Litt & Stebich (1999)[16] Engels et al. (2016)[14]

* Relative to marker layer

** Birks et al. (2000) dataset only

Supplementary Methods 1: Tephra age estimates

Age estimates for each of the five tephra layers correlated to known eruptions by Jones et al. (2018)[6] were input into the new Hämelsee age model (see Methods, Supplementary Table 1 and Supplementary Code 1) and provide the backbone to the chronology, including anchoring the Allerød to Younger Dryas floating varve segment of the record to the calendrical timescale. All tephra dates are based entirely upon radiocarbon analyses, avoiding the problems of translating between archives. Dates are stated here with 1 sigma uncertainties, unless reported otherwise. Published, fully radiocarbon-based, Bayesian depositional models for Kråkenes (Norway, Lohne et al., 2013)[11] and Lakes Brazi and Lia (Romania, Kearney et al., 2018)[8] were re-run using the IntCal20 calibration curve (Reimer et al., 2020)[3] in OxCal version 4.4 (Bronk Ramsey, 2008, 2009)[38,39] to provide up-to-date calibrated age estimates for the Saksunarvatn Ash (previously 10,210 ± 35 now 10,178 ± 45), Vedde Ash (previously 12,064 ± 48 now 12,044 ±53) and Askja-S (previously 10,824 ± 97 now 10,865 ± 99) isochrons.

The age of 10,491 ± 109 cal BP for the Ulmener Maar Tephra (UMT) combines three published AMS radiocarbon ages on macrofossils associated with the UMT layer in: i. a temporary pit containing a 5 cm thick UMT layer in the village of Ulmen, just 400 m from Ulmener Maar in West Eifel, Germany (Zolitschka et al., 1995)[40]; ii. the Holzmaar (West Eifel, Germany) sediment record (Hajdas et al. 1995)[41]; iii. the Meerfelder Maar (West Eifel, Germany) sediment record (Brauer et al., 2000)[42]. Dates were combined using the *R_Combine* function in OxCal version 4.4, which combines the ages and runs a Chi squared test prior to calibration (Bronk Ramsey, 2009)[39]. OxCal code as follows:

```
R_Combine("UMT")
 {
  R_Date("ETH-8156",9650,85);
  R_Date("ETH-7246",9515,75);
  R_Date("MFM",9610,40);
 };
```

Reinig et al. (2021)[9] present an age estimate of 13,006 ± 9 cal years BP (2σ) for the Laacher See Tephra (LST) based on annually-resolved radiocarbon dating of three cross-dated tree-ring sequences from samples of trees that were buried within Middle LST deposits. The decadal-scale precision of the new LST age estimate is obtained by wiggle-match dating the ~100 year long tree ring radiocarbon chronology to the Swiss Late Glacial Master Radiocarbon (SWILM-14C) dataset, which is an highly-resolved (± 8 years; 2σ) radiocarbon reference for the Lateglacial, based on dating of subfossil wood. SWILM-14C is incorporated into the IntCal20 calibration dataset (Reinig et al., 2020[43]; Reimer et al., 2020[3]).

Supplementary code 1: OxCal code for HaemChron21

We refer to the Methods section of the main manuscript for details on the construction of the HaemChron21 age/depth model. Additional information regarding the uncertainty estimates in the varved interval (i.e. the central *P_Sequence*): as varve counting uncertainties are cumulative over the full counted interval and the precise location of the uncertainties are unknown, the uncertain varve years were distributed evenly through the varve-counted interval, so that they accumulated away from (above and below) the LST anchor point. Thus, uncertainties at the depth of the LST (1557 cm depth / varve 264) are set to ± 5 and three uncertain varve years were added in the 86 cm section below the LST, leading to a uncertainty of ± 8 for Varve 824 at 1610 cm. The remaining uncertain varve year was placed above the LST, leading to an uncertainty of ± 6 for Varve 0 at 1524.5 cm depth. The OxCal *P_Sequence* function further refined the uncertainties for the varve interval by interpolating between the individually entered varve ages. This provides what we believe to be an artificially precise estimate of uncertainty through the varve section. Therefore, the output uncertainties were reset to unmodeled values, as described above, for Supplementary Table 3 and dates given in the main text.

```
Options()
{
 Resolution=1;
 kIterations=100;
};
Plot()
{
 Outlier_Model("General",T(5),U(0,4),"t");
 P_Sequence("Hamelsee Lower",1,0.5,U(-2,2))
 {
  Boundary()
  {
   z=1696;
  };
  R_Date("OxA-32273", 12450, 65)
  {
   Outlier(0.05);
   z=1694.5;
  };
  R_Date("OxA-32272", 12475, 60)
  {
   Outlier(0.05);
   z=1682.5;
  };
  R_Date("OxA-X-255147", 11975, 50)
  {
   Outlier();
   z=1679.5;
  };
  Boundary("Varve 825")
  {
   z=1610;
  };
 };
 P_Sequence("Varved Interval",1,0.5,U(-2,2))
 {
  Boundary("=Varve 825",N(calBP(13585),8))
  {
   z=1610;
    };
Date("Varve 824",N(calBP(13584),8))
  {
```

```
 z=1609.66;
};
Date("Varve 823",N(calBP(13583),8))
{
 z=1609.33;
};
Date("Varve 822",N(calBP(13582),8))
{
 z=1609;
};
Date("Varve 821",N(calBP(13581),8))
{
 z=1608.75;
};
Date("Varve 820",N(calBP(13580),8))
{
 z=1608.5;
};
Date("Varve 819",N(calBP(13579),8))
{
 z=1608.25;
};
Date("Varve 818",N(calBP(13578),8))
{
 z=1608;
};
Date("Varve 817",N(calBP(13577),8))
{
 z=1607.75;
};
Date("Varve 816",N(calBP(13576),8))
{
 z=1607.5;
};
Date("Varve 815",N(calBP(13575),8))
{
 z=1607.25;
};
Date("Varve 814",N(calBP(13574),8))
{
 z=1607;
};
Date("Varve 813",N(calBP(13573),8))
{
 z=1606.66;
};
Date("Varve 812",N(calBP(13572),8))
{
 z=1606.33;
};
Date("Varve 811",N(calBP(13571),8))
{
 z=1606;
};
Date("Varve 810",N(calBP(13570),8))
{
 z=1605.8;
};
Date("Varve 809",N(calBP(13569),8))
{
 z=1605.64;
};
Date("Varve 808",N(calBP(13568),8))
{
 z=1605.48;
};
Date("Varve 807",N(calBP(13567),8))
{
 z=1605.32;
};
Date("Varve 806",N(calBP(13566),8))
```

```
{
 z=1605.16;
};
Date("Varve 805",N(calBP(13565),8))
{
 z=1605;
};
Date("Varve 804",N(calBP(13564),8))
{
 z=1604.8;
};
Date("Varve 803",N(calBP(13563),8))
{
 z=1604.64;
};
Date("Varve 802",N(calBP(13562),8))
{
 z=1604.48;
};
Date("Varve 801",N(calBP(13561),8))
{
 z=1604.32;
};
Date("Varve 800",N(calBP(13560),8))
{
 z=1604.16;
};
Date("Varve 799",N(calBP(13559),8))
{
 z=1604;
};
Date("Varve 798",N(calBP(13558),8))
{
 z=1603.8;
};
Date("Varve 797",N(calBP(13557),8))
{
 z=1603.6;
};
Date("Varve 796",N(calBP(13556),8))
{
 z=1603.4;
};
Date("Varve 795",N(calBP(13555),8))
{
 z=1603.2;
};
Date("Varve 794",N(calBP(13554),8))
{
 z=1603;
};
Date("Varve 793",N(calBP(13553),8))
{
 z=1602.84;
};
Date("Varve 792",N(calBP(13552),8))
{
 z=1602.7;
};
Date("Varve 791",N(calBP(13551),8))
{
 z=1602.56;
};
Date("Varve 790",N(calBP(13550),8))
{
 z=1602.42;
};
Date("Varve 789",N(calBP(13549),8))
{
 z=1602.28;
};
```

```
Date("Varve 788",N(calBP(13548),8))
{
 z=1602.14;
};
Date("Varve 787",N(calBP(13547),8))
{
 z=1602;
};
Date("Varve 786",N(calBP(13546),8))
{
 z=1601.88;
};
Date("Varve 785",N(calBP(13545),8))
{
 z=1601.77;
};
Date("Varve 784",N(calBP(13544),8))
{
 z=1601.66;
};
Date("Varve 783",N(calBP(13543),8))
{
 z=1601.55;
};
Date("Varve 782",N(calBP(13542),8))
{
 z=1601.44;
};
Date("Varve 781",N(calBP(13541),8))
{
 z=1601.33;
};
Date("Varve 780",N(calBP(13540),8))
{
 z=1601.22;
};
Date("Varve 779",N(calBP(13539),8))
{
 z=1601.11;
};
Date("Varve 778",N(calBP(13538),8))
{
 z=1601;
};
Date("Varve 777",N(calBP(13537),8))
{
 z=1600.8;
};
Date("Varve 776",N(calBP(13536),8))
{
 z=1600.64;
};
Date("Varve 775",N(calBP(13535),8))
{
 z=1600.48;
};
Date("Varve 774",N(calBP(13534),8))
{
 z=1600.32;
};
Date("Varve 773",N(calBP(13533),8))
{
 z=1600.16;
};
Date("Varve 772",N(calBP(13532),8))
{
 z=1600;
};
Date("Varve 771",N(calBP(13531),8))
{
 z=1599.6;
```

```
};
Date("Varve 770",N(calBP(13530),8))
{
 z=1599.3;
};
Date("Varve 769",N(calBP(13529),8))
{
 z=1599;
};
Date("Varve 768",N(calBP(13528),8))
{
 z=1598.5;
};
Date("Varve 767",N(calBP(13527),8))
{
 z=1598;
};
Date("Varve 766",N(calBP(13526),8))
{
 z=1597.8;
};
Date("Varve 765",N(calBP(13525),8))
{
 z=1597.64;
};
Date("Varve 764",N(calBP(13524),8))
{
 z=1597.48;
};
Date("Varve 763",N(calBP(13523),8))
{
 z=1597.32;
};
Date("Varve 762",N(calBP(13522),8))
{
 z=1597.16;
};
Date("Varve 761",N(calBP(13521),7))
{
 z=1597;
};
Date("Varve 760",N(calBP(13520),7))
{
 z=1596.8;
};
Date("Varve 759",N(calBP(13519),7))
{
 z=1596.64;
};
Date("Varve 758",N(calBP(13518),7))
{
 z=1596.48;
};
Date("Varve 757",N(calBP(13517),7))
{
 z=1596.32;
};
Date("Varve 756",N(calBP(13516),7))
{
 z=1596.16;
};
Date("Varve 755",N(calBP(13515),7))
{
 z=1596;
};
Date("Varve 754",N(calBP(13514),7))
{
 z=1595.5;
};
Date("Varve 753",N(calBP(13513),7))
{
```

```
 z=1595;
};
Date("Varve 752",N(calBP(13512),7))
{
 z=1594.75;
};
Date("Varve 751",N(calBP(13511),7))
{
 z=1594.5;
};
Date("Varve 750",N(calBP(13510),7))
{
 z=1594.25;
};
Date("Varve 749",N(calBP(13509),7))
{
 z=1594;
};
Date("Varve 748",N(calBP(13508),7))
{
 z=1593.84;
};
Date("Varve 747",N(calBP(13507),7))
{
 z=1593.7;
};
Date("Varve 746",N(calBP(13506),7))
{
 z=1593.56;
};
Date("Varve 745",N(calBP(13505),7))
{
 z=1593.42;
};
Date("Varve 744",N(calBP(13504),7))
{
 z=1593.28;
};
Date("Varve 743",N(calBP(13503),7))
{
 z=1593.14;
};
Date("Varve 742",N(calBP(13502),7))
{
 z=1593;
};
Date("Varve 741",N(calBP(13501),7))
{
 z=1592.8;
};
Date("Varve 740",N(calBP(13500),7))
{
 z=1592.6;
};
Date("Varve 739",N(calBP(13499),7))
{
 z=1592.4;
};
Date("Varve 738",N(calBP(13498),7))
{
 z=1592.2;
};
Date("Varve 737",N(calBP(13497),7))
{
 z=1592;
};
Date("Varve 736",N(calBP(13496),7))
{
 z=1588;
};
Date("Varve 735",N(calBP(13495),7))
```

```
{
 z=1587.8;
};
Date("Varve 734",N(calBP(13494),7))
{
 z=1587.72;
};
Date("Varve 733",N(calBP(13493),7))
{
 z=1587.64;
};
Date("Varve 732",N(calBP(13492),7))
{
 z=1587.56;
};
Date("Varve 731",N(calBP(13491),7))
{
 z=1587.48;
};
Date("Varve 730",N(calBP(13490),7))
{
 z=1587.4;
};
Date("Varve 729",N(calBP(13489),7))
{
 z=1587.32;
};
Date("Varve 728",N(calBP(13488),7))
{
 z=1587.24;
};
Date("Varve 727",N(calBP(13487),7))
{
 z=1587.16;
};
Date("Varve 726",N(calBP(13486),7))
{
 z=1587.08;
};
Date("Varve 725",N(calBP(13485),7))
{
 z=1587;
};
Date("Varve 724",N(calBP(13484),7))
{
 z=1586.7;
};
Date("Varve 723",N(calBP(13483),7))
{
 z=1586.56;
};
Date("Varve 722",N(calBP(13482),7))
{
 z=1586.42;
};
Date("Varve 721",N(calBP(13481),7))
{
 z=1586.28;
};
Date("Varve 720",N(calBP(13480),7))
{
 z=1586.14;
};
Date("Varve 719",N(calBP(13479),7))
{
 z=1586;
};
Date("Varve 718",N(calBP(13478),7))
{
 z=1585.84;
};
```

```
Date("Varve 717",N(calBP(13477),7))
{
 z=1585.7;
};
Date("Varve 716",N(calBP(13476),7))
{
 z=1585.56;
};
Date("Varve 715",N(calBP(13475),7))
{
 z=1585.42;
};
Date("Varve 714",N(calBP(13474),7))
{
 z=1585.28;
};
Date("Varve 713",N(calBP(13473),7))
{
 z=1585.14;
};
Date("Varve 712",N(calBP(13472),7))
{
 z=1585;
};
Date("Varve 711",N(calBP(13471),7))
{
 z=1584.8;
};
Date("Varve 710",N(calBP(13470),7))
{
 z=1584.6;
};
Date("Varve 709",N(calBP(13469),7))
{
 z=1584.4;
};
Date("Varve 708",N(calBP(13468),7))
{
 z=1584.2;
};
Date("Varve 707",N(calBP(13467),7))
{
 z=1584;
};
Date("Varve 706",N(calBP(13466),7))
{
 z=1583.8;
};
Date("Varve 705",N(calBP(13465),7))
{
 z=1583.6;
};
Date("Varve 704",N(calBP(13464),7))
{
 z=1583.4;
};
Date("Varve 703",N(calBP(13463),7))
{
 z=1583.2;
};
Date("Varve 702",N(calBP(13462),7))
{
 z=1583;
};
Date("Varve 701",N(calBP(13461),7))
{
 z=1580.08;
};
Date("Varve 700",N(calBP(13460),7))
{
 z=1580;
```

```
};
Date("Varve 699",N(calBP(13459),7))
{
 z=1579.5;
};
Date("Varve 698",N(calBP(13458),7))
{
 z=1579;
};
Date("Varve 697",N(calBP(13457),7))
{
 z=1578.99;
};
Date("Varve 696",N(calBP(13456),7))
{
 z=1578.66;
};
Date("Varve 695",N(calBP(13455),7))
{
 z=1578.33;
};
Date("Varve 694",N(calBP(13454),7))
{
 z=1578;
};
Date("Varve 693",N(calBP(13453),7))
{
 z=1577.98;
};
Date("Varve 692",N(calBP(13452),7))
{
 z=1577.84;
};
Date("Varve 691",N(calBP(13451),7))
{
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};
Date("Varve 690",N(calBP(13450),7))
{
 z=1577.56;
};
Date("Varve 689",N(calBP(13449),7))
{
 z=1577.42;
};
Date("Varve 688",N(calBP(13448),7))
{
 z=1577.28;
};
Date("Varve 687",N(calBP(13447),7))
{
 z=1577.14;
};
Date("Varve 686",N(calBP(13446),7))
{
 z=1577;
};
Date("Varve 685",N(calBP(13445),7))
{
 z=1576.9;
};
Date("Varve 684",N(calBP(13444),7))
{
 z=1576.81;
};
Date("Varve 683",N(calBP(13443),7))
{
 z=1576.72;
};
Date("Varve 682",N(calBP(13442),7))
{
```

```
 z=1576.63;
};
Date("Varve 681",N(calBP(13441),7))
{
 z=1576.54;
};
Date("Varve 680",N(calBP(13440),7))
{
 z=1576.45;
};
Date("Varve 679",N(calBP(13439),7))
{
 z=1576.36;
};
Date("Varve 678",N(calBP(13438),7))
{
 z=1576.27;
};
Date("Varve 677",N(calBP(13437),7))
{
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};
Date("Varve 676",N(calBP(13436),7))
{
 z=1576.09;
};
Date("Varve 675",N(calBP(13435),7))
{
 z=1576;
};
Date("Varve 674",N(calBP(13434),7))
{
 z=1575.882;
};
Date("Varve 673",N(calBP(13433),7))
{
 z=1575.819;
};
Date("Varve 672",N(calBP(13432),7))
{
 z=1575.756;
};
Date("Varve 671",N(calBP(13431),7))
{
 z=1575.693;
};
Date("Varve 670",N(calBP(13430),7))
{
 z=1575.63;
};
Date("Varve 669",N(calBP(13429),7))
{
 z=1575.567;
};
Date("Varve 668",N(calBP(13428),7))
{
 z=1575.504;
};
Date("Varve 667",N(calBP(13427),7))
{
 z=1575.441;
};
Date("Varve 666",N(calBP(13426),7))
{
 z=1575.378;
};
Date("Varve 665",N(calBP(13425),7))
{
 z=1575.315;
};
Date("Varve 664",N(calBP(13424),7))
```

```
{
 z=1575.252;
};
Date("Varve 663",N(calBP(13423),7))
{
 z=1575.189;
};
Date("Varve 662",N(calBP(13422),7))
{
 z=1575.126;
};
Date("Varve 661",N(calBP(13421),7))
{
 z=1575.063;
};
Date("Varve 660",N(calBP(13420),7))
{
 z=1575;
};
Date("Varve 659",N(calBP(13419),7))
{
 z=1574.988;
};
Date("Varve 658",N(calBP(13418),7))
{
 z=1574.936;
};
Date("Varve 657",N(calBP(13417),7))
{
 z=1574.884;
};
Date("Varve 656",N(calBP(13416),7))
{
 z=1574.832;
};
Date("Varve 655",N(calBP(13415),7))
{
 z=1574.78;
};
Date("Varve 654",N(calBP(13414),7))
{
 z=1574.728;
};
Date("Varve 653",N(calBP(13413),7))
{
 z=1574.676;
};
Date("Varve 652",N(calBP(13412),7))
{
 z=1574.624;
};
Date("Varve 651",N(calBP(13411),7))
{
 z=1574.572;
};
Date("Varve 650",N(calBP(13410),7))
{
 z=1574.52;
};
Date("Varve 649",N(calBP(13409),7))
{
 z=1574.468;
};
Date("Varve 648",N(calBP(13408),7))
{
 z=1574.416;
};
Date("Varve 647",N(calBP(13407),7))
{
 z=1574.364;
};
```

```
Date("Varve 646",N(calBP(13406),7))
{
 z=1574.312;
};
Date("Varve 645",N(calBP(13405),7))
{
 z=1574.26;
};
Date("Varve 644",N(calBP(13404),7))
{
 z=1574.208;
};
Date("Varve 643",N(calBP(13403),7))
{
 z=1574.156;
};
Date("Varve 642",N(calBP(13402),7))
{
 z=1574.104;
};
Date("Varve 641",N(calBP(13401),7))
{
 z=1574.052;
};
Date("Varve 640",N(calBP(13400),7))
{
 z=1574;
};
Date("Varve 639",N(calBP(13399),7))
{
 z=1573.945;
};
Date("Varve 638",N(calBP(13398),7))
{
 z=1573.91;
};
Date("Varve 637",N(calBP(13397),7))
{
 z=1573.875;
};
Date("Varve 636",N(calBP(13396),7))
{
 z=1573.84;
};
Date("Varve 635",N(calBP(13395),7))
{
 z=1573.805;
};
Date("Varve 634",N(calBP(13394),7))
{
 z=1573.77;
};
Date("Varve 633",N(calBP(13393),7))
{
 z=1573.735;
};
Date("Varve 632",N(calBP(13392),7))
{
 z=1573.7;
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Date("Varve 631",N(calBP(13391),7))
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Date("Varve 630",N(calBP(13390),7))
{
 z=1573.63;
};
Date("Varve 629",N(calBP(13389),7))
{
 z=1573.595;
```

```
};
Date("Varve 628",N(calBP(13388),7))
{
 z=1573.56;
};
Date("Varve 627",N(calBP(13387),7))
{
 z=1573.525;
};
Date("Varve 626",N(calBP(13386),7))
{
 z=1573.49;
};
Date("Varve 625",N(calBP(13385),7))
{
 z=1573.455;
};
Date("Varve 624",N(calBP(13384),7))
{
 z=1573.42;
};
Date("Varve 623",N(calBP(13383),7))
{
 z=1573.385;
};
Date("Varve 622",N(calBP(13382),7))
{
 z=1573.35;
};
Date("Varve 621",N(calBP(13381),7))
{
 z=1573.315;
};
Date("Varve 620",N(calBP(13380),7))
{
 z=1573.28;
};
Date("Varve 619",N(calBP(13379),7))
{
 z=1573.245;
};
Date("Varve 618",N(calBP(13378),7))
{
 z=1573.21;
};
Date("Varve 617",N(calBP(13377),7))
{
 z=1573.175;
};
Date("Varve 616",N(calBP(13376),7))
{
 z=1573.14;
};
Date("Varve 615",N(calBP(13375),7))
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Date("Varve 614",N(calBP(13374),7))
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 z=1573.07;
};
Date("Varve 613",N(calBP(13373),7))
{
 z=1573.035;
};
Date("Varve 612",N(calBP(13372),7))
{
 z=1573;
};
Date("Varve 611",N(calBP(13371),7))
{
```

```
 z=1572.946;
};
Date("Varve 610",N(calBP(13370),7))
{
 z=1572.903;
};
Date("Varve 609",N(calBP(13369),7))
{
 z=1572.86;
};
Date("Varve 608",N(calBP(13368),7))
{
 z=1572.817;
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{
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Date("Varve 345",N(calBP(13105),5))
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{
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Date("Varve 327",N(calBP(13087),5))
{
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Date("Varve 322",N(calBP(13082),5))
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};
Date("Varve 309",N(calBP(13069),5))
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Date("Varve 295",N(calBP(13055),5))
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Date("Varve 293",N(calBP(13053),5))
{
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Date("Varve 292",N(calBP(13052),5))
{
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};
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Date("Varve 290",N(calBP(13050),5))
{
 z=1559.852;
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{
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{
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 z=1559.639;
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Date("Varve 286",N(calBP(13046),5))
{
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Date("Varve 281",N(calBP(13041),5))
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};
Date("Varve 279",N(calBP(13039),5))
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};
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Date("Varve 277",N(calBP(13037),5))
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Date("Varve 276",N(calBP(13036),5))
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 z=1558.9;
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Date("Varve 275",N(calBP(13035),5))
{
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};
Date("Varve 274",N(calBP(13034),5))
{
 z=1558.8;
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 z=1558.75;
};
Date("Varve 272",N(calBP(13032),5))
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 z=1558.7;
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Date("Varve 270",N(calBP(13030),5))
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Date("Varve 269",N(calBP(13029),5))
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Date("Varve 268",N(calBP(13028),5))
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Date("Varve 267",N(calBP(13027),5))
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Date("Varve 264",N(calBP(13024),5))
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Date("Varve 263",N(calBP(13023),5))
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Date("Varve 261",N(calBP(13021),5))
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};
Date("Varve 256",N(calBP(13016),5))
{
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Date("Varve 255",N(calBP(13015),5))
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 z=1557.747;
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Date("Varve 254",N(calBP(13014),5))
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};
Date("Varve 252",N(calBP(13012),5))
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Date("Varve 249",N(calBP(13009),5))
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};
Date("Varve 247",N(calBP(13007),5))
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Date("Varve 246",N(calBP(13006),5))
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Date("Varve 245",N(calBP(13005),5))
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Date("Varve 244",N(calBP(13004),5))
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Date("Varve 238",N(calBP(12998),5))
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Date("Varve 227",N(calBP(12987),5))
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Date("Varve 219",N(calBP(12979),5))
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Date("Varve 204",N(calBP(12964),5))
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{
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Date("Varve 201",N(calBP(12961),5))
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Date("Varve 167",N(calBP(12927),5))
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Date("Varve 137",N(calBP(12897),6))
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Date("Varve 135",N(calBP(12895),6))
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Date("Varve 132",N(calBP(12892),6))
{
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 z=1548.78;
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Date("Varve 117",N(calBP(12877),6))
{
 z=1548.104;
};
Date("Varve 116",N(calBP(12876),6))
{
 z=1548.052;
};
Date("Varve 115",N(calBP(12875),6))
{
 z=1548;
};
Date("Varve 114",N(calBP(12874),6))
{
```

```
 z=1547.88;
};
Date("Varve 113",N(calBP(12873),6))
{
 z=1547.8;
};
Date("Varve 112",N(calBP(12872),6))
{
 z=1547.72;
};
Date("Varve 111",N(calBP(12871),6))
{
 z=1547.64;
};
Date("Varve 110",N(calBP(12870),6))
{
 z=1547.56;
};
Date("Varve 109",N(calBP(12869),6))
{
 z=1547.48;
};
Date("Varve 108",N(calBP(12868),6))
{
 z=1547.4;
};
Date("Varve 107",N(calBP(12867),6))
{
 z=1547.32;
};
Date("Varve 106",N(calBP(12866),6))
{
 z=1547.24;
};
Date("Varve 105",N(calBP(12865),6))
{
 z=1547.16;
};
Date("Varve 104",N(calBP(12864),6))
{
 z=1547.08;
};
Date("Varve 103",N(calBP(12863),6))
{
 z=1547;
};
Date("Varve 102",N(calBP(12862),6))
{
 z=1546.7;
};
Date("Varve 101",N(calBP(12861),6))
{
 z=1546.56;
};
Date("Varve 100",N(calBP(12860),6))
{
 z=1546.42;
};
Date("Varve 99",N(calBP(12859),6))
{
 z=1546.28;
};
Date("Varve 98",N(calBP(12858),6))
{
 z=1546.14;
};
Date("Varve 97",N(calBP(12857),6))
{
 z=1546;
};
Date("Varve 96",N(calBP(12856),6))
```

```
{
 z=1545.98;
};
Date("Varve 95",N(calBP(12855),6))
{
 z=1545.91;
};
Date("Varve 94",N(calBP(12854),6))
{
 z=1545.84;
};
Date("Varve 93",N(calBP(12853),6))
{
 z=1545.77;
};
Date("Varve 92",N(calBP(12852),6))
{
 z=1545.7;
};
Date("Varve 91",N(calBP(12851),6))
{
 z=1545.63;
};
Date("Varve 90",N(calBP(12850),6))
{
 z=1545.56;
};
Date("Varve 89",N(calBP(12849),6))
{
 z=1545.49;
};
Date("Varve 88",N(calBP(12848),6))
{
 z=1545.42;
};
Date("Varve 87",N(calBP(12847),6))
{
 z=1545.35;
};
Date("Varve 86",N(calBP(12846),6))
{
 z=1545.28;
};
Date("Varve 85",N(calBP(12845),6))
{
 z=1545.21;
};
Date("Varve 84",N(calBP(12844),6))
{
 z=1545.14;
};
Date("Varve 83",N(calBP(12843),6))
{
 z=1545.07;
};
Date("Varve 82",N(calBP(12842),6))
{
 z=1545;
};
Date("Varve 81",N(calBP(12841),6))
{
 z=1544.85;
};
Date("Varve 80",N(calBP(12840),6))
{
 z=1544.68;
};
Date("Varve 79",N(calBP(12839),6))
{
 z=1544.51;
};
```

```
Date("Varve 78",N(calBP(12838),6))
{
 z=1544.34;
};
Date("Varve 77",N(calBP(12837),6))
{
 z=1544.17;
};
Date("Varve 76",N(calBP(12836),6))
{
 z=1544;
};
Date("Varve 75",N(calBP(12835),6))
{
 z=1543.85;
};
Date("Varve 74",N(calBP(12834),6))
{
 z=1543.68;
};
Date("Varve 73",N(calBP(12833),6))
{
 z=1543.51;
};
Date("Varve 72",N(calBP(12832),6))
{
 z=1543.34;
};
Date("Varve 71",N(calBP(12831),6))
{
 z=1543.17;
};
Date("Varve 70",N(calBP(12830),6))
{
 z=1543;
};
Date("Varve 69",N(calBP(12829),6))
{
 z=1542.85;
};
Date("Varve 68",N(calBP(12828),6))
{
 z=1542.68;
};
Date("Varve 67",N(calBP(12827),6))
{
 z=1542.51;
};
Date("Varve 66",N(calBP(12826),6))
{
 z=1542.34;
};
Date("Varve 65",N(calBP(12825),6))
{
 z=1542.17;
};
Date("Varve 64",N(calBP(12824),6))
{
 z=1542;
};
Date("Varve 63",N(calBP(12823),6))
{
 z=1541.84;
};
Date("Varve 62",N(calBP(12822),6))
{
 z=1541.7;
};
Date("Varve 61",N(calBP(12821),6))
{
 z=1541.56;
```

```
};
Date("Varve 60",N(calBP(12820),6))
{
 z=1541.42;
};
Date("Varve 59",N(calBP(12819),6))
{
 z=1541.28;
};
Date("Varve 58",N(calBP(12818),6))
{
 z=1541.14;
};
Date("Varve 57",N(calBP(12817),6))
{
 z=1541;
};
Date("Varve 56",N(calBP(12816),6))
{
 z=1540.8;
};
Date("Varve 55",N(calBP(12815),6))
{
 z=1540.6;
};
Date("Varve 54",N(calBP(12814),6))
{
 z=1540.4;
};
Date("Varve 53",N(calBP(12813),6))
{
 z=1540.2;
};
Date("Varve 52",N(calBP(12812),6))
{
 z=1540;
};
Date("Varve 51",N(calBP(12811),6))
{
 z=1539.85;
};
Date("Varve 50",N(calBP(12810),6))
{
 z=1539.68;
};
Date("Varve 49",N(calBP(12809),6))
{
 z=1539.51;
};
Date("Varve 48",N(calBP(12808),6))
{
 z=1539.34;
};
Date("Varve 47",N(calBP(12807),6))
{
 z=1539.17;
};
Date("Varve 46",N(calBP(12806),6))
{
 z=1539;
};
Date("Varve 45",N(calBP(12805),6))
{
 z=1538.8;
};
Date("Varve 44",N(calBP(12804),6))
{
 z=1538.6;
};
Date("Varve 43",N(calBP(12803),6))
{
```

```
 z=1538.4;
};
Date("Varve 42",N(calBP(12802),6))
{
 z=1538.2;
};
Date("Varve 41",N(calBP(12801),6))
{
 z=1538;
};
Date("Varve 40",N(calBP(12800),6))
{
 z=1537.8;
};
Date("Varve 39",N(calBP(12799),6))
{
 z=1537.6;
};
Date("Varve 38",N(calBP(12798),6))
{
 z=1537.4;
};
Date("Varve 37",N(calBP(12797),6))
{
 z=1537.2;
};
Date("Varve 36",N(calBP(12796),6))
{
 z=1537;
};
Date("Varve 35",N(calBP(12795),6))
{
 z=1536.78;
};
Date("Varve 34",N(calBP(12794),6))
{
 z=1536;
};
Date("Varve 33",N(calBP(12793),6))
{
 z=1535.5;
};
Date("Varve 32",N(calBP(12792),6))
{
 z=1535;
};
Date("Varve 31",N(calBP(12791),6))
{
 z=1534.66;
};
Date("Varve 30",N(calBP(12790),6))
{
 z=1534.33;
};
Date("Varve 29",N(calBP(12789),6))
{
 z=1534;
};
Date("Varve 28",N(calBP(12788),6))
{
 z=1533.66;
};
Date("Varve 27",N(calBP(12787),6))
{
 z=1533.33;
};
Date("Varve 26",N(calBP(12786),6))
{
 z=1533;
};
Date("Varve 25",N(calBP(12785),6))
```

```
{
 z=1532.75;
};
Date("Varve 24",N(calBP(12784),6))
{
 z=1532.5;
};
Date("Varve 23",N(calBP(12783),6))
{
 z=1532.25;
};
Date("Varve 22",N(calBP(12782),6))
{
 z=1532;
};
Date("Varve 21",N(calBP(12781),6))
{
 z=1531.66;
};
Date("Varve 20",N(calBP(12780),6))
{
 z=1531.33;
};
Date("Varve 19",N(calBP(12779),6))
{
 z=1531;
};
Date("Varve 18",N(calBP(12778),6))
{
 z=1530.66;
};
Date("Varve 17",N(calBP(12777),6))
{
 z=1530.33;
};
Date("Varve 16",N(calBP(12776),6))
{
 z=1530;
};
Date("Varve 15",N(calBP(12775),6))
{
 z=1529.75;
};
Date("Varve 14",N(calBP(12774),6))
{
 z=1529.5;
};
Date("Varve 13",N(calBP(12773),6))
{
 z=1529.25;
};
Date("Varve 12",N(calBP(12772),6))
{
 z=1529;
};
Date("Varve 11",N(calBP(12771),6))
{
 z=1528;
};
Date("Varve 10",N(calBP(12770),6))
{
 z=1527.66;
};
Date("Varve 9",N(calBP(12769),6))
{
 z=1527.33;
};
Date("Varve 8",N(calBP(12768),6))
{
 z=1527;
};
```

```
  Date("Varve 7",N(calBP(12767),6))
  {
   z=1526.5;
  };
  Date("Varve 6",N(calBP(12766),6))
  {
   z=1526;
  };
  Date("Varve 5",N(calBP(12765),6))
  {
   z=1525.75;
  };
  Date("Varve 4",N(calBP(12764),6))
  {
   z=1525.5;
  };
  Date("Varve 3",N(calBP(12763),6))
  {
   z=1525.25;
  };
  Date("Varve 2",N(calBP(12762),6))
  {
   z=1525;
  };
  Date("Varve 1",N(calBP(12761),6))
  {
   z=1524.75;
  };
  Boundary("Varve 0",N(calBP(12760),6))
  {
   z=1524.5;
  };
 };
P_Sequence("Hamelsee Upper",1,0.5,U(-2,2))
 {
  Boundary("=Varve 0")
  {
   z=1524.5;
  };
  Date("VALohneIntCal20",N(calBP(12044),53))
  {
   Outlier(0.05);
   z=1492.5;
  };
  R_Date("OxAX255513",10550,160)
  {
   Outlier(0.05);
   z=1489.5;
  };
  R_Date("OxAX255514",10310,130)
  {
   Outlier(0.05);
   z=1477.5;
  };
  Date("YDend")
  {
   z=1474;
  };
  Date("UMTc14",N(calBP(10941),109))
  {
   Outlier(0.05);
   z=1448;
  };
  Date("AskjaKearney18",N(calBP(10865),99))
  {
   z=1445;
  };
  Date("SaksLohneIntCal20",N(calBP(10178),45))
  {
   Outlier(0.05);
   z=1401;
```

```
  };
  Boundary()
  {
   z=1370;
  };
 };
};
```

Supplementary code 2: R code
The code below was used to calculate breakpoints using piecewise linear regression as well as to produce the panels shown in Fig. 3 of the main manuscript.

```
# clear environment
rm(list = ls())
# Set workdirectory - home
setwd("C:/Users/path")

# Load packages:
library(readxl)
library(segmented)
library(ggplot2)

##########
#Krakenes#
##########

#Importing data
KrakAll = read_excel("Krakenes_pollen.xlsx", sheet = "Percentages")

#Calculate rampfit - YD_early
Ramp = cbind(KrakAll$`Salix un`, KrakAll$Age_Engels2021)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("Salix%", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 12650 & Ramp$Age < 13200)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(12750, 12850)))
summary(fit1)
# get the breakpoints
fit1$psi

# Plot for visual check - YD_early
# Not repeated below for other intervals/sites
plot(x=KrakAll$Age_Engels2021, y = KrakAll$`Salix un`,
    type = "l", xlim=cbind(12650,13200), ylim=cbind(0,60),
    main = "Krakenes",
    xlab="Age (cal. yr BP)",
    ylab = "Salix")
Axis(side = 4)
lines(age, predict(fit1), col = "red")


#Calculate rampfit - YD eq
Ramp = cbind(KrakAll$`Salx her`, KrakAll$Age_Engels2021)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("Salix her%", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 12100 & Ramp$Age < 12750)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(12500)))
summary(fit1)
# get the breakpoints
fit1$psi
```

```
#Calculate rampfit - Hol_early
Ramp = cbind(KrakAll$`Salix un`, KrakAll$Age_Engels2021)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("Salix", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 11530 & Ramp$Age < 11800)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(11600)))
summary(fit1)
# get the breakpoints
fit1$psi


#Calculate rampfit - Hol_eq
Ramp = cbind(KrakAll$Betula, KrakAll$Age_Engels2021)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("Betula", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 10400 & Ramp$Age < 11200)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(10800)))
summary(fit1)
# get the breakpoints
fit1$psi

# Figure 3 Plot
plot(x=KrakAll$Age_Engels2021, y = KrakAll$Betula,
    type = "l", xlim=cbind(11500,13000), ylim=cbind(0,30),
    main = "Krakenes",
    xlab="Age (cal. yr BP)",
    ylab = "Betula + Poaceae (%)",
    col="red")
lines(x=KrakAll$Age_Engels2021,y = KrakAll$`Graminea` ,col="green")
Axis(side = 4)
Axis(side = 3)
H.early=cbind(11556, 12819)
abline(v=H.early, col=c("red"), lty=1, lwd=3) #solid, thick
H.midpoint=cbind(11520,12765)
abline(v=H.midpoint, col=c("red"), lty=2, lwd=1) #dashed
H.end=cbind(12641)
abline(v=H.end, col=c("red"), lty=3, lwd=1) #dotted


############
#Hasseldala#
############

rm(list = ls())

#Importing data
HassAll = read_excel("Hasseldala_pollen.xlsx", sheet = "Percentages")


#Calculate rampfit - YD early
```

```
Ramp = cbind(HassAll$Empetrum, HassAll$Age_Engels2021)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("Empetrum", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 12600 & Ramp$Age < 13100)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(12800)))
summary(fit1)
# get the breakpoints
fit1$psi

#Calculate rampfit - onset YD eq
Ramp = cbind(HassAll$Juniperus, HassAll$Age_Engels2021)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("Empetrum", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 12500 & Ramp$Age < 12800)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(12600)))
summary(fit1)
# get the breakpoints
fit1$psi

#Calculate rampfit - HOL early
Ramp = cbind(HassAll$Artemisia, HassAll$Age_Engels2021)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("Artemisia", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 11300 & Ramp$Age < 12300)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(11800)))
summary(fit1)
# get the breakpoints
fit1$psi

#Calculate rampfit - HOL eq
Ramp = cbind(HassAll$Empetrum, HassAll$Age_Engels2021)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("Empetrum", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 11300 & Ramp$Age < 12300)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(11500, 11800, 12000)))
summary(fit1)
# get the breakpoints
fit1$psi

# Figure 3 plot
plot(x=HassAll$Age_Engels2021, y = HassAll$Empetrum,
    type = "l", xlim=cbind(11500,13000), ylim=NULL,
    main = "Hasseldala",
    xlab="Age (cal. yr BP)",
    ylab = "Empetrum + Artemisia (%)",
```

```
    col="red")
lines(x=HassAll$Age_Engels2021,y = HassAll$Artemisia,col="green")
Axis(side = 3)
Axis(side = 4)
H.early=cbind(11888, 12863)
abline(v=H.early, col=c("red"), lty=1, lwd=3) #solid, thick
H.midpoint=cbind(11741,12754)
abline(v=H.midpoint, col=c("red"), lty=2, lwd=1) #dashed)
H.end=cbind(11668, 12623)
abline(v=H.end, col=c("red"), lty=3, lwd=1) #dotted

###########
#Haemelsee#
###########

rm(list = ls())

#Importing data
HaemAll = read_excel("Haemelsee_pollen.xlsx", sheet = "Percentages")
HaemPAR = read_excel("Haemelsee_pollen.xlsx", sheet = "PAR")


#Calculate rampfit - YD early
Ramp = cbind(HaemPAR$PAR_Salix, HaemPAR$Age_Engels2021)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("PAR_Salix", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 12700 & Ramp$Age < 13300)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(12800)))
summary(fit1)
# get the breakpoints
fit1$psi

#Calculate rampfit - YD eq
Ramp = cbind(HaemPAR$PAR_Salix, HaemPAR$Age_Engels2021)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("PAR_Salix", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 12100 & Ramp$Age < 12850)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(12800))) # estimates for the break-point(s)
summary(fit1)
# get the breakpoints
fit1$psi

#Calculate rampfit - HOL early
Ramp = cbind(HaemPAR$PAR_Empetrum, HaemPAR$Age_Engels2021)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("PAR_Empetrum", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 11000 & Ramp$Age < 12200)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(11600, 11800)))
```

```
summary(fit1)
# get the breakpoints
fit1$psi

#Calculate rampfit - HOL eq
Ramp = cbind(HaemAll$Betula, HaemPAR$Age_Engels2021)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("Betula", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 11000 & Ramp$Age < 12200)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(11600)))
summary(fit1)
# get the breakpoints
fit1$psi

#Figure 3 PLot - x axis on age cal BP
plot(x=HaemAll$Age_Engels2021, y = HaemAll$Betula,
    type = "l", xlim=cbind(11500,13000), ylim=cbind(0,80),
    main = "Haemelsee",
    xlab="Age (cal. yr BP)",
    ylab = "Betula (%)+ Poceae (%) + Empetrum (%x10)",
    col="red")
lines(x=HaemAll$Age_Engels2021,y = HaemAll$Poaceae,col="green")
lines(x=HaemAll$Age_Engels2021,y = HaemAll$Empetrum * 10,col="purple")
Axis(side = 3)
Axis(side = 4)
H.early=cbind(11766, 12821)
abline(v=H.early, col=c("red"), lty=1, lwd=3) #solid, thick
H.midpoint=cbind(11689,12799)
abline(v=H.midpoint, col=c("red"), lty=2, lwd=1) #dashed
H.end=cbind(11689, 12730)
abline(v=H.end, col=c("red"), lty=3, lwd=1) #dotted

#Figure 3 plot- x axis relative to LST
plot(x=HaemAll$Age_rel_LST, y = HaemAll$Betula,
    type = "l", xlim=rev(cbind(0,1500)), ylim=cbind(0,80),
    main = "Haemelsee",
    xlab="Age (relative to LST)",
    ylab = "Betula (%)+ Poceae (%) + Empetrum (%x10)",
    col="red")
lines(x=HaemAll$Age_rel_LST,y = HaemAll$Poaceae,col="green")
lines(x=HaemAll$Age_rel_LST,y = HaemAll$Empetrum * 10,col="purple")
Axis(side = 3)
Axis(side = 4)
H.early=cbind(185, 1240)
abline(v=H.early, col=c("red"), lty=1, lwd=3) #solid, thick
H.midpoint=cbind(207,1317)
abline(v=H.midpoint, col=c("red"), lty=2, lwd=1) #dashed
H.end=cbind(276, 1317)
abline(v=H.end, col=c("red"), lty=3, lwd=1) #dotted

###############
#Meerfelder Maar#
###############
```

```
rm(list = ls())

#Importing data
MFM_All = read_excel("MFM_pollen.xlsx", sheet = "Percentages_all")
MFM_PAR = read_excel("MFM_pollen.xlsx", sheet = "PAR_onset YD")


#Calculate rampfit - YD early
Ramp = cbind(MFM_PAR$Pinus, MFM_PAR$Age_2008)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("PAR_Pinus", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 12650 & Ramp$Age < 12870)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(12700)))
summary(fit1)
# get the breakpoints
fit1$psi


#Calculate rampfit - YD eq
Ramp = cbind(MFM_All$Salix, MFM_All$`Age_1999/2016`)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("Salix", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 12580 & Ramp$Age < 12800)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(12600)))
summary(fit1)
# get the breakpoints
fit1$psi

#Calculate rampfit - HOL early
Ramp = cbind(MFM_All$Juniperus, MFM_All$`Age_1999/2016`)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("Juniperus", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 11500 & Ramp$Age < 12500)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(11650, 11800)))
summary(fit1)
# get the breakpoints
fit1$psi

#Calculate rampfit - HOL eq
Ramp = cbind(MFM_All$Betula, MFM_All$`Age_1999/2016`)
Ramp = as.data.frame(Ramp)
colnames(Ramp) = c("Betula", "Age")
Ramp.YD = subset(Ramp, Ramp$Age > 11500 & Ramp$Age < 12000)
Ramp.YD = as.matrix(Ramp.YD)
fit0 = lm(Ramp.YD[,1] ~ Ramp.YD[,2])
age = Ramp.YD[,2]
fit1 = segmented(fit0, seg.Z = ~age, psi= list(age = c(11600, 11650)))
summary(fit1)
```

```
# get the breakpoints
fit1$psi

#plot Figure 3 - x axis in varve yr BP
plot(x=MFM_All$`Age_1999/2016`, y = MFM_All$Betula,
    type = "l", xlim=cbind(11500,13000), ylim=cbind(0,50),
    main = "Meerfelder Maar",
    xlab="Age (varve yr BP)",
    ylab = "Betula & Artemisia (%)",
    col="red")
Axis(side = 4)
Axis(side = 3)
lines(x=MFM_All$`Age_1999/2016`,y = MFM_All$Artemisia,col="green")
H.early=cbind(12726, 11640)
abline(v=H.early, col=c("red"), lty=1, lwd=3) #solid, thick
H.midpoint=cbind(12674,11590)
abline(v=H.midpoint, col=c("red"), lty=2, lwd=1) #dashed
H.end=cbind(12619, 11590)
abline(v=H.end, col=c("red"), lty=3, lwd=1) #dotted


#plot Figure 3 - x axis relative to LST
plot(x=MFM_All$Age_rel_LST, y = MFM_All$Betula,
    type = "l", xlim=rev(cbind(0,1500)), ylim=cbind(0,50),
    main = "Meerfelder Maar",
    xlab="Age (relative to LST)",
    ylab = "Betula & Artemisia (%)",
    col="red")
Axis(side = 4)
Axis(side = 3)
lines(x=MFM_All$Age_rel_LST,y = MFM_All$Artemisia,col="green")
H.early=cbind(1316, 158)
abline(v=H.early, col=c("red"), lty=1, lwd=3) #solid, thick
H.midpoint=cbind(1416,210)
abline(v=H.midpoint, col=c("red"), lty=2, lwd=1) #dashed
H.end=cbind(1416, 265)
abline(v=H.end, col=c("red"), lty=3, lwd=1) #dotted


#######################
#NGRIP inc age conversion#
#######################

# read in the NGRIP data
#NGRIP <- read.table("NGRIP_d18O.txt", header = TRUE)
NGRIP <- read_excel("NGRIP.xlsx", sheet = "NGRIP_d18O")

# convert b2k to BP
NGRIP <- cbind(NGRIP[,1]-50,NGRIP[,2])
# subset data
NGRIP <- NGRIP[NGRIP[,1] > 11450 & NGRIP[,1] < 13450,]

# intcal20-GICC05_BP shift
myshift = read_excel("NGRIP.xlsx", sheet = "shift")
myshift = as.data.frame(myshift)

# convert offsets to GICC05 BP
```

```
myshift[,1] <- myshift[,1] - myshift[,2]
myshift[,2] <- -1*myshift[,2]

# interpolate at resolution of d18O data
myshift1 <- round(approx(myshift[,1], myshift[,2], NGRIP[,1])$y,1)

# if NA, replace with closest values
myshift1 <- round(na.fill(myshift1, "extend"),1)

# plot shifted d18O record
plot(NGRIP[,1]-myshift1, NGRIP[,2], type='l',
   xlab='Age (years BP)', ylab='d18O (permil)')
lines(NGRIP, col=2)
abline(v=seq(11000,14000, by=100), lty=3, lwd=0.5)
legend('topright', c("GICC05 BP", "synchronized to IntCal20"),
     lty=c(1,1), col=c(2,1), cex=0.5)

# plot for fig 3 #NGRIP plotted on IntCAL
plot (x=NGRIP[,1]-myshift1, y=NGRIP[,2],
     type='l',
     xlab='Age (years BP)',
     ylab='d18O (permil)',
     xlim=cbind(11500,13000))
H.IntCAL20=cbind(11647, 12909)
abline(v=H.IntCAL20, col=c("black"), lty=3, lwd=1)
Axis(side = 3)
Axis(side = 4)
```

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