RESULTS

Using the methods and material discussed previously, a well-founded discussion of changes in human social systems in the context of climatic and environmental developments was possible.

CLIMATE AND CHRONOLOGY

Limits of Lateglacial events in the Greenland oxygen isotope record

In the published oxygen isotope record from NGRIP (Andersen et al. 2004; Rasmussen et al. 2006), the data points were usually sampled every 20 years. In contrast to previous sub-divisions which were based either on the deuterium isotopes or on the GRIP instead of the NGRIP record (cf. Lowe et al. 2008; Blockley et al. 2012) and in order to establish a more detailed sub-division of the Lateglacial record, the amplitudes between two data points were used to identify the thus far undefined limits of isotope events within the Lateglacial Interstadial (**tab. 63**). Besides the difference between two data points, the limits were set based on the comparison of the actual oxygen isotope values and the difference accumulated in 100 years (see p. 245-247).

Assuming a relation of higher oxygen isotope values to a milder and more humid climate and of lower values to a cold and dry climate, a comparison of the actual oxygen isotope values makes considerations about the general climate regime possible. The lowest value (-44.97‰) occurred at 16,100 years cal. b2k[30] and the highest (-34,89‰) at 10,200 years cal. b2k. Thus, a mean oxygen isotope value lies around -40.00‰ and, therefore, this mean value is used as a distinctive level for the Lateglacial record. By this level, the oxygen isotope record of NGRIP between 18,000 and 10,000 years cal. b2k can be sub-divided in eight periods (18,000-16,240, 16,220-14,700, 14,680-13,260, 13,240-13,080, 13,060-12,780, 12,760-12,280, 12,260-11,760, 11,740-10,000 years cal. b2k).

Prior to 16,220 years cal. b2k the oxygen isotope values were very unsteady and also often below -40.00‰. However, between 18,000 and 16,240 this level was crossed 16 times. In contrast, during the 1,520 years between 16,220 years cal. b2k and the onset of the Lateglacial Interstadial after 14,700 years cal. b2k only two values lie slightly above this level (-39.98‰ at 15,080 years cal. b2k and -39.92‰ at 14,800 years cal. b2k). Thus, during the first period crossing of the level occurred eight times as often as in the period before the onset of the Lateglacial Interstadial[31]. After 14,700 years cal. b2k the values rise significantly and until 13,260 years cal. b2k the oxygen isotope values drop only three times below -40.00‰ (-40.94‰ at 14,080 years cal. b2k; -40.21‰ at 14,040 years cal. b2k; -40.05‰ at 13,640 years cal. b2k). The former two low points mark a cold phase in the early Lateglacial Interstadial (GI-1d) and the third relates to a short cold reversal in the mid-Lateglacial Interstadial (GI-1c_2). Between 13,240 and 13,080 years cal. b2k, only the value at 13,100 years cal. b2k (-39.77‰) is above -40.00‰. This short cold period can be related to the terminal Lateglacial Interstadial cold event GI-1b. This event was probably equivalent to the so-called

30 b2k refers to »before 2000 A.D.« (see p. 8 and 5).

31 If an identical number of years were chosen in the first part, relating to the period between 17,760 and 16,240 years cal. b2k, the numbers would only slightly decrease to 15 points above -40.00‰ and 7.5 times more crossings than in the following period.

Gerzensee oscillation (Lotter et al. 1992) or the Inner/Intra-Allerød Cold Period (IACP; Lehman/Keigwin 1992) which were observed in several marine and continental records from the north-western European region (e.g. Ammann et al. 2000; Litt/Schmincke/Kromer 2003; Wennrich et al. 2005, 280; Huber et al. 2010, 144). From 13,060 to 12,780 years cal. b2k, the values are generally above -40.00‰. From 12,760 to 12,280 years cal. b2k, the values are usually below this level, only at 12,540 years cal. b2k (-39.09‰) it is crossed again. Between 12,260 years cal. b2k and the onset of the Holocene, the values are still mainly below -40.00‰ but this level is crossed eight times. This observation sustains previous findings of a milder and more unsteady late part of the Lateglacial Stadial (Weber/Grimm/Baales 2011; cf. Bakke et al. 2009). From 11,740 years cal. b2k to the end of the survey at 10,000 years cal b2k no value lies below -40,00‰ anymore. Based on this general comparison of the actual values, the onset of the Holocene can be proposed around 11,740 years cal. b2k, the onset of GI-1 around 14,680 years cal. b2k, and the onset of the GS-2a around 16,220 years cal. b2k.

In the comparison of the differences which accumulated in 100 years between the oxygen isotope values, a uni-directional and substantial change of the climate regime for an intermediate duration can be assumed if the accumulated value increases. The clearest of these changes in the surveyed record occurred between14,740 years cal. b2k (-42.47‰) and 14,600 years cal. b2k (-35.81‰) where three successive accumulation values are higher than 4‰ with the intermediate value even crossing the 5‰ limit. Furthermore, the two prior values (14,780-14,680 years cal. b2k and 14,760 and 14,660 years cal. b2k) lie also above 3‰. These extreme values as well as their concentration illustrate the onset of the Lateglacial Interstadial as the most significant change in the climate regime as observed in the oxygen isotope record between 18,000 and 10,000 years cal. b2k. After the onset of the Lateglacial Interstadial, the 4‰ level is only crossed once more in the surveyed period, between 11,760 and 11,660 years cal. b2k. This change indicates the onset of the Holocene. Between 18,000 and 14,740 years cal. b2k, accumulated values of over 4‰ occurred at three positions: between 16,620 and 16,520 years cal. b2k, between 15,680 and 15.580 years cal. b2k, and between 15,380 and 15,280 years cal. b2k. In the latter two cases, the values decrease further reflecting the continued deterioration of the values during GS-2a or, perhaps, alternative limits for the onset of GS-2a. At 16,520 years cal. b2k the highest oxygen isotope value (-38.29‰) prior to the onset of the Lateglacial Interstadial occurred in the surveyed record.

Generally, the limits were set according to the mean of the steepest part of the record. Therefore, the simple difference of the oxygen isotope values between two data points is considered. This difference reflects the short-term fluctuations in the climate record. Very large differences of over 4‰ between two data points, thus, within 20 years, occurred only twice in the surveyed Pleistocene record: between 16,240 to 16,220 years cal. b2k the value decreased by 4.38‰ from -39.89‰ to -44.27‰ and between 15,280 and 15,260 years cal. b2k, the oxygen isotope value increased from -44.91‰ to -40.55‰ (+4.36‰). The former, very large difference, correlates with the assumed onset of GS-2a based on the comparison of the actual oxygen isotope values. Therefore, the onset of GS-2a is set to this limit. At the latter position, a comparison to the previous as well as the two following data points reveals a significant back and forth fluctuation of the values for approximately 100 years between 15,300 and 15,200 years cal. b2k. This flickering overlaps partially with the accumulated decrease between 15,380 and 15,280 years cal. b2k. At this depth in the NGRIP ice-core was also a bimodal ash deposited (cf. Mortensen et al. 2005). Perhaps, this combination of fluctuating oxygen isotope values coupled with increased volcanic activity suggests an unstable climate (cf. Zielinski 2000; Hall/Meiklejohn/Bumby 2011; Evan 2012; Kutterolf et al. 2013).

The simple difference between two data points surpassed 3‰ twelve times in the record (tab. 63). Only one of these rapid changes occurred after the onset of the Lateglacial Interstadial between 12,200 to 12,180 years cal. b2k where the oxygen isotope value decreased by 3.18‰ from -38.91‰ to -42.09‰.

NGRIP years b2k	NGRIP depth (m)	NGRIP $\delta^{18}O$ (‰)	max. counting error (years)	years to data point above	difference of $\delta^{18}O$ to data point above	*c.* 40 years accumulated amplitude	*c.* 60 years accumulated amplitude	*c.* 80 years accumulated amplitude	*c.* 100 years accumulated amplitude	»event«	volcanic ashes
10,000	1,384.34	-35.10	83	20	0.45	-0.36	0.25	-0.16	0.04		
10,020	1,385.88	-34.94	83	20	-0.16	0.29	-0.52	0.09	-0.32	2nd highest point of the record	
10,040	1,387.37	-35.11	84	20	0.17	0.01	0.46	-0.35	0.26		
10,060	1,388.82	-35.79	84	20	0.68	0.85	0.69	**1.14**	0.33		
10,080	1,390.23	-35.21	85	20	-0.58	0.10	0.27	0.11	0.56		
10,100	1,391.72	-35.32	85	20	0.11	-0.47	0.21	0.38	0.22		
10,120	1,393.18	-35.29	85	20	-0.03	0.08	-0.50	0.18	0.35		
10,140	1,394.61	-35.45	86	20	0.16	0.13	0.24	-0.34	0.34		
10,160	1,396.05	-34.99	86	20	-0.46	-0.30	-0.33	-0.22	-0.80	3rd highest point of the record	
10,180	1,397.61	-35.02	87	20	0.03	-0.43	-0.27	-0.30	-0.19		
10,200	1,399.13	-34.89	87	20	-0.13	-0.10	-0.56	-0.40	-0.43	highest point of the record	
10,220	1,400.55	-35.93	87	20	**1.04**	0.91	0.94	0.48	0.64		
10,240	1,402.07	-35.54	88	20	-0.39	0.65	0.52	0.55	0.09		
10,260	1,403.52	-36.33	88	20	0.79	0.40	**1.44**	**1.31**	**1.34**		
10,280	1,405.04	-36.39	89	20	0.06	0.85	0.46	**1.50**	**1.37**		
10,300	1,406.44	-36.01	89	20	-0.38	-0.32	0.47	0.08	**1.12**		
10,320	1,407.91	-36.01	89	20	0.00	-0.38	-0.32	0.47	0.08		
10,340	1,409.42	-35.20	89	20	-0.81	-0.81	**-1.19**	**-1.13**	-0.34		
10,360	1,410.77	-36.12	89	20	0.92	0.11	0.11	-0.27	-0.21		Saksurnavatn Ash at 1409.89 m (10,347 ± 89 b2k*)
10,380	1,412.14	-36.18	89	20	0.06	0.98	0.17	0.17	-0.21		
10,400	1,413.48	-36.36	89	20	0.18	0.24	1.16	0.35	0.35		
10,420	1,414.80	-35.96	90	20	-0.40	-0.22	-0.16	0.76	-0.05		
10,420	1,414.80	-35.96	90	20	-0.40	-0.22	-0.16	0.76	-0.05		
10,440	1,416.18	-36.12	90	20	0.16	-0.24	-0.06	0.00	0.92		
10,460	1,417.50	-36.04	90	20	-0.08	0.08	-0.32	-0.14	-0.08		
10,480	1,418.84	-35.53	90	20	-0.51	-0.59	-0.43	-0.83	-0.65		
10,500	1,420.22	-36.34	90	20	0.81	0.30	0.22	0.38	-0.02		

Tab. 63 NGRIP oxygen isotope record with calculated amplitudes and volcanic ashes. First four columns taken from the file »GICC05_NGRIP_20y_10sep2007« at www.iceandclimate.nbi.ku.dk/data/ (see p. 247-245). Accumulated amplitudes were calculated with values in the lines above in the previous column. To facilitate the reading of the table, NGRIP $\delta^{18}O$ values are set in bold if they are below -40.0 ‰. Very low values (< -42.49) are shaded in light grey and very high values (-36.0 >) are shaded in dark grey. In addition, if the amplitude values surpassed +/- 1.0 they were also set in bold. Furthermore, increasing values were shaded in increasingly dark grey from +/- 2.0 to 5.22. Volcanic ashes are given according to Mortensen et al. 2005. ***** given ages are according to Rasmussen et al. 2006, X-12 tab. 4. All other ages of the volcanic ashes are calculated based on the first two columns assuming constant deposition between the value before and after the depth given for the ash layer.

NGRIP years b2k	NGRIP depth (m)	NGRIP $\delta^{18}O$ (‰)	max. counting error (years)	years to data point above	difference of $\delta^{18}O$ to data point above	*c.* 40 years accumulated amplitude	*c.* 60 years accumulated amplitude	*c.* 80 years accumulated amplitude	*c.* 100 years accumulated amplitude	»event«	volcanic ashes
10,520	1,421.55	-35.46	90	20	-0.88	-0.07	-0.58	-0.66	-0.50		
10,540	1,422.87	-35.73	90	20	0.27	-0.61	0.20	-0.31	-0.39		
10,560	1,424.23	-35.86	91	20	0.13	0.40	-0.48	0.33	-0.18		
10,580	1,425.59	-35.99	91	20	0.13	0.26	0.53	-0.35	0.46		
10,600	1,426.93	-35.89	91	20	-0.10	0.03	0.16	0.43	-0.45		
10,620	1,428.22	-36.12	91	20	0.23	0.13	0.26	0.39	0.66		
10,640	1,429.54	-36.13	91	20	0.01	0.24	0.14	0.27	0.40		
10,660	1,430.85	-36.16	91	20	0.03	0.04	0.27	0.17	0.30		
10,680	1,432.22	-35.50	91	20	-0.66	-0.63	-0.62	-0.39	-0.49		
10,700	1,433.50	-35.77	92	20	0.27	-0.39	-0.36	-0.35	-0.12		
10,720	1,434.84	-36.05	92	20	0.28	0.55	-0.11	-0.08	-0.07		
10,740	1,436.11	-36.45	92	20	0.40	0.68	0.95	0.29	0.32		
10,760	1,437.43	-35.88	92	20	-0.57	-0.17	0.11	0.38	-0.28		
10,780	1,438.71	-36.22	92	20	0.34	-0.23	0.17	0.45	0.72		
10,800	1,439.92	-36.83	92	20	0.61	0.95	0.38	0.78	**1.06**		
10,820	1,441.16	-35.84	92	20	-0.99	-0.38	-0.04	-0.61	-0.21		
10,840	1,442.44	-36.59	93	20	0.75	-0.24	0.37	0.71	0.14		
10,860	1,443.80	-36.09	93	20	-0.50	0.25	-0.74	-0.13	0.21	peak	
10,880	1,445.12	-37.23	93	20	**1.14**	0.64	**1.39**	0.40	**1.01**		
10,900	1,446.33	-37.60	93	20	0.37	**1.51**	**1.01**	**1.76**	0.77		
10,920	1,447.53	-37.25	93	20	-0.35	0.02	**1.16**	0.66	**1.41**		
10,940	1,448.64	-37.15	93	20	-0.10	-0.45	-0.08	**1.06**	0.56		
10,960	1,449.92	-37.00	93	20	-0.15	-0.25	-0.60	-0.23	0.91		
10,980	1,451.03	-38.01	94	20	**1.01**	0.86	0.76	0.41	0.78	low point	
11,000	1,452.29	-36.53	94	20	**-1.48**	-0.47	-0.62	-0.72	**-1.07**		
11,020	1,453.54	-37.05	94	20	0.52	-0.96	0.05	-0.10	-0.20		
11,040	1,454.75	-36.44	94	20	-0.61	-0.09	**-1.57**	-0.56	-0.71		
11,060	1,455.98	-36.64	94	20	0.20	-0.41	0.11	**-1.37**	-0.36		
11,080	1,457.18	-36.89	94	20	0.25	0.45	-0.16	0.36	**-1.12**		
11,100	1,458.38	-37.11	94	20	0.22	0.47	0.67	0.06	0.58		
11,120	1,459.59	-36.71	95	20	-0.40	-0.18	0.07	0.27	-0.34		
11,140	1,460.85	-36.43	95	20	-0.28	-0.68	-0.46	-0.21	-0.01		
11,160	1,461.97	-37.13	95	20	0.70	0.42	0.02	0.24	0.49		
11,180	1,463.16	-36.62	95	20	-0.51	0.19	-0.09	-0.49	-0.27		
11,200	1,464.37	-37.25	95	20	0.63	0.12	0.82	0.54	0.14		

Tab. 63 (continued)

NGRIP years b2k	NGRIP depth (m)	NGRIP δ^{18}O (‰)	max. counting error (years)	years to data point above	difference of δ^{18}O to data point above	*c.* 40 years accumulated amplitude	*c.* 60 years accumulated amplitude	*c.* 80 years accumulated amplitude	*c.* 100 years accumulated amplitude	»event«	volcanic ashes
11,220	1,465.52	-37.39	95	20	0.14	0.77	0.26	0.96	0.68		
11,240	1,466.67	-37.60	95	20	0.21	0.35	0.98	0.47	**1.17**		
11,260	1,467.90	-36.57	95	20	**-1.03**	-0.82	-0.68	-0.05	-0.56		
11,280	1,469.13	-36.16	96	20	-0.41	**-1.44**	**-1.23**	**-1.09**	-0.46	peak	
11,300	1,470.36	-36.58	96	20	0.42	0.01	**-1.02**	-0.81	-0.67		
11,320	1,471.51	-37.54	96	20	0.96	**1.38**	0.97	-0.06	0.15		
11,340	1,472.66	-36.67	96	20	-0.87	0.09	0.51	0.10	-0.93		
11,360	1,473.88	-36.91	96	20	0.24	-0.63	0.33	0.75	0.34		
11,380	1,475.02	-37.45	96	20	0.54	0.78	-0.09	0.87	**1.29**		
11,400	1,476.16	-37.63	96	20	0.18	0.72	0.96	0.09	**1.05**	low point	
11,420	1,477.23	-37.11	97	20	-0.52	-0.34	0.20	0.44	-0.43	peak	
11,440	1,478.16	-38.46	97	20	**1.35**	0.83	**1.01**	**1.55**	**1.79**	steepest part mean: 11,430 b2k	
11,460	1,479.15	-38.26	97	20	-0.20	**1.15**	0.63	0.81	**1.35**		
11,480	1,480.13	-38.72	97	20	0.46	0.26	**1.61**	**1.09**	**1.27**	low point	
11,500	1,481.24	-37.41	97	20	**-1.31**	-0.85	**-1.05**	0.30	-0.22	steepest part mean: 11,490 b2k	
11,520	1,482.32	-37.84	97	20	0.43	-0.88	-0.42	-0.62	0.73		
11,540	1,483.41	-36.90	97	20	-0.94	-0.51	**-1.82**	**-1.36**	**-1.56**		
11,560	1,484.59	-36.60	98	20	-0.30	**-1.24**	-0.81	**-2.12**	**-1.66**		
11,580	1,485.69	-36.87	98	20	0.27	-0.03	-0.97	-0.54	**-1.85**		
11,600	1,486.95	-36.78	98	20	-0.09	0.18	-0.12	**-1.06**	-0.63		
11,620	1,488.10	-36.41	98	20	-0.37	-0.46	-0.19	-0.49	**-1.43**	first peak	
11,640	1,489.26	-36.57	98	20	0.16	-0.21	-0.30	-0.03	-0.33		
11,660	1,490.44	-36.68	98	20	0.11	0.27	-0.10	-0.19	0.08		
11,680	1,491.45	-38.49	98	20	**1.81**	**1.92**	**2.08**	**1.71**	**1.62**	steepest part mean: 11,670 b2k	rhyolitic ash at 1491.48 m (11,681 b2k)
11,700	1,492.33	-39.04	99	20	0.55	**2.36**	**2.47**	**2.63**	**2.26**	mean between low point and peak: 11,690 b2k; Steffensen et al. 2008, mean of multi-proxy values: 11,698 ± 99 b2k	
11,720	1,492.94	-39.60	99	20	0.56	**1.11**	**2.92**	**3.03**	**3.19**		
11,740	1,493.62	-39.72	100	20	0.12	0.68	**1.23**	**3.04**	**3.15**		
11,760	1,494.26	**-40.85**	100	20	**1.13**	**1.25**	**1.81**	**2.36**	**4.17**	lowest point before GH	
11,780	1,494.85	**-40.55**	101	20	-0.30	0.83	0.95	**1.51**	**2.06**		

Tab. 63 (continued)

NGRIP years b2k	NGRIP depth (m)	NGRIP $\delta^{18}O$ (‰)	max. counting error (years)	years to data point above	difference of $\delta^{18}O$ to data point above	*c.* 40 years accumulated amplitude	*c.* 60 years accumulated amplitude	*c.* 80 years accumulated amplitude	*c.* 100 years accumulated amplitude	»event«	volcanic ashes
11,800	1,495.43	-39.87	102	20	-0.68	-0.98	0.15	0.27	0.83		
11,820	1,496.06	**-40.45**	102	20	0.58	-0.10	-0.40	0.73	0.85		
11,840	1,496.68	**-40.97**	103	20	0.52	**1.10**	0.42	0.12	**1.25**		
11,860	1,497.25	-39.17	104	20	**-1.80**	**-1.28**	-0.70	**-1.38**	**-1.68**		
11,880	1,497.81	-38.93	104	20	-0.24	**-2.04**	**-1.52**	-0.94	**-1.62**		
11,900	1,498.35	**-41.52**	105	20	**2.59**	**2.35**	0.55	**1.07**	**1.65**		
11,920	1,498.93	-39.73	106	20	**-1.79**	0.80	0.56	**-1.24**	-0.72		
11,940	1,499.53	**-41.94**	106	20	**2.21**	0.42	**3.01**	**2.77**	0.97		rhyolitic ash at 1499.14 m (11,927 b2k)
11,960	1,500.15	**-40.34**	107	20	**-1.60**	0.61	**-1.18**	**1.41**	**1.17**		
11,980	1,500.74	**-41.54**	108	20	**1.20**	-0.40	**1.81**	0.02	**2.61**		
12,000	1,501.29	**-40.54**	108	20	**-1.00**	0.20	**-1.40**	0.81	-0.98		
12,020	1,501.85	-39.60	109	20	-0.94	**-1.94**	-0.74	**-2.34**	-0.13		
12,040	1,502.51	**-40.17**	110	20	0.57	-0.37	**-1.37**	-0.17	**-1.77**		
12,060	1,503.09	-39.32	110	20	-0.85	-0.28	**-1.22**	**-2.22**	**-1.02**		
12,080	1,503.65	**-40.77**	111	20	**1.45**	0.60	**1.17**	0.23	-0.77		
12,100	1,504.25	**-40.74**	112	20	-0.03	**1.42**	0.57	**1.14**	0.20		
12,120	1,504.78	**-41.89**	112	20	**1.15**	**1.12**	**2.57**	**1.72**	**2.29**		
12,140	1,505.35	**-40.61**	113	20	**-1.28**	-0.13	-0.16	**1.29**	0.44		
12,160	1,505.87	**-41.76**	114	20	**1.15**	-0.13	**1.02**	0.99	**2.44**		
12,180	1,506.37	**-42.09**	114	20	0.33	**1.48**	0.20	**1.35**	**1.32**		Vedde Ash at 1506.18 m (12,171 ± 114 b2k*)
12,200	1,506.94	-38.91	115	20	**-3.18**	**-2.85**	**-1.70**	**-2.98**	**-1.83**	inner GS-1 peak; end of inner GS-1 warming	
12,220	1,507.49	**-41.40**	115	20	**2.49**	-0.69	-0.36	0.79	-0.49		
12,240	1,508.03	**-40.90**	116	20	-0.50	**1.99**	**-1.19**	-0.86	0.29		
12,260	1,508.58	-39.90	117	20	**-1.00**	**-1.50**	0.99	**-2.19**	**-1.86**		rhyolitic ash at 1508.18 m and 1508.26 m (12,246 b2k and 12,248 b2k)
12,280	1,509.20	**-40.71**	117	20	0.81	-0.19	-0.69	**1.80**	**-1.38**		
12,300	1,509.74	**-41.01**	118	20	0.30	**1.11**	0.11	-0.39	**2.10**	onset of inner GS-1 warming	
12,320	1,510.29	**-40.41**	119	20	-0.60	-0.30	0.51	-0.49	-0.99		
12,340	1,510.78	**-40.95**	119	20	0.54	-0.06	0.24	**1.05**	0.05		
12,360	1,511.34	**-41.73**	120	20	0.78	**1.32**	0.72	**1.02**	**1.83**		rhyolitic ash at 1511.34 m (12,360 b2k)

Tab. 63 (continued)

NGRIP years b2k	NGRIP depth (m)	NGRIP $\delta^{18}O$ (‰)	max. counting error (years)	years to data point above	difference of $\delta^{18}O$ to data point above	*c.* 40 years accumulated amplitude	*c.* 60 years accumulated amplitude	*c.* 80 years accumulated amplitude	*c.* 100 years accumulated amplitude	»event«	volcanic ashes
12,380	1,511.83	**-41.17**	121	20	-0.56	0.22	0.76	0.16	0.46		
12,400	1,512.41	**-40.73**	121	20	-0.44	**-1.00**	-0.22	0.32	-0.28		
12,420	1,512.95	**-41.21**	122	20	0.48	0.04	-0.52	0.26	0.80		
12,440	1,513.56	**-41.05**	123	20	-0.16	0.32	-0.12	-0.68	0.10		
12,460	1,514.20	**-41.39**	123	20	0.34	0.18	0.66	0.22	-0.34		
12,480	1,514.75	**-40.02**	124	20	**-1.37**	**-1.03**	**-1.19**	-0.71	**-1.15**		
12,500	1,515.27	**-41.91**	125	20	**1.89**	0.52	0.86	0.70	**1.18**		
12,520	1,515.84	**-40.62**	125	20	**-1.29**	0.60	-0.77	-0.43	-0.59		
12,540	1,516.38	-39.09	126	20	**-1.53**	**-2.82**	-0.93	**-2.30**	**-1.96**		
12,560	1,516.89	**-40.95**	127	20	**1.86**	0.33	-0.96	0.93	-0.44		
12,580	1,517.46	**-40.54**	127	20	-0.41	**1.45**	-0.08	**-1.37**	0.52		
12,600	1,517.94	**-41.43**	128	20	0.89	0.48	**2.34**	0.81	-0.48		
12,620	1,518.39	**-42.71**	129	20	**1.28**	**2.17**	**1.76**	**3.62**	**2.09**	lowest point in GS-1	
12,640	1,518.90	**-40.59**	129	20	**-2.12**	-0.84	0.05	-0.36	1.50		
12,660	1,519.50	**-41.82**	130	20	**1.23**	-0.89	0.39	**1.28**	0.87		basaltic ash (Tv-1 / I-THOL-2) at 1519.1 m (12,647 b2k)
12,680	1,520.04	**-40.92**	131	20	-0.90	0.33	**-1.79**	-0.51	0.38		
12,700	1,520.59	**-42.27**	131	20	**1.35**	0.45	**1.68**	-0.44	0.84	lowest point after GI-1	
12,720	1,521.21	**-41.82**	132	20	-0.45	0.90	0.00	**1.23**	-0.89		
12,740	1,521.82	**-41.95**	132	20	0.13	-0.32	**1.03**	0.13	**1.36**	low point a	
12,760	1,522.36	**-41.06**	133	20	-0.89	-0.76	**-1.21**	0.14	-0.76		
12,780	1,522.91	-39.86	134	20	**-1.20**	**-2.09**	**-1.96**	**-2.41**	**-1.06**	peak a; steepest part mean: 12,770 b2k	intermediate ash at 1522.27 m (12,757 b2k)
12,800	1,523.44	**-40.17**	134	20	0.31	-0.89	**-1.78**	**-1.65**	**-2.10**		
12,820	1,524.02	**-40.36**	135	20	0.19	0.50	-0.70	**-1.59**	**-1.46**	low point b; mean between last peak and lowest point after GI-1: 12,820 b2k	
12,840	1,524.70	-39.88	136	20	-0.48	-0.29	0.02	**-1.18**	**-2.07**		
12,860	1,525.30	-38.98	136	20	-0.90	**-1.38**	**-1.19**	-0.88	**-2.08**	peak b	
12,880	1,525.94	-39.81	137	20	0.83	-0.07	-0.55	-0.36	-0.05	Steffensen et al. 2008, mean of multi-proxy values: 12,884 ± 139 b2k	rhyolitic ash at 1525.88 m (12,878 b2k)
12,900	1,526.67	**-40.11**	138	20	0.30	**1.13**	0.23	-0.25	-0.06	low point c	
12,920	1,527.42	-39.42	138	20	-0.69	-0.39	0.44	-0.46	-0.94		
12,940	1,528.24	-37.79	139	20	**-1.63**	**-2.32**	**-2.02**	**-1.19**	**-2.09**	last peak	

Tab. 63 (continued)

NGRIP years b2k	NGRIP depth (m)	NGRIP $\delta^{18}O$ (‰)	max. counting error (years)	years to data point above	difference of $\delta^{18}O$ to data point above	*c.* 40 years accumulated amplitude	*c.* 60 years accumulated amplitude	*c.* 80 years accumulated amplitude	*c.* 100 years accumulated amplitude	»event«	volcanic ashes
12,960	1,528.98	-38.25	139	20	0.46	**-1.17**	**-1.86**	**-1.56**	-0.73		
12,980	1,529.76	-39.11	140	20	0.86	**1.32**	-0.31	**-1.00**	-0.70		
13,000	1,530.73	-38.96	140	20	-0.15	0.71	**1.17**	-0.46	**-1.15**		
13,020	1,531.50	-39.87	141	20	0.91	0.76	**1.62**	**2.08**	0.45		
13,040	1,532.26	-39.55	141	20	-0.32	0.59	0.44	**1.30**	**1.76**		intermediate ash at 1531.93 (13,031 b2k)
13,060	1,533.12	-39.49	142	20	-0.06	-0.38	0.53	0.38	**1.24**	peak	
13,080	1,533.86	**-40.52**	142	20	**1.03**	0.97	0.65	**1.56**	**1.41**	low point; steepest part mean: 13,070 b2k	
13,100	1,534.55	-39.77	143	20	-0.75	0.28	0.22	-0.10	0.81	peak	
13,120	1,535.21	**-40.57**	143	20	0.80	0.05	**1.08**	**1.02**	0.70		
13,140	1,535.89	**-40.17**	144	20	-0.40	0.40	-0.35	0.68	0.62		
13,160	1,536.56	**-41.51**	145	20	**1.34**	0.94	**1.74**	0.99	**2.02**		
13,180	1,537.23	**-40.08**	145	20	**-1.43**	-0.09	-0.49	0.31	-0.44		
13,200	1,537.94	**-40.53**	146	20	0.45	-0.98	0.36	-0.04	0.76		
13,220	1,538.64	**-40.10**	146	20	-0.43	0.02	**-1.41**	-0.07	-0.47		
13,240	1,539.37	**-40.58**	147	20	0.48	0.05	0.50	-0.93	0.41	low point	
13,260	1,540.00	-39.45	147	20	**-1.13**	-0.65	**-1.08**	-0.63	**-2.06**	steepest part mean: 13,250 b2k	
13,280	1,540.80	-39.30	148	20	-0.15	**-1.28**	-0.80	**-1.23**	-0.78	mean between peak and low point: 13,270 b2k	rhyolitic ash at 1540.3 m (13,277 b2k)
13,300	1,541.65	-38.97	148	20	-0.33	-0.48	**-1.61**	**-1.13**	**-1.56**	peak	
13,320	1,542.48	-39.03	149	20	0.06	-0.27	-0.42	**-1.55**	**-1.07**		
13,340	1,543.37	-39.35	149	20	0.32	0.38	0.05	-0.10	**-1.23**		
13,360	1,544.20	-39.07	150	20	-0.28	0.04	0.10	-0.23	-0.38		
13,380	1,545.02	-38.56	150	20	-0.51	-0.79	-0.47	-0.41	-0.74		
13,400	1,545.94	-38.36	151	20	-0.20	-0.71	-0.99	-0.67	-0.61		
13,420	1,546.78	-38.76	151	20	0.40	0.20	-0.31	-0.59	-0.27		
13,440	1,547.75	-38.14	152	20	-0.62	-0.22	-0.42	-0.93	**-1.21**		
13,460	1,548.55	-38.56	152	20	0.42	-0.20	0.20	0.00	-0.51		
13,480	1,549.46	-38.79	153	20	0.23	0.65	0.03	0.43	0.23		
13,500	1,550.33	-38.33	153	20	-0.46	-0.23	0.19	-0.43	-0.03		
13,520	1,551.27	-37.74	154	20	-0.59	**-1.05**	-0.82	-0.40	**-1.02**	peak	
13,540	1,552.17	-38.08	155	20	0.34	-0.25	-0.71	-0.48	-0.06		
13,560	1,553.16	-38.29	155	20	0.21	0.55	-0.04	-0.50	-0.27		

Tab. 63 (continued)

NGRIP years b2k	NGRIP depth (m)	NGRIP $\delta^{18}O$ (‰)	max. counting error (years)	years to data point above	difference of $\delta^{18}O$ to data point above	*c.* 40 years accumulated amplitude	*c.* 60 years accumulated amplitude	*c.* 80 years accumulated amplitude	*c.* 100 years accumulated amplitude	»event«	volcanic ashes
13,580	1,553.95	-38.99	156	20	0.70	0.91	**1.25**	0.66	0.20	mean between low point and peak+steepest part: 13,580 b2k	rhyolitic ash at 1553.85 m (13,578 b2k)
13,600	1,554.75	-39.36	156	20	0.37	**1.07**	**1.28**	**1.62**	**1.03**		
13,620	1,555.50	-39.64	157	20	0.28	0.65	**1.35**	**1.56**	**1.90**		
13,640	1,556.26	**-40.05**	157	20	0.41	0.69	**1.06**	**1.76**	**1.97**	low point intermediate GI-1	
13,660	1,557.08	-39.21	158	20	-0.84	-0.43	-0.15	0.22	0.92		
13,680	1,557.89	-39.09	158	20	-0.12	-0.96	-0.55	-0.27	0.10	mean between peak2 and low point: 13,670 b2k	
13,700	1,558.84	-38.67	159	20	-0.42	-0.54	**-1.38**	-0.97	-0.69	peak2	
13,720	1,559.72	-38.93	159	20	0.26	-0.16	-0.28	**-1.12**	-0.71	mean between peak1 and low point: 13,710 b2k	
13,740	1,560.62	-37.66	160	20	**-1.27**	**-1.01**	**-1.43**	**-1.55**	**-2.39**	peak1, steepest part mean: 13,730 b2k	
13,760	1,561.51	-38.45	160	20	0.79	-0.48	-0.22	-0.64	-0.76		
13,780	1,562.43	-39.42	161	20	0.97	**1.76**	0.49	0.75	0.33		
13,800	1,563.36	-38.81	161	20	-0.61	0.36	**1.15**	-0.12	0.14		
13,820	1,564.34	-37.86	162	20	-0.95	**-1.56**	-0.59	0.20	**-1.07**		
13,840	1,565.20	-39.05	162	20	**1.19**	0.24	-0.37	0.60	**1.39**		
13,860	1,566.16	-37.96	163	20	**-1.09**	0.10	-0.85	**-1.46**	-0.49		
13,880	1,567.16	-38.00	163	20	0.04	**-1.05**	0.14	-0.81	**-1.42**		
13,900	1,568.06	-38.43	164	20	0.43	0.47	-0.62	0.57	-0.38		
13,920	1,568.98	-38.21	165	20	-0.22	0.21	0.25	-0.84	0.35		
13,940	1,569.95	-38.61	165	20	0.40	0.18	0.61	0.65	-0.44		
13,960	1,570.75	-38.03	166	20	-0.58	-0.18	-0.40	0.03	0.07	peak	
13,980	1,571.51	-39.99	166	20	**1.96**	**1.38**	**1.78**	**1.56**	**1.99**	steepest part mean: 13,970 b2k	
14,000	1,572.26	-39.03	167	20	-0.96	1.00	0.42	0.82	0.60	mean between low point and peak: 14,000 b2k	
14,020	1,572.97	-39.73	167	20	0.70	-0.26	**1.70**	**1.12**	**1.52**		
14,040	1,573.59	**-40.21**	168	20	0.48	**1.18**	0.22	**2.18**	**1.60**	low point	basaltic ash at 1573.0 m (14,021 b2k)
14,060	1,574.28	-39.90	168	20	-0.31	0.17	0.87	-0.09	**1.87**		rhyolitic ash at 1573.95 m (14,050 b2k)

Tab. 63 (continued)

NGRIP years b2k	NGRIP depth (m)	NGRIP $\delta^{18}O$ (‰)	max. counting error (years)	years to data point above	difference of $\delta^{18}O$ to data point above	*c.* 40 years accumulated amplitude	*c.* 60 years accumulated amplitude	*c.* 80 years accumulated amplitude	*c.* 100 years accumulated amplitude	»event«	volcanic ashes
14,080	1,575.03	**-40.94**	169	20	**1.04**	0.73	**1.21**	**1.91**	0.95	low point early GI-1	
14,100	1,575.90	-38.05	169	20	**-2.89**	**-1.85**	**-2.16**	**-1.68**	-0.98	steepest part mean: 14,090 b2k	
14,120	1,576.77	-38.34	170	20	0.29	**-2.60**	**-1.56**	**-1.87**	**-1.39**		
14,140	1,577.59	-38.01	170	20	-0.33	-0.04	**-2.93**	**-1.89**	**-2.20**	mean between peak and low point: 14,150 b2k	
14,160	1,578.54	-38.68	171	20	0.67	0.34	0.63	**-2.26**	**-1.22**		rhyolitic ash at 1577.61 m (14,140 b2k)
14,180	1,579.30	-38.04	171	20	-0.64	0.03	-0.30	-0.01	**-2.90**		intermediate ash at 1579.15 m (14,176 b2k)
14,200	1,580.19	-37.59	172	20	-0.45	**-1.09**	-0.42	-0.75	-0.46		
14,220	1,581.18	-37.46	173	20	-0.13	-0.58	**-1.22**	-0.55	-0.88	peak	
14,240	1,582.16	-38.42	173	20	0.96	0.83	0.38	-0.26	0.41		
14,260	1,583.16	-37.76	174	20	-0.66	0.30	0.17	-0.28	-0.92		
14,280	1,584.06	-37.19	174	20	-0.57	**-1.23**	-0.27	-0.40	-0.85		
14,300	1,585.16	-37.13	175	20	-0.06	-0.63	**-1.29**	-0.33	-0.46		
14,320	1,586.22	-37.05	175	20	-0.08	-0.14	-0.71	**-1.37**	-0.41		
14,340	1,587.24	-37.54	176	20	0.49	0.41	0.35	-0.22	-0.88		
14,360	1,588.24	-36.81	176	20	-0.73	-0.24	-0.32	-0.38	-0.95		
14,380	1,589.20	-37.49	177	20	0.68	-0.05	0.44	0.36	0.30		
14,400	1,590.16	-36.07	178	20	**-1.42**	-0.74	**-1.47**	-0.98	**-1.06**		
14,420	1,591.12	-37.17	178	20	**1.10**	-0.32	0.36	-0.37	0.12		
14,440	1,592.08	-37.29	179	20	0.12	**1.22**	-0.20	0.48	-0.25		
14,460	1,593.14	-37.04	179	20	-0.25	-0.13	0.97	-0.45	0.23		
14,480	1,594.21	-36.86	180	20	-0.18	-0.43	-0.31	0.79	-0.63		
14,500	1,595.05	-36.26	180	20	-0.60	-0.78	**-1.03**	-0.91	0.19		
14,520	1,596.12	-36.11	181	20	-0.15	-0.75	-0.93	**-1.18**	**-1.06**		basaltic ash at 1595.1 m (14,501 b2k)
14,540	1,597.21	-36.14	181	20	0.03	-0.12	-0.72	-0.90	**-1.15**		
14,560	1,598.32	-36.14	182	20	0.00	0.03	-0.12	-0.72	-0.90		
14,580	1,599.47	-36.98	182	20	0.84	0.84	0.87	0.72	0.12		
14,600	1,600.52	-35.81	183	20	**-1.17**	-0.33	-0.33	-0.30	-0.45	peak; highest value of the record prior to the Holocene	
14,620	1,601.40	-36.74	184	20	0.93	-0.24	0.60	0.60	0.63		
14,640	1,602.32	-37.48	184	20	0.74	**1.67**	0.50	**1.34**	**1.34**		

Tab. 63 (continued)

NGRIP years b2k	NGRIP depth (m)	NGRIP $\delta^{18}O$ (‰)	max. counting error (years)	years to data point above	difference of $\delta^{18}O$ to data point above	*c.* 40 years accumulated amplitude	*c.* 60 years accumulated amplitude	*c.* 80 years accumulated amplitude	*c.* 100 years accumulated amplitude	»event«	volcanic ashes
14,660	1,603.31	-37.52	185	20	0.04	0.78	**1.71**	0.54	**1.38**		
14,680	1,604.17	-37.97	185	20	0.45	0.49	**1.23**	**2.16**	0.99	mean between low point and peak: 14,670 b2k; Steffensen et al. 2008, mean of multi-proxy values: 14,688 ± 186 b2k	
14,700	1,604.89	**-40.64**	186	20	**2.67**	**3.12**	**3.16**	**3.90**	**4.83**	steepest part mean: 14,690 b2k	
14,720	1,605.38	**-41.96**	187	20	**1.32**	**3.99**	**4.44**	**4.48**	**5.22**		
14,740	1,605.96	**-42.47**	189	20	0.51	**1.83**	**4.50**	**4.95**	**4.99**	low point before GI-1	
14,760	1,606.49	**-40.81**	189	20	**-1.66**	**-1.15**	0.17	**2.84**	**3.29**		
14,780	1,607.08	**-41.03**	191	20	0.22	**-1.44**	-0.93	0.39	**3.06**		
14,800	1,607.68	-39.92	191	20	**-1.11**	-0.89	**-2.55**	**-2.04**	-0.72	peak	
14,820	1,608.28	**-40.68**	191	20	0.76	-0.35	-0.13	**-1.79**	**-1.28**		
14,840	1,608.80	**-42.44**	192	20	**1.76**	**2.52**	**1.41**	**1.63**	-0.03	low point	
14,860	1,609.36	**-40.78**	193	20	**-1.66**	0.10	0.86	-0.25	-0.03		
14,880	1,609.88	**-41.18**	194	20	0.40	**-1.26**	0.50	1.26	0.15		
14,900	1,610.39	**-40.14**	194	20	**-1.04**	-0.64	**-2.30**	-0.54	0.22	peak	
14,920	1,610.90	**-41.47**	195	20	**1.33**	0.29	0.69	-0.97	0.79		
14,940	1,611.37	**-41.76**	195	20	0.29	**1.62**	0.58	0.98	-0.68		
14,960	1,611.83	**-41.65**	196	20	-0.11	0.18	**1.51**	0.47	0.87		
14,980	1,612.30	**-40.88**	196	20	-0.77	-0.88	-0.59	0.74	-0.30		
15,000	1,612.83	**-42.61**	197	20	**1.73**	0.96	0.85	**1.14**	**2.47**		
15,020	1,613.32	**-42.37**	198	20	-0.24	**1.49**	0.72	0.61	0.90		
15,040	1,613.72	**-41.54**	198	20	-0.83	**-1.07**	0.66	-0.11	-0.22		
15,060	1,614.18	**-43.17**	198	20	**1.63**	0.80	0.56	**2.29**	**1.52**	low point	
15,080	1,614.66	-39.98	199	20	**-3.19**	**-1.56**	**-2.39**	**-2.63**	-0.90	peak	
15,100	1,615.13	**-43.51**	200	20	**3.53**	0.34	**1.97**	**1.14**	0.90	low point	
15,120	1,615.55	**-42.76**	202	20	-0.75	**2.78**	-0.41	**1.22**	0.39		
15,140	1,615.98	**-40.12**	204	20	**-2.64**	**-3.39**	0.14	**-3.05**	**-1.42**		
15,160	1,616.39	**-42.26**	204	20	**2.14**	-0.50	**-1.25**	**2.28**	-0.91		
15,180	1,616.84	**-42.99**	205	20	0.73	**2.87**	0.23	-0.52	**3.01**		
15,200	1,617.32	**-42.08**	205	20	-0.91	-0.18	**1.96**	-0.68	**-1.43**		
15,220	1,617.73	**-40.57**	206	20	**-1.51**	**-2.42**	**-1.69**	0.45	**-2.19**	peak	
15,240	1,618.18	**-43.57**	207	20	**3.00**	**1.49**	0.58	**1.31**	**3.45**	low point	

Tab. 63 (continued)

NGRIP years b2k	NGRIP depth (m)	NGRIP $\delta^{18}O$ (‰)	max. counting error (years)	years to data point above	difference of $\delta^{18}O$ to data point above	*c.* 40 years accumulated amplitude	*c.* 60 years accumulated amplitude	*c.* 80 years accumulated amplitude	*c.* 100 years accumulated amplitude	»event«	volcanic ashes
15,260	1,618.67	**-40.55**	208	20	**-3.02**	-0.02	**-1.53**	**-2.44**	**-1.71**	peak	
15,280	1,619.12	**-44.91**	209	20	**4.36**	**1.34**	**4.34**	**2.83**	**1.92**	2nd lowest point of the record	
15,300	1,619.63	**-41.99**	209	20	**-2.92**	**1.44**	**-1.58**	**1.42**	-0.09		bimodal ash at 1619.58 m (15,298 b2k)
15,320	1,620.11	**-41.29**	211	20	-0.70	**-3.62**	0.74	**-2.28**	0.72		
15,340	1,620.56	**-42.08**	211	20	0.79	0.09	**-2.83**	**1.53**	**-1.49**		
15,360	1,621.02	**-40.75**	213	20	**-1.33**	-0.54	**-1.24**	**-4.16**	0.20		
15,380	1,621.45	**-40.66**	214	20	-0.09	**-1.42**	-0.63	**-1.33**	**-4.25**		
15,400	1,621.92	**-40.04**	214	20	-0.62	-0.71	**-2.04**	**-1.25**	**-1.95**	peak	
15,420	1,622.38	**-43.26**	215	20	**3.22**	**2.60**	**2.51**	**1.18**	**1.97**		
15,440	1,622.83	**-42.38**	216	20	-0.88	**2.34**	1.72	**1.63**	0.30		
15,460	1,623.27	**-42.89**	217	20	0.51	-0.37	**2.85**	**2.23**	**2.14**		
15,480	1,623.77	**-41.61**	218	20	**-1.28**	-0.77	**-1.65**	**1.57**	0.95		
15,500	1,624.25	**-41.95**	219	20	0.34	-0.94	-0.43	**-1.31**	**1.91**		
15,520	1,624.71	**-43.57**	219	20	**1.62**	**1.96**	0.68	**1.19**	0.31		
15,540	1,625.17	**-41.88**	220	20	**-1.69**	-0.07	0.27	**-1.01**	-0.50		
15,560	1,625.60	**-43.21**	221	20	**1.33**	-0.36	**1.26**	**1.60**	0.32		
15,580	1,626.03	**-44.56**	223	20	**1.35**	**2.68**	0.99	**2.61**	**2.95**	low point	
15,600	1,626.44	**-42.31**	224	20	**-2.25**	-0.90	0.43	**-1.26**	0.36		
15,620	1,626.87	**-42.15**	224	20	-0.16	**-2.41**	**-1.06**	0.27	**-1.42**		
15,640	1,627.34	**-42.12**	226	20	-0.03	-0.19	**-2.44**	**-1.09**	0.24		
15,660	1,627.74	**-42.20**	226	20	0.08	0.05	-0.11	**-2.36**	**-1.01**		
15,680	1,628.16	**-40.39**	226	20	**-1.81**	**-1.73**	**-1.76**	**-1.92**	**-4.17**	peak	
15,700	1,628.56	**-43.50**	226	20	**3.11**	**1.30**	**1.38**	**1.35**	**1.19**		rhyolitic ash at 1628.25 m (15,685 b2k)
15,720	1,628.98	**-43.08**	227	20	-0.42	**2.69**	0.88	0.96	0.93		
15,740	1,629.41	**-44.63**	228	20	**1.55**	**1.13**	**4.24**	**2.43**	**2.51**	3rd lowest point of the record	
15,760	1,629.81	**-42.79**	230	20	**-1.84**	-0.29	-0.71	**2.40**	0.59		
15,780	1,630.21	**-44.02**	231	20	**1.23**	-0.61	0.94	0.52	**3.63**		
15,800	1,630.60	**-43.85**	231	20	-0.17	**1.06**	-0.78	0.77	0.35		
15,820	1,631.06	**-40.21**	231	20	**-3.64**	**-3.81**	**-2.58**	**-4.42**	**-2.87**	peak	
15,840	1,631.51	**-41.70**	233	20	**1.49**	**-2.15**	**-2.32**	-1.09	**-2.93**		
15,860	1,631.99	**-41.15**	234	20	-0.55	0.94	**-2.70**	-2.87	**-1.64**		
15,880	1,632.52	**-40.81**	234	20	-0.34	-0.89	0.60	**-3.04**	**-3.21**		

Tab. 63 (continued)

NGRIP years b2k	NGRIP depth (m)	NGRIP $\delta^{18}O$ (‰)	max. counting error (years)	years to data point above	difference of $\delta^{18}O$ to data point above	*c.* 40 years accumulated amplitude	*c.* 60 years accumulated amplitude	*c.* 80 years accumulated amplitude	*c.* 100 years accumulated amplitude	»event«	volcanic ashes
15,900	1,632.96	**-43.15**	235	20	**2.34**	**2.00**	**1.45**	**2.94**	-0.70	low point	
15,920	1,633.38	**-42.98**	235	20	-0.17	**2.17**	**1.83**	**1.28**	**2.77**		
15,940	1,633.83	**-41.55**	237	20	**-1.43**	**-1.60**	0.74	0.40	-0.15		
15,960	1,634.32	**-40.53**	237	20	**-1.02**	**-2.45**	**-2.62**	-0.28	-0.62	peak	
15,980	1,634.76	**-41.60**	240	20	**1.07**	0.05	**-1.38**	**-1.55**	0.79		
16,000	1,635.26	**-41.94**	241	20	0.34	**1.41**	0.39	**-1.04**	**-1.21**		
16,020	1,635.70	**-42.30**	243	20	0.36	0.70	**1.77**	0.75	-0.68		
16,040	1,636.21	**-41.42**	245	20	-0.88	-0.52	-0.18	0.89	-0.13		
16,060	1,636.66	**-41.29**	246	20	-0.13	**-1.01**	-0.65	-0.31	0.76		
16,080	1,637.12	**-42.99**	247	20	**1.70**	**1.57**	0.69	**1.05**	**1.39**		
16,100	1,637.54	**-44.97**	248	20	**1.98**	**3.68**	**3.55**	**2.67**	**3.03**	lowest point of the record	
16,120	1,637.99	**-43.25**	249	20	**-1.72**	0.26	**1.96**	**1.83**	0.95		
16,140	1,638.43	**-40.35**	250	20	**-2.90**	**-4.62**	**-2.64**	-0.94	**-1.07**	peak	
16,160	1,638.85	**-43.59**	252	20	**3.24**	0.34	**-1.38**	0.60	**2.30**	low point	
16,180	1,639.30	**-41.86**	254	20	**-1.73**	**1.51**	**-1.39**	**-3.11**	**-1.13**		
16,200	1,639.76	**-41.64**	254	20	-0.22	**-1.95**	**1.29**	**-1.61**	**-3.33**		
16,220	1,640.23	**-44.27**	255	20	**2.63**	**2.41**	0.68	**3.92**	**1.02**	low point	
16,240	1,640.66	-39.89	255	20	**-4.38**	**-1.75**	**-1.97**	**-3.70**	-0.46	peak; steepest part mean: 16,230 b2k	
16,260	1,641.06	**-42.36**	257	20	**2.47**	**-1.91**	0.72	0.50	**-1.23**	low point	
16,280	1,641.51	**-41.99**	257	20	-0.37	**2.10**	**-2.28**	0.35	0.13		
16,300	1,641.94	**-40.71**	259	20	**-1.28**	**-1.65**	0.82	-3.56	-0.93		
16,320	1,642.37	**-42.10**	260	20	**1.39**	0.11	-0.26	2.21	**-2.17**		
16,340	1,642.79	**-42.33**	261	20	0.23	**1.62**	0.34	-0.03	**2.44**		
16,360	1,643.27	**-42.50**	262	20	0.17	0.40	**1.79**	0.51	0.14	low point	
16,380	1,643.76	-39.74	264	20	**-2.76**	**-2.59**	**-2.36**	-0.97	**-2.25**	peak	
16,400	1,644.22	**-42.81**	265	20	**3.07**	0.31	0.48	0.71	**2.10**	low point	
16,420	1,644.71	**-41.62**	265	20	**-1.19**	**1.88**	-0.88	-0.71	-0.48		
16,440	1,645.15	**-40.74**	266	20	-0.88	**-2.07**	**1.00**	**-1.76**	**-1.59**		
16,460	1,645.64	**-42.58**	267	20	**1.84**	0.96	-0.23	**2.84**	0.08	low point	
16,480	1,646.11	**-41.26**	268	20	**-1.32**	0.52	-0.36	**-1.55**	**1.52**		
16,500	1,646.55	**-41.18**	269	20	-0.08	**-1.40**	0.44	-0.44	**-1.63**		
16,520	1,646.99	-38.29	269	20	**-2.89**	**-2.97**	**-4.29**	**-2.45**	**-3.33**	peak	
16,540	1,647.48	**-40.38**	272	20	**2.09**	-0.80	-0.88	**-2.20**	-0.36		
16,560	1,647.90	**-41.68**	272	20	**1.30**	**3.39**	0.50	0.42	-0.90		
16,580	1,648.30	**-41.52**	273	20	-0.16	**1.14**	**3.23**	0.34	0.26		

Tab. 63 (continued)

NGRIP years b2k	NGRIP depth (m)	NGRIP $\delta^{18}O$ (‰)	max. counting error (years)	years to data point above	difference of $\delta^{18}O$ to data point above	*c.* 40 years accumulated amplitude	*c.* 60 years accumulated amplitude	*c.* 80 years accumulated amplitude	*c.* 100 years accumulated amplitude	»event«	volcanic ashes
16,600	1,648.75	**-40.58**	273	20	-0.94	-1.10	0.20	**2.29**	-0.60		
16,620	1,649.20	**-42.77**	275	20	**2.19**	**1.25**	**1.09**	**2.39**	**4.48**		
16,640	1,649.73	**-42.78**	277	20	0.01	**2.20**	**1.26**	**1.10**	**2.40**	low point	
16,660	1,650.24	**-40.88**	278	20	**-1.90**	**-1.89**	0.30	-0.64	-0.80		
16,680	1,650.75	**-41.55**	279	20	0.67	**-1.23**	**-1.22**	0.97	0.03		
16,700	1,651.20	**-40.65**	280	20	-0.90	-0.23	**-2.13**	**-2.12**	0.07		
16,720	1,651.66	**-42.69**	281	20	**2.04**	**1.14**	**1.81**	-0.09	-0.08	low point	
16,740	1,652.10	-39.36	282	20	**-3.33**	**-1.29**	**-2.19**	**-1.52**	**-3.42**	peak	
16,760	1,652.56	**-40.72**	283	20	**1.36**	**-1.97**	0.07	-0.83	-0.16		
16,780	1,653.03	**-41.80**	284	20	**1.08**	**2.44**	-0.89	**1.15**	0.25	low point	
16,800	1,653.52	**-40.92**	285	20	-0.88	0.20	**1.56**	**-1.77**	0.27		
16,820	1,653.96	-39.26	287	20	**-1.66**	**-2.54**	**-1.46**	-0.10	**-3.43**	peak	
16,840	1,654.49	**-40.64**	288	20	**1.38**	-0.28	**-1.16**	-0.08	**1.28**		
16,860	1,654.97	-39.46	290	20	**-1.18**	0.20	**-1.46**	**-2.34**	**-1.26**		
16,880	1,655.41	**-40.35**	292	20	0.89	-0.29	**1.09**	-0.57	**-1.45**		
16,900	1,655.84	**-40.30**	293	20	-0.05	0.84	-0.34	**1.04**	-0.62		
16,920	1,656.28	**-42.10**	294	20	**1.80**	**1.75**	**2.64**	**1.46**	**2.84**		
16,940	1,656.66	**-41.25**	295	20	-0.85	0.95	0.90	**1.79**	0.61		
16,960	1,657.11	**-42.41**	296	20	**1.16**	0.31	**2.11**	**2.06**	**2.95**	low point	
16,980	1,657.54	**-40.69**	298	20	**-1.72**	-0.56	**-1.41**	0.39	0.34		
17,000	1,658.02	**-42.12**	299	20	**1.43**	-0.29	0.87	0.02	**1.82**		
17,020	1,658.50	**-40.42**	300	20	**-1.70**	-0.27	**-1.99**	-0.83	**-1.68**		
17,040	1,658.94	**-42.23**	301	20	**1.81**	0.11	**1.54**	-0.18	0.98		
17,060	1,659.44	**-40.00**	303	20	**-2.23**	-0.42	**-2.12**	-0.69	**-2.41**		
17,080	1,659.92	-39.76	306	20	-0.24	**-2.47**	-0.66	**-2.36**	-0.93		
17,100	1,660.37	-38.99	306	20	-0.77	**-1.01**	**-3.24**	**-1.43**	**-3.13**	peak	
17,120	1,660.89	**-42.35**	308	20	**3.36**	**2.59**	**2.35**	0.12	**1.93**	low point	
17,140	1,661.36	-39.80	309	20	**-2.55**	0.81	0.04	-0.20	**-2.43**	peak	
17,160	1,661.88	**-40.26**	310	20	0.46	**-2.09**	**1.27**	0.50	0.26		
17,180	1,662.31	**-40.48**	310	20	0.22	0.68	**-1.87**	**1.49**	0.72		
17,200	1,662.80	**-40.56**	312	20	0.08	0.30	0.76	**-1.79**	**1.57**		
17,220	1,663.28	**-40.17**	313	20	-0.39	-0.31	-0.09	0.37	**-2.18**		
17,240	1,663.78	**-41.24**	313	20	**1.07**	0.68	0.76	0.98	**1.44**		
17,260	1,664.18	**-42.24**	315	20	**1.00**	**2.07**	**1.68**	**1.76**	**1.98**	low point	
17,280	1,664.59	-39.81	316	20	**-2.43**	**-1.43**	-0.36	-0.75	-0.67		

Tab. 63 (continued)

NGRIP years b2k	NGRIP depth (m)	NGRIP $\delta^{18}O$ (‰)	max. counting error (years)	years to data point above	difference of $\delta^{18}O$ to data point above	c. 40 years accumulated amplitude	c. 60 years accumulated amplitude	c. 80 years accumulated amplitude	c. 100 years accumulated amplitude	»event«	volcanic ashes
17,300	1,665.04	-39.80	317	20	-0.01	**-2.44**	**-1.44**	-0.37	-0.76	peak	
17,320	1,665.49	**-41.58**	318	20	**1.78**	**1.77**	-0.66	0.34	**1.41**	low point	
17,340	1,665.89	**-40.55**	321	20	**-1.03**	0.75	0.74	**-1.69**	-0.69		
17,360	1,666.33	**-40.64**	322	20	0.09	-0.94	0.84	0.83	**-1.60**		
17,380	1,666.86	-39.94	323	20	-0.70	-0.61	**-1.64**	0.14	0.13	peak	
17,400	1,667.31	**-41.25**	325	20	**1.31**	0.61	0.70	-0.33	**1.45**		
17,420	1,667.78	**-42.94**	328	20	**1.69**	**3.00**	**2.30**	**2.39**	**1.36**	low point	
17,440	1,668.19	**-42.38**	328	20	-0.56	**1.13**	**2.44**	**1.74**	**1.83**		
17,460	1,668.65	**-41.52**	329	20	-0.86	**-1.42**	0.27	**1.58**	0.88		
17,480	1,669.09	**-40.75**	330	20	-0.77	**-1.63**	**-2.19**	-0.50	0.81		
17,500	1,669.55	**-40.72**	331	20	-0.03	-0.80	**-1.66**	**-2.22**	-0.53		
17,520	1,669.95	**-41.49**	332	20	0.77	0.74	-0.03	-0.89	**-1.45**		
17,540	1,670.38	**-41.22**	333	20	-0.27	0.50	0.47	-0.30	**-1.16**		
17,560	1,670.80	-38.85	333	20	**-2.37**	**-2.64**	**-1.87**	**-1.90**	**-2.67**	peak	
17,580	1,671.20	**-40.46**	333	20	**1.61**	-0.76	**-1.03**	-0.26	-0.29		
17,600	1,671.65	**-41.85**	334	20	**1.39**	**3.00**	0.63	0.36	**1.13**	low point	
17,620	1,672.12	-39.58	335	20	**-2.27**	-0.88	0.73	**-1.64**	**-1.91**	peak	
17640	1,672.61	-39.70	336	20	0.12	**-2.15**	-0.76	0.85	**-1.52**		
17,660	1,673.08	**-40.89**	337	20	**1.19**	**1.31**	-0.96	0.43	**2.04**		
17,680	1,673.63	**-40.04**	338	20	-0.85	0.34	0.46	**-1.81**	-0.42		
17,700	1,674.11	**-40.70**	338	20	0.66	-0.19	**1.00**	**1.12**	**-1.15**		
17,720	1,674.49	**-42.53**	340	20	**1.83**	**2.49**	**1.64**	**2.83**	**2.95**	low point	
17,740	1,674.92	**-41.35**	341	20	**-1.18**	0.65	**1.31**	0.46	**1.65**		
17,760	1,675.35	**-41.31**	342	20	-0.04	**-1.22**	0.61	**1.27**	0.42		
17,780	1,675.80	**-41.04**	343	20	-0.27	-0.31	**-1.49**	0.34	**1.00**		
17,800	1,676.27	**-40.90**	343	20	-0.14	-0.41	-0.45	**-1.63**	0.20		
17,820	1,676.80	-38.95	345	20	**-1.95**	**-2.09**	**-2.36**	**-2.40**	**-3.58**	peak	
17,840	1,677.31	**-41.45**	346	20	**2.50**	0.55	0.41	0.14	0.10		
17,860	1,677.78	**-42.40**	346	20	0.95	**3.45**	**1.50**	**1.36**	1.09		
17,880	1,678.20	**-43.36**	347	20	0.96	**1.91**	**4.41**	**2.46**	**2.32**	low point	
17,900	1,678.67	**-41.14**	347	20	**-2.22**	**-1.26**	-0.31	**2.19**	0.24		
17,920	1,679.16	**-40.93**	348	20	-0.21	**-2.43**	**-1.47**	-0.52	**1.98**		
17,940	1,679.64	**-42.52**	349	20	**1.59**	**1.38**	-0.84	0.12	**1.07**		
17,960	1,680.05	**-41.74**	350	20	-0.78	0.81	0.60	**-1.62**	-0.66		
17,980	1,680.47	**-43.47**	351	20	**1.73**	0.95	**2.54**	**2.33**	0.11		
18,000	1,680.96	**-42.27**	351	20	**-1.20**	0.53	-0.25	**1.34**	**1.13**		

Tab. 63 (continued)

main isotope events	onset in NGRIP (GICC05)		
GH-11.4 (PBO)	×	×	**11,490 ± 97** (^{18}O)
GH	11,703 ± 99 (d)	**11,681 ± 111** (^{18}O)	11,670 ± 99 (^{18}O)
GS-1	12,896 ± 138 (d)	12,819 ± 202 (^{18}O)	**12,770 ± 133** (^{18}O)
GI-1a	13,099 ± 143 (GRIP)	×	**13,070 ± 142** (^{18}O)
GI-1b	13,311 ± 149 (GRIP)	×	**13,250 ± 147** (^{18}O)
GI-1c$_1$	×	×	**13,580 ± 156** (^{18}O)
GI-1c$_2$	×	×	**13,730 ± 160** (^{18}O)
GI-1c$_3$	13,954 ± 165 (GRIP)	×	**13,970 ± 166** (^{18}O)
GI-1d	14,075 ± 169 (d)	×	**14,090 ± 169** (^{18}O)
GI-1e	14,692 ± 186 (d)	**14,687 ± 187** (^{18}O)	14,690 ± 187 (^{18}O)
GS-2a	not clear	×	**16,230 ± 255** (^{18}O)
ref.	Lowe et al. 2008, 10 tab. 1	Steffensen et al. 2008, 683 tab. 1	present study

Tab. 64 Dates (given in years cal. b2k) for the onsets of the main Lateglacial isotope events in the NGRIP ice-core record (GICC05). These dates are the calculated results of the present study (right; see text and **tab. 63**). In addition, the dates based on the weighted mean dates calculated from the $\delta^{18}O$ (^{18}O) record of NGRIP given in the high-resolution approach of Steffensen et al. 2008 (see **tab. 1**) and the onsets of the events proposed by the INTIMATE group are given for comparative reasons. The latter are based on data of the deuterium excess record (d) of NGRIP and the onsets for $\delta^{18}O$ events in GRIP (GRIP) which were transferred by depths (given by Björck et al. 1998) and volcanic markers (Rasmussen et al. 2006) to NGRIP (Lowe et al. 2008; cf. Blockley et al. 2012). The GH-11.4 event (previously 11.2, cf. Walker et al. 1999, 1147 f.) or Preboreal Oscillation (PBO) is regarded by these authors as difficult to define, whereas this fluctuation was considered clearly visible in the three ice-cores (NGRIP, GRIP, DYE-3) used for the construction of the GICC05 in the Holocene (Vinther et al. 2006, X-7). Set in bold are the limits used in this study.

In the following sample, significant volcanic activity related to the Vedde Ash (see p. 310-318) was again observed, sustaining a possible interrelation of volcanic activity and the climatic development as observed in the oxygen isotopes in Greenland.

The different frequency of rapid changes between two data points indicate the greater instability of the Pleistocene, in particular, the Late Pleniglacial climate (twice above 4‰, eleven times above 3‰). In contrast, the climate from the Lateglacial Interstadial onwards is characterised by greater stability in the intermediate- and short-term means.

Even though these intermediate- and short-term differences were not as extreme as in the Late Pleniglacial, the decisions where to position the exact limits of the sub-events within GI-1 were made as outlined above (**tab. 64**). The mid-point of the highest difference value was also used for the onset of GS-1. The transition from GI-1a to GS-1 stretched over almost 250 years and was relatively diffuse due to several flickering episodes (**fig. 29**). Therefore, the value given for this limit in different approaches varies between different proxies (cf. Steffensen et al. 2008) as well as between the decisions taken by researchers to set the limit to the onset, the end, the mean between them, or the steepest part of the transition (see **tab. 64**). In a high-resolution study of the oxygen isotope values, the highest value before the transition is given at 12,925 years cal. b2k and the lowest value after the transition is given at 12,712 years cal. b2k (Steffensen et al. 2008). These ages allow the calculation of the mean value between them (**tab. 64**). However, since the current project works with the steepest part this date for the onset of GS-1 is neglected. The last value above -40.00‰ occurred at 12,780 years cal. b2k and for the following 500 years this value was only once reached again. Before 12,780 years cal. b2k values below -40.00‰ were reached three times: at 12,800, 12,820, and 12,900 years cal. b2k. However, since between 12,900 and 12,800 years cal. b2k no value is below -40.00‰, this part is rather attributed to the interstadial part. The accumulated values were also highest between 12,800 and 12,700 years cal. b2k (-2.10‰) but comparably large accumulations occurred between 12,940 and 12,840 years cal. b2k (-2.09‰) and between 12,860 and 12,740 years cal. b2k (-2.08‰; -2.07‰). This short survey marks the period between 12,940 and 12,700 years cal. b2k as the relevant deterioration phase. The steepest gradient between two data points (-1.63‰) occurs between

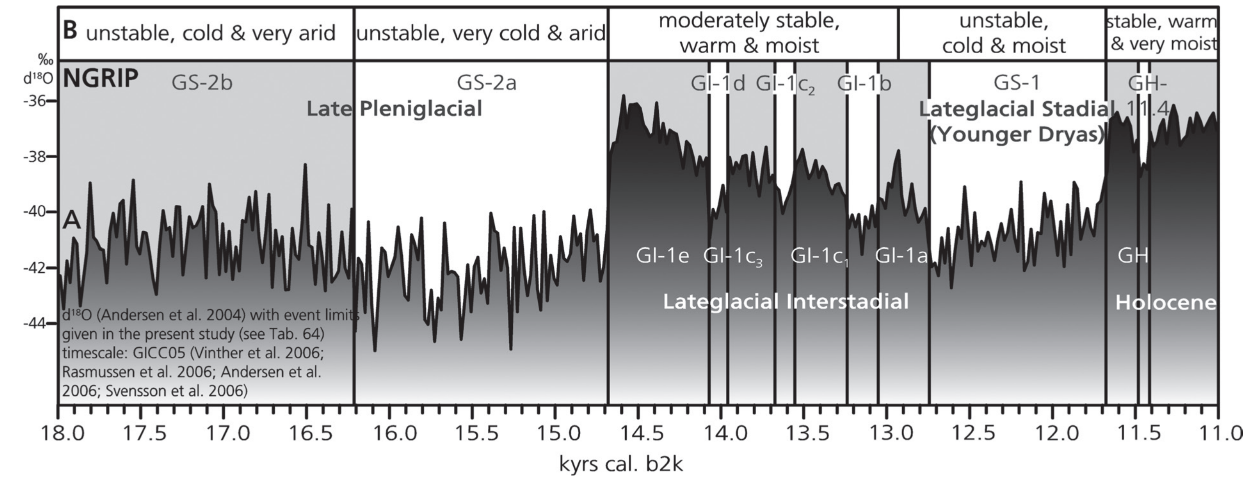


Fig. 29 Oxygen isotope record from NGRIP. **A** Limits (black bars) of the eventstratigraphy (see **tabs 63-64**). Grey shaded areas represent periods of more interstadial values than the surrounding values (for instance, the values in GS-2b are more interstadial than in GS-2a but still these values are as stadial as the values in GS-1). – **B** General climatic interpretation of the isotope record (supplemented with indications of aridity connected to the Heinrich 1 event and the continental precipiation; Hatté/Guiot 2005; Stanford et al. 2011b).

12,940 and 12,920 years cal. b2k which becomes even steeper if the last peak is set to 12,925 years cal. b2k in the high-resolution record. This decline continues to 12,900 years cal. b2k after which the last, short of higher values follows. The steepest decline (-2.12‰) in the vicinity of the transition phase occurred between 12,640 and 12,620 years cal. b2k where the lowest value of GS-1 was reached. Consequently, the values afterwards increased again and, therefore, no accumulated change towards a deterioration was observable. Prior to this steep gradient a basaltic ash layer was identified as Tv-1/I-THOL-2 in the ice-core records (Mortensen et al. 2005). In the biostratigraphic analysis of the northern Icelandic Lake Torfadalsvatn, where the Tv-1 ash was found, the ash layer occurred shortly before the onset of the terrestrial Younger Dryas as defined by the sediment and the pollen composition (Rundgren 1995). Thus, according to this comparison and a correlation of the Younger Dryas with GS-1, this major gradient would mark the onset of GS-1. Yet, this gradient marks rather the end of the extreme deterioration but not the transition. The only other gradient surpassing 1‰ between two data points in this part of the record laid between 12,780 and 12,760 years cal. b2k (-1.20‰). Since the three indicators (-40.00‰ limit, accumulated amplitude, and gradient between two data points) concentrate around this period, the onset of GS-1 is also set to 12,770 years cal. b2k. However, the comparison with the northern Icelandic biostratigraphy already advise to be prudent with the comparison of terrestrial sequences.

Besides the limit for the onset of GS-1, a further two high-resolution ages for the oxygen isotope events were available (Steffensen et al. 2008). Since these dates relate closely with the limits found in this study (**tab. 63**), these ages were chosen for the limits of the oxygen isotope record as the more accurate ones (**tab. 64**).

With the limits of the events also the duration of the events can be determined which can help in the numerical comparison with other annually resolved archives.

In the following sub-chapters, the onset of the Holocene (GH) or the end of the Lateglacial Stadial (GS-1) is occasionally emphasised because this limit is relatively well defined and represents an important correlation point for the Lateglacial records (cf. Material-Climate, p. 12-30). In contrast, the onset of GS-1 or end of GI-1 is not so well suited as correlation point because the transition between warm climate and cold climate values is a relatively long interval with several fluctuations. Furthermore, the marked onset of the Lateglacial Interstadial that appeared very pronounced in the oxygen isotope record is also used infrequently because in many records the lower part of the Lateglacial Interstadial was not reliably preserved. Thus, the number of onsets of oxygen isotope event as chronological marker is rather limited. Therefore, volcanic markers become an important additional help in a correlation of Lateglacial records.

The Lateglacial chronostratigraphy of north-western Europe

For the development of a reliable, high-resolution chronostratigraphy of the Lateglacial only a few suitable records exist. Some of these few records have to be compiled to approach a comprehensive result which can be used for the north-western European record. In this study, the suitable records are compared to the isotope record from the Greenland ice-cores. Some of the suitable records are considered to make further precision of the ice-core chronologies possible but others are correlated to the NGRIP ice-core in the new Greenland ice-core chronology (GICC05) for a higher precision. However, since some of these records are based on proxy data other than isotopes, a correlation creates new standard chronologies for these different proxy records based on the GICC05.

The correlation of these variable records and archives in the same high-precision chronology makes considerations about the interrelation of various climatic and environmental developments necessary. Therefore, climatically and environmentally independent correlation markers are relevant in the construction of a generally valid chronostratigraphy.

Tephrochronology

Besides the limits of the oxygen isotope events, the volcanic record related to NGRIP represents an important set of correlation points. Therefore, volcanic events have to be identified and dated. The identification is usually in the form of ash particles and their chemical composition but also other volcanic indicators such as sulphate peaks can be used. However, the latter does not identify a particular volcanic eruption but only that a volcanic eruption occurred. Dating an eruption is possible in several ways: Material found in the ashes can be dated radiometrically or the ash is set into a chronostratigraphic framework such as a standard pollen profile or a laminated sequence. To use these volcanic events as relative chronostratigraphy, they are best set in relation to other volcanic events. However, many records contain only a single volcanic indicator and therefore a relatively precise dating of some important events such as the Vedde Ash or the Laacher See eruption (LSE) is necessary.

The Ca^{2+} corrected sulphate content in ice-cores is assumed to reflect mainly the volcanic sulphate input into the atmosphere (De Angelis et al. 2003). Sometimes direct evidence of volcanic eruptions is preserved in the ice-cores in the form of tephra layers or single ash shards which allow for a determination of the geochemical composition of the ash and, thus, assumptions about its origin. To use these important markers in this project, the ashes and ash shards as well as the gypsum (Ca^{2+}) corrected sulphate content recorded in NGRIP (Mortensen et al. 2005) were transferred to the GICC05 timescale by the use of depths (**tab. 63**) and a continuous accumulation model (see p. 247 f.).

The resulting graph reveals a tendency of more frequent volcanic activity relating to cold events (**fig. 30**). Moreover, five of the seven prominent peaks in the Ca^{2+} corrected sulphate content occurred during cold periods. Thus, besides the increase of frequency also the intensity of the volcanic activities increased during the cold periods. A connection of glaciation and volcanism was considered previously (Hall / Meiklejohn / Bumby 2011; Kutterolf et al. 2013) as well as the impact of volcanism on the climate system (Zielinski 2000) but these relations are of no substantial relevance in the current study.

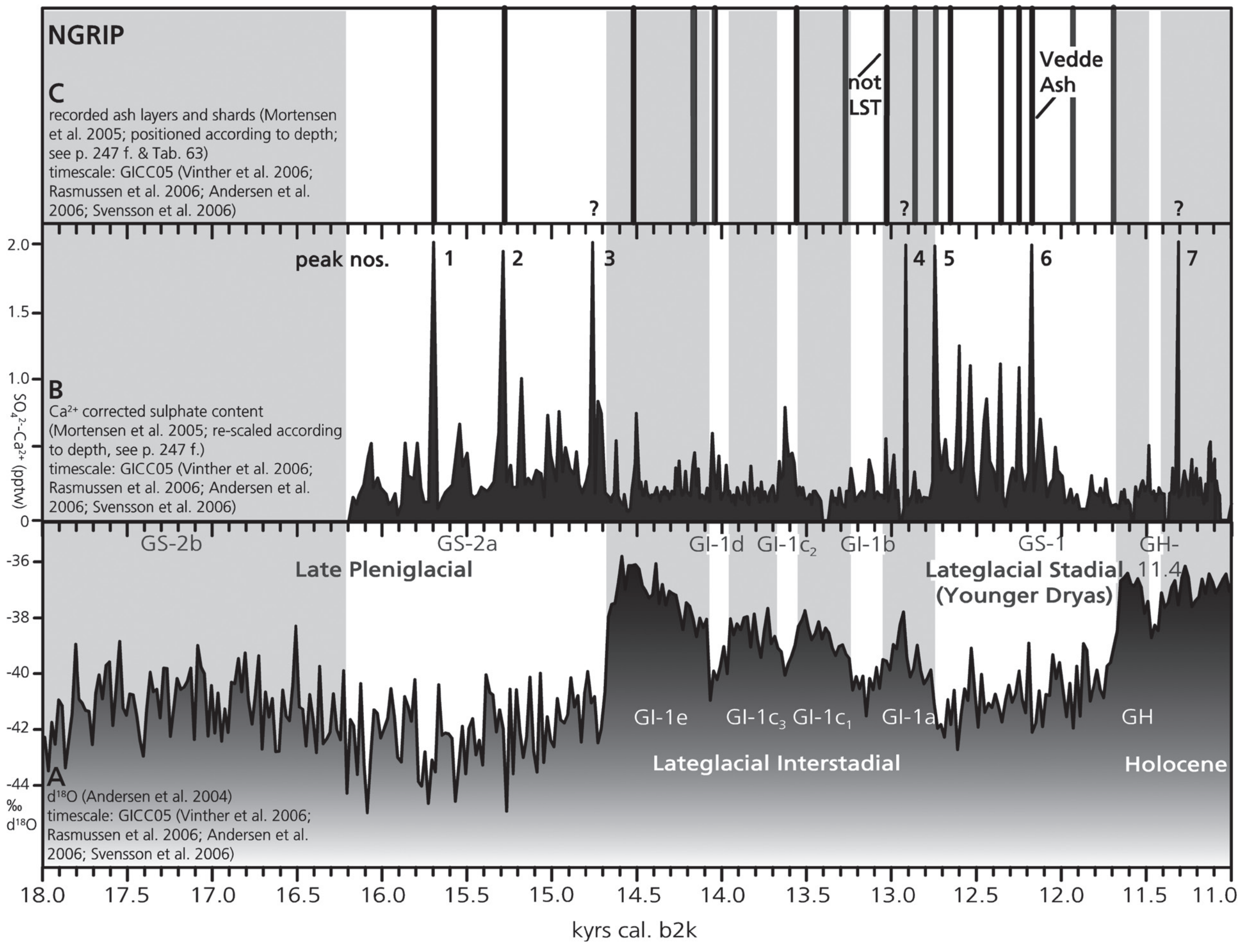


Fig. 30 Volcanic indicators in NGRIP. **A** Oxygen isotope record in NGRIP with event limits (shaded grey and white; see **fig. 29**). – **B** Ca^{2+} corrected sulphate content recorded in NGRIP (Mortensen et al. 2005) was rescaled and positioned in the GICC05 according to depth. The peaks with significantly high values are numbered. – **C** Ash layers (black bars) and single ash shards (grey bars) identified in NGRIP (Mortensen et al. 2005) were positioned in the GICC05 according to depth. Significant peaks of the Ca^{2+} corrected sulphate content (see B) without a correlating ash in NGRIP were marked by a ?. – For further details see p. 247 f. and text.

Many of the identified volcanic ashes found in NGRIP originated from Icelandic volcanoes but their ashes were seldom dispersed into Central Europe as visible tephra layers (cf. Blockley et al. 2007). However, three of the seven significant peaks in the Ca^{2+} corrected sulphate content in NGRIP were not related to ash shards: peak 3 at 14,766 ± 191 years cal. b2k, peak 4 at 12,918 ± 138 years cal. b2k, and peak 7 at 11,308 ± 96 years cal. b2k. This absence of volcanic deposits indicate the dependency of the volcanic ash dispersal to the meteorological conditions and atmospheric circulations. Thus, identifiable particles of volcanic eruptions were not deposited evenly. Furthermore, site formation processes could relocate particularly micro-particles within the stratigraphic column or remove them completely (cf. Weber et al. 2010; Brock et al. 2011; Housley et al. 2012). Therefore, the quest for micro-particles, the so-called micro- or cryptotephras, not only in ice-cores but also in marine and terrestrial sequences requires a wide-spread and fine-meshed sampling program supplemented by a comprehensive site formation analyses. However, due to the quasi-synchrony and the independence of these marker horizons, the construction of a Lateglacial tephrostratigraphy as well as a database on the geographic distribution of the tephras are important chronostratigraphic endeavours. Environmental and archaeological stratigraphies in northern Europe are currently studied to approach this endeavour (Lowe 2001; Turney et al. 2006; Lowe 2011; Housley et al. 2012; cf. http://c14.arch.ox.ac.uk/reset/embed.php?File=WP6.html).

A known prominent volcanic marker horizon in the Lateglacial is the Vedde Ash (Blockley et al. 2007; Housley et al. 2012; Lane et al. 2012b). This ash was unambiguously identified in NGRIP at 12,171 ± 114 years cal. b2k (Mortensen et al. 2005; Rasmussen et al. 2006) and correlated to a significant peak (no. 6) in the Ca^{2+} corrected sulphate content (**fig. 30**). The position of the Vedde Ash was already used as marker horizon in the construction of the GICC05 (Vinther et al. 2006; Rasmussen et al. 2006). However, this marker was thus far only identified in non-laminated parts of the continental sequences (Blockley et al. 2007; Lane et al. 2012a) making a numerical comparison, for example of the duration between the Vedde Ash and the end of the Lateglacial Stadial or between the LSE and the Vedde Ash, impossible. However, this tephra is searched for in on-going cryptotephra analysis programs. A possible impact of the Vedde Ash was detected in the Gościąż sequence and dated to 12,181 ± 53 years cal. b2k. This date is in accordance with the date from NGRIP. In the future, an anchoring of stratigraphies on this marker horizon can probably help to confirm other correlations.

In the final Lateglacial Interstadial, the LSE and its tephras (LST) form an important correlation marker. Thus far, LST were not identified in the Greenland records. Ash found in NGRIP a few centimetres below peak 4 were previously considered to represent the LST but due to the chemical composition this layer was attributed to the Icelandic Hekla volcano (Mortensen et al. 2005, 214). Above the significant peak 4 another peak followed but with lower values. This peak was related to rhyolitic ash found in NGRIP and again improbable to relate to the mainly phonolitic LST. In GISP2, the LSE was assumed to be represented by peak values in the total volcanic sulphate (Zielinski et al. 1996) and the electric conductivity measurements (ECM; Taylor et al. 1993a; Baales et al. 2002) because the LSE is usually related to a significant sulphate input into the atmosphere based on a petrological method (Schmincke / Park / Harms 1999). If peak 4 in the Ca^{2+} corrected sulphate content of NGRIP was interpreted comparably to the sulphate content in GISP2, the age difference between the Vedde Ash and the possible LSE signal comprised 747 ± 24 years in NGRIP. Furthermore, the difference between the onset of the Lateglacial Stadial as defined in this study and the assumed LSE would be 148 years, and if the decline in the deuterium excess was chosen as limit for the Lateglacial Stadial only 22 years passed between the possible LSE signal and the onset of GS-1 (**tab. 30**). The age difference to the onset of the Holocene (see **tab. 29**) would comprise 1,237 ± 27 years.

In contrast to the Vedde Ash, the LST was found in the laminated segments of several varve records such as in Meerfelder Maar (MFM), Holzmaar, Hämelsee, and Rehwiese as well as in the stratigraphies of Lake Siethen (Kleinmann / Merkt / Müller 2002), Lake Steisslingen (Eusterhues et al. 2002), and Soppensee (**tab. 30**; Lotter 1991a; Blockley et al. 2008; Lane et al. 2011). Moreover, trees buried by this natural hazard were incorporated in the GLPC (Kromer et al. 2004) which also forms an important Lateglacial radiocarbon calibration data set. Consequently, the position of the LSE is also relevant for the radiocarbon calibration.

Besides the evidence of some laminated archives, a previous age estimate of the LSE considered several radiometric dates from samples found within the LST near the volcano and concluded that the LSE occurred in late spring / early summer of 12,966 years cal. b2k (Baales et al. 2002). In this previous estimate, the period between the LSE and the onset of the Lateglacial Stadial[32] and the duration of the Lateglacial Stadial were taken from the laminated archives and the weighted mean was chosen as bridging period to the onset of the Holocene which was defined by the CEDC (Baales et al. 2002). This onset was corrected since this publication and the ice-core chronologies used to bridge the duration of the Lateglacial Stadial were also refined further. Therefore, this date cannot simply be adopted in this study.

32 In the terrestrial archives the Younger Dryas is considered the equivalent of the Lateglacial Stadial (Lotter et al. 1992; Hoek / Bohncke 2001; Litt et al. 2001).

However, the approach of estimating the age of the LSE remains valid. The onset of the Holocene was a relatively short-term transition, which occurred in several chronostratigraphic archives within only a matter of decades. Therefore, the Pleistocene/Holocene transition represents a better marker horizon than the often diffuse onset of the Lateglacial Stadial. The transition from the Lateglacial Interstadial to the Lateglacial Stadial stretched frequently over several decades or some centuries such as in the NGRIP oxygen isotopes (see p. 293-310).
However, the precise onset of the Holocene is dependent on the defining parameters, in particular to which main factor this parameter responded (e. g. air temperature, precipitation, wind intensity) and in which time. Thus, the defining parameters of the Holocene have to be named to attempt a reliable correlation along this marker (**tab. 65**). The onset of the Holocene in the CEDC was defined by an increase of tree-ring width which doubled within less than 30 years around 11,640 years cal. b2k (Friedrich et al. 1999, 29; Friedrich et al. 2004). This increase was quasi-simultaneously recorded in trees from several sites in the Danube basin and, therefore, interpreted as an indicator of changes in climatic factors influencing tree-ring growth such as a better water supply, higher temperatures, or a longer growing season (Friedrich et al. 1999, 29-31). However, the development of the associated ^{14}C age scale in the younger portion of the Younger Dryas and the older portion of the Holocene revealed an earlier onset of changes in this proxy than the increase in tree-ring growth. A change in the carbon isotope exchange between the atmosphere and the ocean reservoir was considered as a possible reason for this earlier change and this explanation would indicate »a gradual increase of ocean transport already several centuries before the end of YD [present author: Younger Dryas, end defined by the increase of tree-ring width]« (Friedrich et al. 1999, 32). Thus, proxies which are more dependent on the ocean dynamics could have reacted earlier on the changes towards the Holocene amelioration than the tree-ring growth. Another problematic issue in this way of estimating the age of the LSE is that the Lateglacial Stadial was often documented incompletely in annually resolved archives. The duration of the Younger Dryas is, therefore, difficult to establish reliably, in particular in terrestrial archives where the LST was also found. In north-western Europe, only the MFM, the Rehwiese, and the Polish varve records seemed to contain a complete varve sequence of the Younger Dryas but the Polish records did not contain the LST (**fig. 31**). Furthermore, the deep sea record from the Cariaco basin was assumed to contain a complete record of the Lateglacial Stadial (Hughen et al. 1998a; Hughen et al. 2004c). However, indications for the LSE were also absent from this record and, therefore, the Cariaco basin record is not further considered in this matter. Moreover, problems within the chronostratigraphy of this record during the Lateglacial and particularly the Lateglacial Stadial are discussed in a following sub-chapter.
To estimate the precise duration of the Lateglacial Stadial, the onset must be defined. However, several proxy values changed gradually to stadial conditions at this transition and the response of some terrestrial proxies depended on very local factors. For example, Holzmaar is located only a few kilometres north-east of MFM. Even though the varve chronologies from both maars were correlated along the LST and the early Holocene Ulmener Maar tephra, the period between the LST and the onset of the sedimentologically (260 years) as well as the palynologically defined Younger Dryas (274 years) in the Holzmaar record was considerably longer than in the MFM record (201 and 200 years respectively; **tab. 65**). Moreover, the calculated high-precision ages for the beginning of the transition from GI-1 to GS-1 in NGRIP varied in different proxies between 12,939 (layer thickness) and 12,870 years cal. b2k (calcium ions) and for the end of the transition between 12,896 (deuterium excess) and 12,712 years cal. b2k (oxygen isotopes; Steffensen et al. 2008, 683 tab. 1) with mean ages for the onset between 12,897 (deuterium excess) and 12,804 years cal. b2k (calcium ions). Since approximately 200 years were counted between the LSE and the onset of the Younger Dryas in the terrestrial laminated archives (**tab. 65**), an estimated age difference for the onset of the Lateglacial Stadial of more than 90 years depending on the defining parameter is an important problem

archive	years between LSE and the onset of the Lateglacial Stadial	defining characteristics of the Lateglacial Stadial	duration of the Lateglacial Stadial	defining characteristics of the Holocene	age for onset of the Holocene (in years cal. b2k)	age of LSE (in years cal. b2k)	ref.
NGRIP (sulphate peak)	148 / 22	oxygen isotope decrease / deuterium excess decrease	1,089 ± 22 / 1,193 ± 39	oxygen isotope increase / deuterium excess increase	11,681 ± 111 / 11,703 ± 99	12,918 ± 138	Mortensen et al. 2005; see text and **tab. 64**
Meerfelder Maar (MFM)	200	increase of varve thickness, westerly winds, and NAP	1,039 ± 22 / 1,089 ± 39	increase of *Juniperus* sp. and *Filipendula* sp., biogenic opal, total organic carbon, decrease of sediment accumulation rate / regular organic varves	11,690 ± 40 / 11,640 ± 40	12,930 ± 40	Brauer/Endres/Negendank 1999; Litt/Stebich 1999; Brauer et al. 2008
Holzmaar	205 / 260-274	end of *Stephanodiscus parvus* dominance / increase of minerogenic sediment, Poaceae and *Artemisia* sp., decrease of *Betula* sp.	715 ± 43 / 692 ± 41 / 654 ± 39 (*c.* 320 varves missing)	increase of planktonic diatoms / increase of organic detritus and *Filipendula* sp. / increase of *Pinus* sp. and decrease of NAP	11,690 ± 129 / 11,658 ± 128 / 11,682 ± 129	*c.* 12,930	Lotter/Birks/Zolitschka 1995; Leroy et al. 2000; Zolitschka et al. 2000
Hämelsee	197 (70-200)	increase of clay/silt laminae, layer thickness, grain size, and NAP (reworking of calcite, deposition of sand)	× (56 varves into the Younger Dryas)	increase of AP	11,610 ± 118	*c.* 12,950	Merkt/Müller 1999
Rehwiese	205 (200-223)	decrease of *Betula* sp. and varve thickness; increase of NAP and *Pinus* sp.	982 ± 10 / 1,035 ± 10	increase of calcite precipitation / decrease in *Artemisia* sp. and *Juniperus* sp. and increase in *Betula* sp.	11,743 ± 40 / 11,690 ± 40	*c.* 12,930	Neugebauer et al. 2012
Lake Siethen	200	increase of NAP and cold water rotifer; decrease of calcareous content and *Betula* sp.	× (some varves into the Younger Dryas)	establishment of calcite lamination, decrease of NAP and cold water rotifer	×	*c.* 12,950	Kleinmann/Merkt/Müller 2002
Lake Steisslingen	190 (240)	sediment composition; increase of *Pinus* sp. and NAP (end of varve formation)	× (*c.* 50 varves into the Younger Dryas)	predominance of *Betula* sp. and decrease of *Pinus* sp.	*c. 11,630*	*c.* 12,930	Eusterhues et al. 2002
Soppensee	185-235	increase of calcite varves and of NAP	*c.* 400 varves (several unlaminated segments)	high values of *Pinus* sp. and decrease of NAP; increased pollen accumulation rates; oxygen isotope increase	*c.* 11,036	*c.* 12,900	Lotter 1991b; Hajdas et al. 1993; Hajdas/Bonani/Zolitschka 2000
Dättnau (tree-ring growth decrease)	*192 (214-314)*	*disturbance in growth patterns; decrease of mean segment length*	×	× *(in CEDC: increased width of tree-rings)*	*11,640 (CEDC)*	*13,250-13,060 ± 70; 12,900*	Friedrich et al. 1999; Kaiser et al. 2012
GLPC (Kruft trees)	*c.* 200	increase in $\Delta^{14}C$	× (140 tree-rings into the Younger Dryas)	× *(in CEDC: increased width of tree-rings)*	*11,640 (CEDC)*	*c. 13,200*	Kromer et al. 2004

Tab. 65 Dating of the eruption of the Laacher See volcano in relation to the onset of the Lateglacial Stadial and the Holocene. Problematic correlations are set in italic. **×** not given; **AP** arboreal pollen; **NAP** non-arboreal pollen. – For further details see text.

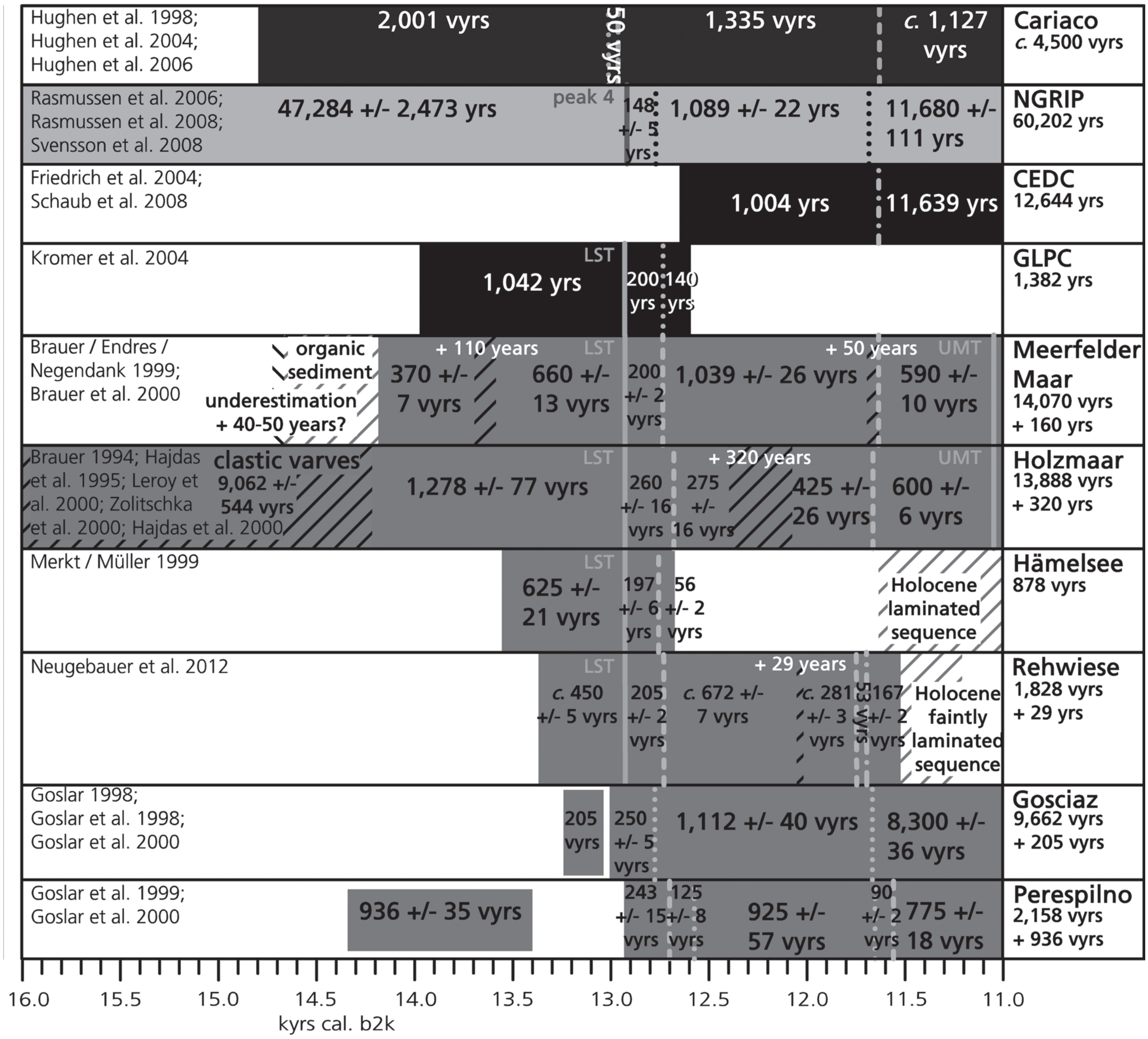


Fig. 31 Archives with laminated sequences in the Lateglacial (see **fig. 10**). Solid lines: position of tephra layers; dashed lines: sedimentologically defined limits; dotted lines: isotopically defined limits; dashed and dotted lines: palynologically or dendrochronologically defined limits.

when dating the LSE. Thus, comparable to the onset of the Holocene the defining parameters for the onset of the Younger Dryas have to be mentioned to be able to correlate quasi-simultaneously reacting proxy data sets.

The most reliable age estimate for the LSE was established in the MFM record. According to the varve chronology from the MFM, the LSE was dated to 12,930 ± 40 years cal. b2k (Brauer et al. 1999, 324; cf. Brauer et al. 2000b, 363). The transition towards the Holocene began around 11,690 years cal. b2k with an increase of juniper (*Juniperus* sp.) and *Filipendula* sp. in the pollen profile and a poor preservation of the varves (Brauer et al. 1999, 325 f.). From 11,640 years cal. b2k onwards, well defined organic varves were formed again and juniper and the NAP decreased in the pollen profile at this point, whereas birch (*Betula* sp.) rose significantly (Litt / Stebich 1999). Thus, the date of 11,640 years cal. b2k marks the establishment of interstadial conditions, whereas the results of climate change towards the Holocene were identifiable some

50 years earlier. Consequently, the period between the LST and the onset of the Holocene encompassed 1,240-1,290 ± 26[33] varve years in the MFM record depending on the correlation.
The date for the onset of the climate change towards the Holocene is comparable to the NGRIP record (11,681 years cal. b2k, see **tab. 64**), whereas the date for the establishment of interstadial conditions is concomitant with the growth increase in tree-ring width in the CEDC (11,640 years cal. b2k; Friedrich et al. 2004). In combination with the considerations about the carbon isotopes of the CEDC, the development in the MFM record suggests different response times of the proxy data depending on the influence of different climatic factors. The oxygen isotope record in NGRIP as well as the air temperature and general hydrology near the MFM appear more instantly governed by the Northern Atlantic circulation (cf. Sirocko et al. 2005; Brauer et al. 2008). If the two dates from NGRIP and MFM are tested for coherence in a χ^2-test, they are absolutely consistent ($p = 100\,\%$) in a weighted mean age of 11,689 ± 38 years cal. b2k. In contrast, the tree-ring growth pattern of the CEDC and the organic productivity in the MFM seem to lag some decades behind this amelioration. If the periods between the Holocene amelioration and the volcanic indicator in NGRIP and MFM are statistically tested, they are consistent in a statistical weighted mean of 1,238 ± 17 varve years ($p = 100\,\%$).
In the Rehwiese record, the LST was set according to the MFM record to 12,930 years cal. b2k. In contrast to many other chronological archives including the MFM, the biostratigraphic transition towards the Holocene was considered a more gradual process in the Rehwiese record. The first indications of a change in the sediment composition towards interstadial conditions occurred with an increase of calcite precipitation after 11,744 years cal. b2k. If this change was selected as indicator as in the MFM record, the period between the LST and the onset of the Holocene were only 1,193 ± 12[34] varve years. Since the varve chronologies of Rehwiese and MFM were correlated along the LST, this difference indicates that the sedimentological onset of the Holocene was not correlative in the two records. Concomitant with the change in the sediment composition at 11,744 years cal. b2k, an increase in juniper, *Artemisia* sp., and birch pollen occurred (Neugebauer et al. 2012, fig. 5). However, the first signals assumed to relate to climatic change in the pollen profile were decreasing values of *Artemisia* sp. and juniper and a small increase of birch pollen at 11,690 years cal. b2k (Neugebauer et al. 2012, 95). However, other species followed gradually in the Rehwiese pollen profile and full interstadial values were reached according to the palynological analysis around 11,500 years cal. b2k when *Filipendula* sp. increased in this record (Neugebauer et al. 2012, 95). Thus, the palynological onset of the Holocene proceeded very differently in the Rehwiese and the MFM records. The decrease of juniper and the concomitant increase of birch occurred some 50 years earlier at Rehwiese than at the MFM, whereas the increase of *Filipendula* sp. was recorded some 190 years earlier in the MFM record. Moreover, the *Filipendula* sp. increase occurred before the juniper decrease in MFM, whereas it occurred after the juniper decrease at Rehwiese.
Thus, the palynological and the sedimentological onset of the Holocene are different in the two records. In contrast, the biostratigraphic and sedimentological onset of the Younger Dryas is similar in both records (**tab. 65**). The biostratigraphic onset was observed between 12,730 and 12,707 years cal. b2k in the Rehwiese record and a sharp decrease in varve thickness occurred 205 varves after the LST (Neugebauer et al. 2012, 96). A possibility of explaining the different ages in the two records during the Pleistocene/Holocene transition is an underestimation of missing varves in a 7.4 cm thick, disturbed section in the Rehwiese cores within the younger half of the Younger Dryas (Neugebauer et al. 2012, 94). However, a bipartition was observed in the varve composition of the Rehwiese and the MFM record during the Younger Dryas. The limit between the two sub-portions of the Younger Dryas was dated to 12,320 years cal. b2k and to 12,290

33 Assuming a counting error of 1-2 % (Brauer/Endres/Negendank 1999, 21).

34 Assuming a counting error of 1 % (Neugebauer et al. 2012, 94).

years cal. b2k respectively (Neugebauer et al. 2012, 100). Thus, this limit fell in the Rehwiese record into the portion between the LST and the disturbed section and still the response of the sediment composition in the Rehwiese record was preceding the MFM record by approximately 30 years. Consequently, the difference in the response time of the sediment composition in the two records seem to gradually increase from the correlation along the LST to the onset of the Holocene. Based on the palynological comparison of the two records, it appears improbable that this difference resulted from a systematic underestimation in the Rehwiese record. Presumably, different factors were the main influences in the sediment composition in these records. For instance, the more continental position and the closer vicinity of the Rehwiese archive to the Scandinavian ice-sheet were suggested as possible differentiating factors (Neugebauer et al. 2012, 100). However, a final decrease of total varve thickness, thickness of the calcite sub-layers, and potassium coincided with a minimum of total organic carbon (TOC) falls in the Rehwiese record to approximately 11,620 years cal. b2k (Neugebauer et al. 2012, fig. 8). In the pollen profile, birch values slowly decrease, whereas pine (*Pinus* sp.) begins to increase at this point. Juniper and artemisia were still present but remained at small values (Neugebauer et al. 2012, fig. 5). After this position several parameters stabilise on interstadial values and, therefore, this position can be considered as the establishment of the Holocene. This establishment is comparable with the onset of the Holocene in the CEDC and to the organic varves in the MFM. Statistically, these three dates are also consistent (mean of χ^2-test: 11,626 ± 11 years cal. b2k; $p = 78.33\,\%$). The period from the LST to this point encompasses 1,312 ± 13 varve years which is also statistically consistent with the duration of this period in the MFM (mean of χ^2-test: 1,308 ± 12 varve years; $p = 75.0\,\%$).

If the various mean values were compared and added the age of the LSE would range between 12,934[35] and 12,927[36] years cal. b2k. This age estimate falls around the counted age in the MFM which is partially due to the strong influence of this record on this estimated age.

As previously mentioned, the LST was not detected in the two Polish lake records. In Lake Gościąż the varve formation began between 13,116 and 12,932[37] years cal. b2k and in Lake Perespilno the varve formation began at approximately 12,870 years cal b2k (**fig. 31**). Thus, if the LSE is dated to approximately 12,930 years cal. b2k, the LST should be present within the laminated part of Lake Gościąż. According to the mean duration of the period between the LST and the onset of the Holocene in the MFM and the Rehwiese record, the LST could possibly be also found at the onset of the varve formation in Lake Perespilno. The lack of a clear indicator for this event in the Polish lakes could suggest an older age for the LSE. However, it might also be possible that only small amounts of air-borne ashes reached the Polish lakes and resulted in no or an ephemeral or invisible deposit and an undetectable impact on the lake environments. Cryptotephra analyses from these two sites are therefore of some importance for the Lateglacial chronostratigraphy.

An oxygen isotope analysis was conducted on both Polish records. To receive another age estimate for the period between the Holocene and the LSE, the duration of the Younger Dryas in the two Polish records could be taken and added by the years between the LSE and the onset of the Younger Dryas. Both records were assumed to be directly correlative to the NGRIP oxygen isotope records and, therefore, the 148 years between the peak 4 and the onset of GS-1 in NGRIP could be added to the duration. Alternatively, if the terrestrial influence on these records was considered stronger, then the approximately 200 years between the LST and the onset of the Younger Dryas had to be added to the duration of the Younger Dryas. If the limits of the Younger Dryas are set according to the steepest part of the oxygen isotope records (**fig. 31**),

35 This is the result of adding 1,308 ± 12 varve years to 11,626 ± 11 years cal. b2k based on the CEDC, MFM terrestrial stabilisation and Rehwiese terrestrial stabilisation.

36 This is the result of adding 1,238 ± 17 varve years to 11,689 ± 38 years cal. b2k based on NGRIP and MFM climatic response.

37 This age range depended on the varve counting error and the error of the Pleistocene/Holocene limit (see p. 329-333).

the duration of the Lateglacial Stadial in Lake Gościąż ranged between 1,260 and 1,312 varve years and between 1,073 and 1,125 varve years in Lake Perespilno. The latter seems too short and an increase in the water levels preceding the Pleistocene/Holocene transition was possibly the reason for an early reaction of the oxygen isotopes in this record (Goslar et al. 1999, 908). The calculated duration in the former record is consistent with the NGRIP and climatic indicators from MFM as well as with the organic varve formations in the MFM and the establishment in the Rehwiese record. Thus, this calculation further sustains the age estimate of the LSE along the MFM.
Besides the varve records, the position of the LSE was also located in the GLPC (**fig. 10**). ^{14}C dates from poplars buried by the LST near the village of Kruft were integrated in the data set of the GLPC (Kromer et al. 2004, 1205). The sampled poplars still contained their bark and a date was taken from the outermost rings of poplar no. 8 (Hd-18438, 11,065 ± 22 years ^{14}C-BP; Baales/Bittmann/Kromer 1998) allowing only a minimal temporal difference between the dated growing phase and the LSE. Further ^{14}C dates from the region were also made on barks and produced comparable results (Baales et al. 2002). The onset of the Younger Dryas was determined in the GLPC by an increase of $\Delta^{14}C$ relating to a significant decline in the calibration curve. According to the integration of the poplars in the GLPC, the last rings of the poplars were formed some 200 tree-ring years before the onset of this significant decline. Thus, the period between the LSE to the onset of the Younger Dryas was in this record consistent with the European varve records (**tab. 65**). Based on this relation, the position of the LSE also became an important issue for the radiocarbon calibration curve (see p. 358-364). Originally, the GLPC was ^{14}C wiggle-matched to the Cariaco basin record though the significant decline in the calibration data set and the LSE was thereby estimated to date to approximately 13,200 years cal. b2k (Kromer et al. 2004). In this comparison, the younger portion of the Cariaco basin record was correlated to CEDC (Hughen et al. 2000) and most of the Pleistocene portion was compared to an age-depth model based on the snow accumulation in GISP2 (Hughen et al. 1998a; cf. Meese et al. 1997), which was later also used in the construction of the ss09sea age model (Johnsen et al. 2001). However, due to the subsequent shift in the older part of the Preboreal pines which are a part of the CEDC, this result must be shifted some 70 years older (Friedrich et al. 2004, 1116). The Pleistocene part of the Cariaco basin record has been correlated since to the chronology of the Hulu Cave record (Hughen et al. 2006) and recently to the GICC05 (Deplazes et al. 2013). These correlations resulted in minor shifts of the Cariaco basin calibration data set at the transition of the Lateglacial Interstadial to the Lateglacial Stadial. Nevertheless, these shifts indicated the insecurity of the Cariaco basin chronology in this part. Therefore, a correlation of the GLPC along the LST in the European varve records could provide a more reliable and precise age estimate.

In summary, this compilation of the partially different definitions of the Younger Dryas and the age difference between the LSE and the onset of the Younger Dryas as well as the Holocene demonstrate that the various climatic and environmental reactions are time transgressive and, thus, an onset for these events is often not well suited as a correlation point in a chronostratigraphic framework. Another volcanic episode such as the Vedde Ash or the Ulmener Maar tephra are much better suited for this type of comparisons.
Finally, based on the above correlations and dates, the most reliable dating of the LSE remains the age estimated from the MFM at 12,930 ± 30 years cal. b2k. Peak 4 of the Ca^{2+} corrected sulphate content in NGRIP is absolutely consistent with this date.

Oxygen isotope records

Besides the Greenland ice-cores, four archives with oxygen isotope records were presented in the climate and chronostratigraphic archives (see Material-Climate, p. 17 f. and p. 23-25): the Hulu Cave, the Qingtian Cave, Lake Gościąż, and Lake Perespilno. These four archives are terrestrial sequences and only the latter two came from north-western Europe. The formation and composition of these terrestrial isotope records were more complex than in the Greenland ice (see p. 248 f.). The oxygen isotope records from the Greenland ice-cores were considered to reflect, in particular, the past air temperature at the coring site (Steffensen et al. 2008). In contrast, the oxygen isotope records from the Chinese speleothems were assumed as proxy for the intensity of the Asian monsoon at the sampled site (Wang et al. 2001; Liu et al. 2008). The Lake Gościąż oxygen isotopes probably reflected the air temperature at the coring site as well as the local hydrological regime (Kuc / Różański / Dubliński 1998). Due to the comparable development of Lake Gościąż and Lake Perespilno, the formation of the oxygen isotopes in both records were probably influenced by the same mechanisms. Based on the more complex formation, offsets between the terrestrial and the ice-core isotope records need to be discussed in regard to whether they represent deficiencies in the chronology of the records or a difference in reaction time for the oxygen isotope signal due to different influences. In the former, the records should be shifted to the reliable and / or more precise age estimate. In the latter case, this procedure would lead to incorrect correlations of the complete record (cf. Blaauw et al. 2010). The Polish lakes yielded varve chronologies which make further numerical comparisons possible. The records from the Chinese speleothems were combined with band counting, radiometric and, thus, absolute ages giving a second way of verifying the reliable position of the chronology. Moreover, the cumulative counting error of laminated stratigraphies was counter-checked by the radiometric ages and thereby the age estimate became more precise, particularly in the older Pleistocene record.

Of the four terrestrial oxygen isotope records used in this study, the long archive of the Hulu Cave (**fig. 6**) was used, particularly in the recent decade, to define the Pleistocene chronostratigraphy more precisely (e. g. Hughen et al. 2006; Weninger / Jöris 2008). This archive comprises the complete Lateglacial, whereas the other three records yielded only sub-periods from the younger half of the Lateglacial.

In the Hulu Cave, absolute ages were given for the three major shifts in the Lateglacial record: the onset of the Lateglacial Interstadial, the end of the Lateglacial Interstadial, and the onset of the Holocene (**tab. 66**). In addition, the onset of a last severe period in the Late Pleniglacial which is probably comparable to the onset of GS-2a in the ice-core records was observable as a sharp gradient (Wang et al. 2001). Furthermore, the limits for an episode of higher oxygen isotope values which perhaps correlates to GI-1b were also given and age estimates made for the onset of GI-1b and GI-1a were possible (Liu et al. 2008). The Pleistocene-Holocene transition was estimated to date around 11,523 ± 100 years cal. b2k, the transition of GI-1 to GS-1 to *c.* 12,873 ± 60 years cal. b2k, the onset of GI-1a to 13,160 ± 100 years cal. b2k, the onset of GI-1b to 13,320 ± 90 years cal. b2k, and the onset of the Lateglacial Interstadial to 14,695 ± 60 years cal. b2k (Wang et al. 2001; Liu et al. 2008, 695). Clearly, the numerical comparison with the NGRIP record (see **tab. 66**) already reveals a difference of 70 to 160 years for the four youngest limits, whereas the onset of the Lateglacial Interstadial is very similar in both records. The sharp gradient marking the onset of the final severe period in the Late Pleniglacial was recorded in the oxygen isotope record of the high-resolution stalagmite YT and dated to 16,123 ± 60 years cal. b2k. Due to the large counting errors in the ice-core records at this depth, the date suggested for the onset of GS-2a in NGRIP and the date from the Hulu Cave are, despite over 100 years difference, consistent.

In the original publication, the Hulu Cave age for the onset of GS-2a is based on $^{230}Th/^{234}U$-dating in the three stalagmites and on band counting in the YT stalagmite (Wang et al. 2001). Between 16,141 and

main isotope events	NGRIP	Hulu Cave		Qingtian Cave		Lake Gościąż	Lake Perespilno
GH-11.4 (PBO)	11,490 ± 97	×	11,118	×	×	×	×
GH	11,681 ± 111	11,523 ± 100	11,524	×	×	11,662 ± 50	11,650 (^{18}O); 11,560 (sediment)
GS-1	12,770 ± 133	12,873 ± 60	12,873	12,630 / 12,820	12,680 (^{18}O); 12,635 / 12,713 (lt)	12,774 ± 90[2]	12,550-12,600 (^{18}O); 12700 (sediment)
GI-1a	13,070 ± 142	13,160 ± 100	13,144	13,040 ± 100	12,988 (^{18}O); 13,007 (lt)	×	×
GI-1b	13,250 ± 147	13,320 ± 90	13,370	13,220 ± 100	13,211 (^{18}O); 13,248 (lt)	×	×
GI-1c$_1$	13,580 ± 156	×	×	×	×	×	×
GI-1c$_2$	13,730 ± 160	×	×	×	×	×	×
GI-1c$_3$	13,970 ± 166	×	14,152	×	×	×	×
GI-1d	14,090 ± 169	×	14,313	×	×	×	×
GI-1e	14,687 ± 187	14,695 ± 60	14,658	×	×	×	×
GS-2a	16,230 ± 255	16,123 ± 60	16,123	×	×	×	×
ref.	see **tab. 64**	Wang et al. 2001; Liu et al. 2008, 695	Wang et al. 2001, supplemental tab. 2*	Liu et al. 2008	Liu et al. 2008, supplemental tab. 1-2*	Kuc/Różański/Dubliński 1998; Ralska-Jasiewiczowa/Demske/van Geel 1998; Goslar/Arnold/Pazdur 1998	Goslar et al. 1999

Tab. 66 Comparison of the dates (given in years cal. b2k) for the onsets of the main Lateglacial oxygen isotope events in various records. **(lt)** layer thickness; **(^{18}O)** oxygen isotope; ***** reading and calculation are made by the present author from supplemental tables (see p. 245-249). – For further details see text.

16,105 years cal. b2k approximately every 9th band was sampled. In this period of 36 years the values increased for 2.01‰ and remained relatively high afterwards for more than a century (Wang et al. 2001, supplemental tab. 2). If the oxygen isotope record of the Hulu Cave is treated comparable to the NGRIP record, the sharpest increase between two data points (1.21‰) occurred between 16,128 and 16,118 years cal. b2k. One ^{230}Th/^{234}U date came from some 220 bands after the sharp gradient in this high-resolution stalagmite (YT-02: 15,908 ± 59 years cal. b2k, Wang et al. 2001, supplemental tab. 1). In the low resolution PD stalagmite two ^{230}Th/^{234}U dates were before the sharp gradient (PD-490: 16,139 ± 333 years cal. b2k, Wang et al. 2001, supplemental tab. 1) and from after the sharp gradient (PD-470: 15,831 ± 402 years cal. b2k, Wang et al. 2001, supplemental tab. 1). The high-resolution H82 stalagmite was not sampled for oxygen isotopes in this region and, thus, the relation of the ^{230}Th/^{234}U date (H82-2: 16,115 ± 105 years cal. b2k, Wang et al. 2001, supplemental tab. 1) to the gradient is uncertain. Nonetheless, the comparison of the band counting and the radiometric dating in the YT stalagmite are very consistent and the additional information from the other stalagmites are also consistent with this high-precision date. The lowest oxygen isotope value in the surveyed period in the NGRIP record is comparably dated to 16,100 years cal. b2k (**tab. 63**). However, no sharp decrease was recognised in the ice-core record immediately before this point (**fig. 32**). Although a higher value (-40.35‰) occurred at 16,140 years cal. b2k, the decrease was more gradual in the ice-core record and lay within the generally high values of the fluctuating amplitude of the

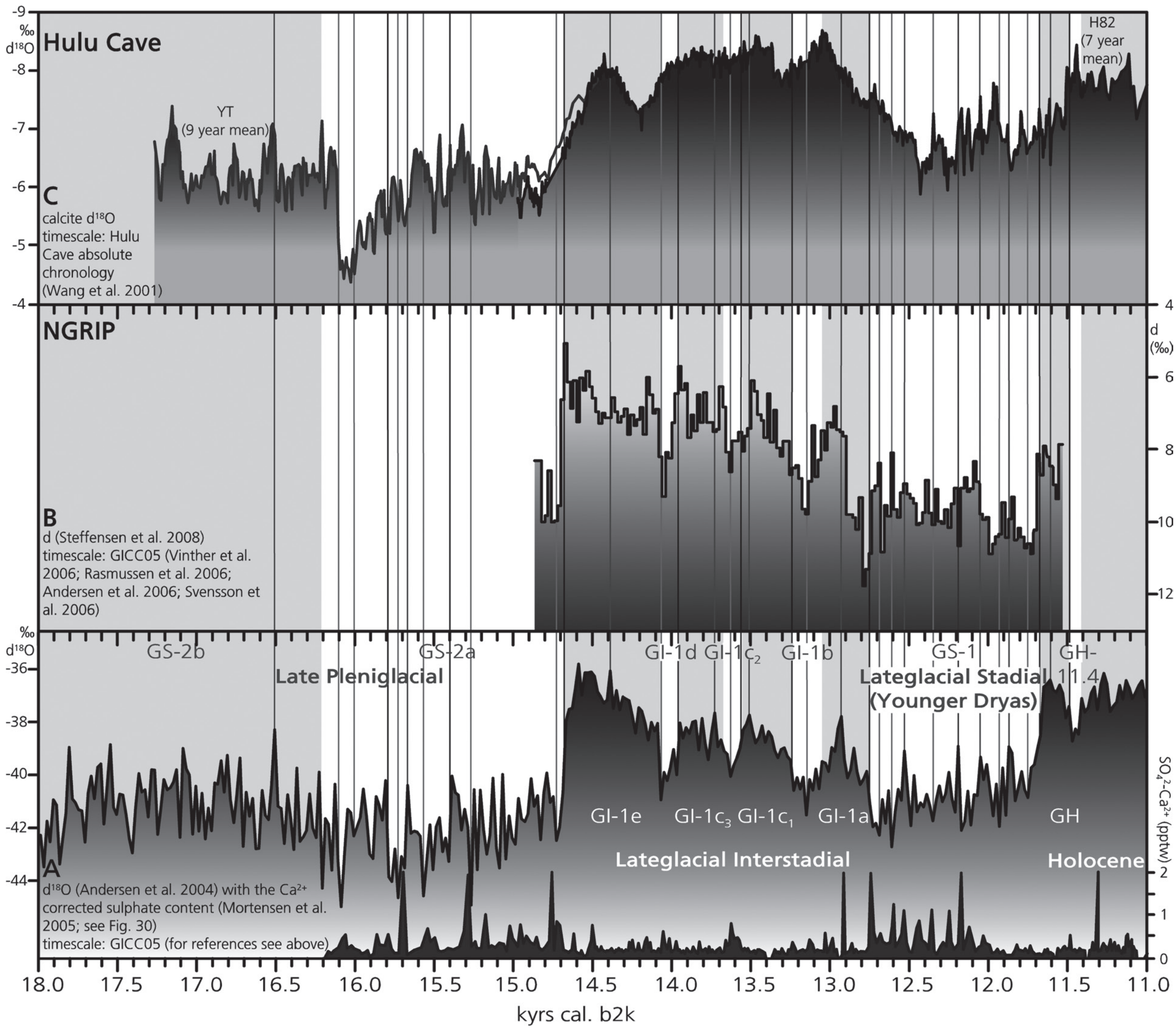


Fig. 32 Comparison of the NGRIP record with the Hulu Cave record. Thin bars given as guide lines (light grey: low; medium grey: high; black: transition). **A** Oxygen isotope record from NGRIP with the Ca^{2+} corrected sulphate content but without associated ash layers (see **fig. 30**). Grey shaded areas represent events of more interstadial values than the surrounding values. – **B** Deuterium excess record from NGRIP. – **C** Oxygen isotope record of the Hulu Cave stalagmites YT (grey) and H82 (black; Wang et al. 2001, fig. 2). – For further details see p. 248 f. and text.

Late Pleniglacial. A shift of the NGRIP record to the more precise date for the onset from the Hulu Cave can be neglected for several reasons: One reason is that the difference of the two records is well within the counting errors of NGRIP. Another reason is the comparatively gradual development of the NGRIP oxygen isotope record and, thus, some chronological offset could be explained by different reaction times and amplitudes between the two records. If further high and low values in the Late Pleniglacial part of the records are compared (**fig. 32**), a very similar behaviour of the two records is apparent. Thus, the onset of GS-2a might have begun with a deterioration in the Atlantic region reflected in the Greenland record and the Asian monsoon record only reacted as this development continued for a longer period.

The transition from the Late Pleniglacial to the Lateglacial Interstadial was estimated to have taken some 180 years centred around 14,695 ± 60 years cal. b2k in the Hulu Cave record (Wang et al. 2001). The estimates for the dating in the Hulu Cave were based on band counting in the H82 and the YT stalagmites, a TIMS-$^{230}Th/^{234}U$ date some 200 bands before the maximum value (14,439 years cal. b2k) in the YT

stalagmite, and two $^{230}Th/^{234}U$ dates from the PD stalagmite taken before and after the transition. The $^{230}Th/^{234}U$ date from the YT stalagmite produced an age of 14,613 ± 71 years cal. b2k (YT-01; Wang et al. 2001, supplemental tab. 1), which was within 30 years in relation to the band counting. In this part of the record a sample from the YT stalagmite contained approximately 20 layers. Thus, the $^{230}Th/^{234}U$ date and the band counting appear very consistent. In comparison with the accumulated counting error of the NGRIP record, the standard deviation of the TIMS-date is considerably smaller and helps to make a Lateglacial chronostratigraphy more accurate. In contrast, the samples from the PD stalagmite taken from before the transition (PD-348: 15,073 ± 464 years cal. b2k) and from after the transition (PD-387: 14,505 ± 391 years cal. b2k; Wang et al. 2001, supplemental tab. 1) were much less precise. In the YT record, the amplitude that accumulated in 100 years usually exceeded 0.5‰ during the period from 14,806 to 14,599 years cal. b2k, marking these 207 years as the main transition. The oxygen isotope values shifted in this period from -6.14‰ at 14,793 years cal. b2k to -7.56‰ at 14,599 years cal. b2k with the sharpest gradient at the beginning between 14,793 and 14,777 years cal. b2k (0.32‰; Wang et al. 2001, supplemental tab. 2). The H82 stalagmite is sampled in closer spaces in this part (as low as two bands per sample) and, therefore, the sequence appeared less stable. The accumulated amplitudes shifted generally more than 0.5‰ between 14,711 and 14,455 years cal. b2k. Thus, this period began a bit later and was more gradual than in the YT stalagmite. However, if the oxygen isotope values are compared, the last high value (-5.87‰) was also in the H82 sequence at 14,793 years cal. b2k but the first low (-7.29‰) was already reached at 14,604 years cal. b2k (Wang et al. 2001, supplemental tab. 2). This was followed by a short and small set back before values continued to decrease to the maximum of -8.27‰ at 14,441 years cal. b2k. The YT record was only sampled until 14,439 years cal. b2k where it also reached its lowest value (-8.05‰). Also the steepest gradient between two data points occurred in a comparable position in both records: in YT record, this shift occurred between 14,660 and 14,637 years cal. b2k (0.25‰) and record a comparable shift (0.24‰) occurred between 14,660 and 14,656 years cal. b2k in the H82. Since, in this project the mid-point of this steepest shift is usually selected for the onset the limit between GS-2a and GI-1 would fall to 14,658 years cal. b2k in the Hulu Cave record (**tab. 66**). The mid-points between the first peak and the last minimum were equivalent to the NGRIP record (YT: 14,696 years cal.b2k; H82: 14,699 years cal. b2k). The dates for the limits and for the mid-points of the transition as well as the estimate for the duration of the transition are almost identical to the observations in the NGRIP record in which the transition was recognised between 14,780 and 14,600 years cal. b2k (see p. 294). Even though this transition is numerically almost identical in both records, the exact development of the proxy record appeared rather inconsistent as was demonstrated by significant shifts (**fig. 32**). The intensity of the reactions were different: some short-term fluctuations observed in NGRIP were not reflected in the Hulu Cave record, and the latter seemed in general to progress more gradually. Opposite reactions of marine and speleothem $\delta^{18}O$ on glacial melting were discussed as partially causing this more gradual development at the limits of the Lateglacial Interstadial in the Hulu Cave record in comparison to the Greenland ice-cores (Wang et al. 2001, 2347). Therefore, the offset of these limits is attributed to the different response times and, therefore, the two records are assumed as chronologically correlative and no record is shifted.
Furthermore, the transition from the Lateglacial Interstadial to the Lateglacial Stadial was also a very gradual process which stretched over several hundred years in the oxygen isotope record from the Hulu Cave stalagmites (Wang et al. 2001, fig. 2). Besides a possibly suppressed response time in the Chinese record, the development from GI-1a to GS-1 was also very gradual in the NGRIP record characterising this transition as a slow-progressing, long-term change. The date of 12,873 ± 60 years cal. b2k for the limit in the Hulu Cave record was based on band counting in the high-resolution H82 stalagmite and two $^{230}Th/^{234}U$ dates in the low-resolution PD stalagmite. One of these $^{230}Th/^{234}U$ dates was taken at the last interstadial peak (at

17.9 mm; PD-210: 12,962 ± 227 years cal. b2k) and the second date was taken at the first stadial minimum in this record (at 12.0 mm; PD-140: 12,607 ± 294 years cal. b2k). In this part of the high-resolution H82 stalagmite, a sample comprised usually seven bands. This closely sampled oxygen isotope record is again more unstable and, thus, several fluctuations become visible in this transition. An interstadial peak occurred already at 13,062 years cal. b2k (-8.67 ‰) and the stadial minimum is reached at 12,442 years cal. b2k (-5.88 ‰). The mean between these two points is 12,752 years cal. b2k. The first value below 8.0 ‰ was recorded at 12,952 years cal. b2k and the last value above 8.0 ‰ occurred at 12,917 years cal. b2k. The first value below 7.0 ‰ occurred at 12,614 years cal. b2k and the last value above 7.0 ‰ was recorded at 12,573 years cal. b2k. The only value below 6.0 ‰ was the stadial minimum. Thus, in the 620 bands between the two main peaks, values changed only gradually. The highest accumulated amplitude occurred at the end of the transition between 12,545 and 12,442 years cal. b2k. In this period the oxygen isotope values increased by 1.03 ‰ in 103 years and also the next value from 12,538 to 12,435 years cal. b2k was higher (0.80 %) than any other accumulated amplitude in this transition. In the 620 year long transition, further periods where several values of higher amplitudes accumulated over approximately 100 years followed closely on one another can be found. One of these periods occurred between 12,731 and 12,607 years cal. b2k (0.61 ‰, 0.47 ‰, 0.55 ‰, 0.58 ‰). A second period occurred at the onset of the transition between 13,062 and 12,931 years cal. b2k (0.61 ‰, 0.76 ‰, 0.53 ‰, 0.60 ‰, 0.81 ‰) and continued with single values crossing a 0.5 ‰ amplitude until the accumulated amplitude for the time from 12,917 to 12,814 years cal. b2k. Towards the end of this period of accumulated amplitudes, the steepest gradient between two data points (0.40 ‰) occurred between 12,876 and 12,869 years cal. b2k. This gradient was used to determine the onset of GS-1 (**tab. 66**; cf. Wang et al. 2001, supplemental tab. 2). The second steepest gradient occurred at the end of the transition between 12,456 and 12,449 years cal. b2k (0.37 ‰) and the third steepest at the onset of the transition between 13,014 and 13,007 years cal. b2k (0.30 ‰). Furthermore, at five positions the values increased for more than 0.25 ‰: 13,034-13,028 years cal. b2k, 12,731-12,724 years cal. b2k, 12,676-12,669 years cal. b2k, 12,559-12,552 years cal. b2k, and 12,476-12,470 years cal. b2k.

Thus, detailed inspection of the oxygen isotope record from the Hulu Cave displays a comparable, stepwise deterioration at the end of the Lateglacial Interstadial as the Greenland ice-cores (cf. p. 293-310). The first indications for a deterioration in the Hulu Cave preceded those in the NGRIP record by some 130 years, whereas the minimum values of the deterioration seemed to succeed those from the Greenland ice-core by some 200 years. However, the accumulated amplitude values and a relatively steep gradient occurred around 12,731 years cal. b2k and, thus, highlighting a reaction to climatic changes around the same period when oxygen isotope values in the NGRIP record also changed significantly. Furthermore, the extremely low values of GS-1 in NGRIP appeared to not be registered in the Hulu Cave record but the minimum in GS-1 at 12,620 years cal. b2k in NGRIP was followed by a transgression of the oxygen isotope values below 7.0 ‰ in the Hulu Cave record. By 12,607 years cal. b2k, the values in the Hulu Cave record stabilised. Subsequently, the final phase of the deterioration in the Chinese stalagmite corresponded with a short increase of values in the NGRIP record around 12,540 years cal. b2k (-39.09 ‰) and the subsequent deterioration. In this case, the reactions of the Hulu Cave and the NGRIP record were quasi-synchronous during this time period and, perhaps, the climatic factors influencing the Hulu Cave record also buffer the registration of stadial limits by contrasting signals. Another possibility is that the Hulu Cave record and the NGRIP record were not synchronous in this part and, consequently, one of the records had to be shifted. However, these remarks serve to illustrate the difficulty of defining the onset of the Lateglacial Stadial.

The original age estimate for the onset of the Holocene in the Hulu Cave record was based on band counting in the high-resolution stalagmite H82, on a $^{230}Th/^{234}U$ date from the same stalagmite, and a $^{230}Th/^{234}U$ date for the transition in the PD stalagmite (low resolution; PD-85: 11,584 ± 310 years cal. b2k, Wang et al.

2001, supplemental tab. 1). This $^{230}Th/^{234}U$ date was taken between a low point interpolated to date to 11,770 years cal. b2k and a peak dating to 11,532 years cal. b2k (mean: 11,651 years cal. b2k). In H82, the end of the first Holocene warming was dated by a TIMS-$^{230}Th/^{234}U$ measurement to 11,052 ± 97 years cal. b2k (H82-1; Wang et al. 2001, supplemental tab. 1). In this record, the first full interstadial values were reached after a sharp increase of the $\delta^{18}O$ values between 11,536 (-6.99‰) and 11,515 years cal. b2k (-8.04‰; mean: 11,526 years cal. b2k; Wang et al. 2001, supplemental tab. 2). The latter date correlated with the transition towards the GH-11.4 event in the NGRIP record (cf. Walker et al. 1999, 1147f.; Vinther et al. 2006, X-7). The increase of the oxygen isotope values in the Hulu Cave was preceded by several fluctuations. These fluctuations between two data points began around 11,695 years cal. b2k in the H82 stalagmite. The sharpest gradient between two data points occurred between 11,626 and 11,620 years cal. b2k where the values deteriorated by 1.12‰ to the lowest value before the establishment of interstadial conditions. Very high values of accumulated amplitudes were reached only after 11,620 years cal. b2k with the highest values (0.94‰) falling between 11,559 and 11,447 years cal. b2k. Before this period, accumulated amplitudes above 0.5‰ were only reached twice: between 11,717 and 11,620 years cal. b2k (0.60‰) and in the period between 11,667 and 11,559 years cal. b2k (0.83‰; 0.64‰; 0.67‰;0.50‰). Thus, although the full Holocene mode of the Asian monsoon, which is probably reflected by the Hulu Cave oxygen isotope record, was reached around 11,525 years cal. b2k, a transition period from the Lateglacial Stadial to the Holocene mode began already around 11,720 years cal. b2k (Wang et al. 2001, supplemental tab. 2) with a period of various changes concentrated around 11,623 years cal. b2k. This limit succeeded the limit for the Pleistocene-Holocene transition in the North Atlantic by several decades but the first indicators of a changing climate regime were again comparable to the onset of the Holocene as indicated by the deuterium excess records in NGRIP. Perhaps, the notably delayed reaction of the Hulu Cave oxygen isotope record to Holocene amelioration could be explained as the onset of the Lateglacial Interstadial with opposite reactions of marine and speleothem $\delta^{18}O$ on glacial melting in the two types of records (Wang et al. 2001, 2347). In fact, a significant meltwater flux into the oceans (meltwater pulse 1b [MWP-1b][38]) was discussed for the early Holocene (Fairbanks 1989, 639) and this input might have caused again some delayed reactions in the Hulu Cave record. However, a chronological offset cannot be excluded thus far.

In summary, the detailed comparison of the oxygen isotope records from the Hulu Cave and NGRIP across the three main transitions in the Lateglacial record indicates that the two records react quasi-synchronously to some major climatic impulses. The remaining offsets can partially result from counting/dating errors and partially from various response times to the climatic triggers. Stalagmites respond slower and/or less intense, and often only on long-term impulses, whereas the ice-core records react rapidly and, therefore, these records appear to have a greater fluctuation. It is possible that the dependence of the oxygen isotopes in the stalagmites on various sources resulted occasionally in a neutralization of the climatic signals. Due to these different responses of the speleothem records and the ice-core records at the onsets of some isotopic events, the limits given by the Hulu Cave record should not be simply correlated to the limits of the NGRIP record or vice-versa.

To further evaluate whether the offset between the Hulu Cave record and the NGRIP record is due to different response times or due to problems in the chronologies, the Hulu Cave oxygen isotope record can be compared to the same proxy record from the Central Chinese Qingtian Cave (**fig. 33**; Liu et al. 2008)

38 The existence and the significance of the Holocene MWP-1b was questioned (Bassett et al. 2005) but influx of meltwater and a possibly accelerated rate of sea-level rise is undoubted (Bard/Hamelin/Delanghe-Sabatier 2010), 1237). Furthermore, the various freshwater outbursts from the North American ice-dammed Lake Agassiz are well documented (Teller/Leverington 2004). In fact, an outflow of comparable dimensions to the massive mid-Lateglacial outburst was recorded for the early Holocene. This Holocene outflow was discussed to have had an impact on the thermohaline circulation of (at least) the North Atlantic Ocean (Teller/Leverington/Mann 2002).

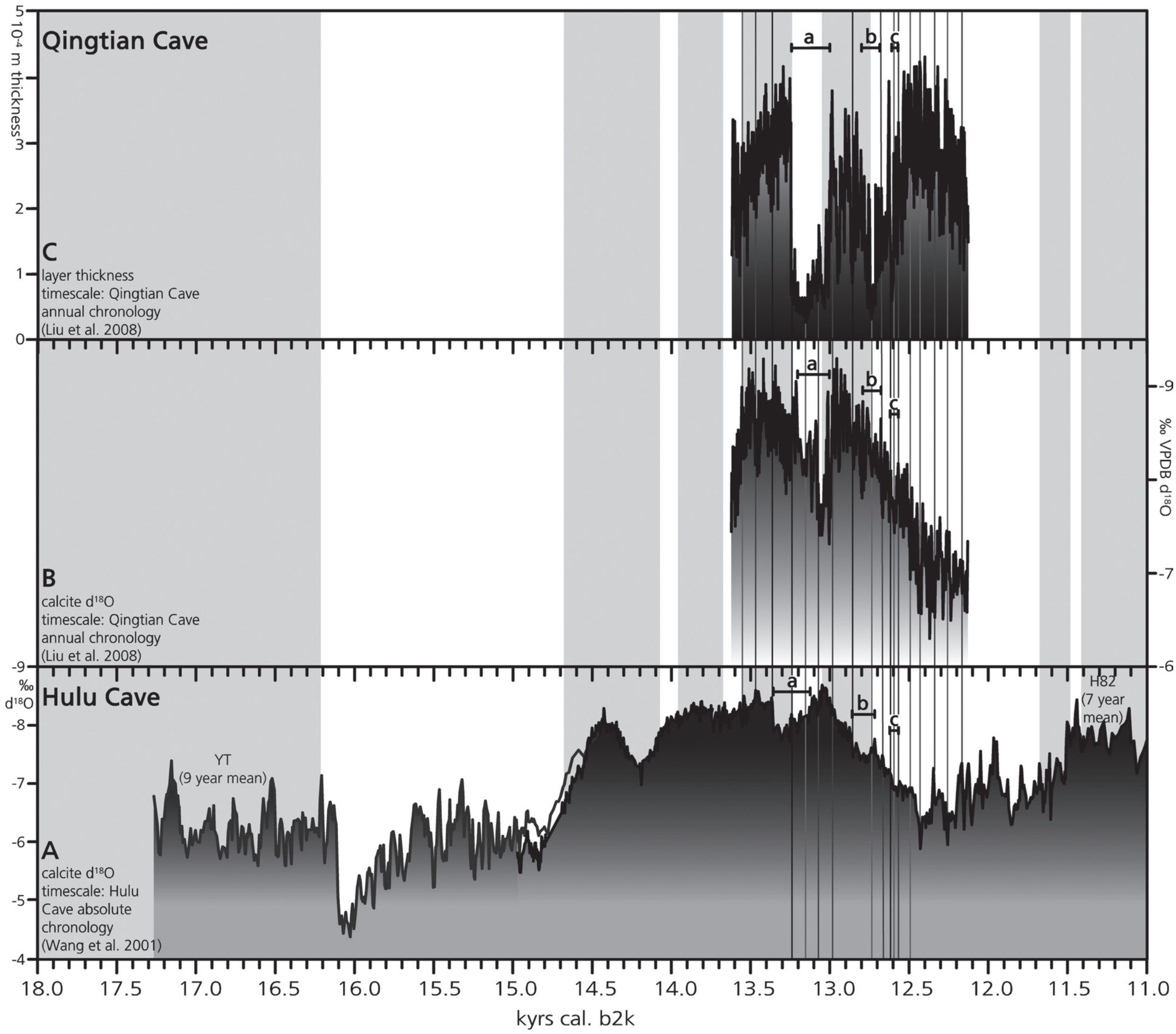


Fig. 33 Comparison of the Hulu Cave record with the Qingtian Cave record. Thin bars given as guide lines (light grey: low; medium grey: high; black: transition). Grey shaded areas represent events of more interstadial values than the surrounding values in NGRIP (see **fig. 29**). Compared episodes a, b, and c are indicated by crossbars. **A** Oxygen isotope record of the Hulu Cave stalagmites YT (grey) and H82 (black; Wang et al. 2001, fig. 2). – **B** Oxygen isotope record of the Qingtian Cave (Liu et al. 2008, fig. 3). – **C** Layer thickness record of the Qingtian Cave (Liu et al. 2008, fig. 3). – For further details see text.

which subsequently can be compared with the NGRIP record (**fig. 34**). The Qingtian record is another high-precision speleothem record with seven high-precision $^{230}Th/^{234}U$ dates that confirmed the band counting and dated the sequence from the mid-Lateglacial Interstadial to the early Lateglacial Stadial. A comparison of the Hulu Cave record helped in particular to define various episodes within the younger half of the Lateglacial Interstadial in both records. Both Chinese oxygen isotope records were assumed to respond to the same control mechanism and revealed similar reactions (Liu et al. 2008, 695). For example, the onset of the Lateglacial Stadial is also a very gradual process in the Qingtian Cave record (**fig. 7**). This transition encompassed the period from approximately 12,820 to 12,440 years cal. b2k (mean: 12,630 years b2k; Liu et al. 2008). In detail, the oxygen isotope value changed over several hundred years between a maximum in the terminal Lateglacial Interstadial (12,908 years cal. b2k, -9.14‰) and the first low point in the Lateglacial Stadial (12,495 years cal. b2k; -6.93‰; Liu et al. 2008, supplemental tab. 1). The lowest value is not reached before 12,372 years cal. b2k (-6.29‰; mean between the two maxima: 12,640 years cal. b2k).

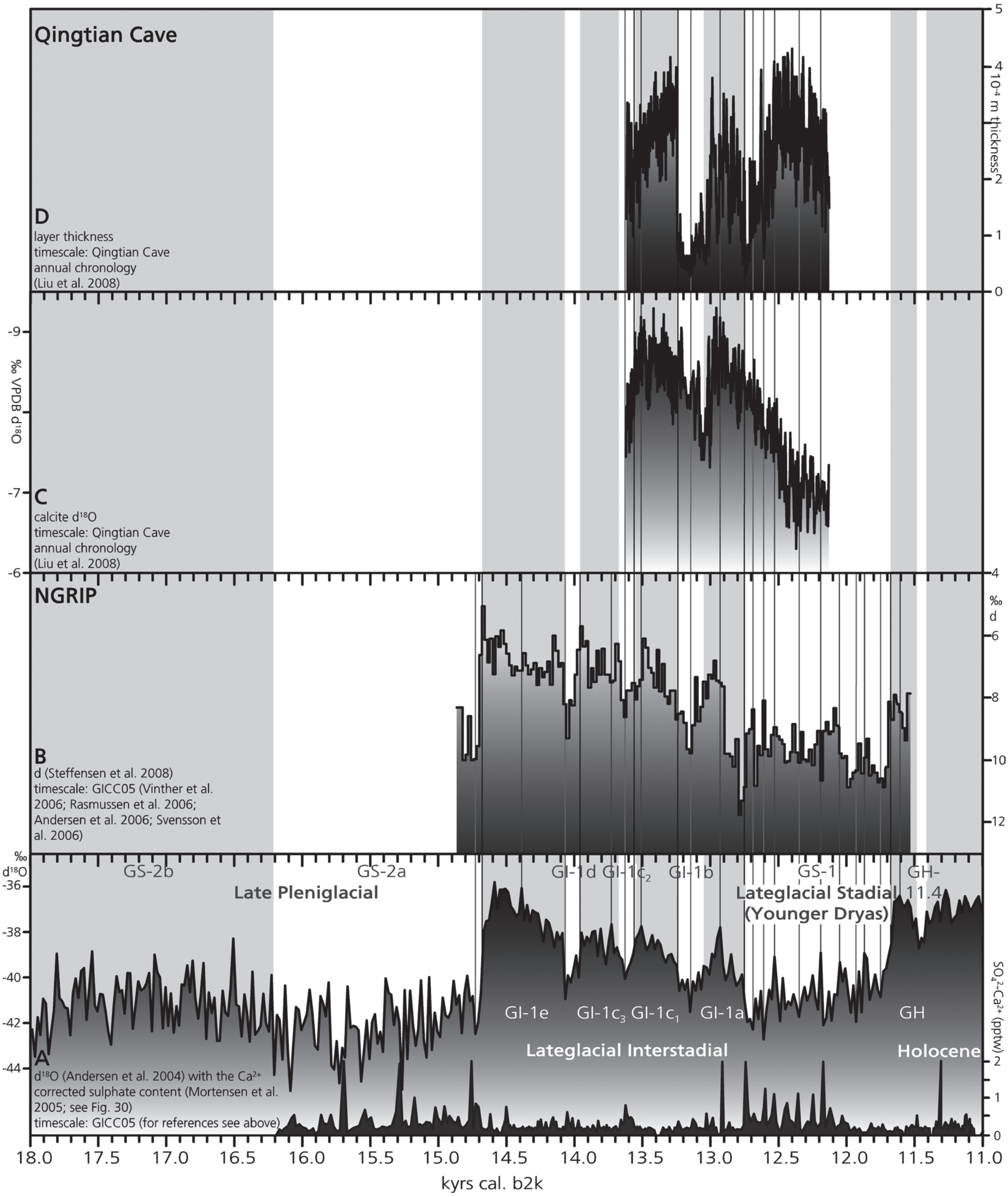


Fig. 34 Comparison of the NGRIP with the Qingtian Cave record. Thin bars given as guide lines (light grey: low; medium grey: high; black: transition). **A** Oxygen isotope record from NGRIP with the Ca^{2+} corrected sulphate content but without associated ash layers (see **fig. 30**). Grey shaded areas represent events of more interstadial values than the surrounding values. – **B** Deuterium excess record from NGRIP. – **C** Oxygen isotope record of the Qingtian Cave (Liu et al. 2008, fig. 3). – **D** Layer thickness record of the Qingtian Cave (Liu et al. 2008, fig. 3). – For further details see text.

These values were several decades younger than the maximum values in the Hulu Cave record and, thus, more comparable to the NGRIP record. In this transition, the most significant decrease between two data points occurred between 12,794 and 12,791 years cal. b2k (-0.87‰) in the Qingtian Cave record. This decrease followed an even larger increase between 12,798 and 12,796 years cal. b2k (0.94‰). After this fluctuation, the values again increase gradually. Seven smaller fluctuations with amplitudes ranging between 0.44 and 0.72‰ followed in the next 300 years. A high value in the accumulated amplitudes (-1.12‰) occurred between 12,766 and 12,668 years cal. b2k. However, the largest accumulated amplitudes occurred between 12,535 to 12,425 years cal. b2k (-1.12‰; -1.56‰). This accumulation is almost identical with the highest accumulated amplitude in the Hulu Cave record between 12,545 and 12,442 years cal. b2k. From a total of seven larger fluctuations between two data points in the Qingtian Cave record five occurred in this period of the highest accumulated amplitude. The largest (-0.72‰) fluctuation was between 12,485 and 12,482 years cal. b2k which is possibly correlative with the shift between 12,456 and 12,449 years cal. b2k or 12,476 and 12,470 years cal. b2k in the Hulu Cave record. Even though the two records were similar, the transition in the Qingtian Cave oxygen isotope record yielded some chronological offsets to the developments in the Hulu Cave record. Besides the oxygen isotope record, the development of the layer thickness could be compared in the Qingtian Cave record. Variations in layer thickness were assumed to depend primarily on soil CO_2 production, cave temperature, and hydrological conditions (Liu et al. 2008). Between 12,820 to 12,804 years cal. b2k the layer thickness was of medium (100-250 µm) to very thick (250 µm >) dimensions. Subsequently, the layer thickness began decreasing (Liu et al. 2008, supplemental tab. 2) and in the period between 12,759 and 12,713 years cal. b2k the layers became very thin (generally below 100 µm thickness). After this low, a period of significant increase of more than 175 µm between two data points followed (12,713 and 12712 years cal. b2k). The values gradually increased and began a short period of very thick values between 12,634 and 12,626 years cal. b2k, which ended again with a significant shift between 12,626 (373.87 µm) and 12,625 years cal. b2k (194.84 µm). The values decreased relatively steeply and a short period of very thin layers followed between 12,611 and 12,600 years cal. b2k. Between 12,599 (100.05 µm) and 12,598 years cal. b2k (284.35 µm) the last significant shift towards higher values occurred and from 12,567 years cal. b2k onwards very thick layers prevailed in general (Liu et al. 2008, supplemental tab. 2).

Thus, although the development of the Hulu Cave and the Qingtian Cave record was observable as similar in the general course of interstadial and stadial values, the intensity of these values were sometimes very different between the two caves. The differences in the amplitude were considered as a result of the different altitudes and the different geographical locations (Liu et al. 2008, 695).

Furthermore, if the two records are compared in detail, chronological offsets occurred in the onset of the Lateglacial isotope events (**tab. 66**). The offset between the two records increased significantly towards the onset of the Lateglacial Stadial (159 years for onset GI-1b, 153 years for the onset GI-1a, and 193 years for the onset of GS-1; **tabs 66-67**). To make the comparison independent of the Greenland developments three short-term fluctuations (episodes a-c) in the stalagmite records were compared in the transition from the Lateglacial Interstadial to the Lateglacial Stadial (**fig. 33; tab. 67**). For these episodes, the offset between the Hulu Cave and the Qingtian Cave records almost vanished towards the Lateglacial Stadial (**fig. 33; tab. 67**). Episode a is probably correlative with the Greenland isotope event GI-1b. This episode was also dated by a $^{230}Th/^{234}U$ date on the Qingtian Cave stalagmites which produced an age of 12,998 ± 82 years cal. b2k (QT-198; Liu et al. 2008, tab. 1) and was situated some 25 layers before the transition to the last warm period of the interstadial part as given for the Qingtian Cave (Liu et al. 2008, 695). Episode a had approximately the same duration in the oxygen isotopes of the Hulu Cave (13,370-13,144 years cal. b2k, 226) as in the same proxy record from the Qingtian Cave (13,211-12,988 years cal. b2k, 223 years) but began

record	Hulu Cave, oxygen isotopes	offset	Qingtian Cave, oxygen isotopes	offset	Qingtian Cave, layer thickness	offset to Hulu Cave
end of episode c	12,584	10 years	12,594	5 years	12,599	-15 years
onset of episode c	12,628	1 year	12,629	-3 years	12,626	2 years
duration of episode c	44 years	-9 years	35 years	-8 years	27 years	17 years
end of episode b	12,735	-52 years	12,683	13 years	12,696	39 years
onset of episode b	12,873	-80 years	12,793	-9 years	12,784	89 years
duration of episode b	138 years	-28 years	110 years	-22 years	88 years	50 years
end of episode a	13,144	-156 years	12,988	19 years	13,007	137 years
onset of episode a	13,370	-159 years	13,211	37 years	13,248	122 years
duration of episode a	226 years	-3 years	223 years	18 years	241 years	-15 years
ref.	Wang et al. 2001, supplemental tab. 2		Liu et al. 2008, supplemental tab. 1		Liu et al. 2008, supplemental tab. 2	

Tab. 67 Comparison of the dates (given in years cal. b2k) and the durations (given in stalagmite band years) for some episodes in the Chinese stalagmite records (see **fig. 33**). Episode a is considered as the equivalent of GI-1b and the onset of episode b is taken as limit between GI-1 and GS-1. Durations are shaded light grey. – For further details see text.

almost 160 years earlier in the Hulu Cave (**tab. 67**). The reaction of the layer thickness in the Qingtian Cave had a longer duration and was comparable to the development of the oxygen isotopes in the Hulu Cave. However, the response of the layer thickness in the Qingtian Cave also began over 100 years later than the oxygen isotopes in the Hulu Cave (13,248-13,007 years cal. b2k, 241 years). Furthermore, the highest values of episode a occurred early in the Hulu Cave, whereas in the Qingtian Cave the oxygen isotope values were highest in the late part of this episode. In the beginning of this episode, the Qingtian values were similar to the Hulu Cave record but around 13,020 years cal. b2k an extreme decline in the monsoon intensity was recorded in the Qingtian Cave lasting for some 40 years. The layer thickness was comparable to the Hulu Cave record but a short episode of thicker layers occurred between 13,029 and 13,015 years cal. b2k similar to the oxygen isotopes from the same stalagmites. The offset between the Qingtian Cave and the Hulu Cave record was either a result of chronological reasons or different geographical location. In the latter case, the more maritime climate at the Hulu Cave could have concealed an extreme reaction of the monsoon intensity in the second part of episode a and/or the more continental position of Qingtian Cave had enhanced it. A possible reason for varied changes in the monsoon patterns are the aerosol dispersal of volcanic eruptions as was shown by the comparison of multi-proxy data and historical eruptions as well as modern general circulation models (Anchukaitis et al. 2010; Turner/Harris/Highwood 2012). The dispersal of aerosols could partially depend on the geographical position of the volcano and also on the season of the eruption (Timmreck/Graf 2006). Simulations of the distribution of the aerosols from the super-volcanic LSE, which occurred during this period, suggested no significant differences in the monsoon intensity between the positions of the Qingtian Cave and the Hulu Cave (Graf/Timmreck 2001). Furthermore, the Ca^{2+} corrected sulphate content of NGRIP was relatively steady in this period but the comparison with the NGRIP record correlated this reaction with an almost concomitant decline in the deuterium excess and the oxygen isotope record from NGRIP. Perhaps, this strong signal from the North Atlantic had a higher impact on the more western Qingtian Cave than the eastern Hulu Cave which was probably more strongly influenced by the western Pacific.

In direct comparison the layer thickness of the Qingtian Cave is very similar to the development of the deuterium excess in the NGRIP record (**fig. 34**). The deuterium excess is assumed to be related to the ocean surface temperature in the source region of the Greenland precipitation, i.e. a region near and around the equator during the glacial periods (Masson-Delmotte et al. 2005) and the layer thickness of these relatively southern stalagmites is assumed to be controlled by the hydrological conditions, among other local factors (Liu et al. 2008). Thus, a closer relation of the layer thickness and the deuterium excess is not very surprising. However, the oxygen isotope records of the speleothems are considered to be influenced by the Asian monsoon and its seasonality (cf. Wang et al. 2001). The seasonality of the Asian monsoon depends on the atmospheric circulation over the Asian landmass and the Indian Ocean and the Chinese Sea and the intensity of the monsoon is thought to be linked to various atmospheric and oceanic factors such as the thermohaline circulation of the oceans or the atmospheric moisture transfer as well as to solar activity (Wang et al. 2005). Thus, the Asian monsoon system is particularly governed by the difference of the Asian landmass to the mostly equatorial watermasses. Thus, the oxygen isotope record from Qingtian Cave can also be comparable to the development of the deuterium excess but this relation is only partially observable in the Qingtian Cave record. The general development of the oxygen isotope record is very comparable to the development of the deuterium excess values in NGRIP but the precise timing seems more comparable to the oxygen isotope record from NGRIP. In contrast, the Hulu Cave record appears generally a bit offset to the oxygen isotope record from NGRIP within the Lateglacial Interstadial, whereas the comparison during the Late Pleniglacial revealed a very similar development (fig. 32). Thus, these offsets in the Hulu Cave fall into the range analysed in detail for the H82 stalagmite. This record was correlated to the YT stalagmite record at the onset of the Lateglacial Interstadial (see p. 321 f.) and a $^{230}Th/^{234}U$ date in the early Holocene. Since the offsets seems to occur only during the Lateglacial Interstadial and the transition to the Lateglacial Stadial, the radiometric dating seems to be in accordance with the band counting again. Moreover, the Qingtian Cave record which is sustained with seven $^{230}Th/^{234}U$ dates falls into this period and again shows a high chronological similarity to NGRIP (tab. 66). Thus, with these two records (Qingtian Cave and NGRIP) share high concordence, it seems more plausible that the reason for the offsets originated in the Hulu Cave record. A possible reason for the offsets of the Hulu Cave could be that the formation of the bands in H82 altered during the Lateglacial Interstadial. Another reason could be shifts in the seasonality of the monsoon signals for the two Chinese records in this period (Liu et al. 2008). Based on the comparison of the Qingtian Cave and the Hulu Cave records, the NGRIP and Qingtian Cave correlation is given more priority in the present project for the precision of the Lateglacial chronostratigraphy. However, the highly comparable development of the Qingtian Cave and the NGRIP record and/or the explanations for the offsets due to opposing signals make no further shifts in the Lateglacial chronostratigraphy necessary.

In contrast to the Chinese oxygen isotope records, the record from Gościąż provided very sharp signals for the onset and the end of the Lateglacial Stadial with 150 varve years and 80 varve years between the peak values (tab. 66; fig. 9; Kuc/Różański/Dubliński 1998, 160). Probably, this closer resemblance to the NGRIP record was due to the more comparable influences on the oxygen isotope record in Lake Gościąż and NGRIP (fig. 35). The limits were set to the mid-point between the two peak values, not the sharpest gradient between them. If the sharpest gradient was chosen the limits would shift *c.* 20 years younger for the onset and about eight years older for the end of the Lateglacial Stadial. Even though this difference is well within the counting error of the estimated duration of 1,140 ± 40 varve years (Kuc/Różański/Dubliński 1998), the duration with these years subtracted (1,112 years) emphasises the almost identical duration of GS-1 in Lake Gościąż and NGRIP (1,089 years; tab. 68).

However, the dating of the onset of the Holocene in the oxygen isotope record (mean value between two peak values) from Lake Gościąż was established by varve counting (Kuc/Różański/Dubliński 1998; Goslar 1998c) and the correlation of the varve thickness to the width of tree-rings in the CEDC (see p. 23-30; Goslar 1998a; Goslar/Arnold/Pazdur 1998). Thereby the onset of the Holocene was dated to 11,560 ± 50 years cal. b2k and the onset of the Lateglacial Stadial to 12,700 ± 90 years cal. b2k (Goslar/Arnold/Pazdur 1998, 166). A supplementary age estimation was based on wiggle-matching of a ^{14}C data series to the calibration record from the CEDC (Goslar et al. 1998a) and resulted in ages of 11,490 ± 120 years cal. b2k and

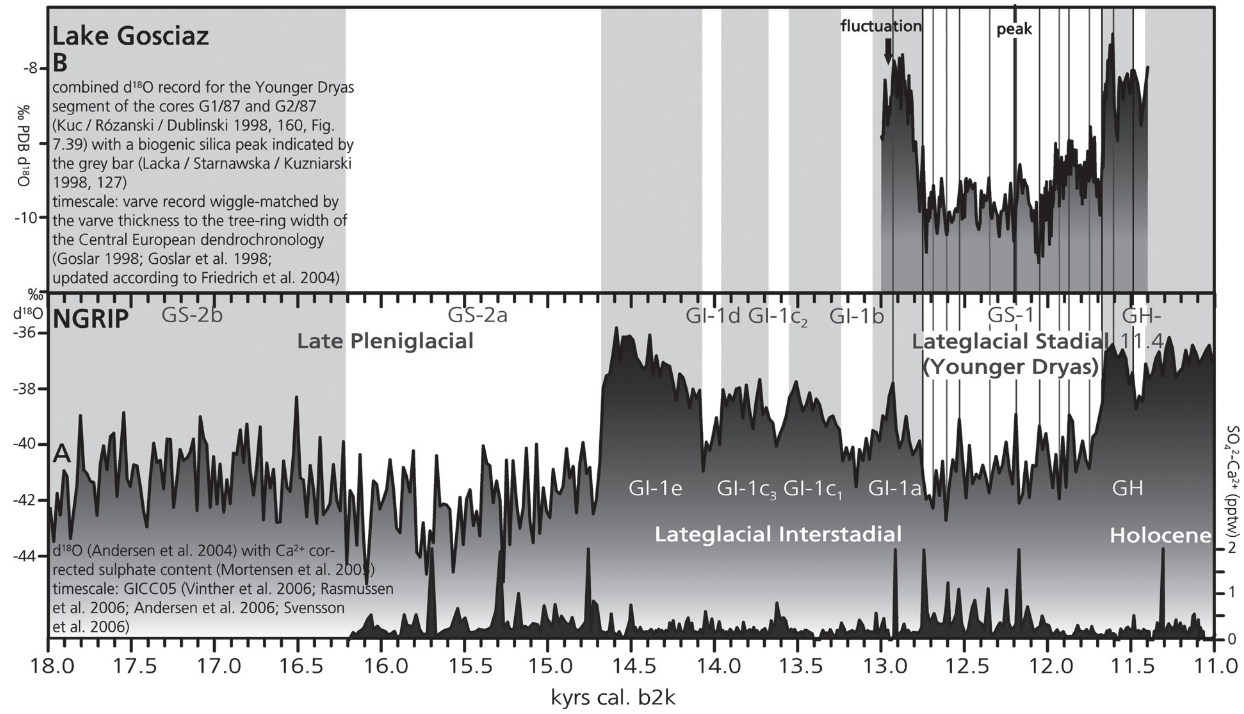


Fig. 35 Comparison of NGRIP and Lake Gościąż. Thin bars given as guide lines (light grey: low; medium grey: high; black: transition). **A** Oxygen isotope record from NGRIP with the Ca^{2+} corrected sulphate content but without associated ash layers (see **fig. 30**). Grey shaded areas represent events of more interstadial values than the surrounding values. – **B** Oxygen isotope record from Lake Gościąż (Kuc/Różański/Dubliński 1998; Goslar 1998c; shifted according to Friedrich et al. 2004) and biogenic silica peak indicated as dark grey bar (Łącka/Starnawska/Kuźniarski 1998). – For further details see text.

12,630 ± 130 years cal. b2k for the same limits (Goslar/Arnold/Pazdur 1998). A revision of this correlation suggested a shift of a further 14 years older (Spurk et al. 1998) but the necessity of this shift was questioned because the difference was well within the error estimate of the dendrochronology (Goslar et al. 2000, 336). In this revision, the onset of the Holocene was determined at varve no. 1072 which was dated to 11,546 ± 36 years cal. b2k according to the ^{14}C wiggle-matching (Goslar et al. 2000). The Holocene part of the dendrochronological record has since been shifted another 80 years older (Friedrich et al. 2004) resulting in a shift of the calculated age for the onset of the Holocene to 11,626 ± 36 years cal. b2k. However, the ^{14}C series from Lake Gościąż (**fig. 9**) displayed some uncertainties in comparison with the CEDC, especially in the Lateglacial period (Goslar et al. 2000, 341), and the record from Lake Perespilno behaved comparably due to the correlation with the Gościąż series (Goslar et al. 1999; Goslar et al. 2000). A constant offset between the ^{14}C data series from Lake Gościąż and the dendrochronological calibration record remained after the additional shifts were performed. Reservoir effects were not usually considered in data series from freshwater environments but more recent studies pointed to contamination by freshwater reservoirs which could occasionally result in offsets of some hundred years (Olsen et al. 2010). Therefore, these dates are rejected pending a revision of geochemical processes which could explain the constant offset of the ^{14}C dates. Nonetheless, the shifts of the dendrochronological data equally affected the ages given by the correlation of the varve thickness from the Gościąż record with the dendrochronological data. A shift of these ages to 94 years older resulted in and age of 11,654 ± 50 years cal. b2k for the onset of the Holocene and 12,794 ± 90 years cal. b2k for the onset of the Lateglacial Stadial. If the record is shifted accordingly and, in addition, the limits of the Lateglacial Stadial are shifted to the steepest part of the transitions in the record, the resulting dates of 11,662 ± 50 years cal. b2k and 12,774 ± 90 years cal. b2k are almost identical to those

main isotope events	NGRIP	(GICC05)	Hulu Cave		Qingtian Cave	Lake Gościąż	Lake Perespilno
GS-1	1,089 ± 22 yrs		1,350 (*1,349*) yrs		×	1,140 *(1,112)* ± 40 yrs	950-900 yrs *(1,125 ± 70 yrs)*
GI-1a	300 ± 9 yrs	1,917 ± 54 yrs	1,822 (*1,785*) yrs	287 (*271*) yrs	410 / 220 (*308*) yrs	×	×
GI-1b	180 ± 5 yrs			160 (*226*) yrs	180 (*223*) yrs	×	×
GI-1c_1	330 ± 9 yrs			×	×	×	×
GI-1c_2	150 ± 4 yrs			×	×	×	×
GI-1c_3	240 ± 6 yrs			×	×	×	×
GI-1d	120 ± 3 yrs			(*161*) yrs	×	×	×
GI-1e	597 ± 18 yrs			(*345*) yrs	×	×	×
GS-2a	1,543 ± 68 yrs		1,428 (*1,465*) yrs		×	×	×
ref.	see **tab. 64**		Wang et al. 2001; Liu et al. 2008, 695		Liu et al. 2008	Kuc/Różański/Dubliński 1998	Goslar et al. 1999

Tab. 68 Duration of the main Lateglacial isotope events in the oxygen isotope records. The limits of the NGRIP ice-core record (GICC05) are set according to the onsets given in **tab. 64**. The duration is given in ice-core years (yrs) and with the increase of the counting error within the event, not the accumulated total counting error. For the Chinese stalagmite records the limits are set according to the published values and the durations are given in stalagmite band years (yrs). For Lake Gościąż the estimated duration is given according to Kuc/Różański/Dubliński 1998 and in varve years (yrs). For Lake Perespilno also varve years (yrs) are given. The value in parentheses is the change in the sediment record of this lake. Correlations to comparable limits as used for the isotope records from the Greenland ice-core (see **tab. 64**) are given in italic and in parentheses. – For further details see text.

from the ice-core records (**tab. 66**). Some minor inconsistencies still remained between the oxygen isotope records from Lake Gościąż and NGRIP but the general pattern is very similar (**fig. 35**). In regard to the onset of the Holocene, the offset between the two records can be explained by the more complex formation and resulting composition of terrestrial isotope values. For instance, fluctuations in the hydrological system of the lake and its surrounding (e. g. Starkel 2002) could mask the climatic signal of the air temperature for the onset of the Holocene such as discussed for the lowest part of the Gościąż record (Kuc/Różański/Dubliński 1998, 159). Thus, a delayed reaction time of terrestrial climate signals compared to the ice-core records is an explainable lag. Consequently, a correlation of terrestrial records with the Greenland ice-core eventstratigraphy on the steepest gradient of the Holocene/Pleistocene transition is not advisable for approaches utilising high resolution records (cf. Friedrich et al. 1999, 33). This lag of terrestrial proxies becomes even more apparent through the comparison for the palynological onset of the Younger Dryas which followed some 20 years after the isotopic onset (cf. Ralska-Jasiewiczowa/Demske/van Geel 1998, 138-140; Goslar/Arnold/Pazdur 1998, 166 f.). The onset of the Holocene in the palynological record was almost concomitant with the increase in the varve thickness and the oxygen isotopes but the first indications of a changing environment were recorded some 30 years before this limit and continued some 10-20 years afterwards (Ralska-Jasiewiczowa/Demske/van Geel 1998, 140). However, the establishment of light shrub forest environments succeeded the isotope limit by almost 50 years and the expansion of trees was recorded 200-300 years later in this area (Ralska-Jasiewiczowa/Demske/van Geel 1998, 143).

In comparison with the MFM, this record contained enough varves between the onset of the Holocene and the onset of lamination to also contain the LST. However, visible ashes of the north-eastern fan of the LST were not found in the two Polish lakes. Either the LST was not deposited in the Polish lake sediments due to wind directions or the LST is present in the stratigraphy but not recognised yet, perhaps due to size (cryptotephra) or taphonomy (re-deposition). In fact, a small fluctuation in the lowest part of the oxygen isotope record (**fig. 35**) could correlate to a short-termed climatic deterioration such as caused by a volcanic eruption (cf. Friedrich et al. 1999).

A comparable short-termed, single episode was formed by a concomitant peak in biogenic silica (**fig. 35**) and phosphorus (sample size: six varve years) defining an eutrophication stage of the lake (Łącka/Starnawska/Kuźniarski 1998, 127). According to the difference of 527 ± 3 years between the onset of the Holocene and the biogenic silica peak in the Gościąż record, this peak would date to 12,181 ± 53 years cal. b2k. Eutrophication can occur due to nutrient surplus which may occur as a result of changes in the depositional environment (Pennington 1981, 216 f.). In fact, the maximum varve thickness was reached in this part of the record (Goslar 1998d, 106). Possibly, this increased deposition in Lake Gościąż was connected to a short amelioration period which was also recorded in the southern German Ammersee (Grafenstein et al. 1999, fig. 4) and caused presumably by thawing of soils which were frozen during the first severely cold part of the Lateglacial Stadial (Grafenstein et al. 1999). In the MFM sequence, a sharp change in the sediment record occurred 440 years after the onset of the Younger Dryas, i. e. 650 years before the onset of the Holocene around 12,290 years cal. b2k (Brauer et al. 1999, 325; Lücke/Brauer 2004). In contrast to the Ammersee record, varves became thinner mainly due to the absence of diatom bloom but, comparable to the Ammersee record, also due to a characteristic »graded silt layer [developed] at the base indicating surface runoff processes during the snow-melt in spring or early summer« (Brauer et al. 1999, 325). This amelioration in combination with the more open vegetation (Ralska-Jasiewiczowa/Demske/van Geel 1998), constant or increased precipitation (Goslar et al. 1998b), and higher wind actions (cf. Brauer et al. 2008; Neugebauer et al. 2012) would have dissolved more minerals and resulted in a higher sediment flow which resulted in the nutrient surplus and eutrophication of the lake. Perhaps, the biogenic silica peak in the varve record of Lake Gościąż also correlated with this accumulation of surface runoff processes following a climatic amelioration phase which according to the MFM chronology proceeded the Vedde Ash by some 120 years.

In the eastern German Lake Siethen, where besides the LST also the Icelandic Saksunarvatn Ash was documented, a peak of the ash concentration was recorded concomitant with peaks of silicon (Si), titanium (Ti), and aluminium (Al) in the mid-Younger Dryas (Kleinmann/Merkt/Müller 2002, 60-62). In this record, a greater than 10 cm thick influx of clastics was observed and assumed to come from the littoral zone due to the general increase of algae, in particular, the (rather eutrophic) *Cosmarium* sp. However, the very common littoral cladocera species *Bosmina longirostris* (Gr.) which also prefers eutrophic habitats sharply decreased at this point similar to the pollen of *Pinus* sp. and *Juniperus* sp., whereas a short and sharp increase of *Betula* sp. and *Salix* sp. pollen was recorded (cf. Kleinmann/Merkt/Müller 2002, 60 Abb.1). Stratigraphically below this disruption, laminated sediments of a better quality than the early Younger Dryas were deposited for a short period (Kleinmann/Merkt/Müller 2002, 61) and reflected a possible amelioration phase. Whether the disruption in the Lake Siethen sequence was solely associated with the preceding indications of amelioration and subsequent sediment flows or was additionally connected to the deposition of a volcanic ash such as the Icelandic Vedde Ash cannot be decided without a cryptotephra analysis of the profile.

However, varve thickness was generally high during the Lateglacial Stadial in Lake Gościąż and the short-termed and not recurrent peak in phosphorus remains unexplained. Furthermore, an indicator diatom taxa inhabiting eutrophic lakes (*Asterionella formosa*; Marciniak 1998, 147) had a minimum value at the corresponding depth (Marciniak 1998, 145 f.). A comparable pattern (increased input of silica, but no clear eutrophication indicators among the diatoms) was reported from north-eastern German sequences as a reaction to the deposition of the LST (de Klerk et al. 2008). Nevertheless, in the cladocera community which was sampled at other intervals, a small increase of the eutrophic littoral species *Bosmina longirostris* was observable in the record from the shallow northern bay around the depth of the biogenic silica peak, but this increase of eutrophic indicator species was not found in the cores from the deeper parts of the lake (Szeroczyńska 1998) from where the records usually originated.

If the short-lived episode in the Gościąż record was interpreted in analogy to the north-eastern German sequences as a reaction to volcanic activity, the Vedde Ash would be a very probable candidate. This ash was identified in the NGRIP record at 12,171 ± 114 years cal. b2k concomitant with the end of a mid-GS-1 amelioration phase. The date of 12,181 ± 53 years cal. b2k for the biogenic silica peak is consistent with the date for the Vedde Ash. Thus, if this association was correct, it would further confirm the chronology of the Gościąż record.

However, the Vedde Ash marks the end of an intense period in the Ca^{2+} corrected sulphate content in NGRIP beginning with peak 5 and containing several Icelandic ash deposits (**fig. 30**). Thus, a correlation with an older volcanic event in the NGRIP record is also possible and rather probable than a correlation with a younger eruption than the Vedde Ash (**fig. 35**). If the biogenic silica peak correlated to an older volcanic event, some error in the chronology of Lake Gościąż exceeding the counting errors had to be taken into account.

Between this peak and the onset of the Younger Dryas, as defined by the oxygen isotope values, some 585 varves were deposited. The period between this peak and the onset of the Younger Dryas is very similar to the period between the Vedde Ash and the onset of GS-1 in the NGRIP record (see above and p. 312).

Furthermore, the period between the Vedde Ash and the Ca^{2+} corrected sulphate peak 4 in NGRIP comprised 747 years and the period between the ice-core date of the Vedde Ash and the LST as dated by the MFM would comprise 759 years. Consequently, the number of varves counted below the biogenic silica peak in Lake Gościąż (n = 827 varves) indicates again that the varve formation in Lake Gościąż had begun before the LSE and, thus, the LST could be found within the laminated part of this record. In fact, if the Gościąż and the NGRIP records are correlated along the biogenic silica peak and the Vedde Ash a small fluctuation in the lowest part of the oxygen isotope record (**fig. 35**) correlates with the sulphate peak in the NGRIP record.

Since the association of the biogenic silica peak with a cryptotephra, particulary the Icelandic Vedde Ash, remains to be confirmed, the ice-core record is not shifted 18 years older towards the more precise Gościąż date to achieve a more precise Lateglacial chronostratigraphy. Furthermore, the chronology of Lake Gościąż relies on more analogies and correlations than the continuous NGRIP record and the difference of the biogenic silica peak and the Vedde Ash falls within the error estimates of both records.

In the other Polish stratigraphy, Lake Perespilno, an extreme peak or low in several minerals in the mid- to late Younger Dryas part of the sequence is concomitant with a small fluctuation in the magnetic susceptibility around varve no. 1923 (cf. Goslar et al. 1999). However, this indication of a volcanic eruption occurred some 300 years before the onset of the Holocene in this record and in comparison with the position of the Vedde Ash in the NGRIP record as well as with the biogenic silica peak in the Gościąż sequence, the Perespilno event might be some 100-200 years younger.

The short chronology from Lake Perespilno was synchronised palynologically with the record from Lake Gościąż (Bałaga/Goslar/Kuc 1998; Goslar et al. 1999) and, therefore, the close resemblance seems unsurprising. However, the oxygen isotopes from Lake Perespilno reacted with some offset to the NGRIP and the Lake Gościąż record, in particular during the Lateglacial Interstadial to Lateglacial Stadial transition (**tab. 66**). This offset was attributed to the changing budget of water in the lake environment (Goslar et al. 1999, 908). Perhaps, the more continental climate influenced absorption of the strong signals from the North Atlantic already in the Perespilno record and, therefore, the onset of the Lateglacial Stadial of this record is more comparable to the developments in the Chinese speleothems, particularly the Qingtian Cave, than the NGRIP record. However, at the Pleistocene/Holocene transition the onset of the oxygen isotopes in Perespilno is again very comparable to the Lake Gościąż and the NGRIP record suggesting that the hydrological impact was not very strong during this transition in Perespilno.

As a result for the Lateglacial chronology, the terrestrial oxygen isotope records confirmed the NGRIP limits in general and only partially helped to test and minimise the counting error. However, this detailed comparison provided some interesting suggestions in regard to the climate system and/or the registration in non-ice-core records: The components additional to the air temperature in the terrestrial oxygen isotope records not only seemed to make the climatic system more complex but also made it appear more inert to climatic impulses of the North Atlantic. In particular, the Asian monsoon was clearly affected by the impact of the oceanic signal but only continued developments in the oceans seemed to result in changes in the monsoon system. This decreasing sensitivity of terrestrial regimes resulted in more stable climates in the terrestrial sphere. A more continuous stability provided the possibility for adaptation and the establishment of stable biotic communities. However, some question relating to the influence of the hydrological components remained to be further evaluated. For example, how significant were the contrasting climatic signals of the air temperature and the hydrological system on the oxygen isotope records of terrestrial archives? How did the influence change, particularly during transitional periods? As long as the formation and composition of the considered terrestrial records is not understood in more detail, correlations of the terrestrial records with the Greenland ice-core records need to consider possible that offsets due to various reaction times between these records occurred and not due to incorrect chronologies.

Chronologies from laminated archives

Besides the terrestrial oxygen isotope curves, the dendrochronological archives and the varve records provided important climatic records combined with a high-precision chronology. These records give insights into the reaction of the ocean (Cariaco basin) and to the responses of the terrestrial sphere to the changes in the atmosphere and oceans.

The CEDC is the only climate and chronostratigraphic record which yielded a continuous chronology from modern day into the Lateglacial. In this archive, the growth patterns of the tree-rings served as climate proxy (Friedrich et al. 1999; Hua et al. 2009). A sudden increase of tree-ring widths was identified at 11,640 years cal. b2k (Friedrich et al. 2004) when tree-rings became on average more than one millimetre thicker within some 20 years (cf. Friedrich et al. 1999). The onset of the Holocene in the CEDC was often correlated with the isotopically defined onset of the Holocene event (GH) in the ice-core records. The period of thick tree-ring values lasted only *c.* 100 years after which the tree-ring width decreased again in two steps to values almost as low as previously. Around 11,410 years cal. b2k widths increased again but the tree-rings remained relatively unstable with large fluctuations. In the Preboreal pine record the isotopes ^{2}H and ^{13}C were measured (Friedrich et al. 1999, fig. 8). These records displayed constant increase since the Lateglacial Interstadial. A small decline was observable in the isotope values around the second increase in the tree-ring width at 11,410 years cal. b2k followed by an accelerated increase of the isotope values. Thus, the isotope values in the trees reacted to the Holocene amelioration with a delay of approximately 250 years in comparison to the tree-ring width. Possibly, water supply for the trees increased due to massive river discharges induced by melting glaciers and this surplus of water counteracted the temperature amelioration at the onset of the Holocene (Friedrich et al. 1999, 33). Hence, the isotopic record from the dendrochronological data set was not correlative to the extremely rapid onset in the isotope record from the Greenland ice-cores but displayed a delay comparable to the oxygen isotope record at the Hulu Cave.

However, the onset of the Holocene in the CEDC post-dated the signal by 41-63 years for the onset of GH in the five proxy records (oxygen isotopes, deuterium excess, insoluble dust content, calcium content, and annual layer thickness) analysed in a high-resolution study of the NGRIP ice-core (Steffensen et al. 2008). Clearly, this offset falls into the counting errors of NGRIP which has reached 98 years at this point (cf. Vinther et al. 2006; Rasmussen et al. 2006). In this case, the NGRIP record should be shifted towards the

main isotope events	NGRIP	CEDC	GLPC in Cariaco correlation (Australian)	Swiss correlation (Schaub et al. 2008a data)	CELM in IntCal09 corrected Swiss correlation
GH-11.4 (PBO)	11,490 ± 97	11,549 / 11,473	×	×	×
GH	11,681 ± 111	11,640	×	×	×
GS-1	12,770 ± 133	×	12,960 (12,810)	12,870 (12,900)	12,841-12,813
GI-1a	13,070 ± 142	×	×	13,170 (13,015)	13,013-12,985
GI-1b	13,250 ± 147	×	*13,440*	13,470 (13,280)	13,358-13,330
GI-1c_1	13,580 ± 156	×	*13,770*	×	×
GI-1c_2	13,730 ± 160	×	*13,810*	×	×
GI-1c_3	13,970 ± 166	×	*14,195*	×	14,220-14,192
GI-1d	14,090 ± 169	×	*14,215*	×	14,242-14,214
GI-1e	14,687 ± 187	×	×	×	×
GS-2a	16,230 ± 255	×	×	×	×
ref.	see **tab. 64**	Friedrich et al. 2004	Friedrich et al. 2001b; Kromer et al. 2004; Hua et al. 2009	Schaub et al. 2008a; Schaub et al. 2008b	Kaiser et al. 2012

Tab. 69 Comparison of the dates (given in years cal. b2k) for the onsets of the correlatives of the main Lateglacial isotope events in the European dendrochronological records. In the GLPC in Cariaco correlation the relative tree-ring no. 1,000 was correlated with 14,370 years cal. b2k (Kromer et al. 2004, 1206) and, thus, shifted the relative tree-ring chronology *c.* 50 yrs older than in Friedrich et al. 2001b. Italic values are according to the correlations given in Friedrich et al. 2001b but the ages were interpolated according to the tree-ring numbers in Kromer et al. 2004. Grey values were read from the published tree-ring growth patterns by the present author. – For further details see text.

tree-ring record but the question would arise: which of the proxy data should be considered correlative with the tree-ring width? The three main factors influencing the tree-ring growth are air temperature, precipitation, and duration of the growing season (Friedrich et al. 1999, 31; Friedrich et al. 2001b, 1226; cf. Schaub et al. 2008a, 30). Thus, higher temperatures, better water supply, and/or a longer growing season would have caused thicker tree-rings. Michael Friedrich and his colleagues assumed that the great similarity of the tree-ring growth patterns in various regions was mainly controlled by air temperature because precipitation was influenced by more local factors (Friedrich et al. 2001b, 1226). However, the combination of hydrological and thermal influences on the terrestrial oxygen isotope records was previously considered as reasons for delayed reactions (cf. p. 319-334). Perhaps, Friedrich and his colleagues underestimated the magnitude of the water stress influencing these terrestrial records and, consequently, the tree growth patterns. Another possible explanation for the offset of the two data sets, besides the counting errors, are changes in the influencing factors of the Greenland oxygen isotopes during this transitional period (cf. Landais et al. 2010; Thornalley et al. 2011). Influencing factors of the Greenland oxygen isotopes different from the air temperature are, for instance, evaporative origin or seasonality of the precipitation (Jouzel et al. 1997). These factors are related to the thermohaline circulation of the North Atlantic and are considered as major influences of the deuterium excess record (cf. Masson-Delmotte et al. 2005). In fact, the deuterium excess is the first high-resolution proxy record to change towards Holocene conditions (Steffensen et al. 2008). Consequently, a greater influence of these factors on the oxygen isotopes in Greenland could have led to a response of this proxy preceding the atmospheric thermal signal. Thus, the offset must not necessarily have a chronological reason but could reflect different response times. Therefore, both records remain unshifted and due to the counting error of the NGRIP record the limits for the onset of the Holocene are considered consistent.

The CEDC extends, thus far, only into the early mid-Younger Dryas and ends at 12,643 years cal. b2k (**tab. 69**; Friedrich et al. 2004; Schaub et al. 2008b; cf. Kaiser et al. 2012). The gap into the early Lateglacial Stadial is not yet unambiguously bridged. Thus, the ice-core records as a continuous data set across this

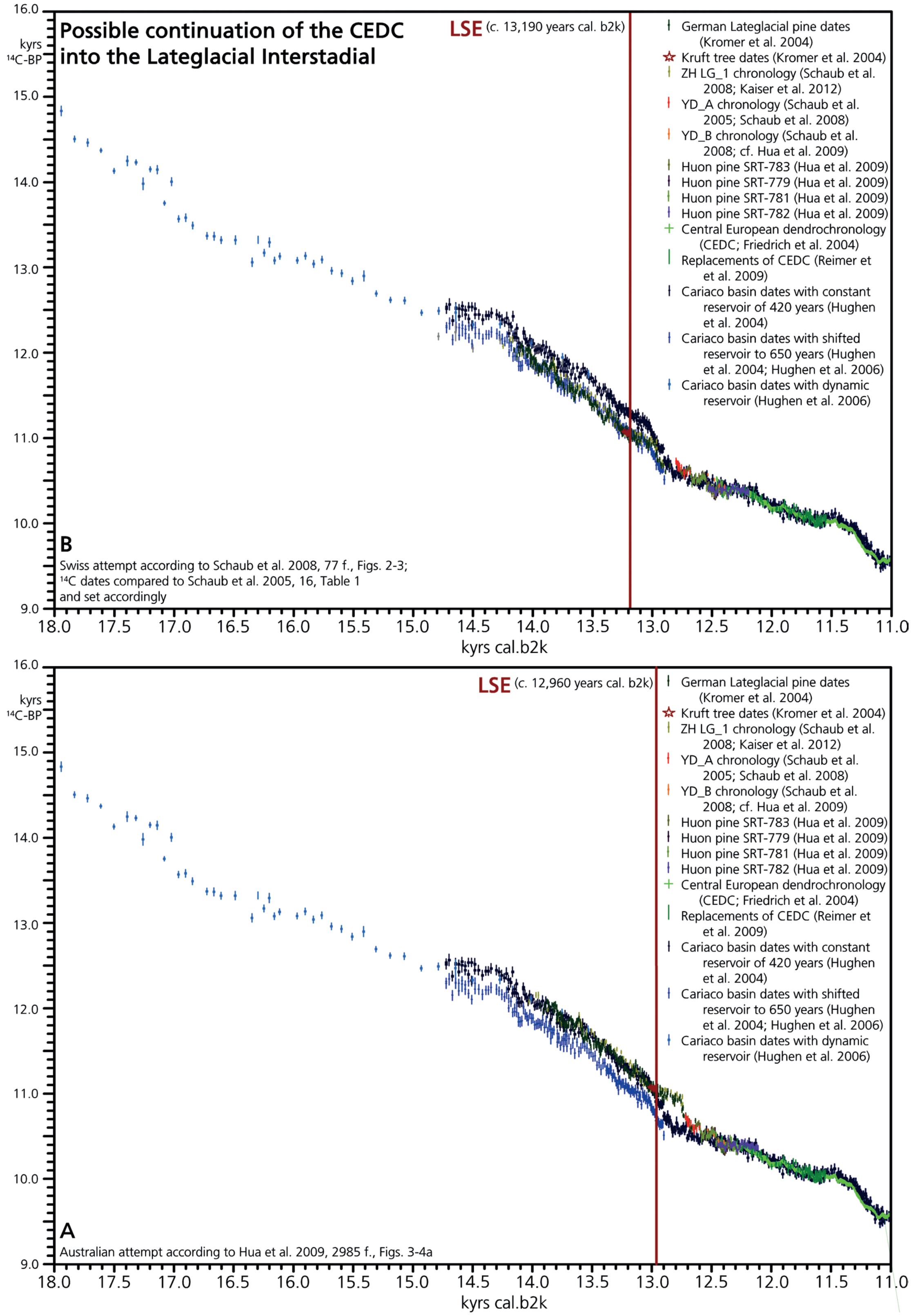


Fig. 36 Comparison of the ^{14}C calibration series according to **A** the Australian attempt (Hua et al. 2009) and **B** the Swiss attempt (Schaub et al. 2008b). Timescales shifted from cal. BP to cal. b2k. – For further details see text.

gap provided the more robust chronology. Nevertheless, the correlation of the tree-ring data can provide interesting insights in the reaction of the tree communities to climate changes, sustain the numerical chronostratigraphy, and are very valuable in the creation of a reliable ^{14}C calibration. The two recently proposed extensions of the CEDC and connections to the Lateglacial tree-ring chronologies (Kromer et al. 2004; Schaub et al. 2008a; Kaiser et al. 2012) produced comparable result for the duration of the Younger Dryas (Schaub et al. 2008b; Hua et al. 2009). Thus far, both records were wiggle-matched by their ^{14}C series to the existing calibration data but no dendrochronological confirmation was given for these correlations yet (cf. Kaiser et al. 2012).

The Australian Huon pines were correlated to the GLPC (**fig. 36A**). The onset of the Younger Dryas in the GLPC is defined by a sharp change in $\Delta^{14}C$ values (Kromer et al. 2004) which according to the new correlation began instantly after the correlation around 12,810 years cal. b2k and continued over 130 years (Hua et al. 2009, 2986). Consequently, the GS-1 would last 1,170 years (**tab. 70**). This rapid change was dated some 240 years older in the original correlation of the GLPC to the Cariaco basin data set (Kromer et al. 2004; Hua et al. 2009, 2985).

A comparable shift of the GLPC some 300 years younger than in the original correlation and also 60 years younger than suggested by the Australian Huon pines was previously suggested based on the best fit in a correlation of $\Delta^{14}C$ values with a climate corrected ^{10}Be flux record (Muscheler et al. 2008). The correlated $\Delta^{14}C$ record was based on the GLPC as well as CEDC data sets and the climate corrected ^{10}Be flux record was taken from GISP2 with a chronology synchronised on the GICC05 timescale. However, by this correlation the end of the GLPC would date to 12,550 years cal. b2k and would clearly have overlapped with the extension of the CEDC into the Lateglacial Stadial (Schaub et al. 2008b; Hua et al. 2009). The age for the onset of the Younger Dryas would shift to *c.* 12,690 years cal. b2k. This correlation was rejected by the Australian as well as the Swiss attempt. Besides inaccuracies of the correlation arising from the precision of the ^{10}Be measurements, further uncertainties can result from an uncorrected possible climatic influence on the deposition of the ^{10}Be isotopes, from unknown reservoirs of the ^{14}C ages, and from the chronologies of both data sets in general (Muscheler et al. 2008, 2). Thus, further improvements of these sectors are necessary, for example a closely sampled ^{10}Be record from NGRIP. With these improvements a more direct comparison of the ^{14}C records and the ice-core records could help to further enhance the precision and accuracy of the Lateglacial chronostratigraphy.

The Swiss attempt at bridging the early Younger Dryas gap was principally through correlation to the deep sea record from the Cariaco basin (**fig. 36B**; Schaub et al. 2008b). Even though the reservoir ages in the Cariaco basin record were considered relatively constant, significant fluctuations were suggested for the last glacial period (Hughen et al. 2006). For the Lateglacial this type of shift from reservoir ages of approximately 420 years during the Lateglacial Stadial to 650 years for the period between 13,050 and 14,050 years cal. b2k was signified by the comparison with the floating GLPC chronology (Kromer et al. 2004; Hughen et al. 2004c). The Swiss attempt applied this shift from approximately 12,900 years cal. b2k backwards, i.e. from the end of the transition from the Lateglacial Interstadial to the Lateglacial Stadial as defined by the ^{14}C isotope curve (Schaub et al. 2008a). Additionally, the Swiss data set was correlated to the Dättnau sequence and, consequently, to the CELM (Kaiser et al. 2012) as well as to the GLPC itself (Schaub et al. 2008b). The onset of the Younger Dryas was again correlated with the sharp gradient in the ^{14}C data series and an increase in the average growth rate of the tree-rings (Schaub et al. 2008b, 82f.). In addition, a reduction of the segment lengths covered by the single trees was observed concomitantly. This transition occurred according to the data of Matthias Schaub and his colleagues some 250 years after the end of the extended Holocene dendrochronology (Schaub et al. 2008b, 83f.) and, thus, around 12,893 years cal. b2k. According to the correlation with the Cariaco basin record, the onset of the Younger Dryas was set to tree-ring

main isotope events	NGRIP (GICC05)		GLPC (Australian attempt)	Swiss data (Schaub et al. 2008a) data)	CELM	MFM		Holzmaar	Rehwiese	Hämelsee	Cariaco basin
GS-1	1,089 ± 22 yrs		1,320 (1,170) yrs	1,230 (1,260) yrs	1,201-1,173 yrs	1,089 (1,039) yrs (sediment)		1,012 yrs (sediment); 974 (pollen)	982 yrs (microfacies); 1,230-1,017 yrs (pollen)	×	1,335 (1,235) yrs (grey scale)
GI-1a	300 ± 9 yrs		×	300 (115) yrs	200-144 yrs			229 yrs (pollen)			400 yrs
GI-1b	180 ± 5 yrs		×	300 (265) yrs	373-317 yrs	671 yrs (pollen)		274 yrs (pollen)	660 yrs (pollen+ sediment)	625 yrs (pollen+ sediment)	
GI-1c$_1$	330 ± 9 yrs		330 yrs	×			1,341 yrs (preserved; interpolated: 1,851 ± 180 yrs [sediment]; 1,771 ± 180 yrs [pollen])	40 / 380 yrs (pollen)			400 yrs
GI-1c$_2$	150 ± 4 yrs	1,917 ± 54 yrs	40 yrs	×	890-834 yrs	190 yrs (pollen)		×	×	×	
GI-1c$_3$	240 ± 6 yrs		385 yrs	×		130 yrs (pollen)		×	×	×	400 yrs
GI-1d	120 ± 3 yrs		20 yrs	×	50-1* yrs	130 yrs (pollen)		×	×	×	
GI-1e	597 ± 18 yrs		×	×	×	220 yrs (preserved; interpolated [sediment+pollen]: 650 yrs)		×	×	×	c. 608 yrs
GS-2a	1,543 ± 68 yrs		×	×	×	×		1,820 yrs	×	×	
ref.	see **tab. 64**		Friedrich et al. 2004; Kromer et al. 2004; Hua et al. 2009	Friedrich et al. 2004; Schaub et al. 2008b; Schaub et al. 2008a	Friedrich et al. 2004; Kaiser et al. 2012	Brauer/Endres/Negendank 1999; Litt/Stebich 1999; Brauer et al. 2008		Leroy et al. 2000; Zolitschka et al. 2000	Neugebauer et al. 2012	Merkt/Müller 1999	Hughen et al. 2000; Hughen et al. 2004b

Tab. 70 Durations of the main Lateglacial isotope events and the correlatives in the various laminated sequences. The limits of the NGRIP ice-core record (GICC05) are set according to the onsets given in **tab. 64**. The duration is given in ice-core years (yrs) and with the increase of the counting error within the event, not the accumulated total counting error. ***** one year is given here because negative durations are not possible for events but if the oldest possible onset for GI-1c is subtracted from the youngest possible onset of GI-1d the result would be -6 years. The limits in the Meerfelder Maar record (MFM) are set according to changes in the varve composition (sediment) for the main changes in the Lateglacial (Brauer/Endres/Negendank 1999; Brauer et al. 2008) but only differences in the vegetation record (pollen) are recognised during the Lateglacial Interstadial and the limits are set accordingly (Litt/Stebich 1999). In the Holzmaar record 320 varves are added in the GS-1 section (Leroy et al. 2000; Zolitschka et al. 2000).

no. 1,350 which dated approximately to 12,870 years cal. b2k (**fig. 36**; Schaub et al. 2008b, 82[39]). In this correlation, the Younger Dryas would have encompassed 1,230 years (**tab. 69**).
In a numerical comparison, the Australian results more closely resembled the oxygen isotope record from NGRIP and the $^{230}Th/^{234}U$ date from the Hulu Cave than the Swiss attempt. In fact, in a more recent presentation (Kaiser et al. 2012), the Swiss YD_A chronology was compared to the IntCal09 calibration which relied on the Australian attempt (Reimer et al. 2009). This suggestion would shift the YD_A chronology some 70 years younger on the calendar timescale than was suggested by Matthias Schaub and his colleagues (Schaub et al. 2008b). In this case, an overlap of the YD_B chronology with the YD_A record should be observable over some 70 years in the dendrochronological record. In the CELM a sharp decline in ^{14}C ages was recorded between the maximum values dated to *c.* 2,215 and *c.* 2,330 years relative tree-ring ages with the steepest part around the relative tree-ring no. 2,246 (Kaiser et al. 2012, fig. 6). Besides the ^{14}C ages, the number of available trees significantly decreased whereas the tree-ring width generally increased but began to wiggle strongly (Kaiser et al. 2012, fig. 5). However, a smaller excursion in the tree-ring width began some 50 tree-rings earlier around the ring no. 2,200 and the onset of the Younger Dryas as an environmental event displayed by tree growth patterns (event 9) was set to this 50 years earlier increase (Kaiser et al. 2012, 86 f.). In this comparison, ring no. 899 of the CELM was anchored at 14,142-14,114 years cal. b2k (Kaiser et al. 2012). Consequently, the onset of event 9 dated to 12,841-12,813 years cal. b2k. Nevertheless, uncertainties in the IntCal09 data, in particular, at the onset of the Lateglacial Stadial caused Klaus Felix Kaiser and his colleagues to consider the anchorage of the CELM with the IntCal09 calibration record only as an approximation (Kaiser et al. 2012, 87).
Since the onset of the Lateglacial Stadial was a very gradual transition in climatic and environmental parameters, a better correlation point should be used for the construction of a Lateglacial chronostratigraphy. The widely recognised volcanic LSE event marks a good correlation point in this period. Some poplars (*Populus* sp.) preserved near the volcano within the LST were matched to the GLPC (**fig. 10**) and, thus, related the dating of the LSE exactly to this still floating dendrochronological record (Baales/Bittmann/Kromer 1998; Friedrich et al. 1999, 34; Kromer et al. 2004, 1205). The sharp decline of ^{14}C ages at the onset of the Younger Dryas post-dated the LSE in this record by some 200 years (Kromer et al. 2004, 1205 f.).
For a better understanding the floating GLPC (Kromer et al. 2004) and the equally floating CELM (Kaiser et al. 2012) are correlated based on some shared tree-ring sequences and ^{14}C dates (see **tab. 2; fig. 37**). In the dendrochronological comparison, the first 200 years of both records were assumed to be mainly influenced by Dättnau sequence (cf. Kaiser et al. 2012, 86; Friedrich et al. 2001b, 1226). The comparison reveals that the two records correlate either in the tree-ring growth patterns or in the ^{14}C dates. The ^{14}C dates and tree-ring growth patterns were correlated in both records according to the respective relative tree-ring numbers[40]. However, in the two possible correlations, different positions of the LSE became apparent. This clarification is of some importance if the LSE is used as a correlation point. The assumed impact of the LSE which was identified by a disturbance in the tree-ring growth patterns (E7) in the Dättnau record (Friedrich

39 For the onset of the Younger Dryas various dates were given such as 12,900 years cal. b2k (i.e. ring no. 1,320) or ring no. 1,400 (i.e. 12,820 years cal. b2k; Schaub et al. 2008b, 83) but ring no. 1,350 corresponds to a significant decrease in the Allerød to Younger Dryas transition (Schaub et al. 2008b, 83) and is selected as onset according to the convention in the current study.

40 The comparison of the ^{14}C dates given in Kromer et al. 2004, 1204 fig. 1 & supplementary data and the ones given in Friedrich et al. 2001b, 1227 fig. 7 indicate that the same relative ring numbers/positions were used and, consequently, the connection of ^{14}C dates and tree-ring growth patterns seems correct for the GLPC. The CELM data were given in the same article, the tree-ring growth patterns in the relative Zürich scale (Kaiser et al. 2012, 86 fig. 5) and the ^{14}C dates in the SWILM relative scale (Kaiser et al. 2012, 87 fig. 6). These two scales were assumed to be identical and Klaus Kaiser did not correct this assumption as false in a written communication in May 2011. Still, this assumption remains a possible source of erroneous correlations.

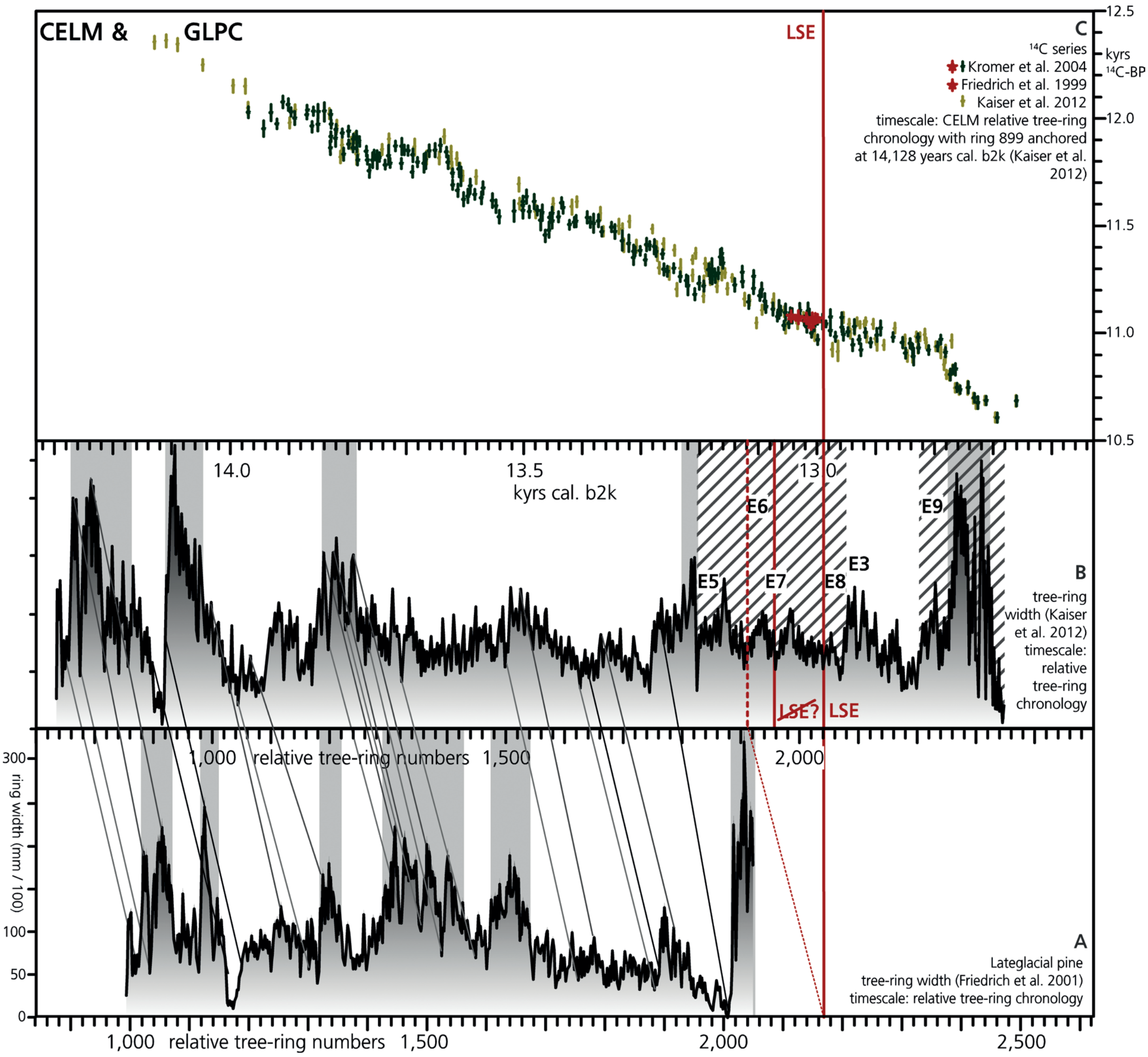


Fig. 37 Correlation of Central European Lateglacial Master chronology (CELM; Kaiser et al. 2012; see **fig. 11**) with the German Lateglacial pine chronology (GLPC; Kromer et al. 2004; see **fig. 10**) along the shared ^{14}C dates. Grey shaded areas relate to periods with an average tree-ring growth of more than 1.25 mm/yr. Thin bars are given as guide lines (light grey: low; medium grey: high; black: transition. – Dotted line: LST correlation) for the correlation along the tree-ring growth patterns. **A** Tree-ring width record of the GLPC given with relative tree-ring number as timescale (Kromer et al. 2004). – **B** Tree-ring width record of the CELM given with relative tree-ring number as timescale (Kaiser et al. 2012). Dark grey hatched areas are events E6 and E9 according to Kaiser et al. 2012, fig. 5, where also the short-term events E5, E7 and E8 are given. E3 is set according to Schaub et al. 2008a, 36-38. – **C** ^{14}C series (some dates were set slightly apart for better readability). Timescale according to the correlation of CELM with IntCal09 (Kaiser et al. 2012) and shifted from cal. BP to cal. b2k.

et al. 1999, 34) was not correlative with the position of the LSE as assumed from the poplars in the GLPC (Friedrich et al. 1999, 36-38). Besides the growth disturbance E7 which occurred in what was assumed to be GI-1b, further short-termed disturbances in the Swiss records were documented, for example, a some 100 years younger event (E8) fell to the transition from the assumed GI-1b to the assumed early GI-1a (Kaiser et al. 2012, 85 f. fig. 5). Another short-termed but sharp event (E3) occurred another 20-25 years later than E8 within early GI-1a (Schaub et al. 2008a). The latter two positions were in accordance with the position of the LST in laminated sequences of Central Europe based on the vegetation development (Lotter et al. 1992; Litt et al. 2001, 1247 tab. 3; Magny et al. 2006). However, the correlation of the CELM with the GLPC revealed that none of these events is equivalent with the LSE in the GLPC which according to the correlation of ^{14}C dates post-dated the E7 in the CELM by some 80 years (**fig. 37**). If the two records were correlated along the tree-ring growth patterns the LSE in the GLPC would predate the E7 in the CELM record by some 40 years. Thus, the two different correlations are offset by approximately 125 years with the ^{14}C wiggle matching resulting in the younger ages.

According to the classic correlation of the ^{14}C dates of the floating GLPC with the Cariaco basin calibration data set, the LSE was dated to approximately 13,200 years cal. b2k (Kromer et al. 2004, fig. 2). Based on the shift suggested by the Swiss attempt, the LSE would date to approximately 13,070 years cal. b2k, whereas the Australian Huon pine attempt would result in an age of approximately 12,965 years cal. b2k. The IntCal09 corrected Swiss attempt resulted in an age of approximately 12,961-12,913 years cal. b2k. These latter dates are consistent with the date for the LSE in the MFM varve record (12,930 ± 30 years cal. b2k) as well as the Ca^{2+} corrected sulphate peak 4 in NGRIP at 12,918 ± 138 years cal. b2k (see p. 9-12 and p. 310-312. 317 f.; cf. Mortensen et al. 2005). Since all dates relate on the correlation of the ^{14}C ages, the possible offset of 125 years in the tree-ring growth patterns make no difference in these ages. In general, the Swiss attempt would be given priority in the present analysis due to the intra-hemispheric and also Central European character of the underlying data but the offset between the date for the LSE as given by the Swiss attempt to date the MFM as well as assumed by the sulphate content of NGRIP is too significant to be neglected.

In addition, the correlation of the tree-ring growth patterns is difficult due to partially intense reactions of the tree-rings to very local factors (cf. Schaub et al. 2008a). The position to which the YD_A chronology was placed according to the suggestion of the IntCal09 corrected Swiss attempt appears to correlate with the onset of the Younger Dryas (event 9) in the CELM (Kaiser et al. 2012) and the onset of the extended CEDC record. The exact position in the current project was chosen according to the correlation of the GLPC ^{14}C data set along the LSE in the MFM record. In this correlation, a significant overlap of the YD_A chronology with the YD_B chronology would have also resulted in a small overlap of the CELM with the YD_B dendrochronological record (**fig. 38**). The very low values at the younger end of the CELM as well as the very low values at the onset of the YD_B chronology correlate with a short but significantly low value in the YD_A chronology. This low point correlates to the lowest point in the NGRIP oxygen isotope record in GS-1. Furthermore, a small peak in the YD_A chronology followed by another low point immediately before the end of the YD_A chronology are correlative with the developments at the onset of the YD_B chronology. In this correlation the assumed onset of the Younger Dryas in the CELM dendrochronological record correlates with the onset of the Lateglacial Stadial in the oxygen isotopes in NGRIP (**fig. 38**). This onset of the Younger Dryas in the dendrochronological records was marked in the CELM and also in the YD_A chronology by an increase of the tree-ring width which quickly declined again in the YD_A chronology but further increased in the CELM dendrochronological record. The number of trees for the CELM is very low in this part and the tree-ring growth patterns are influenced intensely by age-related factors (Kaiser et al. 2012, 86) making the pattern of the YD_A chronology more reliable in this part. Furthermore, if the 125 years offset between the two different correlations of the GLPC and the CELM were based on a miscorrelation in the CELM record (see above) the dendrochronological record of the CELM would have to be shifted 125 years older on the timescale. In this case, the CELM and the YD_A chronology would only overlap for a few years or decades. Moreover, the increasing tree-ring width values at the end of the CELM would correlate with the end of GI-1a and the final decline in these values would be concomitant with the onset of the GS-1 in the NGRIP record. Even though these uncertainties about the position of the CELM record remain, the position of the YD_A according to the revised Swiss attempt appears reliable based on the dendrochronological comparison but the very short overlap of the involved records and the reduction in number of trees makes this correlation still insecure.

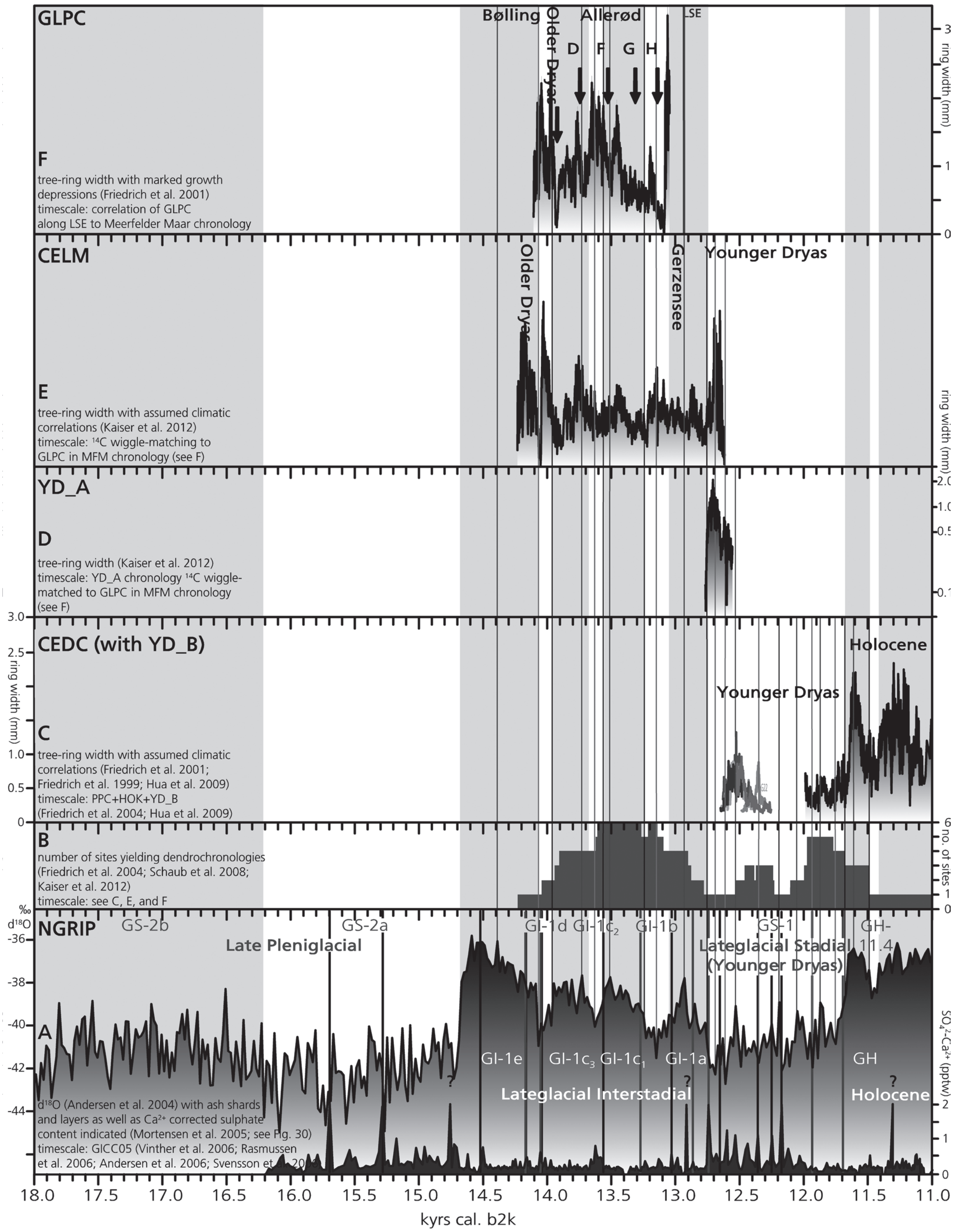


Fig. 38 Comparison of NGRIP with the European dendrochronologies. Thin bars given as guide lines (light grey: low; medium grey: high; black: transition). **A** Oxygen isotope record from NGRIP with the Ca^{2+} corrected sulphate content but without associated ash layers (see **fig. 30**). Grey shaded areas represent events of more interstadial values than the surrounding values. – **B** Number of sites from Central Europe yielding dendrochronologies (Friedrich et al. 2004; Schaub et al. 2008b; Kaiser et al. 2012). Timescale is according to C and E. – **C** Central European dendrochronology (Friedrich et al. 2004; Schaub et al. 2008b; Hua et al. 2009). – **D** YD_A chronology (Schaub et al. 2008b; Kaiser et al. 2012). – **E** Central European Lateglacial Master chronology (Kaiser et al. 2012). – **F** German Lateglacial pine-chronology (Friedrich et al. 2001b; Kromer et al. 2004). – Correlations of tree-ring growth patterns with climatic bio-chronozones in C-F are given according to the respective authors. For further details see text.

Without a secure connection between the CEDC and the Lateglacial tree-ring chronologies (YD_A, GLPC, CELM) the full chronostratigraphic potential of the latter cannot be explored. Thus far, the chronostratigraphic value of the dendrochronological record in the Lateglacial Interstadial depends partially on how good the tree-ring growth patterns reflect the climate signal (cf. Friedrich et al. 2001b; Schaub et al. 2008a). However, a comparison of the various attempts at identifying the isotope events in the Lateglacial Interstadial section of the tree-ring growth patterns illustrates the importance of very local *stimuli* and also the apparently varied response times of the tree-rings (**fig. 38**; cf. Friedrich et al. 2001b; Kaiser et al. 2012). These local factors were also revealed by the number of trees per site which is usually given in the original publications and indicates besides the reliability of the chronology also the density of tree cover at this spot and the local preservation quality. In contrast, the number of sites containing preserved trees reflects the general conditions of preservation as well as the spread of forest cover in Central Europe (**fig. 38B**). However, to evaluate the exact number of sites is partially difficult because some chronologies such as the Danube one were made of trees from several spots in the gravels. These trees were often driftwood which stranded on the river banks and got covered by the gravels. Their origin cannot be further specified but the Danube or the Upper Rhine valley and are therefore counted as a single site in this study. The gravels in the Upper Rhine valley also produced several pine remains (cf. Friedrich et al. 2004, fig. 1) of which at least some can be attributed to the Late Pleniglacial (cf. Rosendahl et al. 2006). However, this material did not contribute to a dendrochronology and cannot be exactly positioned on a calender time scale. Therefore, this region is not counted in the graph.

Besides the CEDC, the Eifel maars provided an almost continuous chronology up to present day. However, due to discontinuous varve formation in the upper part of the MFM record and a hiatus in the early Holocene of this record as well as disturbances in the mid-Holocene part of the Holzmaar record (Brauer et al. 2000b; cf. Lücke et al. 2003), these records cannot be regarded as completely continuous. Based on a comparison of both records an almost continuous varve chronology could be established that was correlated along the Ulmener Maar tephra at 11,050 years cal. b2k and along the LST in the final Lateglacial Interstadial. The micro-hiatus of approximately 240 varves in the early Holocene of the MFM occurred some 1,000 varves on top of the Ulmener Maar tephra and, therefore, did not affect the Lateglacial.

In the MFM record the transition between the Younger Dryas and the Pleistocene was defined by a decrease in varve thickness and a change from a minerogenic to organic dominated sedimentation at 11,640 ± 40 years cal. b2k (**tab. 71**; Brauer/Endres/Negendank 1999; Brauer et al. 2000b). This change was concomitant with an increase of pine (*Pinus* sp.) in the pollen profile marking the palynological onset of the Holocene (Litt/Stebich 1999). However, the decrease of the varve thickness was gradual and lasted until 11,580 ± 40 years cal. b2k (cf. Brauer/Endres/Negendank 1999, fig. 4). In the 4 cm below the transition, the varve preservation was poor and as a result the exact point of change could not be set unambiguously based on the varve thickness. According to the varve chronology, this section of poorly preserved varves began at 11,690 ± 40 years cal. b2k if a maximum error of 20 % for the recognition of varves was taken into account (Brauer et al. 1999, 324). In the Holzmaar sequence, also a change from organic to rather organic-minerogenic sediment was observed and dated to 11,658 ± 128[41] years cal. b2k (Leroy et al. 2000, 54-57). In the pollen composition, an instant response of *Filipendula* sp. which indicate mean temperatures in July of a minimum of 10°C was used to characterise the onset of the Holocene which preceded the change in the sediment by some decades and was set to 11,682 ± 129 years cal. b2k (Leroy et al. 2000, 64). The increase of pine occurred some decades later around 11,625 years cal. b2k and was succeeded by an

41 The error estimate is based on a counting error of 1.1 % which adds up constantly in the Holocene and Lateglacial part of the record (Brauer et al. 1994, 329; Zolitschka 1998).

main isotope events	NGRIP	MFM	Holzmaar	Hämelsee	Rehwiese	Cariaco Basin
GH-11.4 (PBO)	11,490 ± 97	×	×	×	×	×
GH	11,681 ± 111	11,640 (11,690) ± 40 (varve thickness)	11,690 ± 129 (diatom); 11,682 ± 129 (pollen); 11,658 ± 128 (sediment composition); 11,640 ± 128 (AP increase)	11,660 ± 119 (amelioration); 11,628 ± 118 (sediment composition; algae; caldocera); 11,610 ± 118 (pollen)	11,690-11,410 (pollen); 11,743 (micro-facies)	11,630 ± 16 (grey scale)
GS-1	12,770 ± 133	12,729 ± 40 (varve thickness + pollen)	12,670 (sediment)[1]; 12,656 (pollen, PAZ 9)[1]	*c.* 12,750	12,725 (micro-facies); 12,730-12,707 (pollen)	12,965 ± 16 (grey scale); 13,015± 10 (^{14}C)
GI-1a	13,070 ± 142	*c.* 12,900 (pollen)	12,885 (pollen, PAZ 7)[1]	*c.* 12,950	×	×
GI-1b	13,250 ± 147	*c.* 13,100 (pollen)	13,159 (pollen, PAZ 6)[1]	*c.* 13,175	×	*c.* 13,365
GI-1c_1	13,580 ± 156	13,400 ± 40 (pollen)	13,199 (pollen, PAZ 5)[1]; 13,539 (pollen, PAZ 3)1	*c.* 13,320	×	×
GI-1c_2	13,730 ± 160	13,590 ± 40 (pollen)	13,355 (pollen, PAZ 4)[1]; 13,635 (pollen, PAZ 2, Older Dryas)[1]	×	×	*c.* 13,765
GI-1c_3	13,970 ± 166	13,730 (*13,840*) ± 40 (pollen) 13,750 (*13,860*) ± 40 (sediment)	13,723 (pollen, PAZ 2, Bølling)[1]	×	×	×
GI-1d	14,090 ± 169	13,850 (*13,960*) ± 40 (pollen + sediment)	×	×	×	*c.* 14,165
GI-1e	14,687 ± 187	14,070 (*14,180*; onset of varve preservation; interpolated onset [sediment+pollen]: 14,500 (*14,610*) ± 220)	14,730 ± 300 (peak of sedimentation rate; other onsets [increased lacustrine productivity]: 14,240 ± 270; [pollen preservation, onset allochtonous varves]: 14,208[1])	×	×	*c.* 14,773
GS-2a	16,230 ± 255	×	16,550	×	×	×
ref.	see **tab. 64**	Brauer/Endres/Negendank 1999; Litt/Stebich 1999; Litt et al. 2001; Brauer et al. 2008	Leroy et al. 2000; Zolitschka et al. 2000	Merkt/Müller 1999; Litt et al. 2001	Neugebauer et al. 2012	Hughen et al. 2000; Hughen et al. 2004b; Hughen et al. 2006

Tab. 71 Comparison of the dates (given in years cal. b2k) for the onsets of the correlatives of the main Lateglacial isotope events in the varve records. Ages in grey are according to the reading of the present author. Italic ages set in parentheses in the MFM column contain additional 110 years due to a comparison of a 4 cm slump and turbidite section with the Lake Wollingst (Brauer et al. 2000a). [1] Varve chronology according to Leroy et al. 2000 with additional 320 years for the ages before the mid-Younger Dryas. – For further details see text.

increase of birch (*Betula* sp.) around 11,600 years cal. b2k. Furthermore, an increased occurrence of planktonic diatoms were already observed at 11,690 ± 129 years cal. b2k in the Holzmaar record (Leroy et al. 2000, 66 f.). Hence, the Holocene/Younger Dryas transition in the Holzmaar record dated to the same period as in the MFM record (Brauer et al. 2000b) but in detail the response times were different. The sedimentological response was some 30 years slower in the Holzmaar than in the MFM, whereas the first palynological indicator reacted some 40 years previous to the MFM record. If in both records the increase of pine is compared, the Holzmaar record again lagged behind the MFM record by some 15 years. Even though the localities are situated very close to each other, the topography might have caused the different response times of the vegetation and as a result the establishment of the new sedimentological regime. Nevertheless, the development of the varves in the MFM and the Holzmaar record documented exactly the offset between the limits of this important transition in the Greenland oxygen isotope record and the CEDC (see **tab. 69**) with an onset of changing climates around 11,690 years cal. b2k and an establishment of the new climatic and environmental conditions around 11,640 years cal. b2k.

The onset of the Younger Dryas was previously determined by the general composition and formation of the sediment as well as the palynological development from 12,730 years cal. b2k (Brauer et al. 1999; Litt/Stebich 1999). More recently, a high-resolution analysis of the MFM sediments identified the precise onset at 12,729 varve years cal. b2k (Brauer et al. 2008). This date marked a significant shift in wind track patterns in north-western Europe. These patterns are influenced by fluctuations in the polar front (i. e. drifting oceanic ice), which is also an important factor influencing in the deuterium excess (Guiter et al. 2003, 70). However, the change in deuterium excess marking the onset of the Lateglacial Stadial was recorded almost 170 years earlier in the NGRIP record (Steffensen et al. 2008). In the MFM record, an approximately 30 year prelude to this shift was detected with short intervals of varying wind and moisture climate and the varve thickness gradually began decreasing some 50 years before the shift (Brauer et al. 2008, 521 fig. 2). Although this period clearly post-dates the change in the deuterium excess (12,896 ± 138 years cal. b2k), it coincided almost perfectly with the onset of GS-1 in the oxygen isotope record (**tab. 64**). In the deuterium excess record, a small recovery of the values can be observed after the significant low values at the onset of this new deuterium excess regime (**fig. 3**). Thus, the coincidence of the changed wind track patterns in the MFM record with the decreased air temperatures in Greenland supportes the suggestion of different response times to the onset of the Lateglacial Stadial in the high latitudes atmosphere and in the low latitudes ocean. If this process of the Lateglacial Stadial cooling was related to some type of Heinrich event (Andrews et al. 1995; Dokken/Jansen 1999) various phases of this event with different effects at different latitudes could be a possible explanation for these offsets (cf. Stanford et al. 2011b). However, a problem in the varve chronology of the Eifel maars cannot be excluded completely. For instance, the Younger Dryas section of the nearby Holzmaar only encompasses 654 varve years and the limit from the Lateglacial Interstadial to Lateglacial Stadial would date to 12,350 varve years cal. b2k (Leroy et al. 2000, 57). Since the two maar records were correlated along the Ulmener Maar tephra and the LST, the amount of varves between those markers were relevant for the interpolation of the missing varves in the Holzmaar record. According to this comparison some 320 varves were missing in the Holzmaar record (Leroy et al. 2000; Brauer et al. 2000b). Based on sharp changes in the pollen record, Suzanne A. G. Leroy and her colleagues assumed that the majority of varves were missing in the mid-Younger Dryas section around 12,075 varve years cal. b2k (Leroy et al. 2000, 67). This could explain the considerably short duration of the Younger Dryas. However, bioturbation and underestimation due to poor varve quality were also considerable as alternative explanations for missing varves. Nevertheless, the onset of the Younger Dryas as revealed by the sediment as well as by the pollen is considerably younger than in the nearby MFM also with the 320 additional varve years (Leroy et al. 2000). Since the records were correlated tephrochronologically, different response times or possible inconsistent definitions appear the most probable explanation for this discrepancy. Moreover, in the MFM record, no disturbed sediment was observed within the Lateglacial Stadial except for the 4 cm below the Pleistocene/Holocene transition and, thus, only an unrecognised hiatus in this record could explain a chronological offset. In contrast to the Holzmaar record, no sharp change in the pollen profile was observed (cf. Litt/Stebich 1999).

In the MFM, a change from organic to clastic varves was observed at 12,290 varve years cal. b2k reflecting a significant change in the depositional system of the lake (Brauer et al. 1999, 325). This change reflects reduced wind intensities (cf. Brauer et al. 2008) that could be correlated with a warming episode recognised during the mid-GS-1 in the NGRIP oxygen isotope record (see p. 293 f. and **tab. 63**; cf. p. 332). If this correlation is correct the MFM record and the NGRIP record were still quasi-simultaneous in the mid-Lateglacial Interstadial. Even though the LST has not, to date, been indentified in the NGRIP record (cf. Mortensen et al. 2005), peak 4 in the Ca^{2+} corrected sulphate content (**fig. 30**) could be correlated with the dating of the LST in the MFM record. If this correlation is substantiated, the MFM and the NGRIP record were almost synchronous from the onset of the Holocene to the LSE.

The limits within the Lateglacial Interstadial were mainly based on the development of the pollen record in both maars (Litt/Stebich 1999; Leroy et al. 2000) because the sediment showed only small and gradual lithological differences in this part (Brauer/Endres/Negendank 1999; Brauer et al. 2000b; Brauer et al. 2000a). However, in the MFM record some 4 cm of slump and turbidite were found below 13,590 years cal. b2k. Based on a palynological correlation with the northern German Lake Wollingst, a further 110 varve years were added to the varve chronology (Brauer et al. 2000a). In the Holzmaar record, the comparable palynological zone of an increase of birch ended by an increase of sagebrush (pollen zone 2, Bølling part) was clearly much shorter than in the MFM (Leroy et al. 2000, 62 f.). Thus, either the additional 110 years overestimate this period in the Eifel region or 162 varves had to be added to the Holzmaar record below this point. The end of this period dated to 13,635 years cal. b2k and, thus, *c.* 45 years older than in the MFM. Besides a chronological gap in the MFM record, a delayed response in the MFM record could be a possible explanation for this difference. For both records there are no further marker horizons which could tie them reliably to the calendar chronology and the limits set according to the palynological analysis are very arbitrary in relation to the onsets of the isotope events.

In general, the lithological sub-divisions are more comparable to the main isotopes events than the pollen record but the only remaining lithological limits are the onset of varve formation and organic sediment in the MFM record and the onset of biogenic varve formation in the Holzmaar record which were both related to the onset of the Lateglacial Interstadial (Brauer/Endres/Negendank 1999; Leroy et al. 2000; Zolitschka et al. 2000). In the MFM, the varve formation began only around 14,070 years cal. b2k (with added 110 years: 14,180 years cal. b2k). At this point the Lateglacial Interstadial lake environment stabilised but more organic than clastic sediments were already deposited 75 cm below this onset (Brauer/Endres/Negendank 1999). Assuming a constant sedimentation in comparison to the first 200 continuous varves, the 75 cm between the onset of the varve formation and the onset of the Lateglacial Interstadial were calculated to have encompassed at least a further 430 varves (Brauer/Endres/Negendank 1999; Brauer et al. 2000a). Thus, according to this calculation the onset of the Lateglacial Interstadial in the MFM occurred by least at 14,500 years cal. b2k (with added 110 years: 14,610 years cal. b2k). If the 50 varves of assumed underestimation (Litt et al. 2001) were added to this calculated age the onset of the Lateglacial Interstadial in the MFM record is again almost identical with the onset of the Lateglacial Interstadial in NGRIP (**tab. 71**). A sedimentological transition reflecting an increased lake productivity occurred around 14,250 years cal. b2k in the Holzmaar record (Zolitschka et al. 2000; cf. Lücke et al. 2003). The preservation of sufficient pollen began around 14,208 years cal. b2k (Leroy et al. 2000). A significant peak in the sedimentation rate dated to 14,730 years cal. b2k was related to thawing in the drainage area and subsequent meltwater input into the lake (Zolitschka et al. 2000). This episode was possibly correlative with the climatic amelioration at the onset of the Lateglacial Interstadial. This limit predated the onset of the Lateglacial Interstadial in the oxygen isotope records by only a few decades. Furthermore, in the clastic varves a peak of the total inorganic carbon around 16,550 years cal. b2k reflected probably a peak of aeolian input (Zolitschka et al. 2000). Possibly, this aeolian input correlated to the onset of the dry GS-2a event as observed in the Hulu Cave record (see p. 319-321). However, if these episodes were correlative the ages in the Late Pleniglacial section are overestimated in the Holzmaar record.

In addition to the Eifel maars, several lakes and kettleholes in northern and north-eastern Germany produced laminated sequences. The sequences of the northern German lakes were correlated along palynologically steep gradients from the elm decline and the chronology was based on a composite of well laminated parts from various lakes (Plußsee, Hämelsee, and Belauer See; Merkt/Müller 1999, 44 fig. 3) especially from the well preserved layers in the Hämelsee record (Merkt/Müller 1999, 49). The onset of the Holocene was set according to the rapid spread of birches at 11,610 ± 118[42] years cal. b2k (Merkt/Müller 1999, 49), even though increasing birch values indicate a possible climatic amelioration some 50 years earlier (Merkt/Müller 1999, 55). An abrupt change in the sedimentation (grain size and concentration of clastics) accompanied by changes in the cladocera and algae communities occurred 15-20 years earlier than the palynological onset (Merkt/Müller 1999, 58). The change from clastic to organic sedimentation in the Hämelsee record was consequently placed at approximately 11,628 ± 118 years cal. b2k. The geochemical composition of the sediment took a further 15 years after the palynological onset of the Holocene until interstadial values were established. Thus, the transition from the Pleistocene to the Holocene was recorded in the northern German records some decades later than in the Eifel maars. This transition still revealed a very comparable pattern with first climatic indications preceding the significant changes in the environmental parameters which were almost concomitant to developments further south. However, below the transition, the lamination in the northern German lakes was generally poor and, consequently, exact age estimates were hard to establish.

Only the north-eastern German Rehwiese record yielded a reliable varve formation throughout this period. This record was correlated to the MFM record using the LST. Comparable to the northern German records, a first small increase of birch dated to 11,690 years cal. b2k occurred alongside a decrease of sagebrushes (*Artemisia* sp.) and juniper (*Juniperus* sp.). These changes marked the onset of the Pleistocene to Holocene transition in the Rehwiese record. In contrast to the Holzmaar record, the increase of *Filipendula* sp. began considerably later around 11,500 years cal. b2k. In the Rehwiese record, the end of the transition was set to the expansion of bulrush (*Typha latifolia*; Neugebauer et al. 2012), which indicates a mean July temperature of 13°C (Isarin/Bohncke 1999). This expansion occurred in the non-laminated part of the sediment and was interpolated to date to 11,410 years cal. b2k. Thus, the palynological transition was very gradual in this record but the first climatic changes were also recorded at 11,690 years cal. b2k. In comparison with the Eifel maars, the Rehwiese pollen suggested a temperature gradient which shifted from south-west to north-east and mean July temperatures which were common for the onset of the transition in the Eifel were established only some 180 years later in the Berlin area. In the Rehwiese record, the sedimentological and the geochemical change preceded again the palynological changes by some 50 years (Neugebauer et al. 2012, 100). In particular, the varve formation and the calcite precipitation shifted already at this early point around 11,743 years cal. b2k. This early onset suggested a response of the lake environment to the climate

42 The overall counting error for the Lateglacial part of the Hämelsee is given as 3 % with control counts providing counting errors of less than 2 % (Merkt/Müller 1999, 47). The counting error was calculated as adding up from the elm decline downwards with 2 %.

change some 30 years before the high-resolution proxy records in Greenland began reacting (Steffensen et al. 2008). If this early response of the lake environment is considered improbable some 50 varves must be missing between the LST and this onset of the Holocene in the Rehwiese record. In regard to the development of the pollen, the chronology of the Rehwiese record seems comparable to the Eifel maars and the northern German lakes and, thus, this early response of the lake appears rather valid. Moreover, the early reacting proxies reflect decreasing allochtonous input into the lake and an increasing primary productivity as well as, indirectly, an elongated warm period (Neugebauer et al. 2012, 97). Due to the generally low allochtonous input the presence of a local vegetation cover throughout the Lateglacial stadial was suggested for the Rehwiese record (Neugebauer et al. 2012, 101) and this presence of an established vegetation cover could explain the almost instant response in this record.

In the sediment record of Rehwiese, a second part of the Younger Dryas began at 12,326 varve years cal. b2k and was considered correlative to a warm episode which was recorded for example in the varve record of the MFM and in the oxygen isotope record of NGRIP. However, Ina Neugebauer and her colleagues advised some caution with this correlation because the more lateral position of Rehwiese in relation to the North Atlantic climate system might have caused some differences in detail (Neugebauer et al. 2012, 100). In the comparison of the chronology of the Rehwiese and of the MFM record, this consistent onset of the intermediate phase in the Younger Dryas indicates that the two records are still correlative at this part of the Lateglacial chronostratigraphy.

The onset of the Younger Dryas was in contrast to most other records, a very rapid transition in the Rehwiese record. It occurred in less than 25 years around 12,719 varve years cal. b2k in the pollen profile and within a year at 12,725 varve years cal. b2k in the sedimentological record (Neugebauer et al. 2012). This onset correlates with the onset of the Younger Dryas in the MFM. Since the Rehwiese record was correlated to the MFM chronology along the LST only a 210 varves below this transition, this correlation seems unsurprising. In the northern German lake sequences, the onset of the Younger Dryas was correlated with the duration of the Younger Dryas in Lake Gościąż (Merkt/Müller 1999). In the Hämelsee record a total of *c.* 675 varves were preserved and can be sub-divided in three sections: some 50 varves on top of the Younger Dryas/Allerød transition, 197 varves between this transition and the LST, and 428 varves below the LST. This number of varves below the LST correlates with the approximately 450 varves in the Rehwiese record (Neugebauer et al. 2012, 96). Further, uncorrelated sections provided estimates for the duration of pollen zones such as the Lake Wollingst (Brauer/Endres/Negendank 1999). In regard to the significant offsets between the palynologically defined zones (**tab. 69**) and the additional uncertainty arising in the chronology from uncorrelated sequences and untested chronostraigraphies, these parts are not further considered in this study.

The European lake varves have been chronostratigraphically correlated to the NGRIP record. However, the accumulated counting error of these records was comparable to the counting error of NGRIP and, therefore, produced no more precise dating of the limits. In addition, these records documented climatic shifts and combined them with biotic reactions. In particular, wind, air temperature, and water availability had significant impacts on the vegetation record. This direct combination of climate indicators and vegetation development indicated that occasionally vegetation zones are not concomitant with oxygen isotope and climatic developments. In contrast, vegetation records sometimes reacted to more local developments and are consequently not well suited as chronostratigraphic markers.

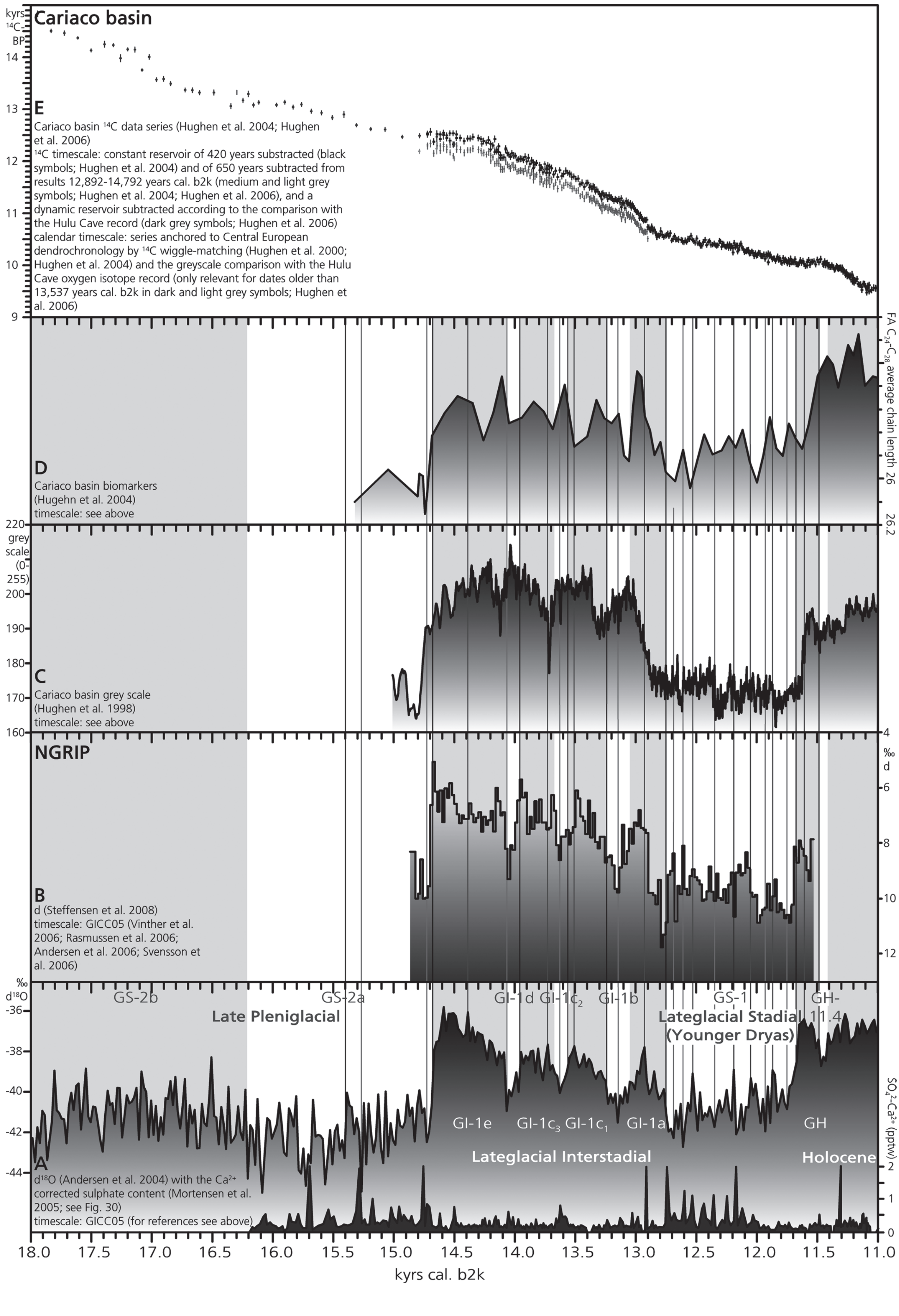
Besides the various European varve chronologies, the deep sea record from the Cariaco basin yielded a floating laminated chronology (**fig. 4**). The $\Delta^{14}C$ values from the laminated parts of the Cariaco basin grey scale were correlated with those of the CEDC. For the parts older than the end of the dendrochronology, the laminated parts and the grey scale were previously correlated to the accumulation rate in GISP2 and its chronology (Hughen et al. 1998a; cf. Hughen et al. 2004c). Subsequently, the grey scale was correlated with the Hulu Cave record (Hughen et al. 2006). Three of the 46 tie points of this correlation fall into the Lateglacial: the Pleistocene/Holocene transition, the Interstadial transition/Lateglacial Stadial, and the Late Pleniglacial/Lateglacial Interstadial transition. The anchorage of the Lateglacial chronology in the Cariaco basin record to the CEDC and, thus, the onset of the Holocene remained widely unaffected since the comparison to the Hulu Cave record was only used for the period below 14,750 years cal. b2k. In the section between 12,450 and 14,750 years cal. b2k $^{230}Th/^{234}U$-dated fossil corals supplement the correlation. The onset of the Holocene was set according to a correlation of a steep gradient in the grey scale record to the CEDC to 11,630 years cal. b2k (Hughen et al. 2004c).

In the Cariaco basin, a gradual change from the Lateglacial Interstadial to the Lateglacial Stadial was recorded by the means of the grey scale, the $\Delta^{14}C$, and the biomarker record (Hughen et al. 2004b; Hughen et al. 2004c, 1164). A last peak occurred around 13,080 years cal. b2k in the grey scale indicating weak trade-winds and a concomitant minimum occurred in the $\Delta^{14}C$ record (with values of *c.* 11,200 years ^{14}C-BP[43]) following on a small wiggle in both records (Hughen et al. 2004b, 1958 fig. 3). This onset of declining/increasing values was discussed as a result of a shut down of the North Atlantic deep water formation and, thus, the onset of the Younger Dryas was placed to the last peak of the sediment and isotope record (Broecker 2003, 1519). At this point the values for the arid grassland vegetation were almost as strong as at the onset of the Lateglacial Stadial but the wet forest vegetation increased significantly again afterwards. A last peak of prevailing forest vegetation was signalled by the biomarkers some 50 years after the last peak of the other data. Around 12,940 years cal. b2k (*c.* 10,890 years ^{14}C-BP) a short but sharp decline occurred in the grey scale which is followed by increased values in the $\Delta^{14}C$ record. However, both curves recovered quickly again to almost pre-decline values. The steepest part of the $\Delta^{14}C$ incline followed some 25 years later (*c.* 10,880 years ^{14}C-BP). In the grey scale a prolonged depression formed around this steep incline beginning *c.* 12,910 years cal. b2k and lasting some 20 years. Afterwards the reflectance of the Cariaco sediments shortly recovered before a last steep decline occurred. Subsequently, minimal values for the sediment reflectance and the forest vegetation and maximum values of $\Delta^{14}C$ occurred around 12,885 years cal. b2k (*c.* 10,700 years ^{14}C-BP), some 200 calender years after the last $\Delta^{14}C$ and grey scale peak (Hughen et al. 2004b, 1958 fig. 3). In the same period some 500 years pass on the ^{14}C timescale forming a steep decline or »cliff« in the calibration curve. After this lowpoint the values in the grey scale stabilise for some 120 years before some extreme minima occurred after *c.* 12,760 years cal. b2k (*c.* 10,570 years ^{14}C-BP). During these 120 years, the $\Delta^{14}C$ data wiggled considerably with a general increase of the values before the absolute maximum of this time window was reached at *c.* 12,830 years cal. b2k (*c.* 10,600 years ^{14}C-BP). This maximum was followed by decreasing values with a minimum at 12,710 years cal. b2k (*c.* 10,570 years uncorrected ^{14}C-BP). Also, the vegetation development signalled a slight recovery of the wet forest environments until *c.* 12,830 years cal. b2k but was followed by peak values of arid grasslands around 12,710 years cal. b2k. If only the very low values in the Cariaco basin grey scale were counted the Younger Dryas comprised only 1,235 varve years (Hughen et al. 2004c, 1164). Moreover, the pattern displayed by the marine data from Cariaco basin resemble closely the Greenland ice-core data and showed comparably that the gradual trend towards stadial conditions was a long process (cf. Fiedel 2011) with vegetation proxies lagging behind the climatic parameters by some decades. Furthermore, if the correlation of the Cariaco record is correct it might indicate that the long lasting process began some 150 years earlier in the low latitude marine (last peak: 13,080 years cal. b2k) than in the high latitude ice-core record (last peak: 12,925 years cal. b2k).

43 The ^{14}C ages are given with a constant reservoir correction of 420 years because the exact position of a switch in the reservoir ages from 420 to 650 years at the Lateglacial Interstadial to the Lateglacial Stadial transition identified by comparison of the Cariaco basin record with the floating GLPC (e. g. Hughen et al. 2004c; Kromer et al. 2004) is not known.

Nevertheless, in such a case the stabilisation of the grey scale values concomitant with the changed deuterium excess data clearly suggested a shift in the low latitudinal North Atlantic regime as a source of this stadial event. Furthermore, the position of this shift explains the offset in the atmospheric parameters tied to the higher latitudes. Yet, an offset in the chronology cannot be completely excluded.
According to the comparison of the period between the onset of the Holocene and the LSE in the MFM and the duration of the Lateglacial Stadial in the Cariaco basin, the LSE would have occurred in the early Younger Dryas of the Cariaco basin. Besides the possibility that the Younger Dryas began considerably early in the subtropical Cariaco basin, this age difference can be explained by an overestimation of the duration of the Lateglacial Stadial in the Cariaco basin or a lack of at least 45 varve years in the MFM record. The possibility of overestimation was rejected by Konrad Hughen and colleagues (Hughen et al. 2004c, 1164), although a relatively high proportion of the record was formed by weakly laminated (*c.* 35 %) or unlaminated parts (< 1 %; Hughen et al. 2004c, 1163). This composition made the counting of varves problematic and required the correlation of the Cariaco basin varve chronology with other records. However, without an indication for the position of the LSE in the Cariaco record, a conclusion between the possible underestimation of the MFM record and a potentially different climatic regime in the Cariaco basin based on this single evidence should not be made. However, further indications for an overestimation in the chronology of the Cariaco record were provided by the radiocarbon calibration data set (see p. 359-364).
In addition, comparison of the limits within the Lateglacial Interstadial in the oxygen isotope and deuterium record of NGRIP and the grey scale record of the Cariaco basin several tie points in the Cariaco basin predate the reactions in the NGRIP record (**fig. 39**). An update of the record resulted in a lengthening of several parts of the record including the Younger Dryas (Hughen et al. 2004c). However, a change in the sedimentation regime resulting in an overestimate of the varves, for instance due to the deposition of four layers per year, was excluded for the Younger Dryas (Hughen et al. 2004c, 1164). However, if the wiggles in the Younger Dryas are compared, the records of the deuterium excess in NGRIP and the Cariaco basin grey scale are very similar until the early GI-1b event. Only after this point the records vary considerably. At the onset of GI-1b, the age difference between the oxygen isotope record from NGRIP and the Cariaco basin grey scale ranged around 110 years, whereas at the onset of GI-1c_2 the difference decreased to 35 years and it increased again to 75 years at the onset of GI-1d (**tab. 71**).
Since the onset of the Lateglacial Interstadial was correlated to the Hulu Cave record (Hughen et al. 2006), this part is again very comparable to the NGRIP record. The last minimum values occurred around 14,790 years cal. b2k and the peak in the grey scale is reached around 14,755 years cal. b2k. In contrast, the maximum values in the fatty acids and the ^{13}C record occurred some decades or centuries later (Hughen et al. 2004b). The onset is considerably sharper than the onset of the Younger Dryas but it predated the NGRIP records by some 100 years (**tab. 71**). This offset of approximately 100 years at the beginning of the Lateglacial Interstadial was previously recognised in the comparison of the Cariaco basin record with the GISP2 chronology and demonstrated a gradual development during the latter half of the Lateglacial Interstadial (Hughen et al. 1998b). The observed difference is either due to an underestimate of ice-core layers in NGRIP

Fig. 39 Comparison of NGRIP with the Cariaco basin record. Thin bars given as guide lines (light grey: low; medium grey: high; black: transition). **A** Oxygen isotope record from NGRIP with the Ca^{2+} corrected sulphate content but without associated ash layers (see **fig. 30**). Grey shaded areas represent events of more interstadial values than the surrounding values. – **B** Deuterium excess record from NGRIP. – **C** greyscale record (Hughen et al. 1998a). – **D** average chain length index of C_{24}-C_{28} *n*-alkanoic homologs from the fatty acids (FA) of leaf waxes (Hughen et al. 2004b). – **E** series of ^{14}C dates in three different versions: one with constant reservoir of 420 years subtracted (black symbols); one with 650 years subtracted from the results between 12,892 and 14,792 years cal. b2k (medium and light grey symbols; Hughen et al. 2004c; Hughen et al. 2006), and one with a dynamic reservoir subtraction according to the correlation with the Hulu Cave record (for results older than 13,537 years cal. b2k; Hughen et al. 2006). – For further details see text.


Cariaco basin
kyrs 14C BP
E
Cariaco basin 14C data series (Hughen et al. 2004; Hughen et al. 2006)
14C timescale: constant reservoir of 420 years substracted (black symbols; Hughen et al. 2004) and of 650 years subtracted from results 12,892-14,792 years cal. b2k (medium and light grey symbols; Hughen et al. 2004; Hughen et al. 2006), and a dynamic reservoir subtracted according to the comparison with the Hulu Cave record (dark grey symbols; Hughen et al. 2006)
calendar timescale: series anchored to Central European dendrochronology by 14C wiggle-matching (Hughen et al. 2000; Hughen et al. 2004) and the greyscale comparison with the Hulu Cave oxygen isotope record (only relevant for dates older than 13,537 years cal. b2k in dark and light grey symbols; Hughen et al. 2006)
D
Cariaco basin biomarkers (Hugehn et al. 2004)
timescale: see above
FA C24-C28 average chain length
grey scale (0-255)
C
Cariaco basin grey scale (Hughen et al. 1998)
timescale: see above
NGRIP
B
d (Steffensen et al. 2008)
timescale: GICC05 (Vinther et al. 2006; Rasmussen et al. 2006; Andersen et al. 2006; Svensson et al. 2006)
‰ d
‰ d18O
GS-2b
GS-2a
Late Pleniglacial
GI-1d
GI-1c2
GI-1b
GS-1
GH-11.4
Lateglacial Stadial (Younger Dryas)
GI-1e
GI-1c3
GI-1c1
GI-1a
GH
Lateglacial Interstadial
Holocene
A
d18O (Andersen et al. 2004) with the Ca2+ corrected sulphate content (Mortensen et al. 2005; see Fig. 30)
timescale: GICC05 (for references see above)
SO42–-Ca2+ (pptw)
kyrs cal. b2k

or an overestimate in the Cariaco basin. The similarity of the ages in the NGRIP and the Hulu Cave record at the onset of the Lateglacial Interstadial suggests that rather an overestimation occurred in the Cariaco basin record. Another possible reasons for the offset are various response times and an earlier response in the Cariaco basin. However, the deuterium excess data relating Greenland to the lower latitudes during glacial periods (cf. Masson-Delmotte et al. 2005) reacted in a comparable fashion to the other proxies in NGRIP. Thus, an overestimation of 100 years in the Cariaco basin record appears as a probable reason but an exact onset for this age difference cannot be identified unambiguously. Nevertheless, the comparison of the ^{14}C calibration data set from the Cariaco Basin with the European dendrochronological records (see p. 359-363) sustains the necessity of adjusting the chronology of Cariaco Basin record. Due to the connection with the radiocarbon calibration, this adjustment is further specified later.

In conclusion, the Holocene amelioration appears to have begun around 11,680 years cal. b2k or, more precisely, the climate system influencing the North Atlantic climate zone switched probably to an interstadial mode after 11,703 ± 99 years cal. b2k (cf. Rasmussen et al. 2006; Steffensen et al. 2008; Walker et al. 2009). This shift in the climate regime caused general changes in the Northwest-European climate system and, in particular, in the glacio-hydrological cylce resulting in processes such as thawing of previously frozen grounds and/or melting of glaciers. To some degree, these processes probably masked the global climatic signals in the terrestrial records. The continental system restabilised some decades later (cf. Muscheler et al. 2008) and the terrestrial sequences of north-western Europe produced a signal of amelioration and increased organic productivity almost simultaneously around 11,640 years cal. b2k.
Consequently, for the purpose of correlating north-western European sequences in a general chronostratigraphy the type of record and of the signal needs to be considered. Since these data sets mainly represent terrestrial sequences which besides temperature also react on further factors such as the hydrological surrounding, a correlation at 11,640 years cal. b2k (dendrochronology, Lake Gościąż, Lake Perespilno, MFM) is used in the current project. Nevertheless, some processes such as the succession of biomes is controlled by various factors ranging from global to local scale. Thus, also parameters such as the concentration of clastics in sediments may react later in some regions, for example, in more northern latitudes or areas in the vicinity of an ice sheet (cf. Levesque/Cwynar/Walker 1997), whereas other areas such as places in more southern latitudes or protected valleys (cf. van Leeuwaarden/Janssen 1987) could react more instantly on an amelioration. However, the correlation of the various important Northwest-European records suggested that this delay fell within the standard deviation or counting errors of most records. In consequence, the climatic and environmental change from the Late Pleistocene to a fully established Holocene occurred across north-western Europe within a century or less.
For the purpose of considering human reaction on climatic change, it needs to be kept in mind that the climatic as well as first environmental changes (decreasing dust intensity, temperature amelioration, thawing of permafrost, and melting of glaciers) began presumably some 30-70 years earlier than the definition of the Holocene onset. Consequently, the Lateglacial/Early Holocene hunter-gatherer groups probably faced first signs of (severely) changing environments one or more generations before Holocene conditions were established in the terrestrial data. Adaptation process of these groups to their changing surrounding could have begun from the first signs onwards, i.e. even before the Holocene was established in the terrestrial environmental records.
Comparable to the onset of the Holocene, the onset of the Lateglacial Stadial in north-western Europe is not a sudden event, although it occurred abruptly in some proxy records. In general, the onset of the Lateglacial Stadial was a continuous process which took several decades to a few centuries to be accomplished. This gradual transition was a general pattern of this climatic event. The here described development of a

gradual cooling terminated by an abrupt, more intense cooling is a typical onset in a stadial cycle (Wolff et al. 2010). Various parameters were affected during the transition. For instance, the $\Delta^{14}C$ as well as the grey scale record from the Cariaco basin display a comparable pattern of a peak following on the short-term episode in the records and then a gradual decline followed over the next *c.* 200 years before stadial conditions were established. In several records, this transition lasted approximately 200 years. After this transition, the human surrounding transformed gradually into a cold adapted landscape in some parts of Europe, possibly accelerated by increased wind intensities and storm tracks (Brauer et al. 2008). In contrast, in protected areas the environment seemed partially unaffected (Price 2003) or almost unaltered (cf. Lotter et al. 1992, 195 f.; Eusterhues et al. 2002, 356). Moreover, the event encompassed more than 1,000 years in which the climate as well as the environmental record changed. The impact of this event on human behaviour therefore needs to be considered in comparison to the actual changes affecting the immediate surrounding (cf. Weber / Grimm / Baales 2011).

The onset of the Lateglacial Interstadial was a very comparable process as the onset of the Holocene. The few climatic records which yielded a signal of this major Lateglacial event recorded a very sharp change towards warm / moist climate conditions at 14,690 years cal. b2k. First indications of the amelioration began a few decades earlier, around 14,730 years cal. b2k. In contrast to the Holocene, the pedogenic development slowed the environmental development in many areas (e. g. MFM, Holzmaar) and, thus, a full interstadial mode was reached some centuries later.

The sub-division within the Lateglacial Interstadial was only comparable in the oxygen isotope records. Due to the additional influences, in particular of the hydrological system on the sites, the dates for the limits were also partially offset in the oxygen isotope records. The onset of the various sub-events as read from the vegetation proxies displayed significant discrepancies between the records and disqualify as reliable correlation markers. For example, the onset of a colder period within the younger Lateglacial Interstadial, the so-called Inner or Intra Allerød Cold Period (IACP, Lehman / Keigwin 1992, cf. Obbink / Carlson / Klinkhammer 2010), was considered to be correlative with GI-1b as well as the Gerzensee Oscillation (Lotter et al. 1992). The duration of GI-1b in the oxygen isotope records ranges between 160 and 180 years (see **tab. 68**), whereas the duration for this period in the other proxy records such as the tree-ring growth patterns or the pollen spectra exceeded this duration by 94 to 193 years (see **tab. 70**). In addition, the onset of this period in the European varve lakes post-dated the onset of GI-1b in NGRIP by 75 to 150 years (see **tab. 71**). The Cariaco basin greyscale recorded the onset of a colder period approximately 115 years before the onset of GI-1b and with the assumed shift of this record , the signal in the Cariaco basin would still precede the NGRIP record by 15 years and the terrestrial signals by some 110 to 210 years. Since the records appear relatively well correlated at the major transitions, these significant offsets within the Lateglacial Interstadial suggest that the »minor« climate signals were not strong enough to surpass rapidly the influence of local factors on the various terrestrial proxy records. Thus, the use of these »minor« limits as correlation markers can lead to significant confusion in the comparison of the terrestrial records. In contrast, volcanic tephras represent reliable markers. For instance, interstadial environments were recorded for a further *c.* 200 years after the LSE in the final Lateglacial Interstadial in the terrestrial records (e. g. Brauer et al. 2008; Merkt / Müller 1999; Eusterhues et al. 2002) and also the sharp decline in $\Delta^{14}C$ succeeded the LSE by some 200 years (Kromer et al. 2004). Thus, the use of this marker related the terrestrial tephrostratigraphies to various other proxy records. Even though some uncertainties about the exact position of the LSE remained, the quasi-contemporaneity of the direct evidences for the LSE was unquestioned. Consequently, these reliable markers should be used in particular for the chronological comparison of terrestrial records within the major isotope events.

The Late Pleniglacial was a period with high amplitudes in the oxygen isotope record of the NGRIP ice-core. This period was rarely recorded in the terrestrial records. In the records where the Late Pleniglacial was documented, the numbers of the proxies were usually limited and the few values preceding the onset of the Lateglacial Interstadial were in general reflecting a very cold and dry environment. The onset of this particularly cold and dry phase in the Late Pleniglacial was rather diffuse and, possibly, non-synchronous in the various records.

A rather general observation in this comparison is the sharp signals of ameliorations in contrast to the more diffuse onsets of climatic deteriorations. Thus, the onset of ameliorations are better suited as correlation gradients. Nevertheless, short and sharp cold peaks are also good correlation indicators but these short-lived events are sometimes recorded poorly in the vegetation records.

Further stratigraphies

Stratigraphies from the deep sea usually have to be correlated to the Greenland ice-core records along tephrochronological and/or lithostratigraphic correlation points as well as according to radiometric dating, temperature developments, and/or isotope sequences. These deep sea records reflect climatic developments in the ocean and, thus, indicate changes in a major driving force of the global climate. Therefore, these archives are relevant indicators for the development of the climate in north-western Europe. In the present study, the deep sea record from MD01-2461 (**fig. 5**), offshore Ireland, was chosen as a representative for these records because it provides additional information which were considered relevant for the possible impact of the ocean on the north-western European climate. The timescale of this sediment core was originally set according to the GISP2 age model (Meese et al. 1997) and, thus, must be partially changed to correlate to the NGRIP record in GICC05.

In the stratigraphy of MD01-2461, volcanic ash layers were found of which one was assumed to represent the Vedde Ash (Peck et al. 2007, 864f.). Furthermore, a zone of increased volcanic debris including a peak of rhyolitic material post-dated the Heinrich 1 event in this record (**fig. 40**). The MD01-2461 record was left in the GISP2 age model and simply shifted according to the peak in the rhyolitic ash grains assumed to reflect the Vedde Ash to match with the marker horizon of the Vedde Ash in the NGRIP record (**fig. 40**). When the record was shifted this way the zone of increased volcanic activity post-dating the Heinrich 1 event became correlative with an increase of volcanic activity after the rhyolitic ash layer at 1628.25 m depth in NGRIP (**fig. 40D**; Mortensen et al. 2005, 215f.). Shifted into this position, the development of the sea surface temperature (**fig. 40C**) is also very similar to the development of the oxygen isotope (**fig. 40A**) as well as the deuterium excess record from NGRIP (**fig. 40B**). Therefore, no further alterations of the deep sea record were performed to correlate it to the GICC05. Although some stretching, compressing, and/or shifting might be necessary to fit this record exactly to the GICC05, the lack of further reliable correlation marker prohibits further precision in this project. Thus, the chronology of this record is a tuned timescale and not an independent one. This dependence on a correlation to NGRIP influenced the temporal relation between this record and other records and inhibits further specifications of the durations of various events and major conclusions on the numerical chronostratigraphy based on this record. Nevertheless, some observations can be made based on the relation of the different proxies in this record.

For instance, during the Late Pleniglacial, very low sea surface temperatures as indicated by the relative abundance of planktonic species were concomitant with an almost stagnant phase of IRD accumulation after a period of extreme fluctuations. Perhaps, this low in the sea surface temperature was correlative with the deterioration of the climate towards GS-2a. If this record was compared to the Hulu Cave oxygen isotopes, the deterioration in the deep sea record would have to be shifted 500 years younger. However, in the MD01-2461 record this stagnant period was correlated with the Heinrich 1 event (Peck et al. 2007).

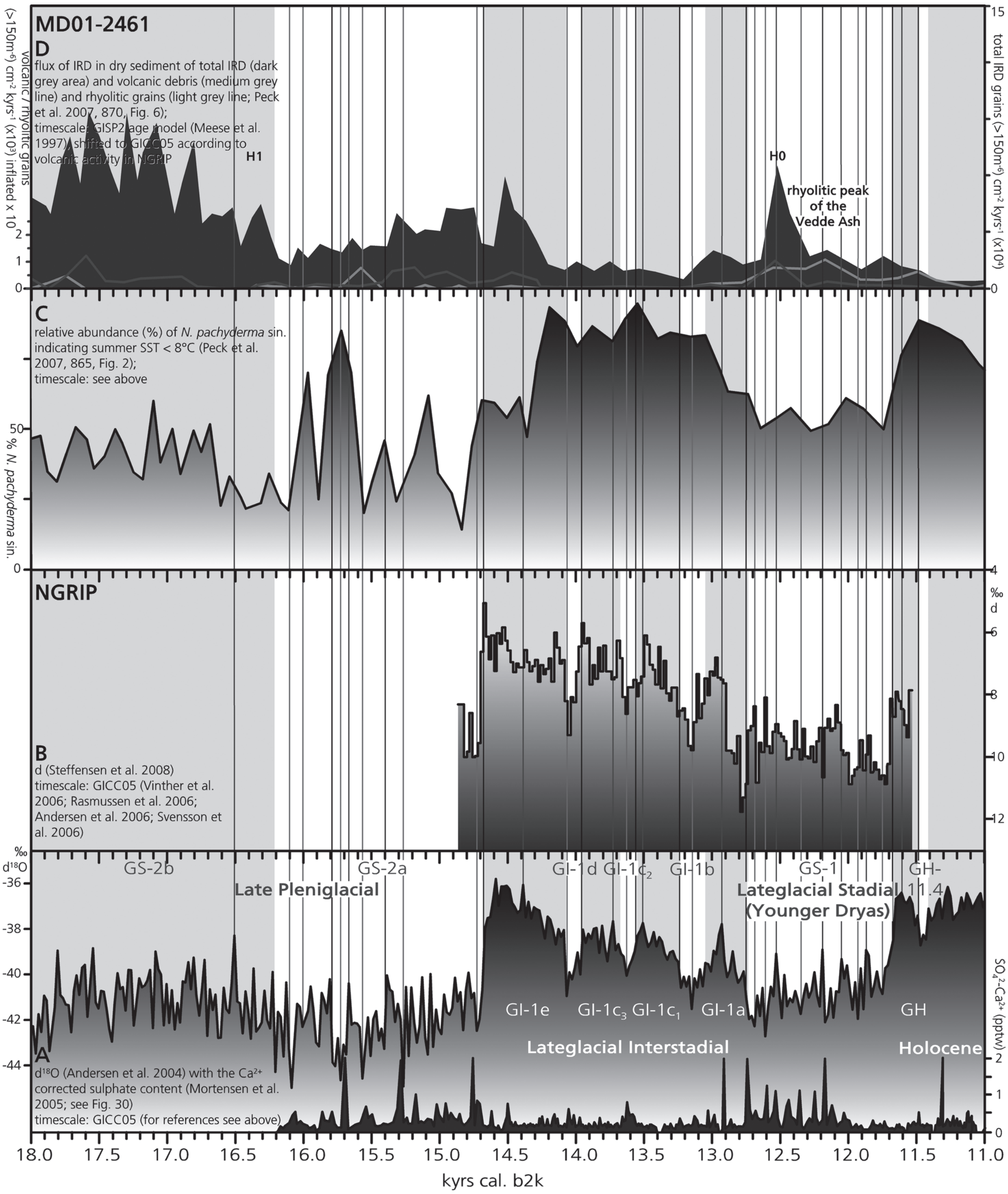


Fig. 40 Comparison of NGRIP and MD01-2461. Thin bars given as guide lines (light grey: low; medium grey: high; black: transition). **A** Oxygen isotope record from NGRIP with the Ca^{2+} corrected sulphate content but without associated ash layers (see **fig. 30**). Grey shaded areas represent events of more interstadial values than the surrounding values. – **B** Deuterium excess record from NGRIP. – **C** relative abundance (%) of *Neogloboquadrina pachyderma* sinistral, an indicator for polar waters and dominant in planktonic assemblages in waters of summer SST < 8°C, in MD01-2461 (Peck et al. 2007) correlated to NGRIP in GICC05 by tephrochronology. – **D** concentration of total IRD (black) and volcanic debris and tephra (grey line) in dry sediment of MD01-2461 (Peck et al. 2007) correlated to NGRIP in GICC05 by tephrochronology. **H1** Heinrich 1 event (Peck et al. 2007; cf. Phase 3 in Stanford et al. 2011b); **H0** Heinrich 0 event (Andrews et al. 1995; cf. Clark et al. 2002). – For further details see text.

In a more recent meta-study of the development of the Heinrich 1 event in the North Altantic, the Heinrich 1 event was sub-divided in several phases beginning as early as 19,050 years cal. b2k (Stanford et al. 2011b). The second phase occurred between approximately 17,550 to 16,750 years cal. b2k and was characterised by »a large-scale iceberg release and melting in the open North Atlantic IRD belt« (Stanford et al. 2011b, 1062) which is a very comparable pattern to the development of IRD before the Heinrich 1 event as specified in MD01-2461 (**fig. 40D**). In the early third phase of the Heinrich 1 event according to Jennifer Stanford and her colleagues, IRD deposition decreased in combination with increased freshening of the surface waters which was perhaps caused by the admixture of surface waters from the Nordic Seas (Stanford et al. 2011b, 1062).

This freshening reached its maximum around 15,150 years cal. b2k and decreased afterwards again. This maximum was clearly not related to a significant IRD deposition in their records. If the MD01-2461 record was shifted 500 years younger to match the deterioration in the Hulu and NGRIP records, the IRD flux of Heinrich 1 (as defined by Peck et al. 2007) would not cease before 15,750 years cal. b2k and the lowest value of IRD in the Late Pleniglacial would occur around 15,650 years cal. b2k.

This low of IRD was followed by an episode of two significant warm peaks in the sea surface temperature during and after which the IRD deposition began to increase again and the sea surface temperatures had some significant lows. The first and most significant low in the sea surface temperature would correlate approximately with 15,150 years cal. b2k in the shifted version. The warm episode clearly preceded the warming of the Lateglacial Interstadial and encompassed possibly several hundred years. Such an amelioration prior to the onset of the Lateglacial Interstadial was mentioned for the British records around 15,550 years cal. b2k by Jennifer Standford and her colleagues (Stanford et al. 2011b, 1062), and the peaks in the sea surface temperature proxy would clearly coincide with this amelioration if the record was shifted 500 years younger. However, the radiocarbon dates which dated the mentioned peak value in the British coleopteran record (Atkinson / Briffa / Coope 1987) can be considered as unreliable by modern standards and the warming identified by this record was meanwhile qualified as correlating with the early Lateglacial Interstadial (Coope / Lemdahl 1995; Coope et al. 1998). Thus far, a warm episode before the Lateglacial Interstadial with the intensity suggested by the planktonic record from MD01-2461 was not observed elsewhere.

Nevertheless, a warming of this intensity in the sea surface waters offshore Ireland would clearly have affected the climate of north-western Europe. One possibility is that the onset of preservation in various environmental records correlated with this warm episode. In the Eifel maars, this onset occurred only some centuries before the onset of the Lateglacial Interstadial and in the Swiss records this onset of the preservation occurred approximately around 15,200 years cal. b2k (Lotter et al. 2012). However, in the Austrian Längsee a sequence comprising material from approximately 19,100 to 13,200 years cal. b2k was analysed in regard to the vegetation change based on pollen and lake water temperature development based on the diatom communities (Huber et al. 2010). Approximately 13 cm below the sharp increase of up to 6°C marking the early Lateglacial Interstadial in the diatom-based water temperature, an up to 3°C warmer episode occurred between 390-380 cm profile depth. In the pollen profile the arboreal pollen, in particular those of *Betula* sp., *Pinus* sp., and *Juniperus* sp., began rising in this depth. The pine pollen reached a first small maximum in the lower part of this episode, whereas juniper had its maximum in the upper part of this episode. Non-arboreal pollen such as the Poaceae and *Artemisia* sp. remained relatively high. A ^{14}C date (KIA-30226[44]) made of three wood fragments from immediately above this episode (377-375 cm) produced an age of 12,467 ± 48 years ^{14}C-BP and another date (KIA-30227) from the younger part of this episode (383-380 cm) was made on a bulked sample of wood fragments, macro-remains of *Betula* sp., and seeds of *Carex* sp. and yielded an

44 This date series was made several years before the technical problems in the Kiel laboratory occurred (cf. http://www.uni-kiel.de/leibniz/).

age of 13,059 ± 74 years ^{14}C-BP (Huber et al. 2010, 136 tab. 3). The two radiocarbon dates following stratigraphically below this episode contained too small amounts of carbon to produce reliable results. Thus, the onset of this amelioration episode cannot be further determined in this record. If the date for the end of this episode is calibrated it ranges around 15,600 years cal. b2k. This age is correlative with the end of the warm episode in the sea surface temperatures if the tuned MD01-2461 record was not shifted 500 years younger. Furthermore, following on this warm episode the sea surface temperatures of the deep sea record had some significant lows which were also observable in the diatom-based water temperature of the Längsee (Huber et al. 2010, 137 fig. 2). If the tuned MD01-2461 record was shifted to match the deterioration of GS-2a, the end of the second peak would only shortly precede 15,150 years cal. b2k and 15,600 years cal. b2k would correlated to the onset of the warm episode in MD01-2461. In addition, after the very strong, second peak in MD01-2461, the period of the more intense deposition of volcanic material followed which according to the comparison with NGRIP is correlative to the increased Ca^{2+} corrected sulphate content before the onset of the Lateglacial Interstadial.

Although the warm episode which followed on the IRD minimum in the Late Pleniglacial was not observed in the records used by Stanford and her colleagues (Stanford et al. 2011b), the ages given by them for the sub-phases 2 and 3 of the Heinrich 1 event are generally in good agreement with the tuning of the MD01-2461 record as performed in this study without the additional shift towards the onset of the GS-2a deterioration. According to this tuning, the decrease in sea surface temperatures (**fig. 40**) appears to rather predate the decline of GS-2a in the NGRIP and the Hulu Cave record and, in fact, if the correlation is sustainable the warming episode would be concomitant with the significant decrease in the Asian monsoon intensity recorded at the Hulu Cave (see **fig. 32**).

Another observation in this record is that the onset of the Lateglacial Interstadial as well as the Lateglacial Stadial were related to peaks of ice rafting debris (IRD) and, thus, iceberg melting events. These melting events could perhaps also explain the delayed reaction in the Chinese oxygen isotope records (see p. 322-329).

With the rapid onset of the amelioration in the sea surface temperatures at the onset of the Lateglacial Interstadial, the deposition of IRD decreased. The Lateglacial Interstadial optimum recorded in the Greenland ice-core and the terrestrial records (Coope et al. 1998) was perhaps associated with this decrease of iceberg melting. However, this continued amelioration led to another important melting event which slowed the warming of the sea surface temperature. The sea surface temperature development formed a moderate plateau during the iceberg release. After this melting event had ceased, the sea surface temperatures established at relatively high levels where they approximately remained until the end of the Lateglacial Interstadial (**fig. 40**). In general, the IRD content decreased very gradually and only minor increases of the IRD deposition suggested further short-termed cooling events after the last peak and following sharp decline in the early Lateglacial Interstadial melting event.

Shortly after the minimum of IRD deposition was reached in the final Lateglacial Interstadial, a first increase of the record led to a first sharp decline in the sea surface temperatures and when the IRD deposition ceased again the sea surface temperatures stopped for a plateau comparable to the values of the onset of the Lateglacial Interstadial. With the very rapid increase to a peak of IRD deposition which was occasionally referred to as Heinrich 0 event (Andrews et al. 1995; Dokken/Jansen 1999; Clark et al. 2001; Broecker et al. 2010) the sea surface temperature decreased further and remained approximately on this level which was a bit lower than the moderate first plateau in the Lateglacial Interstadial.

Another important information which is possible in the MD01-2461 record is that the peak of this Heinrich 0 event predates the Vedde Ash and by the present correlation the offset encompassed more than 300 years (**fig. 40**). Perhaps, the decreasing intensity of this Heinrich 0 event caused the amelioration phase which

was observed in some European records and assumed to have caused some significant melting and surface runoff processes (Brauer et al. 1999; Grafenstein et al. 1999; Kleinmann/Merkt/Müller 2002).
Thus, even though the deep sea record of MD01-2461 was tuned, it provided interesting considerations about the relation of climatic developments and also of environmental developments in north-western Europe. The latter can become particularly useful information in the comparison of the environmental development with the archaeological record (see Discussion-Change, p. 565-568; cf. Bradtmöller et al. 2012).

The Lateglacial radiocarbon calibration curve

The necessity to calibrate radiocarbon ages has often been emphasised (see p. 250-253, p. 259-263, p. 265-269, and references there). Therefore, a large body of high-resolution calibration data sets was collected over the last decades for the northern and for the southern hemisphere (McCormac et al. 2004; Reimer et al. 2004; Hua et al. 2009).
The most reliable of these data sets were dendrochronological sequences which provide an annually resolved calender timescale supplemented by a series of high-precision ^{14}C measurements. For the data sets from the northern hemisphere, the dendrochronological material sampled for the ^{14}C measurements comprised usually approximately 10 tree-rings and produced ages with standard deviations ranging between 15 and 50 ^{14}C years (Reimer et al. 2004). With every new supplementary data, the dendrochronological sequence and, thus, the calender timescale was monitored. Thereby, disturbances caused by cockshafer infestation were detected in the Holocene part resulting in a minor revision of the timescale in 2004 shifting the onset of the Holocene in the CEDC some 20 years older (Friedrich et al. 2004). This shift also affected data sets which were correlated to the previous versions of the CEDC along the Pleistocene/Holocene transition. In addition, the CEDC was extended further into the Lateglacial Stadial and currently constitutes a continuous data set from modern times to 12,644 years cal. b2k (Schaub et al. 2008b).
For the Lateglacial Interstadial the floating, 1,382 years long GLPC (Kromer et al. 2004) is available. The onset of the Lateglacial Stadial is recorded as a steep decline of the ^{14}C ages in this record and the Laacher See eruption (LSE) is documented by a series of dates from poplars which were buried during the eruption (Baales/Bittmann/Kromer 1998; Friedrich et al. 1999; Kromer et al. 2004). The GLPC was thus far not connected to the extended CEDC (Kaiser et al. 2012) but once this connection is achieved, the dendrochronological calibration data set extends into the early Lateglacial Interstadial.
To bridge the gap between the CEDC and the GLPC, other calibration data sets such as the deep sea records from the Cariaco basin were used in the past (Kromer et al. 2004). However, two tree-ring sequences were published in the last five years and assumed to bridge this older part of the Lateglacial Stadial: The Tasmanian Huon pines (Hua et al. 2009) and pines from the Swiss Gänziloo site forming the Younger Dryas A (YD_A) chronology (Schaub et al. 2008b). Based on wiggle-matching of the two new ^{14}C data series with the existing dendrochronological data and/or the deep sea record from the Cariaco basin, the two data sets were considered to fill the gap between the CEDC and the GLPC (see p. 358-364). However, the overlap of the YD_A chronology with the CEDC and the GLPC respectively seemed not sufficient to allow a dendrochronological anchoring of the three data sets (Kaiser et al. 2012). The ^{14}C dates from the YD_A chronology were wiggle-matched to the Cariaco basin record which was itself variously tuned in this portion (Hughen et al. 1998b; Hughen et al. 2004c; Hughen et al. 2006; Deplazes et al. 2013).
The Tasmanian Huon pines originated from the southern hemisphere and, therefore, the associated ^{14}C ages had to be corrected for an inter-hemispheric offset in ^{14}C ages (Hua et al. 2009). The inter-hemispheric offset resulted generally from the larger ocean surface on the southern hemisphere and, therefore, the

greater interaction of the atmospheric and oceanic reservoirs. On average, this increased exchange resulted in older ages on the southern hemisphere. Comparable to the ocean reservoir in ^{14}C data series from deep sea records, the inter-hemispheric offset was not constant and changed its behaviour particularly in periods of different ocean ventilations between almost no offset to almost 100 years. However, an average value of 40 years were substracted from the Huon pine ^{14}C ages (Hua et al. 2009, 2985). This possible fluctuation of the dates some 40-60 years on the ^{14}C age scale have to be kept in mind when comparing this data set to the calibration data sets from the northern hemisphere. Moreover, using this data set in the construction of a radiocarbon calibration curve implicates for each date the possibility of influencing the calibration curve towards too young or too old ages. Therefore, other data sets without inter-hemispheric offset should be preferred in the northern hemisphere. However, in the dendrochronological data from the northern hemisphere the ^{14}C samples are not yet as numerous and densely spaced in this period as in the Huon pine sequence.

To be independent of the tuning of the Cariaco basin record and the assumptions on ocean reservoirs as well as the inter-hemispheric offset, this study firstly positions the GLPC in relation to the CEDC along the onset of the Holocene and the LSE as known from the Lateglacial chronology in the Central European terrestrial sequences (**fig. 31**). The onset of the Holocene is known in the CEDC, whereas the LSE is clearly located in the GLPC. The varve records from MFM and Rehwiese bridge the Lateglacial Stadial and the LST as well as the establishment of the Holocene were identified in these records. The temporal distance of the two marker horizons in these records is further sustained by the findings in NGRIP and Lake Gościąż (see p. 310-318). Thus, the onset of the Holocene is marked by the increase of tree-ring growth in the CEDC (11,640 years cal. b2k) and the GLPC is anchored along the position of the LSE (ring no. 2160) to 12,930 years cal. b2k. Numerically, the two records overlap already some 55 calendar years in this correlation. However, neither closely sampled ^{14}C ages nor a standardised tree-ring growth curve have become available for the older end of the CEDC thus far. Nevertheless, the few available dates preset the general pattern of the radiocarbon calibration curve and make an anchoring of the Swiss pine and the Huon pine calibration data sets along this preset possible (**fig. 41**). In this correlation, the Huon pine sequence overlapped with the last 500 years of the CEDC and the first 100 years of the GLPC and the Swiss Lateglacial Master chronology (SWILM, Kaiser et al. 2012). The Swiss YD_A chronology is also correlative with these first 100 years of the GLPC/SWILM and the Huon pines. However, the Huon pine chronology and the YD_A chronology end immediately before the steepest part of the sudden decrease of ^{14}C ages marking the onset of the Younger Dryas in the GLPC record (Kromer et al. 2004). The GLPC and SWILM calibration data sets continue the dendrochronological calibration data set to almost 13,900 years cal.b2k and the dendrochronological record to almost 14,000 years cal. b2k in this position (**figs 38. 41**).

For the periods older than 13,900 years cal. b2k, dendrochronological calibration data sets from the northern hemisphere have not been established (cf. Reimer et al. 2009; Kaiser et al. 2012). Instead other records such as deep sea records have to be used for the construction of a calibration curve in these older periods (Hughen et al. 1998b; Jöris/Weninger 1998; Fairbanks et al. 2005; Weninger/Jöris 2008; Reimer et al. 2009).

The Cariaco basin record is one of the rare calibration data sets which yielded results for the complete Lateglacial Stadial and Lateglacial Interstadial. However, the calendar age model of this record was only partially confirmed by the laminated sediments because the lamination was often disrupted and/or incomplete (Hughen et al. 2004c). Therefore, the calender ages given for the ^{14}C dates were estimated due to sediment accumulation and tuning with other chronologies such as the one from the GISP2 ice core (Hughen et al. 1998a), from the Hulu Cave (Hughen et al. 2006), or the NGRIP ice core (Deplazes et al. 2013). These estimates could partially be incorrect and, thus, observing differences between radiocarbon calibration data sets from the European dendrochronologies and from the Cariaco basin could be due to incorrect calender

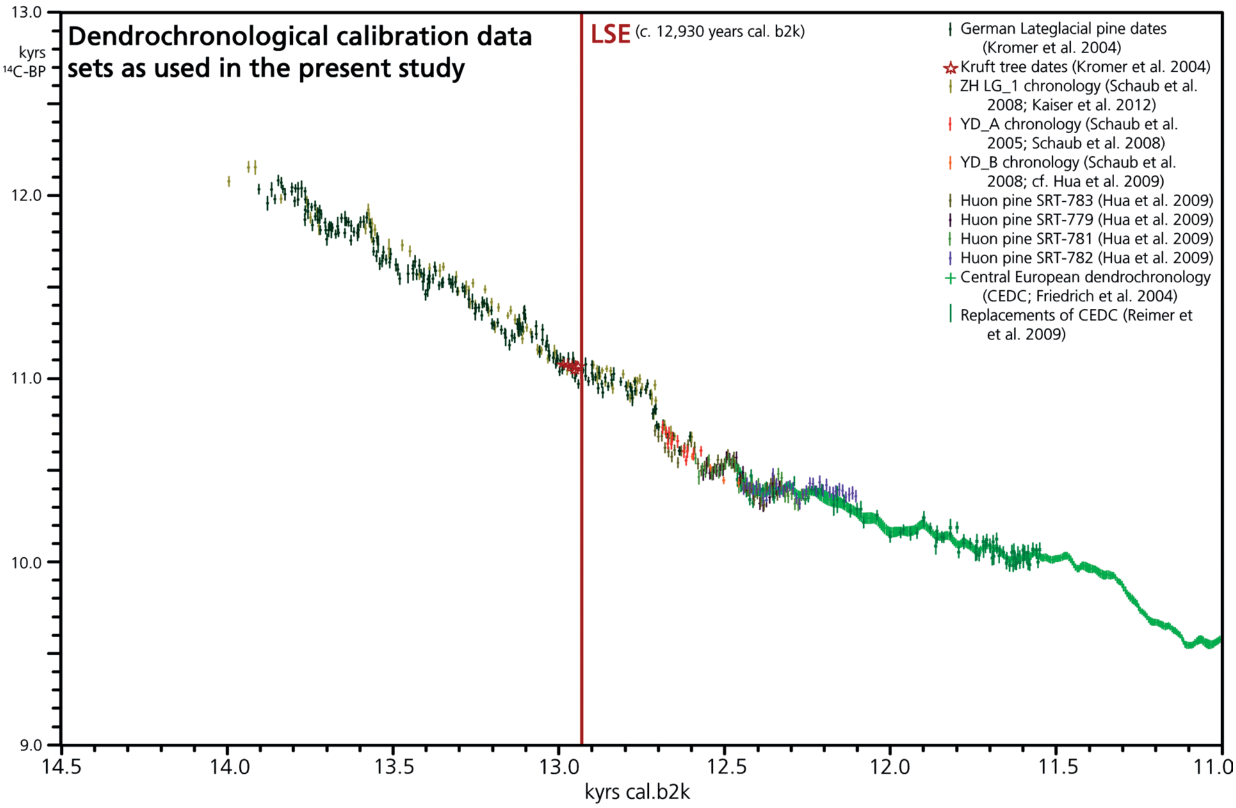


Fig. 41 Radiocarbon calibration data sets from Lateglacial dendrochronological records and location of the LSE in the GLPC. Records correlated as described in the text.

age estimates in the Cariaco basin record as well as incorrect reservoir estimates in the ^{14}C ages of this record. A comparison of the ^{14}C data sets from the CEDC and from the 2004 Lateglacial dates from the Cariaco basin (Hughen et al. 2004c) revealed that these sets were consistent across the Pleistocene/Holocene transition and into the Lateglacial Stadial. However, the steep decline at the onset of the Lateglacial Stadial occurred considerably earlier in the Cariaco basin record. Thus, the two data sets appeared to have develop at a different pace within the older part of the Lateglacial Stadial. The duration of the Lateglacial Stadial as documented in the greyscale record from the Cariaco basin was almost 250 years longer than the same period in the NGRIP oxygen isotope record or the European varve records (**tab. 70**).Consequently, the different comparisons suggested an overestimation of the duration of the Lateglacial Stadial in the Cariaco basin record. A possible explanation for this longer duration could be that the laminated sediments in the Cariaco basin had formed during some periods more than two sub-layers per year. However, this increased formation of sub-annual layers was previously suggested for the Younger Dryas part of the Cariaco basin record but was rejected by Konrad Hugen and his team (Hughen et al. 2004c).

Nevertheless, the Cariaco basin records were compressed by 210 years between 12,901 and 12,320 years cal. b2k which consequently relates to 12,691 to 12,320 years cal. b2k (**fig. 42**). This compression was based on a comparison of the ^{14}C data sets with dendrochronological calibration record and a correlation with this record along the steep decline at the onset of the Lateglacial Stadial. The remaining GI-1 part of the 2004 ^{14}C data set from the Cariaco basin (original data between 14,723 and 12,909 years cal. b2k) was shifted accordingly by 210 years with the youngest date correlating to a calender age of 12,699 years cal. b2k.

Based on a comparison of the Cariaco basin greyscale with the isotope records from NGRIP and the Hulu Cave, a shift of 100 years towards the younger was previously suggested for the Cariaco basin record (see p. 350-352). This shift seemed necessary because in the early Lateglacial Interstadial the calender ages in

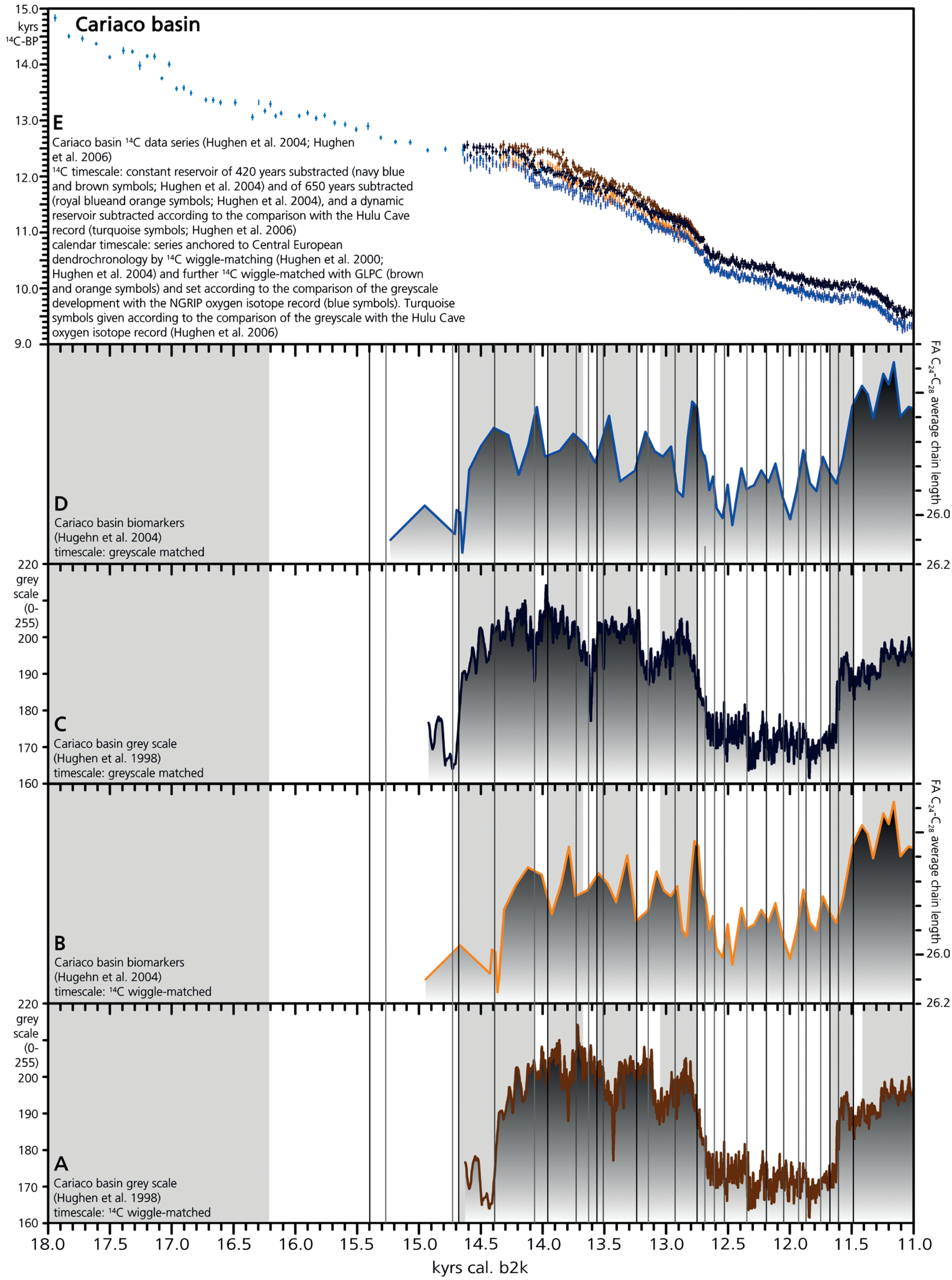


Fig. 42 Comparison of two different age models for the Cariaco basin record. **A**, **B**, **E** (orange and brown symbols) the record according to the best match with the dendrochronological radiocarbon calibration data sets as used in the current approach; **C**, **D**, **E** (blue symbols) the record according to a mixture of ^{14}C wiggle-matching and comparison of the Cariaco basin greyscale to the NGRIP record (see **fig. 39**). Thin bars relate to the NGRIP record and are given as guide lines (light grey: low; medium grey: high; black: transition). – For further details see text.

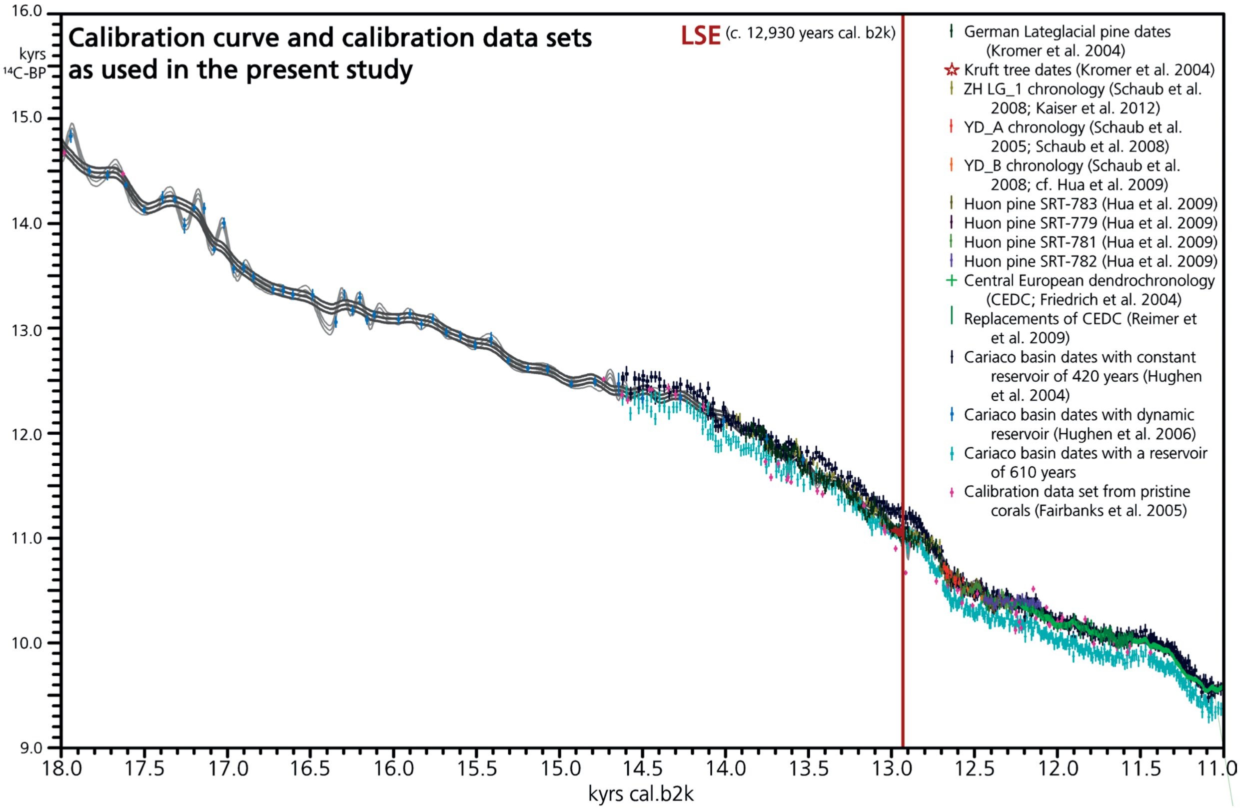


Fig. 43 Calibration curve (with 2σ spline dispersion lines; thick dark grey lines) constructed for the present study and calibration data sets as used in this project. In light grey the calibration curve (with 2σ spline dispersion lines) before smoothing is given. – For further details see text.

the Cariaco basin record seemed to encompass again longer durations than in the NGRIP or the Hulu Cave record. However, after the above described shift to 12,699 years cal. b2k, the onset of the Lateglacial Interstadial was some 100 years younger in the Cariaco basin than in the NGRIP isotope records or the Hulu Cave oxygen isotope curve. Nevertheless, comparing the GI-1 ^{14}C data segment of the Cariaco basin record further to the European dendrochronologies, a compression of additional 174 years could be suggested resulting in the GLPC to begin at 14,339 years cal. b2k. In this case, the ^{14}C ages were consistent and the reservoir ages switched along the Lateglacial Interstadial to Lateglacial Stadial transition from 420 ^{14}C years to 650 ^{14}C years and remained relatively constant on this level in the Lateglacial Interstadial. Only at one point (original data between 14,089 and 14,076 years cal. b2k; shifted and compressed: 13,805 and 13,754 years cal. b2k) the reservoir ages seem to shortly switch to the lower values (420 ^{14}C years) again. However, if the greyscale was correlated accordingly, this proxy record reflected climate changes very differently to the oxygen isotope record from Greenland (**fig. 42A-B**).

In contrast, if the data set older than 12,699 years cal. b2k was shifted according to a comparison of the greyscale with the NGRIP oxygen isotopes, the Cariaco basin record should be stretched again resulting in the earliest ^{14}C date being set at 14,735 years cal. b2k. Then the sub-segment between 14,056 to 14,735 years cal. b2k is compressed by 113 years to an end age of 14,622 years cal. b2k. In this correlation, the steep decrease of ^{14}C ages began in the Cariaco basin record around 12,830 years cal. b2k (**figs 42-43**). In comparison with the GLPC/SWILM data sets, the previously suggested sudden increase of reservoir ages in the Cariaco basin occurred between 12,818 and 12,776 years cal. b2k (**fig. 43**; original values: 13,028 and 12,986 years cal. b2k; cf. Hughen et al. 2004c; Kromer et al. 2004). In contrast to the original suggestion, this correlation suggested a smaller switch in the reservoir ages to only 610 ^{14}C years. Moreover, several, short-termed switches in the reservoir ages during the younger half of the Lateglacial Interstadial, in particular during the equivalents of GI-1c_1 and GI-1b, seemed possible according to this comparison. Between approximately 13,500 and 14,150 years cal. b2k, the reservoir ages switch again to reservoir ages around 420 ^{14}C years (**fig. 43**). A comparison of the Cariaco basin record to the Hulu Cave record already suggested more instable reservoir ages for the Cariaco basin area during the Weichselian Pleniglacial than during the Holocene (Hughen et al. 2006). Furthermore, a simulation study based on a circulation model analysed the development of Atlantic reservoir ages during the Lateglacial Stadial in the context of a shut down of the Atlantic meridional overturning circulation (Ritz/Stocker/Müller 2008). Possibly, the changes in the thermohaline circulation of the North Atlantic indicated by the Heinrich 0 event in MD01-2461 could be correlated with this anomaly. This simulation study suggested a smaller shift in the reservoir ages at the onset of the decline in Δ^{14}C in the transition from the Lateglacial Interstadial to the Lateglacial Stadial followed by a gradual increase of the reservoir ages to higher values than the usual ones and an abrupt, short-termed increase at the recovery of the Atlantic meridional overturning circulation (Ritz/Stocker/Müller 2008, 207). This development was probably indicated by the comparatively steep development of the ^{14}C ages of the Lateglacial dendrochronologies in comparison to the more oblique development of the Cariaco basin dates. Thus, instable episodes of the reservoir ages in the Cariaco basin occurred possibly already during the Lateglacial.

Since the dates given in the Hulu Cave revision of the Cariaco basin record (Hughen et al. 2006) were already changed to a calendar timescale according to a comparison with the oxygen isotope record from the Hulu Cave, the changes of the calendar timescale (shifting, stretching, and compressing) were not applied to these dates. Furthermore, these dates were given with dynamic reservoirs and therefore no additional change on the ^{14}C timescale was considered necessary.

For the period older than 14,622 years cal. b2k, only these Hulu Cave revised dates from the Cariaco basin were available. Further calibration data to supplement these dates could come from pristine corals. In fact, calibration data sets from corals are considered as more accurate and precise than the greyscale data (Fairbanks et al. 2005; Weninger/Jöris 2008). However, Fairbanks and colleagues excluded coral data which could contain more than 0.2 % calcite from their calibration data set due to the possible contamination of the sample and, consequently, of the radiocarbon results (Fairbanks et al. 2005, 1782). Furthermore, they redated some coral samples to achieve more accurate results with higher precisions. Thus, this record compiles the most reliable calibration data sets from pristine corals. The reservoir ages were calculated based on the comparison with the Holocene CEDC data. Comparable to the reservoir ages in the Cariaco basin, a change in these reservoir ages cannot be excluded and seems in parts probable based on the comparison with the Lateglacial Stadial part of the CEDC (**fig. 43**). Moreover, this compilation provided no dates between 14,735 and 17,630 years cal. b2k. Thus, this part of the calibration curve is solely based on the Cariaco basin dates.

These data sets were all compiling in the above described chronologies in the CalCurve composer of the CalPal program and interpolated by the use of the »variable« method[45] resulting in a new calibration curve. The difference between the spline of this curve and the data reached on average 28 ^{14}C years (spline shape of 15.0) but could manually be shifted to only 24 ^{14}C years (spline shape of 8.0 to 11.0; **fig. 43**, light grey curve). However, for the current calibration curve the spline was created with a spline shape of 20.0 (average age difference of 35 ^{14}C years) to smooth some extreme wiggles (**fig. 43**). These wiggles occurred in the GS-2a and GS-2b part of the curve where only the Cariaco basin dates formed the curve. Since these

45 This method uses IMSL (International mathematics and statistics library) in Fortran and the subroutine CSSMH to calculate a smooth cubic spline approximation from noisy data followed by the subroutine CSVAL to evaluate the cubic spline. The result is a cubic spline with variable shape due to a variable SMPAR (smoothing parameter).

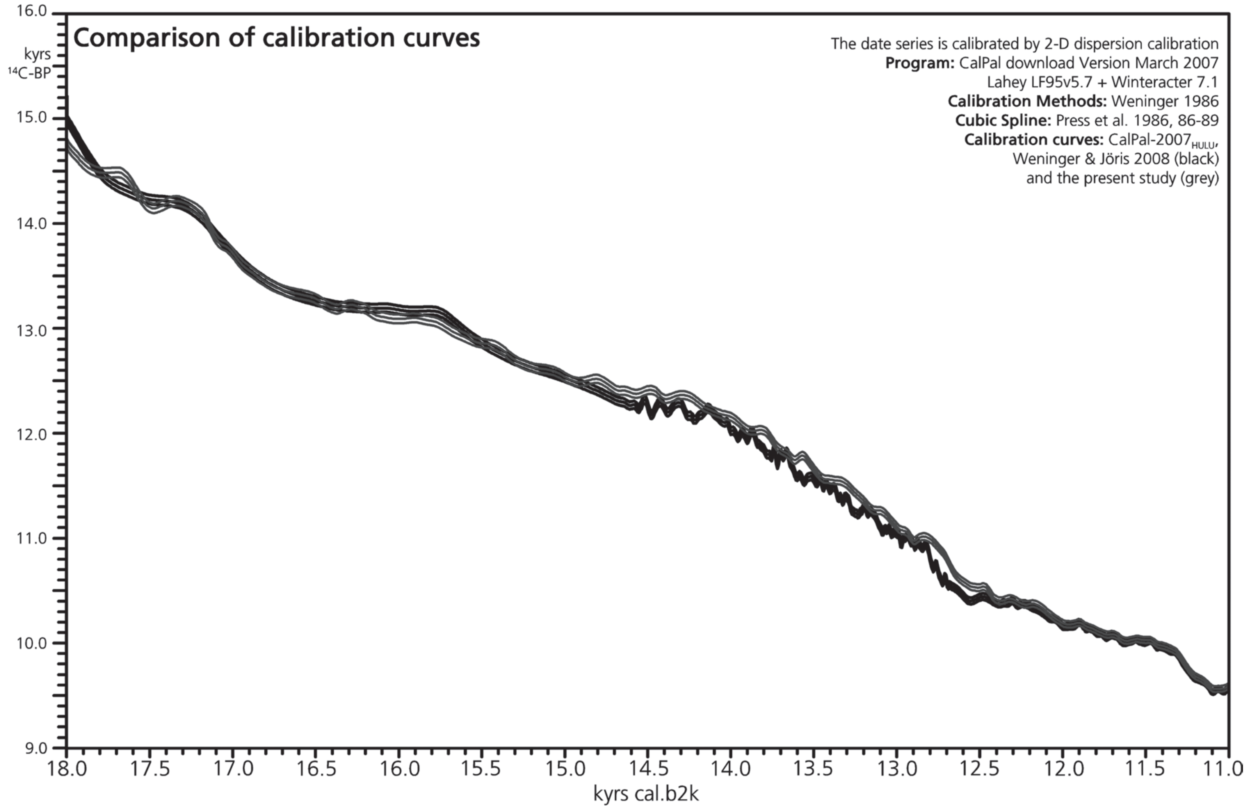


Fig. 44 Comparison of CalPal-2007$_{HULU}$ calibration curve (black) with the calibration of the current project (grey). – For further details see text.

dates could not be further verified in regard to their reservoir ages and a swinging back-and-forth of some 300 ^{14}C years within approximately 200 calender years seemed unusual, a smoothed spline was chosen assuming that some of the Cariaco basin dates might still incorporate inaccuracies.

The resulting calibration curve differs in detail from the CalPal-2007$_{HULU}$ radiocarbon calibration curve, particularly during the Lateglacial Interstadial (**fig. 44**). The Holocene and the younger part of the Lateglacial Stadial are identical in the two calibration curves and the Late Pleniglacial part is also very similar. Thus, the differences are mainly based on the approximately 40 years younger position of the LSE in the curve of this study. Consequently, the calibration with this curve will generally produce the same results as a calibration with the CalPal-2007$_{HULU}$ radiocarbon calibration curve; only in the Lateglacial Interstadial younger results than a calibration with the CalPal-2007$_{HULU}$ radiocarbon calibration curve have to be expected.

Since the calibration curve of this study is closely oriented on the European varve chronologies and the NGRIP record, the calibration results probably relate closely with the events and episodes within the Lateglacial Interstadial. This close correlation should help to relate the environmental and archaeological changes within this period more precisely.

ENVIRONMENT AND CHRONOLOGY

The environmental development of Lateglacial north-western Europe was established in the present study using various lines of evidence: the physical geography, the vegetation development, and the faunal successions in the studied areas.

Physical development of Lateglacial north-western Europe

General remarks

The created maps of Lateglacial north-western Europe display the changes in the sea-level as well as the approximate development of the major ice-sheets. In addition, the Lateglacial landscapes were influenced by isostasy, rivers, and permafrost.

The former was caused by the regressing of the European ice sheets and the subsequent decreasing ice load. For the initiation of ice sheet growths the mean summer temperature is a limiting factor, whereas the volume of ice sheets depends on additional factors such as mean annual temperature or the annual snowfall (Kageyama et al. 2004). Thus, the ice sheet volume can also decrease in cold periods such as GS-2a due to the lack of moisture and snowfall, whereas summer cooling, caused for instance by dammed glacial lakes, can initiate ice sheet growth in periods of temperature amelioration (Krinner et al. 2004). However, visually displayed over long periods, the general trend in the Lateglacial was a regression of the ice sheets causing uplifting of the grounds freed from the ice load. Due to this isostasy as well as other tectonic movements, the exact offset between the modern altitudes and altitudes during the Lateglacial are imperfectly known (cf. Kiden/Denys/Johnston 2002; Reicherter/Kaiser/Stackebrandt 2005; Shennan et al. 2006; Amantov/Fjeldskaar/Cathles 2011). Even though the maps reflect mean values for relatively long periods, the influence of the isostatic uplift on these Lateglacial maps is negligible because of the large scale of the maps. The total difference of the altitudes due to isostatic and/or tectonic movements along, for example, the Belgian coast was probably below 5 m in comparison to the Dutch coast in the studied time period (cf. Kiden/Denys/Johnston 2002). Partially, the uplift was superseded by the accumulating sedimentation load (cf. Amantov/Fjeldskaar/Cathles 2011). Thus, in many parts of the map the difference would be hardly observable due to the large steps in the colour interpolation (see p. 254).

However, the significant movements of the earth's crust caused earthquakes (Mörner 1999; cf. Reicherter/Kaiser/Stackebrandt 2005) and tsunamis (Mörner 1999; Bondevik et al. 2005; Weninger et al. 2008) in northern Europe during the Lateglacial and the early Holocene. Thus far, only very few tsunamis were documented for the Lateglacial (Mörner 1999; Mörner 2008). Due to the geomorphological relief and the position of the coastlines, these natural hazards affected mainly northern Europe in this period and they seemed to have had no direct impact on the human occupation in these presumably sparsely settled areas in this period. Nevertheless, the tsunamis, perhaps in combination with the earthquakes, probably had some impact on the hydrographic development of the Baltic Sea region in general and the development and clearance of the outflow of the Baltic Ice Lake in particular (Mörner 1999; Jensen et al. 2002). In this context, these natural hazards could have also affected the roaming patterns of various mammals and possibly also the human occupation patterns in southern Scandinavia by influencing the natural barrier between Scania, Zealand, Funen, and Jutland (cf. Björck 1995b; Eriksen 1996; Larsson 1996a; Larsson 1999; Schmölcke et al. 2006; Larsson 2009).

Besides the difficulties already inflicted on the reconstruction of the onshore landscapes such as the tectonic movements, the cover by massive sediment deposits, and/or the precise dating of the geomorphological features, the exact development of the Baltic Sea basin is further complicated by the restricted accessibility of the submerged areas, for instance due to weather, currents, and marine traffic. However, based mainly on offshore borehole surveys and onshore stratigraphies, a general history of the development of the Baltic Sea region was established and revealed in part a very different landscape from the modern circum-Baltic region (Björck 1995b; Harff/Björck/Hoth 2011).

The drainage of the European rivers was also in some parts very different from the drainage of modern times and their valleys underwent several changes in the Lateglacial. However, in general the river systems were too small to be acknowledged in the maps of Lateglacial north-western Europe. Moreover, changes in the fluvial system are difficult to date exactly, for various reasons. For example, geo-chemical processes can contaminate the dated samples (cf. Hiller et al. 2003) or later developments led occasionally to the partial or complete destruction of the Lateglacial channels (Chaussé 2003; Badura/Jary/Smalley 2013; cf. Park/Schmincke 1997). However, a general development of most large European river systems is known. In general, the discharge regime and thereby the incision patterns and branching of the rivers changed during the Lateglacial. These changes were influenced by various factors such as the water absorbing capacity of the underground, the melting of glaciers, and the precipitation. For the latter, no direct proxy data are available but based on a geochemical alteration of the sediment due to vegetation growth a simulation model was applied to the Nussloch sequences (Antoine et al. 2001) and yielded a reconstruction of the Lateglacial precipitation patterns (Hatté/Guiot 2005). Even though this analysis refers to a site south of the study are in the Upper Rhine Rift, the general tendency is assumed to be comparable to the study areas. Moreover, the Rhine in the Central Rhineland received its waters from this region.
The changing river courses had some impact on the geomorphology of the valleys, their accessibility, and their ability to serve as guide routes or barriers. For the latter, the seasonality and the according flooding or drying up of the valleys also played an important role.
Besides the large outflow of the Baltic Ice Lake, two further very large drainage rivers had formed during the Lateglacial: one in the area of the English Channel (Antoine et al. 2003a) and the other one west of the Cimbrian Peninsula (Streif 2004; cf. Badura/Jary/Smalley 2013). In addition to the English and northern French rivers which drain into the English Channel until modern times, the Channel river was supplied by the large western European river systems such as the Scheldt, the Meuse, and the Rhine as well as several (south-)eastern English rivers such as the Thames (Busschers et al. 2005; Busschers et al. 2007; Antoine et al. 2003a; Bourillet et al. 2003; Wallinga et al. 2004; Ménot et al. 2006, Makaske/Maas/van Smeerdijk 2008). However, this river was probably formed by several meandering river channels intersected by sand dune formations which were usually set on the northern side of the banks (Hijma et al. 2012). Furthermore, many of the large rivers behaved, presumably, in a comparable way before the confluence. Thus, the area where the Thames and the Rhine coalesced, probably joined by several other smaller rivers, was a large water landscape with a network of river channels. In general, this large water landscape was probably comparable to modern river deltas (Gilg et al. 2000), which can be environmentally productive and therefore favourable landscapes (Bianchi/Allison 2009) but occasionally also migration barriers.
The large river west of the Cimbrian Peninsula was mainly formed by the large rivers systems of the Ems, the Weser, and the Elbe which formed a 30-40 km wide channel (Streif 2004, 9) flowing around Helgioland (Konradi 2000; cf. Houmark-Nielsen/Henrik Kjær 2003) towards the central North Sea basin and from there presumably northwards into the Norwegian Trench. In addition, many western Jutland and Schleswig-Holstein rivers, which flowed in partially deeply incised valleys, formed tributaries to the Heligoland channel, whereas other Danish rivers flowed directly northwards to the Norwegian Trench, the Skagerrak, or the Kattegat. Some of the eastern rivers could have drained into one of the Danish straits and the Baltic Ice Lake. Further large river systems in the eastern North European Plain such as the Oder or the Vistula mainly drained into the Baltic Ice Lake area already during GS-2a (Starkel/Gębica/Superson 2007). During the maximum glaciations in the Late Pleistocene, the northwards drainage of these rivers was temporarily blocked by the Scandinavian ice sheet and glacial valleys and water gaps were established which connected these river systems westwards with the Elbe, the Weser, and the Ems drainage system (Wolstedt 1956; Badura/Jary/Smalley 2013). However, the northwards drainage of these rivers was reestablished soon after

the retreat of the Scandinavian ice sheet (Starkel/Gębica/Superson 2007; cf. Badura/Jary/Smalley 2013). Nevertheless, some basins in the glacial valleys and water gaps remained water-filled into modern times (Neugebauer et al. 2012, 92), whereas others fell dry and were partially filled with sediment and served probably as source for aeolian sediment removal (Badura/Jary/Smalley 2013). Consequently, when exactly the connections ceased and/or until when these connections were perhaps occasionally reactivated, for example when ice-bergs in the Baltic Ice Lake dammed the outflow of meltwaters through the river mouths, remained uncertain. Moreover, the exact topographic development in the area of the modern Baltic Sea is difficult to reconstruct (cf. Lemke et al. 2002; Meyer/Harff 2005; Reicherter/Kaiser/Stackebrandt 2005; Harff et al. 2007; Bellec/Diesing/Schwarzer 2010; Hoffmann/Reicherter 2012). The difficulty is in particular due to the cover by modern sediments, the partial destruction of old topographies by more recent tidal and neotectonic movements, and the problem of dating the submerged structures more precisely.

A comparably difficult area to reconstruct is the basin of the modern North Sea. A land-bridge emerged between the Cimbrian Peninsula and the British Isles during the periods of low sea-level in the Pleistocene such as the LGM. This land which was occasionally referred to as Doggerland (Coles 1998, 47; Coles 2000; cf. Gaffney/Thomson/Fitch 2007) submerged underneath the North Sea again in the Holocene rise of the global sea-level (cf. Weninger et al. 2008). This flooding ended the Lateglacial drainage system.

The general difficulties of reconstructing this Lateglacial drainage system as well as the landscape of Doggerland are the same as in the river systems and the Baltic Sea basin (see above; cf. Ward/Larcombe 2008). Moreover, the majority of new studies on the North Sea basin is based on 3D seismic analyses which can date the developments only relative to each other. Additional borehole samples can help if the samples contain datable material or provide indications to differentiate marine, coastal, freshwater, or terrestrial environments. However, the precise temporal development of the North Sea basin often remains a matter of debate thus far (Moreau et al. 2012). Therefore, the possible notes on the Lateglacial development of this area remain vague. According to 3D seismic analyses which were conducted in some sample areas, a network of rivers, wetlands, and tunnel valleys existed on most parts of the North Sea basin during the Lateglacial (Praeg 2003; Fitch/Thomson/Gaffney 2005; Lonergan/Maidment/Collier 2006; Gaffney/Thomson/Fitch 2007; Stewart/Lonergan/Hampson 2012). However, some rivers from eastern England must have ended in this area but whether they formed dammed lakes in trough-like situations such as the Outer Silver Pit and/or supplied the wetland complex of Doggerland, drained towards the north, or supplied the Channel river (cf. Toucanne et al. 2010), remains unclear thus far. However, with the gradual flooding of the North Sea basin, the drainage areas supplying the Doggerland wetlands, the Channel river, or the Heligoland channel constantly decreased and at least in the case of Doggerland this suspension of the water supply could have caused droughts prior to the final flooding.

Besides water straits, permafrost development played an important role in limiting the expansion of biomes in north-western Europe during the Late Pleistocene (cf. Huijzer/Vandenberghe 1998, 408f.). In permafrosts, only a small part of the subsurface thaws in the warmer seasons making the development of organic life only possible for a limited period and at a limited planting depth. In addition, water also becomes frozen in these grounds and the availability of water consequently decreases. Even though permafrost features were relatively well defined and, therefore, regularly observed in the geological record (Huijzer/Isarin 1997; Renssen/Vandenberghe 2003), a precise dating of the processes creating these features is difficult (Isarin 1997). Permafrost develops under severe cold conditions depending on the soil surface temperature for which air temperatures above the ground, type of vegetation, snow cover, surface slope, and the sediment composition of the ground are controlling factors (Delisle et al. 2009; cf. Haeberli et al. 2010; Vandenberghe et al. 2012). Moreover, a relation of the latitudinal extend of permafrost areas in Late Pleistocene Europe to the sea-ice cover in the North-Atlantic was observed (Renssen/Vandenberghe 2003; Vandenberghe et al. 2012). As a result, the general distribution of permafrost fluctuated with the episodic variations of the North Atlantic sea-ice cover such as during Heinrich events. The sea-ice cover influenced the patterns of the isotherms of the air masses reaching western Europe (Renssen / Vandenberghe 2003) and, generally, a mean annual air temperature of -1°C appears as the limit for the development of permafrost (Delisle et al. 2009). Continuous permafrost, which relates to the presence of permafrost in all places, can develop in regions with a fine-grained sediment texture and a mean annual air temperature of -4°C, whereas in regions with sandy and gravely sediments a mean annual air temperature of about -8°C is necessary to develop continuous permafrost (Renssen / Vandenberghe 2003; cf. Vandenberghe et al. 2012). Thus, in most areas with a mean annual air temperature of -8°C permafrost can develop but sporadic places with permafrost can also persist for a relatively long duration during the process of amelioration (cf. Busschers et al. 2007, 3242), especially in particularly cold places such as northern slopes or deep valleys. Furthermore, the freezing of the ground reaches considerable depths in areas of continuous permafrost and the process of thawing in these great depths is a relatively gradual and slow process (cf. Vandenberghe et al. 2012, 17 f.). In consequence, a relatively quick reestablishment of full permafrost conditions becomes possible in periods when permafrost are thawed only superficially and rapid returns of colder climates occur. Thus, the final disappearance of permafrost conditions is also difficult to estimate exactly.

The accumulation of the loess and coversands (**fig. 45**) is comparably difficult to date. The development and dispersal of these aeolian deposits was generally associated with cold and dry climates (Koster 1988; Kasse 2002; Antoine et al. 2003c) and, thus, their sedimentological composition can be partially compared with more precisely dated climate archives (Antoine et al. 2013; Jary / Ciszek 2013). In addition, the sequence of biotic remains preserved in the wind borne material, in particular pollen, was used for a more precise temporal attribution (Hoek 1997; Kolstrup 2007; Antoine et al. 2013). However, the acidic aeolian sediments are not well suited for pollen preservation (cf. Marshall 2007, 8-10. 122-124). Furthermore, the number of most organic indicators decreases in cold and dry climates and, consequently, the number of relevant material for the creation of a biostratigraphy was often reduced already at the time of the sedimentation. Thus, the stratigraphies with preserved biotic indicators is often biased towards locations with wetter conditions (Kolstrup 2007) in which the preservation was enhanced. The silty and sandy structure of these sediments occasionally allowed for post-depositional exchange of micro-remains such as pollen or cryptotephra particles. These exchanges are again enhanced in areas with wetter conditions and, thus, could pass undetected if they did not produce noticeably arbitrary results and / or if no detailed micro-morphological study of the sediment was conducted (cf. Weber et al. 2010; Housley et al. 2012). Therefore, a chronology of these aeolian sediment sequences made by the use of cryptotephras and micro-fossils becomes more reliable if it is supplemented by micro-morphological and / or pedological studies.

The loess deposits accumulated throughout the Pleistocene but the largest loess deposits originated from the Late Pleistocene, in particular from a period between approximately 30,000 to 15,000 years ago in western Europe (GS-3 and GS-2; Antoine et al. 2003c; cf. Frechen / Oches / Kohfeld 2003). This tendency was also observed in the Eastern European loess sequences (cf. Molodkov / Boliskhovskaya 2006), although thicker deposits of older material were also well preserved in some eastern Central European profiles (Madeyska 2002; Antoine et al. 2013). The formation of loess continued to the onset of the Lateglacial Interstadial and ceased then. The dispersal began again in some parts of Europe during the Lateglacial Stadial (Hilgers et al. 2001).

In contrast to the loess formation, the coversands were generally related to the North European Plain (**fig. 45**) and were mainly assumed to be deposited during the Lateglacial (Kasse 2002; Kolstrup 2007). In the western North European Plain, two phases of coversand deposition (Older and Younger Coversand) were generally distinguished and considered as important marker sections to compare lithostratigraphies

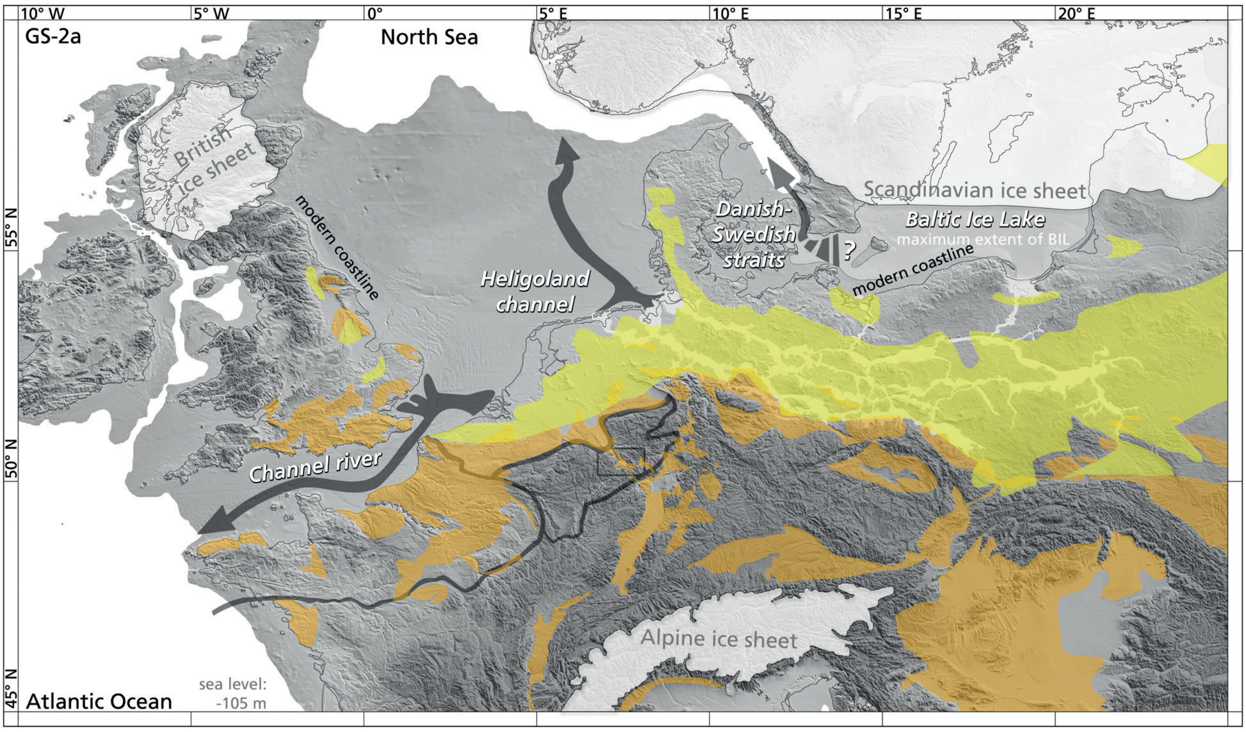


Fig. 45 Map of north-western Europe during GS-2a with approximate limits of significant aeolian deposits and the study areas (see **fig. 1**). Sea-level is set according to Weaver et al. 2003, 1712 fig. 5. An Irish Channel is supported by data from McCabe/Clark/Clark 2005; McCabe/Cooper/Kelley 2007; Edwards/Brooks 2008. The glacially formed valleys and water gaps on the North European Plain are highlighted in light grey (according to Wolstedt 1956; cf. Badura/Jary/Smalley 2013). The limits of the ice sheets are based on data from Lundqvist/Wohlfarth 2001; Boulton et al. 2001; Clark et al. 2004 (cf. Clark et al. 2012); Ivy-Ochs et al. 2006 (see p. 253-259). The loess distribution (orange shaded area) includes besides loess also sandy loess, loess derivates, and loess-like deposits but no aeolian sands or alluvial loess (Haase et al. 2007, fig. 9; Antoine et al. 2013, 18 fig. 1). The sand belt (yellow shaded area) is sketched according to Kasse 2002, 509 fig. 1 and Zeeberg 1998, 128 fig. 1.

(van Geel/Coope/van der Hammen 1989; Hoek 1997; Kolstrup 2007). Based on refined chronologies and more precise characterisations of the deposited material as well as concerns relating to the terminology, Kees Kasse differentiated between sedimentary facies in the coversands and phases of aeolian activity (Kasse 2002). By this distinction, he revealed that the aeolian activity occurred approximately in the same periods and climate regimes as the loess dispersal. However, studies of modern inland drift sands and coversand areas showed that comparable sand sheets also formed in a generally temperate climate regime (Koster 2009). In fact, Kasse also recognised that the activity phases continued for some time into the interstadial conditions Kasse 2002, 523). He explained the increased and widespread formation of sand sheets with four factors: (i) the increasing size of proglacial deflation areas with unconsolidated material which became available after the regression of the British ice sheet and, in particular, the Scandinavian ice sheet (cf. deflation areas indicated by Antoine et al. 2013, 18 fig. 1), (ii) the sparseness of vegetation to bind the material, (iii) the high ratio of wind energy and sediment availability (cf. Brauer et al. 2008), and (iv) the absence of major barriers on the North European Plain (Kasse 2002, 515 f. 521-523). In fact, these factors are generally the same as for the formation of loess (Pye 1995). Therefore, the largely overlapping deposition periods are unsurprising.

The loess deposits, which are often several metres thick, have significantly influenced the European geomorphology and have still changed the topography after Lateglacial Interstadial (Hilgers et al. 2001). These deposition affected, in particular, the study area. The sometimes comparably massive aeolian sand sheets also covered the Lateglacial topography and these coversands have thereby also changed the geomorphology in the affected regions significantly, for instance when forming sand dunes or filling depressions in the landscape (Hoek 2000, 500; cf. Sandersen/Jørgensen 2003). Loess and coversands were, in general, related to rivers (Kasse 2002; Smalley et al. 2009; Badura/Jary/Smalley 2013; cf. Haase et al. 2007), which provide the substrate and wind patterns which spread the substrate (Pye 1995; Koster 1988; Antoine et al. 2009). The general grain-size of the transported substrate makes the difference between loess (silt) and coversands (sand). However, in some areas transitional deposits were observed and described for example as sandy loess (Pye 1995; cf. Haase et al. 2007). Thus, in these areas the distribution maps of coversands and loess partially overlap. Furthermore, distribution maps of loess deposits usually include besides loess deposits also loess derived deposits as well as loess-like sediments (Haase et al. 2007) due to the aeolian origin and the post-depositional processes (Pye 1995). Mapping the various types of loess and evaluating the period of deposition of the loess to map only the Late Weichselian loess deposits exceeds the possibilities of the present study (cf. Antoine et al. 2009; Antoine et al. 2013). A distinct mapping of the coversands which formed during different periods is also beyond the scope of the present study. Nevertheless, an approximate distribution of the European loess belt and the European sand belt is a reminder that modern topographic measurements such as the SRTM data can hardly provide reliable information on the geomorphology of the Lateglacial landscape in these regions.

Besides these aeolian deposits, river dunes and drift sands also altered the landscape in areas of the large river systems (cf. Kasse et al. 2005; Koster 2009; Hijma et al. 2012).

Thus, many areas of north-western Europe were constantly changed by wind borne material, rivers and larger water bodies as well as by tectonic movements during the Lateglacial. The following maps can only produce a static picture of these processes.

Development within four sub-periods

The development of the physical geography in Lateglacial north-western Europe is displayed by maps that reflect four major sub-periods of the Lateglacial: the Late Pleniglacial (GS-2a), the early Lateglacial Interstadial (GI-1e-d), the mid- and late Lateglacial Interstadial (GI-1c-a), and the Lateglacial Stadial (GS-1).

The map relating to north-western Europe during GS-2a (**fig. 46**) reflects approximately the physical geography during the occupation of the Late Magdalenian sites such as Gönnersdorf, Andernach (lower level), Verberie, or Étiolles.

In this period the large European ice sheets had already retreated significantly in comparison to the maximum extension during the LGM. Perhaps, this retreat was related to the generally high aridity during the period following the LGM (cf. Hatté/Guiot 2005). The northern ice sheets which probably had coalesced during the LGM (Sejrup et al. 2009) were clearly separated by the onset of GS-2a (Carr et al. 2006).

The glacial front of the Scandinavian ice sheet had retreated to a latitude in southern Sweden uncovering most of Scania (Boulton et al. 2001; Lundqvist/Wohlfarth 2001). Approximately at the onset of GS-2a, a short-termed readvance of the glacial front was observed (cf. Lundqvist/Wohlfarth 2001, 1131; Sejrup et al. 2009). Probably, this readvance related to the so-called Halland coastal moraine (Lundqvist/Wohlfarth 2001). The well defined Göteborg moraines were already found some 10 km and more further inland (Lundqvist/Wohlfarth 2001). These moraines indicated a second, intense readvance in the early GS-2a. Thus, the velocity of the movements of the glacial front was relatively high in the Late Pleniglacial. Around the mid-Late Pleniglacial, the ice sheet had already retreated over the distance covered by the short-termed readvances, presumably due to the extreme dryness.

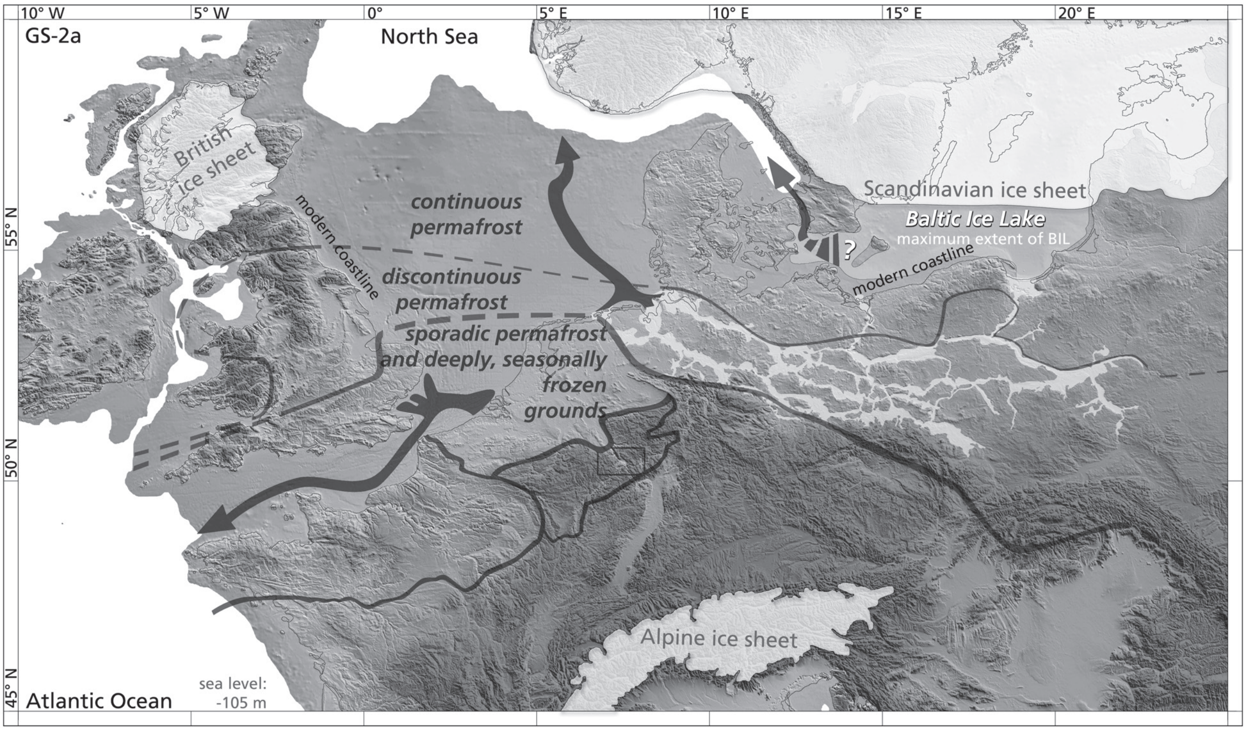


Fig. 46 Map of north-western Europe during GS-2a with approximate limits of permafrost zones and the study areas indicated (see **figs 1. 45**). Permafrost limits are approximations according to the data in Huijzer/Vandenberghe 1998 and the ice wedge presence in Wilczyce (Fiedorczuk/Schild 2002; Irish et al. 2008) as well as assumptions based on the glacial observations in the Giant Mountains (Nývlt/Engel/Tyráèek 2011) and the western Carpathians (Makos/Nitychoruk/Zreda 2013). For the areas where the permafrost lines are dashed no data from which the limits can be deduced was available.

If the proportion and speed of the regression of the British ice sheet was comparable to the Scandinavian one the British ice sheet had reached approximately the Scottish Central Belt during GS-2a. The Grampians, the north-western Highlands, and the Inner Hebrides were probably still covered by glaciers. Based on model calculations, Anthony Brooks and colleagues assumed that the British ice sheet had melted completely by *c.* 15,000 years b2k (Brooks et al. 2011), whereas a model based on the ice sheet related landforms considered relic ice sheets to have still existed in Scotland and Ireland at this time (Clark et al. 2012). However, in comparison to these reconstructions, the British ice sheet of the present study is overestimated indicating that the retreat patterns of the British ice sheet were probably faster than the retreat of the Scandinavian ice sheet. Perhaps, this lower velocity of the Scandinavian ice sheet can be explained by the slowing of the purging ice once the sea estuary through the Norwegian trench was established (cf. Clark et al. 2012). The disintegrating British-Irish ice sheet formed a glacial melt-water channel between Ireland and Great Britain approximately 16,000 years b2k (Edwards/Brooks 2008). Through this channel the meltwaters of the remaining British ice-sheet could partially be drained (cf. Clark et al. 2012). This ice channel disconnected Ireland from the European continent and established its island history. However, situated between the ice-channel and the slowly retreating sea-ice cover of the North Atlantic, Ireland remained probably a cold steppe to icy desert environment at least until the early to mid-Lateglacial Interstadial (cf. Huijzer/Vandenberghe 1998; Wickham-Jones/Woodman 1998).

The retreat of the Alpine ice sheet into higher altitudes freed less landmass than the retreat of the northern ice sheets. In these often short distances between the different Alpine moraines, a more complex history of retreat and readvance could be established (Ivy-Ochs et al. 2008). A widespread readvance of Alpine glaciers termed »Gschnitz-Stadial« was a several centuries long process which according to the so-called exposure dates (based on ^{10}Be isotopes) was considered to be related to the ice-rafting event of Heinrich 1 (Ivy-Ochs et al. 2006). According to these dates, the maximum margins of this »Gschnitz-Stadial« were reached approximately at the onset of GS-2a. At its maximum extent, the ice front stagnated for at least several decades (Kerschner/Ivy-Ochs 2008, 61). Subsequently, the ice sheet continued to retreat into higher altitudes during GS-2a but two further, poorly dated readvances (Clavadel/Senders and Daun) occurred before the onset of the Lateglacial Interstadial. The relation of these readvances to the development of the Scandinavian ice sheet in this period remain unclear due to the uncertain chronology. How much such Alpine readvances can be related to tectonic processes (Norton/Hampel 2010) and/or changing patterns of moisture and precipitation (cf. Turk 2012), particularly during the Heinrich 1 event in the North Atlantic (Stanford et al. 2011b), remains to be analysed.

During the LGM further ice sheets developed on some middle range and higher mountain ranges such as the Jura Mountains (Buoncristiani/Campy 2011), the Vosges Mountains (Andreoli et al. 2006), or southern German Black Forest (Fiebig/Ellwanger/Doppler 2011) alongside the three major European ice sheets. However, by the onset of GS-2a, the majority of these smaller ice sheets had already shrunken to single glaciers of which some persisted into the Holocene, for instance in favourable locations in the Vosges Mountains (Andreoli et al. 2006) as well as in the Giant Mountains (Nývlt/Engel/Tyráèek 2011). In general, these glaciers retreated further during the Late Pleniglacial and Lateglacial Interstadial, for example the relic glaciers of the larger glacial ice sheets in the southern Carpathians (Urdea/Reuther 2009). The LGM ice sheet of the Polish High Tatra, part of the Carpathians, had also shrunk to a single glacier, but comparable to the Scandinavian and the Alpine ice sheets a last major readvance occurred at the onset of GS-2a (Makos/Nitychoruk/Zreda 2013). This readvance was followed by a stepwise melting accelerated by the onset of the Lateglacial Interstadial.

Thus, higher mountain ranges such as the Alps or the Carpathians as well as possibly some smaller areas in the lower mountain ranges such as in the Vosges Mountains or in the Giant Mountains still formed glacial barriers to migration during GS-2a.

Moreover, permafrost could also limit expansion processes in this period (**fig. 46**). The zone of continuous permafrost had probably retreated into northern Europe leaving only some sporadic permafrost relics in north-western Europe (Huijzer/Vandenberghe 1998, 409). Patches of permafrost were still recorded in the early Lateglacial Interstadial in northern Rhineland (Busschers et al. 2007, 3242) suggesting at least sporadic permafrost conditions survived in north-western Europe during GS-2a. However, in neither northern France nor in Central Rhineland were indications of permafrost found that could be related to the Late Magdalenian occupation of these regions. According to the proxy data for temperature (Huijzer/Vandenberghe 1998; cf. Coope et al. 1998), the ground in these regions were probably still deeply frozen for some time throughout the year. These severe cold seasons are confirmed by the archaeological material disturbed by cryoturbation. Furthermore, some lithic material exhibited frost cracks and/or were heavily patinated suggesting the influence of a cold climate. The faunal remains from the archaeological sites comprised animal species such as reindeer (*Rangifer tarandus*), arctic hare (*Lepus timidus*), and arctic fox (*Alopex lagopus*) all of which indicate a cold tundra/steppe environment.

In contrast, the Late Magdalenian material from the south-eastern Polish site of Wilczyce was mainly preserved in a large ice-wedge (Fiedorczuk/Schild 2002; Fiedorczuk et al. 2007) that was still active and successively filled during the period when the site was visited by the Late Pleniglacial hunter-gatherers (Irish et al. 2008). Perhaps, the warm period in the North Atlantic region suggested by the deep sea record of MD01-2461 affected western Europe more intensely and accelerated the withdrawal of the permafrost conditions in the areas adjacent to the North Atlantic (cf. Coope et al. 1998; Renssen/Vandenberghe 2003). In contrast, the more continental climate preserved, at least discontinuous permafrost conditions, further to the south in eastern Europe. Another possibility is that the severe aridity during this period (cf. Hatté/Guiot 2005; Fletcher et al. 2010), prohibited the formation of frost within the dry sediment of western Europe. Since the active ice wedge of Wilczyce was recorded in the vicinity of the relatively protected basin formed by the San confluence into the Vistula, the adjacent higher mountain ranges of the Carpathians were probably also influenced by these cold climate conditions during GS-2a. This review shows that well dated records are not very exhaustive for illustrating and delimiting biome expansions.

Besides the cryosphere, the hydrosphere shaped major changes in the appearance of north-western Europe. The retreating ice sheets in northern Europe gave space for the rising northern Atlantic waters to intrude into the open lands from the north. By the onset of GS-2a, the sea-level had risen approximately 15-20 m above the LGM minimum of -123 m (Hanebuth/Stattegger/Bojanowski 2009). In particular, the deep Norwegian trench and the adjacent Skagerrak and Kattegat straits were filled by sea water soon after the deglaciation of these areas. Thus, this fjord-like estuary was presumably already formed before the onset of GS-2a (Houmark-Nielsen/Henrik Kjær 2003). The readvance of the Scandinavian ice sheet at the onset of GS-2a also reached coastal and marine parts of offshore Norway and partially filled the Norwegian trench with ice streams and ice bergs (Sejrup et al. 2009). The intrusion of sea water into the estuary was at least partially blocked by this glacial front and the formation of pack ice is very probable during this episode. The ice sheet retreated again during the Late Pleniglacial but at some points ice bergs were still launched into the Skagerrak and the Norwegian Trench at the onset of the Lateglacial Interstadial (Houmark-Nielsen/Henrik Kjær 2003, 781).

In the Baltic region a land bridge possibly existed in this period. With increasing deglaciation during GS-2a, the amounts of melt-waters combined with ice-bergs increased in the region south of the Scandinavian ice sheet and created the Baltic Ice Lake with an outflow through the Öresund area (**fig. 47**; Björck 1995a, 21). Through this outflow further ice-bergs were injected into the Kattegat, Skagerrak, and finally the Norwegian trench. To what extent these various sources of drifting ice-bergs resulted in the formation of pack ice or in some areas, such as the Öresund, fast ice for at least some of the year remains to be studied.

Sample studies on the Late Weichselian geomorphology of the North Sea basin, particularly offshore Denmark, highlights deep tunnel valleys which were largely filled shortly after their development (Kristensen et al. 2007; Kristensen et al. 2008). Some of the tunnel valleys were dead end valleys which depending on the individual geomorphology could serve well as traps for groups of migrating animals. Based on the sedimentary record of the North Sea basin, the area offshore from northern Germany appeared relatively level in the Late Weichselian but also contained some steep sided valleys (Streif 2004, 25; cf. Passchier et al. 2010). Comparable to the tunnel valleys in northern Germany (Clausen 2010), Lateglacial deposits of relic glacial lakes and/or kettleholes were found in several of these North Sea valleys (Kristensen et al. 2007). Thus, the landscape of the eastern North Sea landmass was characterised by a water rich landscape cut by tunnel valleys comparable to Lateglacial northern Germany.

Through this landscape the large Heligoland channel river flowed northwards (see p. 366 f.). This drainage was still supplied by the majority of the Danish rivers as well as the large rivers from the North European Plain (cf. Houmark-Nielsen/Henrik Kjær 2003). Even though a wide channel bed was identified in the Heligoland channel (Konradi 2000), the exact filling is unknown. An analogy for the general fluvial style of the large rivers in the Late Pleniglacial (van Huissteden/Kasse 2001; Kasse et al. 2005; Starkel/Gębica/Superson 2007; cf. Antoine et al. 2003a), would most probably be a large braided system rather than a single wide channel. Since the channels in braided river system are usually shallow, this braided river landscape was probably crossable outside melt-water and/or rainy seasons. In regard to the recent morphology of the sea floor and the reconstruction of tunnel valleys, the Heligoland channel river was flanked by a wide but limited floodplain. In times of highwaters, the space for the additional water was consequently restricted and the

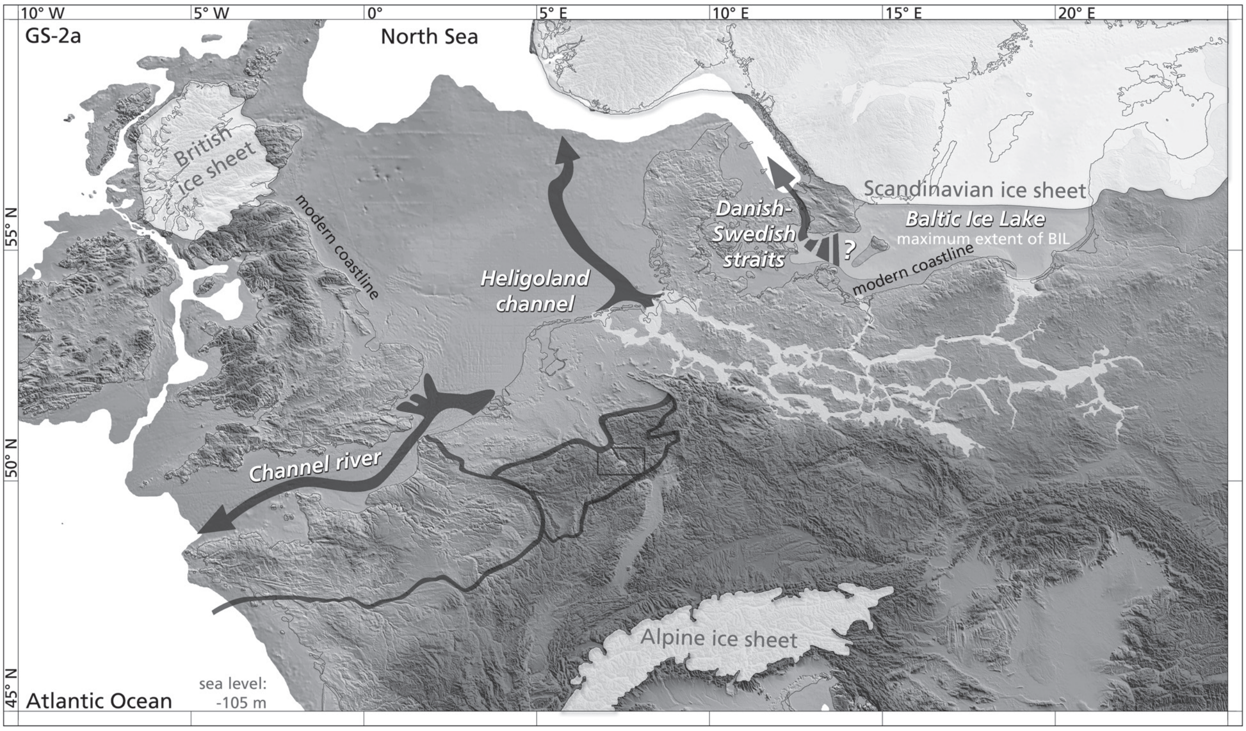


Fig. 47 Map of north-western Europe during GS-2a with the drainage system and the study areas indicated (see figs 1. 45). For the Baltic Ice Lake and possible outflows see Björck 1995a. The white question marks indicate the uncertain drainage of the rivers in the basins of the Baltic Sea and the North Sea. On the North European Plain the glacially formed valleys and water gaps are highlighted in light grey (according to Wolstedt 1956; cf. Badura/Jary/Smalley 2013). The Heligoland channel is sketched according to Konradi 2000 and Streif 2004 (cf. Badura/Jary/Smalley 2013). For the North Sea basin small-scale data gradually increases but still remains difficult to date (cf. Fitch/Thomson/Gaffney 2005; Ward/Larcombe/Lillie 2006; Gaffney/Thomson/Fitch 2007; Ward/Larcombe 2008; Stewart/Lonergan/Hampson 2012). The English Channel river is sketched according to Bourillet et al. 2003; Lericolais/Auffret/Bourillet 2003; Gupta et al. 2007; cf. Gibbard 1988; Antoine et al. 2003a; Ménot et al. 2006; Hijma et al. 2012.

Heligoland channel river probably developed into a wide and deep river during these water-rich seasons. This river presumably had some areas with strong currents and could have formed a barrier to, for instance, migrating reindeer herds.

Borehole and 3D seismic analyses from the western and southern North Sea basin are relatively numerous (Praeg 2003; Fitch/Thomson/Gaffney 2005; Passchier et al. 2010; Hijma et al. 2012; Moreau et al. 2012; Stewart/Lonergan/Hampson 2012). Comparable to the eastern sector of the North Sea basin, many tunnel valleys formed in the south-western North Sea basin and also some large sand ridges such as the Dogger Bank or the Brown Bank (cf. Ward/Larcombe 2008). Even though the exact dating of the observed structures and deposits in in this region are still a matter of debate (Moreau et al. 2012), the tunnel valleys are assumed to have formed during a glaciation prior to the onset of GS-2a. To what extent these tunnel valleys were already filled with sediment or were still recognisable as valleys and whether they contained open waters during GS-2a remains, to date, uncertain. In the south sector of the North Sea basin, the major western European rivers coalesced into the large English Channel river which formed a large braided river system during this period (see p. 366; Antoine et al. 2003a; Gupta et al. 2007; Hijma et al. 2012). In regard to the barrier effect this river system could have had on migratory and expansion processes, the same considerations as to the river system in the Heligoland channel apply. In contrast to this northern system, the English Channel river flowed through areas with only sporadic permafrost and emptied into an Atlantic region without significant sea-ice cover. Furthermore, in many parts of the English Channel the morphology allowed the water courses to spread across the complete width of the modern channel. Thus, in periods of higher water volume, this area would probably have changed into an even wider water landscape. In the context of the drier conditions during GS-2a, this type of water landscape would probably have formed a fertile and therefore attractive area for various species.

The rivers of north-western Europe were generally flowing in high-energy braided systems (Mol / Vandenberghe / Kasse 2000; Lewis / Maddy / Scaife 2001; Antoine et al. 2003b; Kasse et al. 2005; Starkel / Gębica / Superson 2007; cf. Vandenberghe 2003) but some developed locally into meandering river types (Pastre et al. 2003; Turner et al. 2013).

Even though several barriers such as glaciers or large water straits existed for expansion and migratory processes in north-western Europe, these blocked pathways could often be bypassed or crossed during more favourable seasons.

Alongside the conditions related to cold climate and hydrology, the aeolian distribution of sediments shaped the Late Pleniglacial landscape. Based on the position of some Late Magdalenian assemblages within loess deposits, two observation can be made: (i) the majority of loess was already deposited at the beginning of the Late Magdalenian and (ii) loess was still deposited after the Late Magdalenian occupations. The rapid deposition of the archaeological material in aeolian sediments was occasionally assumed as a factor of relatively good preservation. However, at the Late Magdalenian sites of Gönnersdorf and Andernach, this enhanced preservation applied mainly to material deposited in pits and underneath stone plates, whereas faunal material deposited on the surface was strongly weathered, poorly preserved, or probably completely unpreserved (Street / Turner 2013). Thus, the dispersal of loess appeared reduced concomitant with the Late Magdalenian occupation of the Central Rhineland sites.

A possible explanation for the reduction of loess dispersal could be a change in the North Atlantic sea-ice cover. The sea-ice distribution in the North Atlantic influenced the temperatures over the ocean and was thereby connected with the western European air masses resulting in the influence on the North Atlantic climate on the distribution of permafrost (Renssen / Vandenberghe 2003) as well as the loess dispersal in western Europe (Antoine et al. 2013). If the correlation of MD01-2461 is correct, the Late Magdalenian settlement in northern Central Europe can be related to a more favourable period following the Heinrich 1 event. In this period, the sea-ice melted and milder temperatures prevailed in north-western Europe resulting in a regression of permafrost and changes in the wind tracks and intensities yielding a possible reduction in loess accumulation. However, loess deposition did not cease completely and as the warm episode ended the loess dispersal probably increased again. Consequently, the hunter-gatherers of the Late Pleniglacial and the early transition period had to cope with loess bearing winds which periodically varied in their intensity during this time and potentially also with the seasons.

Thus, north-western Europe was still affected by significant geomorphological changes during the Late Pleniglacial and the landscape was presumably exposed to significant seasonal changes driven by the climate system.

The second map (**fig. 48**) provides an outline of Europe during the early Lateglacial Interstadial (GI-1e and GI-1d), which approximates to the time when concentrations such as the south-western area of Gönnersdorf, the concentrations of Marsangy, or the lower horizon of Le Closeau were occupied.

In this period, the retreat of the northern European ice sheets was accelerated by the quickly rising temperature. However, the melting of the global glaciers increased the global sea-level and the northern European estuary expanded. Perhaps this expansion led to an increased area affected by purging ice which again could have slowed the retreat of the Scandinavian ice sheet (cf. Clark et al. 2012). Furthermore, the precipitation and consequently the snowfall also increased in this period which could explain the dating of the Berghem-Moslätt moraines to the early Lateglacial Interstadial (Lundqvist / Wohlfarth 2001, 1131 f.).

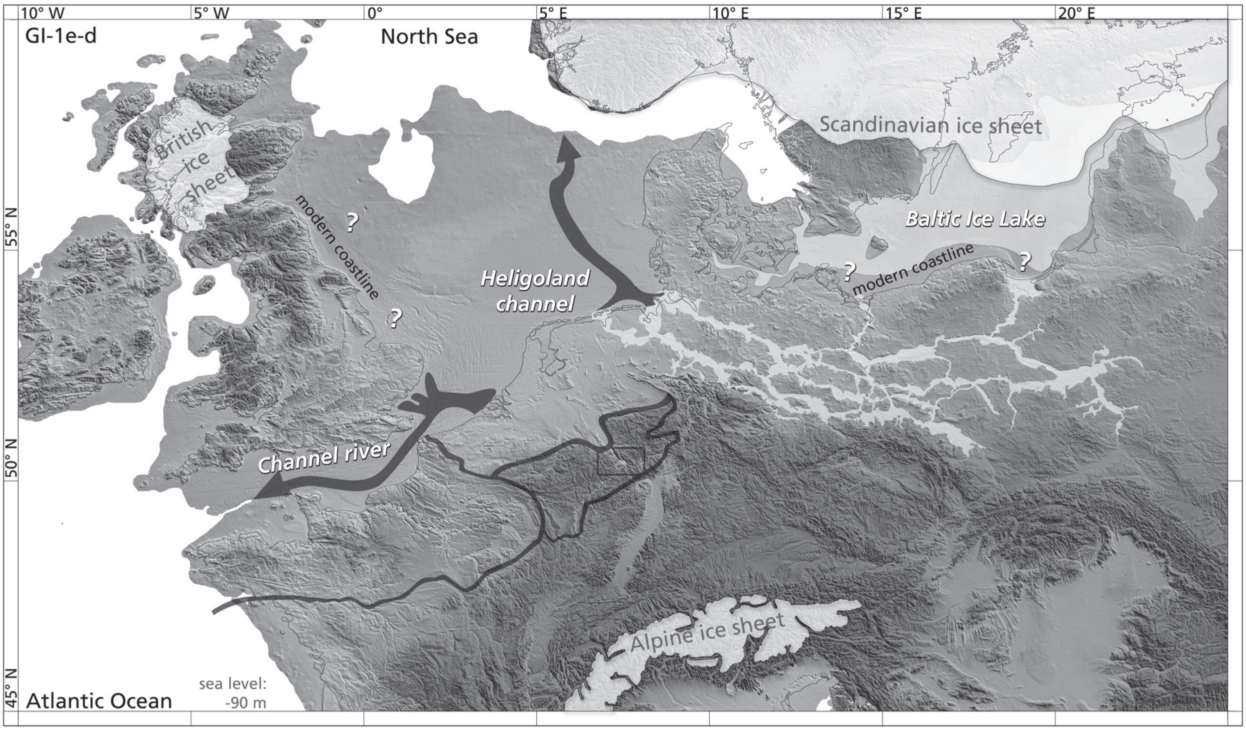


Fig. 48 Map of north-western Europe during GI-1e-d with the drainage system and the study areas indicated (see **figs 1. 45. 47**).

These moraines are smaller than the Göteborg moraines but they were, in many places, characterised by two series of ridges. Perhaps, this formation reflected the reactions to the climatic conditions of the early Lateglacial Interstadial with a first advance at the onset due to increased precipitation, a short recovery after the temperature maximum, and a short-termed readvance due to the cooling of GI-1d. Comparison with the general regression of the Scandinavian ice sheet suggests that the British ice sheet had retreated further inland and probably lost the connection to the Irish channel suring this time. The Central Belt area in Scotland was largely free of glaciers and only the western Grampians and the Highlands were ice covered. Landforms from this period were not identified yet (Clark et al. 2004, cf. Clark et al. 2012) but according to a model calculation, a British ice sheet had already melted completely by this time (Brooks et al. 2011). The only archaeological site in this northern range attributed to approximately this period was discovered at Howburn (Ballin et al. 2010). The chronological attribution was based on typo-technological comparisons with northern German material because no organic material was found in the thin stratigraphic sequence. The site was located south of the Central Belt of Scotland and according to the regression pattern, used in the present study, along with two more recent retreat scenarios (Brooks et al. 2011; Clark et al. 2012), the area around Howburn was already deglaciated during GS-2a. Thus, the location of the site and position of a possible glacial front are very remote from one another, providing no counterindications for the chronological attribution of the site nor the existence of a relic ice sheet.

In the Alps, the Daun readvance was generally dated to the period before the onset of the Lateglacial Interstadial (Ivy-Ochs et al. 2006; Ivy-Ochs et al. 2008). In comparison with the Scandinavian ice sheet and the climatic conditions, a dating of this readvance to the onset and earliest Lateglacial Interstadial might be possible. However, the increasing temperatures in the early Lateglacial Interstadial led to a quick retreat of the ice sheet above the moraines of the Lateglacial Stadial (Ivy-Ochs et al. 2008). The Lateglacial Stadial moraines overran possible glacial structures situated in higher altitudes and thereby destroyed potential evidence for the ice sheet development during the Lateglacial Interstadial (Ivy-Ochs et al. 2006, 117 tab. 1).

In general, the permafrost conditions were assumed to have retreated to a thin band around the major ice sheets (Huijzer/Vandenberghe 1998) but some evidences of sporadic permafrost were still detected in the northern Rhineland (Busschers et al. 2007, 3242). A possible explanation for the continued presence of permafrost is can be found through reference to modern analogies (Osterkamp/Romanovsky 1999). For example, deeply frozen permafrost thaws in a very gradual process and cold periods, such as GI-1d, could lead to the quick reestablishment of permafrost conditions, in particular in permafrost-friendly places such as northern slopes where the thawing process was not previously completed. In some protected parts of north-western Europe, the first soil horizons started to develop during this period (Schwark/Zink/Lechterbeck 2002).

The temperature rise at the onset of the Lateglacial Interstadial resulted, besides the rapid melting of ice sheets, into a significant rise of the global sea-level, termed melt-water pulse 1a (Weaver et al. 2003). This pulse comprised a few hundred years in which the global sea-level rose approximately 20 m, whereas the global sea-level had previously risen 20 m in approximately 5,000 years and after the pulse further *c.* 1,200 years passed before the global sea-level had risen another 20 m. The exact timing of this pulse remains a matter of debate but is clearly associated with the early Lateglacial Interstadial (Weaver et al. 2003; Stanford et al. 2006; Deschamps et al. 2012). During this pulse, the previously stable coastlines of northern and western Europe were significantly shifted inland and submerged thereby possible long established places for hunting and/or gathering of marine resources (cf. Hansen 2006; Langley/Street 2013). However, depending on which timing is chosen the yearly sea-level increase ranged between 4 and 6 cm (Stanford et al. 2006; Deschamps et al. 2012). Perhaps, this increase was detectable for the hunter-gatherers during yearly migrations but in comparison with a human lifetime, this slowness also allowed the gradual adaptation of human groups to this rising sea-level.

In the Baltic region an ice lake was well established in this period, although the continuous uplift of the surrounding areas placed the shorelines significantly below the modern coastlines of the Baltic Sea (Björck 1995a, 21 f.). The more western Storebælt and Lillebælt straits were not significant outlets but possibly formed minor drainage channels towards the Kattegatt (Lemke et al. 2002; Krienke 2002; Jensen et al. 2005). At present the limited availability of environmental analyses suggests that this lake remained a freshwater reservoir (Björck 1995a, 23). The outflow of this ice lake was through the Öresund area, which was probably continuously cut down in this time as indicated by the eroded material deposited in the Kattegat. In the area between the Öresund strait and the Kattegat, delta-like deposits were found suggesting a water landscape with a braided channel network during the early Lateglacial Interstadial (Björck 1995a, 22). In analogy to modern river deltas (e.g. Gilg et al. 2000), this area probably formed a favourable habitat during some parts of the year as well as a natural barrier, due to flooding, during a few months. In some seasons, however, such as late summer the area was probably passable. Thus, excursions into Scania seemed to still be possible during this time.

The chronological development of the North Sea basin is not known in detail. Besides the intrusion of sea water from the north and the presence of the major river systems in the Heligoland channel and the English channel, seismic 3D sample studies revealed the presence of a dense net of water channels and tunnel valleys on the basin floor (Praeg 2003; Fitch/Thomson/Gaffney 2005; Kristensen et al. 2007; Passchier et al. 2010; Hijma et al. 2012; Moreau et al. 2012; Stewart/Lonergan/Hampson 2012). During the Lateglacial Interstadial, this water-rich landscape was probably still very similar to the landscape that had formed at the same time in northern Germany (Clausen 2010).

The precise chronological development of the two major river systems in the North Sea basin is not well known for the Lateglacial. However, it can be assumed to have behaved comparably with the rivers that formed them. In general, the river type changed from braided to meandering systems in this phase (Mol/Van-

denberghe/Kasse 2000; Lewis/Maddy/Scaife 2001; Antoine et al. 2003b; Pastre et al. 2003; cf. Vandenberghe 2003). Therefore, the dominant river channel incised into a deep channel (Starkel/Gębica/Superson 2007). In some areas, such as the Elbe valley, the transition process predated the onset of the Lateglacial Interstadial (Turner et al. 2013), whereas in other areas such as the northern Rhineland the transformation was a more continuous transformation process lasting into the mid-Lateglacial Interstadial (Kasse et al. 2005). The local vegetation cover and the presence of frozen grounds mainly determined the river type (Mol/Vandenberghe/Kasse 2000). These determinants changed during the early Lateglacial Interstadial but their change depended, among others, on the geographic position and the distance to the vegetation refugia. Furthermore, the different response times of the river systems to the climatic changes was also related to the grain size of the transported sediments, and/or geomorphological features such as the basin configuration and the size of the catchment area (Mol/Vandenberghe/Kasse 2000; Vandenberghe 2003). The transported sediment was generally related to the energy of the river but partially also associated to the aeolian deposits. In a detailed study of the sedimentary development in the northern Rhineland, a continuation of the aeolian deposition during this early part of the Lateglacial Interstadial were attested (Busschers et al. 2007, 3242). Moreover, patches of permafrost were also identified in this study. Thus, these observations of frozen grounds and a continued sediment input could explain the delayed response in the northern Rhineland.
In total, this early Lateglacial Interstadial forms the transitional period in which the climatic and geographic conditions changed from the Late Pleniglacial to the Lateglacial Interstadial mode.

The third map (fig. 49) encompasses the mid- to late Lateglacial Interstadial (GI-1c_3 to GI-1a). In this period, humans settled at sites such as Andernach (upper level), Kettig, Niederbieber, Conty, or Le Closeau (upper horizons).
Concurrently, the Scandinavian ice sheet retreated relatively rapidly into middle Sweden and exposed Scania and Blekinge along with most areas of Västergötland and Småland. According to the related ^{14}C dates and varve chronologies, the diffuse Trollhättan moraines were possibly correlative with a readvance during GI-1c_3 and/or GI-1c_2 and the well defined Levene moraines were possibly formed in a short and coherent readvance in GI-1b (Lundqvist/Wohlfarth 2001). In this period, the sea waters had entered the lowlands of middle Sweden from the west and the Scandinavian glaciers still functioned as barrier for the intrusion of the sea-waters further to the east than Lake Vättern (Lundqvist/Wohlfarth 2001, 1134).
Whether a relic British ice sheet still existed in this period remains unclear (cf. Clark et al. 2004; Brooks et al. 2011). According to model calculations, the British ice sheet would have vanished before GS-2a (Brooks et al. 2011). Landforms relating to this stage have not been identified thus far (Clark et al. 2004; cf. Clark et al. 2012). In comparison with the regression velocity of the Scandinavian ice sheet, a small, inland ice sheet would have still existed at the onset of this period covering the western Grampians and the southern Highlands. However, this ice sheet could have retreated significantly during this relatively stable warm and moist period and, perhaps, fallen into several large glaciers or vanished completely. The moraines of the following Lateglacial Stadial readvance that represent one of the few evident stages for the development of the British ice sheet covered a smaller area in the same region. The presence of moraines indicates that the ice cover had retreated to an area smaller than the GS-1 ice sheet before the readvance. How far back the ice sheet retreated prior to the readvance of the Lateglacial Stadial cannot be distinguished. However, the only Scottish material attributed to this period originated from Kilmelfort Cave (Saville/Ballin 2009) which was located west of the possible relic ice sheet. Thus, the archaeological record is in accordance with the possible reconstruction of a relic ice sheet.
The Alpine ice sheet had retreated above the moraines of the Lateglacial Stadial and was partially disintegrating into single glacier fields (Ivy-Ochs et al. 2006). Although the short-termed cold phases within the

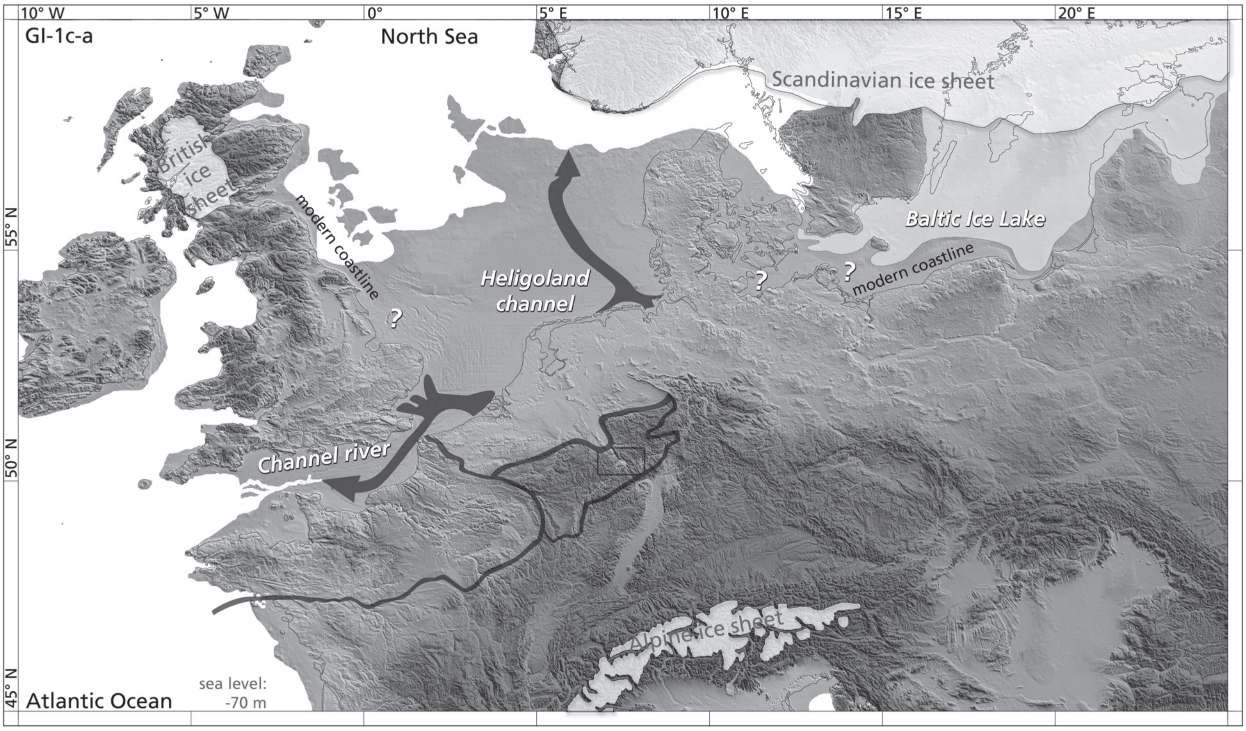


Fig. 49 Map of north-western Europe during GI-1c-a with the drainage system and the study areas indicated (see **figs 1. 45. 47**).

Lateglacial Interstadial probably resulted in readvances, the possible evidence for these readvances was depleted by the readvance of the Lateglacial Stadial which overran these older moraines (Ivy-Ochs et al. 2008, 567). The relatively high temperatures and precipitation probably strengthened the melt-water discharge and, thus, the river valleys were uncovered from the glaciers.

For this period no indications of permafrost were found in north-western Europe. Thus, the various types of permafrost had probably retreated to thin zones around the ice sheets. The increasing vegetation cover in many parts of north-western Europe led to stabilisation of the sediments and decreasing erosion processes (Tolksdorf et al. 2013). In addition, pedogenic processes transformed the top levels of the often aeolian or alluvial sediments in most parts of north-western Europe into various soils during this period.

The rate of the global sea-level rise further slowed down to a rise of approximately 2 cm per year.

The Baltic Ice Lake and the sea level in the Kattegat had reached an equilibrium at approximately 7 m b.s.l. during the mid-Lateglacial Interstadial (Björck 1995a, 22). However, the Baltic area was still affected by uplifting and the Öresund strait was probably eroded to the bedrock at this time hindering the flow of waters out of the ice lake. Thus, the sea level of the Baltic Ice Lake gradually increased above the sea level in the Kattegat. These raising water levels increased the outline of the Baltic Ice Lake and also enabled a continuous outflow through the Öresund strait and, in fact, an overflowing of the bedrock sill (Björck 1995a, 22 f.). This overflowing further enlarged the water strait in this area and, probably, made the area more impassable. Around the Inner Allerød Cold Period the lake level sank rapidly but the reasons for this drainage remained unclear (Björck 1995a, 23-25). Possibly, a connection to the Skagerrak was opened across the Swedish lowlands around Mount Billingen or the Store Belt Strait was opened as additional outflow. The latter case appeared improbable to Svante Björck because the Baltic Ice Lake was dammed up again afterwards (Björck 1995a, 23). However, in the former case, at least for the eastern part, a possibly subglacial connection was suggested and that the subsequent blocking of this strait by ice-bergs prohibited the introduction of saline waters into the freshwater lake (Björck 1995a, 23). The Kattegatt area was affected by significant tectonic activities (Jensen et al. 2002) including an earthquake accompanied by a large tsunami during this time (Mörner 2005; Mörner 2008). Perhaps, this short-termed event allowed additional straits to be opened and large amounts of water to be drained by these straits (cf. Jensen et al. 2002). However, as a result, the lake level fell below the threshold of the Öresund strait and a landbridge between Zealand and Scania was established. Probably, the other Danish straits also became dry connecting Zealand further to Funen and Jutland (cf. Bennike/Jensen 2011). Thus, a wide connection between northern Germany and southern Scandinavia existed towards the end of the Lateglacial Interstadial.

Towards the west, a large landbridge still connected Great Britain with the continent. Since the chronological development of the North Sea basin is not known in detail, the development of the dense net of water channels and tunnel valleys revealed by seismic 3D sample studies on the North Sea basin floor cannot be further distinguished during the Lateglacial (Praeg 2003; Fitch/Thomson/Gaffney 2005; Kristensen et al. 2007; Passchier et al. 2010; Hijma et al. 2012; Moreau et al. 2012; Stewart/Lonergan/Hampson 2012). The development of the two major river systems in this area, the English Channel river and the river west of the Jutland peninsula, is not distinct for the various periods of the Lateglacial. However, in analogy to the general development of fluvial systems of the north-western European rivers during the Lateglacial, some observations on the development of these wide river systems can be made. The increasing vegetation cover and soil formation led to a stabilisation of the landscape and, consequently, a decrease in grain size of the sediments transported in the rivers. Thus, during this phase most European rivers were meandering systems (Mol/Vandenberghe/Kasse 2000; Antoine et al. 2003b; Pastre et al. 2003; Kasse et al. 2005; Starkel/Gębica/Superson 2007; Turner et al. 2013). Presumably, the two major river systems also incised into meandering beds.

During this period, the full Lateglacial Interstadial mode of the climatic and physical conditions had been established. In contrast to the Late Pleniglacial, the aeolian dispersals ceased, soils developed, the ice sheets and permafrost conditions had retreated, temperatures and precipitation were generally high and the wind intensity was low.

The fourth map of Lateglacial north-western Europe reflects the period of the Lateglacial Stadial (**fig. 50**). Reliable archaeological evidence from this period are scarce (Weber/Grimm/Baales 2011) and absent in the Central Rhineland and almost absent in the central Paris Basin. In the western uplands, some sites could be attributed to this period (Baales 1996) and some sites in the Somme basin might be related with the late Lateglacial Interstadial based on techno-typological analysis (Fagnart 1997).

Even though in all three major ice sheet regions distinctive moraines were related to the Younger Dryas, the glacial front of the Scandinavian ice sheet had further retreated in comparison to the mid-Lateglacial Interstadial. The moraines attributed to the Younger Dryas were detectable across the Scandinavian peninsula and reflect in some parts a stillstand of the glaciers and in other parts a significant readvance (Lundqvist/Wohlfarth 2001, 1136). The glaciers continued to retreat, possibly related to the warmer episode within GS-1 or the onset of the Holocene. With the gradual uncovering of the Central Swedish lowlands, sea waters could expand further eastwards, whereas the Baltic Ice Lake pushed into the lowlands from the east. Finally, the dam between these two large open waters broke and the higher Baltic Ice Lake drained into the sea waters. At this point the Baltic Sea basin became a part of the northern European estuary. Nils-Axel Mörner suggested that this possible catastrophic event was related to a tsunami dated to 10,430 Swedish varve years BP (Mörner 1999). This Swedish varve age correlated approximately with the onset of the Preboreal oscillation in the GRIP ice-core (Andrén/Björck/Johnsen 1999) and is in accordance with a previous attribution to the transition from the Lateglacial Stadial to the Holocene (Björck 1995a).

Consequently, the stillstand and/or readvance of the Scandinavian ice sheet around the latitudes of the Central Swedish lowlands encompassed the complete Younger Dryas period.

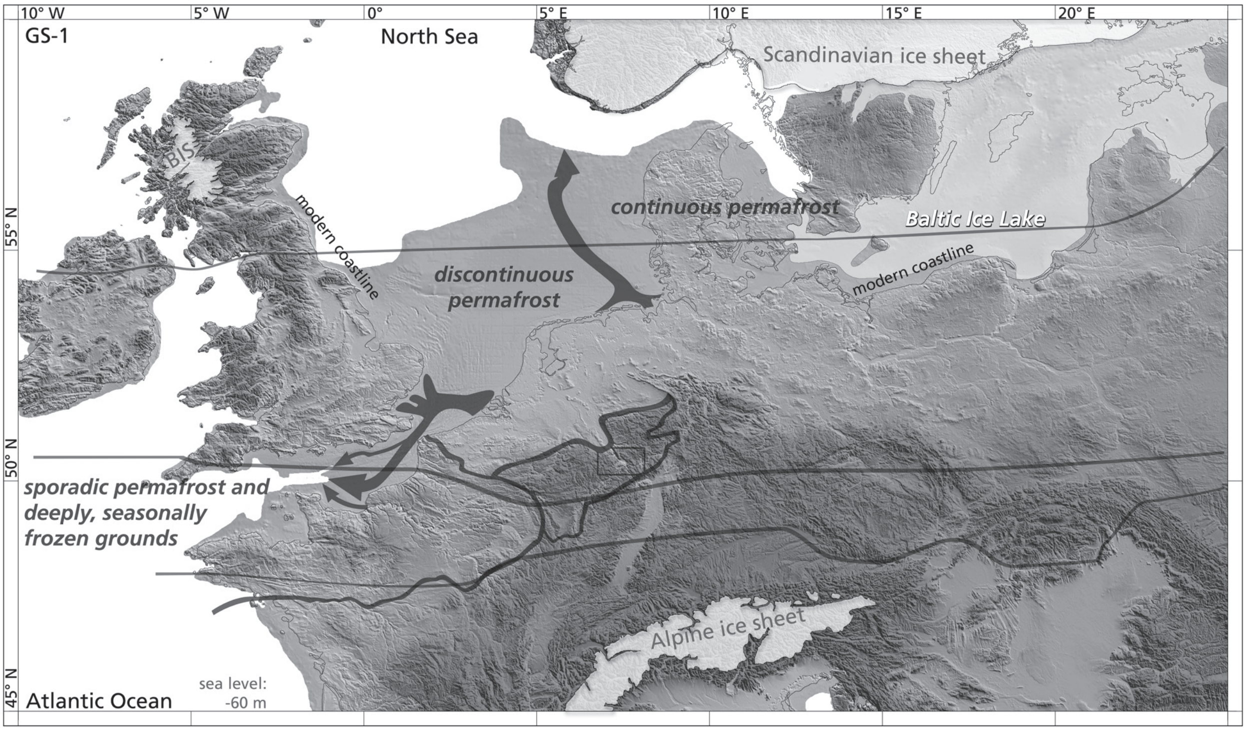


Fig. 50 Map of north-western Europe during GS-1 with approximate limits of permafrost zones and the study areas indicated (see **figs 1. 45. 47**). The permafrost zones are set according to Isarin 1997, 324 fig. 7. The eastern continuation is set according to the temperature gradients in Velichko et al. 2002, fig. 5b.

The moraines of the so-called Loch Lomond readvance are unambiguously attributed to the history of the British ice sheet (Clark et al. 2004). The small inland ice sheet covered the western central Grampians and the southern Highlands reaching across the Great Glen fault. Again, archaeological material from this time is scarce from this area. For example, organic material recovered from the Reindeer Cave (Creag nan Uamh Caves) was dated to the late Lateglacial Stadial (Lawson/Bonsall 1986). This cave is located north-eastwards of the ice sheet. Thus, the location of Scottish sites yielding archaeological material attributed to the Lateglacial is never in conflict with the reconstructions of the British ice sheet.

In the Alps, the glacial front readvanced to lower altitudes and formed the so-called Egesen moraines (Ivy-Ochs et al. 2009). Since summer temperatures were considered to be lower in the Younger Dryas (Isarin/Bohncke 1999), the strength of the spring and summer melt-water streams probably decreased. With the weaker melt-water impulses, the main rivers were less able to keep their channels free of ice. Therefore, the Alpine ice-sheet became more compact again. The maximum expansion of the Egesen moraines was presumably related to the first cold part of the Lateglacial Stadial (Ivy-Ochs et al. 2009). From this maximum extension the ice sheet retreated relatively quickly again with the onset of the warm phase within the Lateglacial Stadial. Two further readvances seem to be related to the onset of the Holocene and these readvances were possibly again due to the increase of precipitation (Ivy-Ochs et al. 2009).

Periglacial conditions returned to north-western Europe with the intense cold reversal in early Lateglacial Stadial (Isarin 1997). Evidence for continuous permafrost was found in southern Scandinavia, Scotland, and northern Ireland. The zone of discontinuous permafrost encompassed most of Poland, northern Bohemia, northern and eastern Germany, the Netherlands, most of Belgium, and the remaining parts of the British Isles. In western Germany the southern limit of the discontinuous permafrost coincided approximately with the southern limit of the Eifel, the Taunus, and the Vogelberg. According to the compilation of René F. Isarin, the southern limit of the zone of deep seasonal frost ran through Brittany, the Paris basin, along the Alpine foothils in southern Germany and northern Austria, and through southern Slovakia (Isarin 1997, 324 fig. 7). After the first period with severe climate conditions, a period of milder temperatures occurred within the Lateglacial Stadial.

Besides the possible retreat of the major ice sheets and potential increase of melt-water discharge, permafrost and deeply frozen ground probably also thawed in some areas during this period resulting in a massive rinsing out of sediments (cf. Grafenstein et al. 1999). Perhaps, this combination of amelioration with high water discharges is an explanation for the development of several eroded layers or colluvia (Guiter et al. 2003, 70), landslides (Vardy et al. 2010), and ceasing of continuous varve formation in this period (Merkt/Müller 1999; Leroy et al. 2000). To what degree the following, final phase was cold enough to reestablish the permafrost conditions remains to be examined. Erosion and landslide events occurred frequently into the transition to the Holocene indicating a continuous instability of the grounds (van Vliet-Lanoë et al. 1992; Bos 2001; Magny/Bégeot 2004).

The continuous rise in the global sea-level slowed down marginally during the Lateglacial Stadial and in the approximately 1,100 years of this stadial, the sea-level rose some 15 m. The sea-level rise was accelerated again at the onset of the Holocene but whether this resulted in another meltwater pulse (1B) and to which period this possible meltwater pulse is dated to is a matter of on-going debate (Bard/Hamelin/Delanghe-Sabatier 2010; Rodrigues et al. 2010; Stanford et al. 2011a).

At the beginning of this period, the lake level of the Baltic Ice Lake recovered from the late Lateglacial Interstadial drainage and was increased in volume again (**fig. 51**). Perhaps the reason for this increase was that the Mount Billingen drainage was blocked by ice again (Björck 1995a, 24). The raising water level overflowed the Öresund strait again and ended the landbridge. Towards the end of this period, the final drainage of the Baltic Ice Lake occurred and lowered the water level in some areas for approximately 25 m (Björck 1995a, 26 f.). In this period, a several kilometres wide connection to the northern oceans was established through the Central Sweden lowlands. This wide connection transformed the freshwater lake into a brackish water basin, the so-called Yoldia Sea. The opening of this connection was related by Nils-Axel Mörner to a major earthquake followed by a tsunami which cleared the strait of ice-bergs (Mörner 1999). However, a hiatus in the stratigraphic sequences from the Lillebælt area suggested also that the Danish straits were involved in the final drainage which cut and eroded some older sediments (cf. Bennike/Jensen 2011). Subsequently, a landbridge was established between Scania, Zealand, Funen, and Jutland due to the uplifting of these areas above the water level. The abrupt lowering of the water level established, on the one hand, significant areas of land, which were initially rather unstable due to the silty deposits of the former ice lake and, on the other hand, drained previous littoral habitats significantly. Consequently, the environments around the Baltic Ice Lake were influenced by these new hydrographic conditions that probably occurred concomitant with the Holocene amelioration and the subsequent melting of the remaining ice-sheets and thawing of the permafrost soils.

The filling of the deeper channel along the British east coast with sea waters from the north did not probably occur before the Holocene (cf. Ward/Larcombe 2008). Thus, the North Sea basin presumably formed a large landbridge which connected England, France, Belgium, the Netherlands, northern Germany, and Denmark. However, the excess from England to France was limited by the wide English Channel river and the west of the Cimbrian Peninsula flowed another large river. The low resolution of the chronological development of the North Sea basin makes an attribution to a specific period in the Late Weichselian impossible. Based on the general development of fluvial styles of some north-western European rivers during the Lateglacial Stadial, these two major river systems in the North Sea area could be further characterised. The response of the European rivers varied. Some remained in a meandering system and further incised into their beds (Antoine et al. 2003b; Pastre et al. 2003; Turner et al. 2013), whereas others switched back to

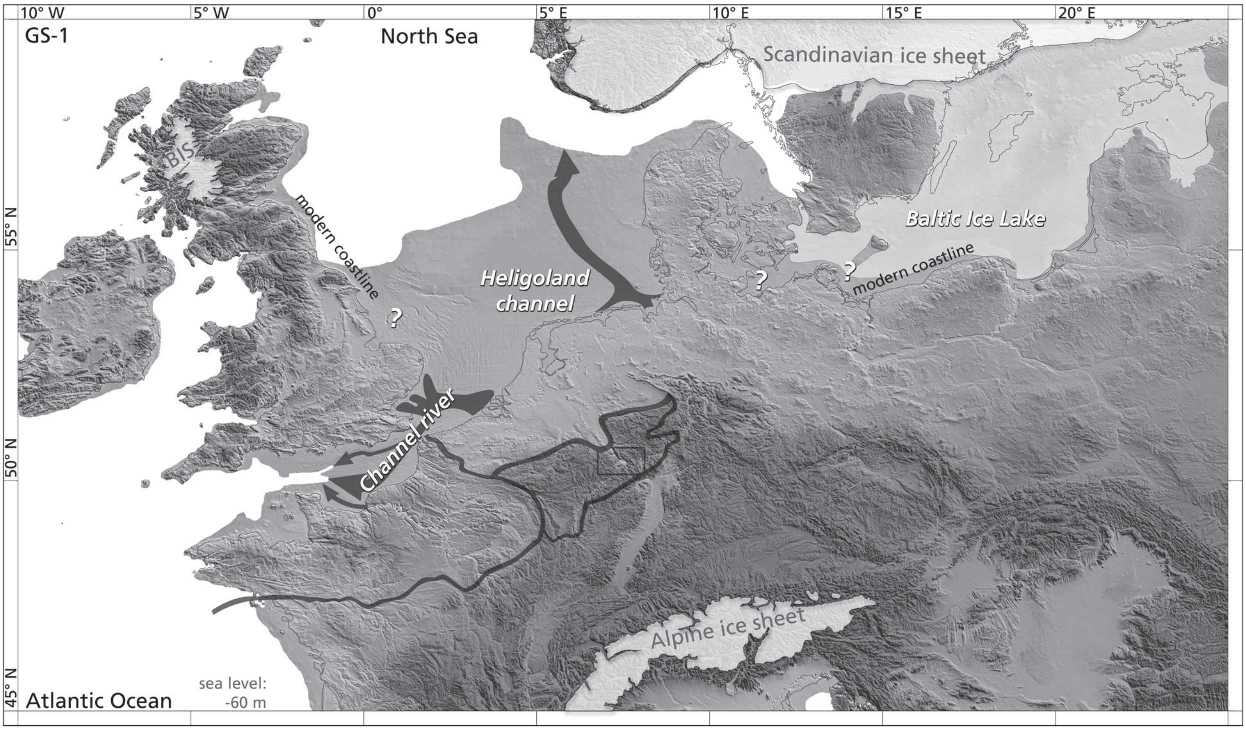


Fig. 51 Map of north-western Europe during GS-1 with the drainage system and the study areas indicated (see **figs 1. 45. 47**).

a braided system (Mol/Vandenberghe/Kasse 2000; Lewis/Maddy/Scaife 2001; Starkel/Gębica/Superson 2007). This response was partially dependent on the geographic position of the rivers, for instance, the Rhine and the Meuse further incised into their beds in the Netherlands, whereas they temporarily reestablished braided systems in western Germany (Busschers et al. 2007). Furthermore, the geomorphological setting seemed also of importance because the stream in the Niers valley was further incised, whereas the Rhine in this area switched to a braided system (Kasse et al. 2005). Besides the relation to the presence of permafrost, the storm track pattern and the dispersal of aeolian sediment partially influenced the behaviour of the rivers due to the creation of unstable bank sediments which could increase the amount of sediment transported by the river. The aeolian dispersal restarted in some places during the Lateglacial Stadial and deposited significant amounts of sediments which changed the local geomorphology (Hilgers et al. 2001; Kaiser/Clausen 2005).

In the western Cimbrian Peninsula the coversands filled several valleys resulting partially in a block and/or redirection of the rivers running into the Heligoland channel (cf. Kaiser/Clausen 2005). Moreover, some tsunamis from this period (Mörner 2008) could have changed the land in the northern estuary and lead to redirections of rivers directly northwards. Thus, the catchment area of the Heligoland channel possibly decreased temporarily during the Lateglacial Stadial. In regard to the periglacial conditions, the increased sediment input, and decreased water amount, the Heligoland channel river probably also returned to a braided system during the Lateglacial Stadial.

Even though the climate signal of the Lateglacial Stadial is comparable to that of the Late Pleniglacial, the development of the landscape during the Lateglacial Interstadial resulted in partially different reactions. In fact, the climatic and geographic indications of the Lateglacial Stadial appeared, in general, more comparable to the conditions during the transition period in the early Lateglacial Interstadial when aeolian deposition still occurred and rivers changed between meandering and the braided system.

Lateglacial vegetation development in the study areas

Besides oxygen isotope records, vegetation profiles have provided the most prominent and distinct sub-division of the Lateglacial Interstadial. However, these vegetation sub-periods have not necessarily correlated across a wider geographic areas due to the partial dependence on regional developments. Moreover, they were also not reacting instantaneously to the developments that occurred in the isotope eventstratigraphy of the Greenland records. Thus, the development of vegetation should be checked against an independent chronology.

Chronology of the pollen profiles

In the present study, two pollen profiles were used as the main source of information for the vegetation development in the studied sub-areas. The Meerfelder Maar (MFM) record provided insights into the changes in the Central Rhineland and the western uplands in general (Litt/Stebich 1999). Furthermore, the MFM yielded a well established varve chronology (Brauer/Endres/Negendank 1999), which is correlated to the oxygen isotope record from NGRIP (see p. 293-310). The LST was an important marker in this record and was dated to 12,930 years cal. b2k in the varve chronology.
In contrast, the record from the Paris Basin is a synchronised pollen diagram (Pastre et al. 2003) that was made of several pollen profiles from the Paris Basin (see **fig. 20**; cf. Leroyer 1994). Since the pollen diagram were checked against various pollen- and lithostratigraphies in the region, the resulting synchronised sequence represents a reliable relative chronology. To relate this succession to the calender timescale, some pollen profiles were supplemented with ^{14}C dates, which were usually made on bulked sediment samples (Pastre et al. 2003, tab. 1; cf. Limondin-Lozouet et al. 2002, tab. 1). In this study, sediment samples are assumed to produce in general no reliable age estimates. This unreliability is due to material of different ^{14}C ages being mixed as a result of the often complex depositional and geochemical processes within sediment deposits and, in particular, within freshwater environments (Hiller et al. 2003; Brock et al. 2011).
However, the synchronised pollen diagram has also been supplemented by two dates made on wood samples and a further two dates made on other plant remains (Pastre et al. 2003, tab. 1; cf. Ponel et al. 2005, figs 3 and 5). All four samples were recovered at Houdancourt in a palaeochannel deposit that was analysed in a multi-proxy project that, unfortunately, yielded a fragmented pollen profile. The calibration results of the four ^{14}C dates are checked in the following against the results of this multi-proxy analysis and the isotope record of NGRIP.
The coleopteran composition of the lowest palaentomological sample from Houdancourt suggested that these remains originated from the time of the thermal optimum in the Lateglacial (Ponel et al. 2005, 2458). The plant remains for the lowest ^{14}C date were found below this palaeontomological sample but already within an organic silt deposit which formed on top of the Pleistocene sands and gravels (Pastre et al. 2003). This stratigraphic position suggested that the most reliable attribution of this date was between the onset of the Lateglacial Interstadial and the end of the calibrated age range (15,480-14,200 years cal. b2k).
The second oldest date was produced from a wood sample and originated from a transition of organic silt deposits to fibrous peat. The calibrated age range of the ^{14}C date (14,210-13,650 years cal.b2k) overlapped the date range of the cold reversal of GI-1d and also partially touched the date range of the cold GI-1c_2 episode (see **tab. 64**). Within the top part of the organic silt, the palaeoentomological sample 7 was taken (Ponel et al. 2005, fig. 3). The upper part of this sample contained coleoptera species indicating a cold climate (Pastre et al. 2003, 2180). On top of the position of the wood sample, birch (*Betula* sp.) and juniper

(*Juniperus* sp.) pollen increased in the Houdancourt profile before a small decrease affected the arboreal pollen in general. Alongside this small decrease in arboreal pollen, birch and juniper increased again and steppic herbs and the true grasses (Poaceae) decreased significantly. Assuming some relation of the climate and the environment as reflected by the pollen composition, this smaller decrease could be related to the short-termed cold episode of GI-1c_2 and the colder species in the coleopteran sample 7 could be attributed to the GI-1d event. The wood originated from the top part of this sample and well before the possible onset of GI-1c_2 in the pollen record. Thus, the most reliable attribution is the first part of GI-1c_3 for this date.
The second youngest date was also made on a wood sample. The calibrated age ranges from 13,720 to 13,200 years cal. b2k and could relate to almost the complete GI-1c_2 and the complete GI-1c_1, as well as the onset of GI-1b (see **tab. 64**). The sample originated from the middle of the fibrous peat where the material became siltier. This position relates approximately to the transition of the palaeoentomological samples 4 to 3 (Ponel et al. 2005, fig. 3). According to the coleoptera composition, the summer temperatures decreased slightly between these two samples. The molluscs suggest still water conditions during this period. On top of the sample in the pollen profile, birch pollen decreased to minimal values, whereas juniper, willow (*Salix* sp.), and pine (*Pinus* sp.) values illustrated a small increase. In addition, the values for *Artemisia* sp. pollen increased suggesting an opening of the landscape. Thus, in general, the sample seemed to originate from the onset of a moist episode with colder summers that resulted in an opening of the vegetation cover. If GI-1c_2 was recorded in the lower part of the pollen diagram, this episode could represent a first indication of the deterioration towards GI-1b and the most reliable position for this calibrated age would be the transition from GI-1c_1 to GI-1b. In contrast, if this deterioration is related to GI-1c_2, the episode in the lower part of the pollen profile could be related to another event. This correlation could further sustain the attribution of the second oldest date to the onset of GI-1c_3 because of the increasing distance of the older wood sample to the position of GI-1c_2 in the profile. According to the correlation of the Houdancourt profile to the synchronised pollen diagram of the Paris basin, two further cold episodes occurred on top of the second oldest date before the onset of the Younger Dryas (Ponel et al. 2005, fig. 5). Within the deterioration on top of the position of the sample the pine pollen began to increase (Pastre et al. 2003, fig. 3). The second deterioration appears of longer duration and more significant and could correlate with GI-1b. Therefore, an attribution of the second youngest date to GI-1c_2 appeared more probable. However, since on top of the sample the palaeoentomological and the palynological data indicate increasing deterioration towards a colder climate, the calibrated age referred either to the onset of GI-1c_2 which corresponded to the lower calibrated age range or to the younger part of GI-1c_1 in which the isotope values from NGRIP indicate a continuous deterioration of the North Atlantic climate towards GI-1b. This position corresponds to the middle of the calibrated age range.
The calibrated age range of the youngest date (13,280-12,960 years cal. b2k) overlapped GI-1b. This sample consisted of plant material and was found in the upper part of the fibrous peat. The paleoentomological sample 2 was taken at approximately the same height in the profile (Ponel et al. 2005, fig. 3). According to the coleopteran data, the summer temperatures increase again in this period, whereas the winter temperatures appeared to decrease but this impression is due to the increasing data range for the winter temperatures (Ponel et al. 2005, fig. 4). In the pollen profile, arboreal pollen are more dominant than in the previous sections. The pine pollen are more abundant than the birch pollen and further increased in this section. Even though the arboreal pollen are abundant, the general number of pollen is low and the higher numbers of steppic herbs than in the previous sections as well as the significantly increased juniper values indicate a colder and more open episode within a forested phase below the stratigraphic position of the sample. Probably, this position related to the end of GI-b and the onset of GI-1a. Moreover, this position for the youngest sample further suggests that the position of the second youngest sample to a position before

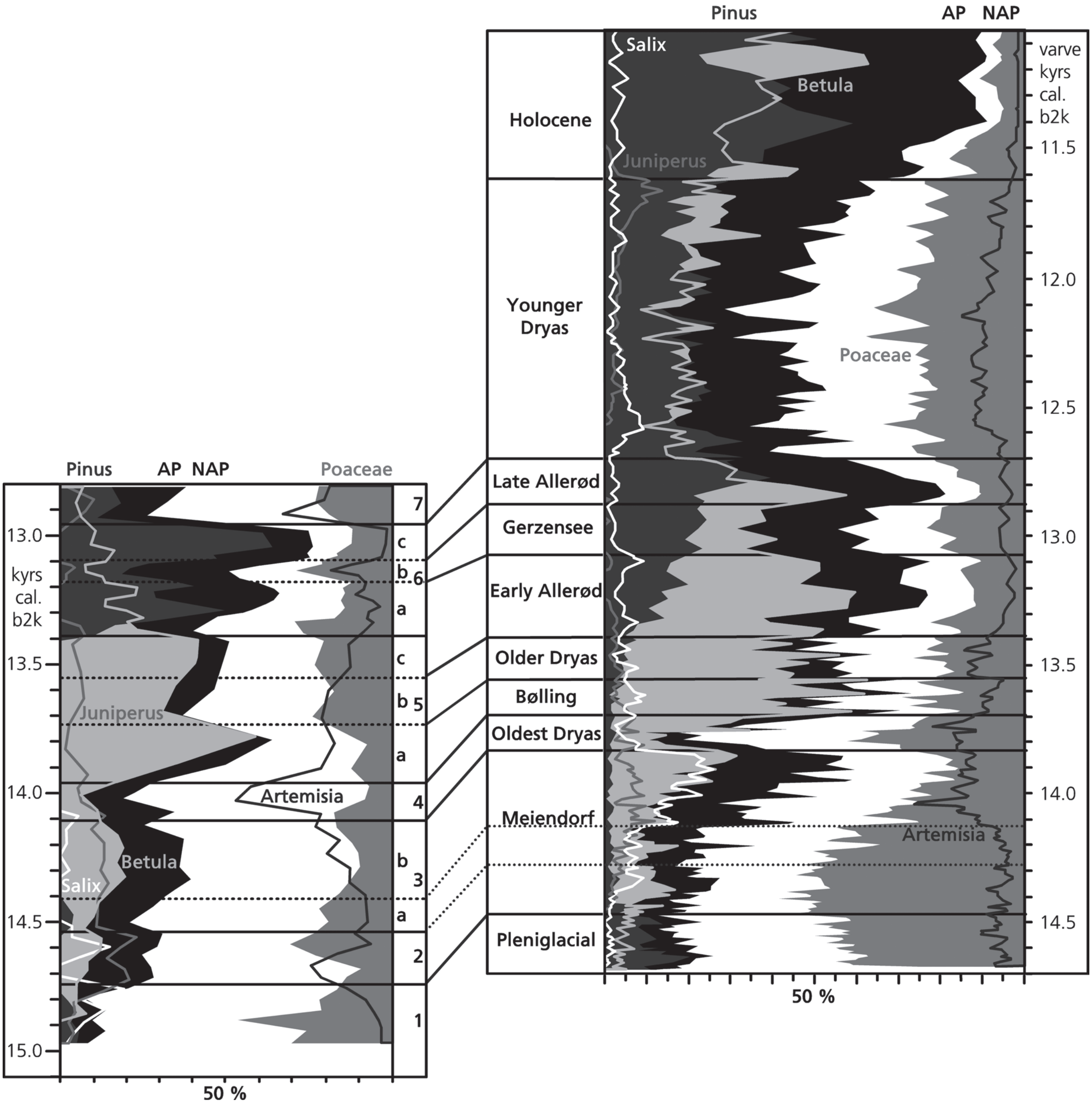


Fig. 52 Synchronised pollen diagram of the Paris Basin fitted to the calender timescale by the calibration of the associated and reliable ^{14}C dates (left) and the simplified Lateglacial pollen diagram from Meerfelder Maar, MFM 6, according to the varve chronology (right; see p. 40-48). The grey lines serve as guidelines for comparable palynological zones. Grey dotted lines: possible sub-zones in the Meiendorf stage of the MFM 6 diagram which are comparable to the Paris Basin record. **AP** arboreal pollen; **NAP** – non-arboreal pollen. – For further details see text.

GI-1b. On top of the youngest sample, the fibrous peat continued for another few centimetres before it was overlain by the calcareous silts of the Younger Dryas.

The synchronised pollen diagram was fitted to the calender timescale according to the oldest and the youngest date. The diagram between these two points was stretched and clinched according to the two intermediate calibrated ages (fig. 52).

However, the MFM pollen profile also requires some modification. In the MFM Bølling zone, a 4.2 cm thick deposit of slump and turbidite was recorded which due to the lack of lamination could not be included in the varve chronology (Brauer et al. 2000a). Thomas Litt and Martina Stebich counted only 130 varve couplets in their Bølling pollen zone (Litt/Stebich 1999, 8f. 13), whereas 140 varve years were attributed to this period according the varve thickness measurements (Brauer et al. 2000a). Based on a palynological comparison with northern German lakes, 110 varves were suggested to be missing due to the 4 cm of slump and turbidite. Clearly, this palynostratigraphic correlation across several hundred kilometres and two very different geomorphological regions during the mid-Lateglacial Interstadial forms an additional source of error in the precision of the chronology. However, the varve thickness above and below this disturbance varied significantly between approximately 0.25 and 2.0 mm per year and up to c. 3.0 mm per year some 100 years below the disturbance. Thus, based on the varve thickness some 100 years before and after the deposit, an age estimate for the unlaminated 42 mm ranges between 14 and 168 years. Since the comparison with the northern German lakes produced more precise age estimates within this range, they were accepted as probable substitution. In regard to the different duration of the Bølling zone in the pollen and the varve thickness study of the MFM, a mean of additional 120 years was added to the pollen profile of the MFM at the position of the disturbance. In addition, a comparison of the pollen diagrams from Holzmaar and Meerfelder Maar indicated a further 35 years difference between these two Eifel records after the addition of the 120 varve years in the MFM (see p. 346). However, this age offset could be explained by different response times. An impact of the deposition of the LST on the varve preservation as observed in other laminated stratigraphies such as the Soppensee (Hajdas et al. 1993) was not documented or considered unimportant for the MFM chronology.

If the northern French diagram was correlated to the calender timescale and the additional varve years were added in the MFM pollen profile as described above, the two diagrams can be compared in more detail (**fig. 52**).

The onset of comparable pollen assemblage zones (PAZ) occurred in general some 50-200 years earlier in northern France than in the Eifel region. Thus, the onset of the uppermost PAZ 7 (Younger Dryas) in the French diagram correlated to approximately the mid-Gerzensee zone in the MFM record. In regard to the short-lived climate events in the Lateglacial Interstadial, a lagged response of more than 100 years to the same climatic event appears improbable. Moreover, parallel analyses of pollen and oxygen isotopes from Swiss lakes (Lotter et al. 1992) and Polish lakes (Ralska-Jasiewiczowa et al. 1998; Goslar et al. 1999) indicated much shorter response times with only annual to decadal lag of the vegetation to climatic changes (cf. Litt et al. 2001).

Several explanations can be found for the lagging onset of the PAZ in the MFM record in comparison to the synchronised Paris Basin diagram:

The development of the vegetation in the western upland zone can be offset due to the generally higher altitudes and the more northern and eastern location of this zone resulting in a later beginning of the process of the Lateglacial biome succession. Further possible explanations are that the correlation of the zones is incorrect or the chronologies and/or their correlation is imprecise or in the composite diagram from the Paris Basin a hiatus remained unrecognised.

The latter cannot be fully excluded but the French pollen diagram was synchronised from several profiles in the Paris Basin. Consequently, a hiatus must have affect all relevant profiles from northern France. A hiatus of this extent would have been recognised also in the archaeological records but at Le Closeau a relatively continuous record was found throughout the Lateglacial Interstadial (see p. 210-219). Therefore, an undetected hiatus seems not very probable as an explanation for the offset between the Paris Basin and the western upland zone.

The chronologies of both records could be imprecise. Although some varves in the MFM record could have been lost due to the deposition of the LST and would require further varves to be added in the chronology of the Lateglacial Interstadial, the comparison of the MFM sediment record with the isotope record of NGRIP indicated a relatively high similarity (see p. 345). The difference between the onsets in the MFM sediment record to the onsets of the NGRIP isotope events ranged between 77 and 130 years (**tab. 71**) which was within the accumulated standard deviations of the records. Accordingly, only a few decades could have been lost by the deposition of the LST in the MFM record. In contrast to the sediment record, the onset of the PAZ in MFM were generally delayed in comparison to the onset of the NGRIP isotope events by some 130 to 180 years (**tab. 71**). This direct comparison within the MFM record sustains that the response to changes in the North Atlantic climate system was quicker in the sediment system than in the vegetation. Thus, an offset between the MFM pollen diagram to the NGRIP isotope events are probable.

In contrast, the calibration results from the Paris Basin were tuned along the NGRIP record. Furthermore, the chronology of the Paris Basin diagram is based only on four calibrated ^{14}C dates from one of the contributing profiles and, thus, an imprecise correlation is a possible source of error. In particular in regard of the onset of the PAZ 7 because this zone remained in the original chronology due to the first reliable age estimate being located in the PAZ 6b and the PAZ 6c (Pastre et al. 2003). Therefore, additional, reliable dates from various profiles are desirable for future comparisons with this synchronised French pollen diagram.

In addition, the resolution of the French diagrams did not reach the very high resolution of the laminated MFM diagram and further resolution of the French diagrams was lost by the synchronisation. Consequently, the MFM record could be segmented more precisely along single wiggles in the pollen profile, whereas the northern French diagram reflects the general tendency of the pollen composition in the Lateglacial. Therefore, some sharp but short-term wiggles in the MFM record could remain unrecorded in the French diagram, whereas other, well preserved events could also be overestimated by the stretching of the Paris Basin diagram. This resolution difference hindered the correlation of the records and made probable that the pollen assemblage zones are not exactly correlative. Additionally, the pollen zones were defined differently in detail and, therefore, some almost contemporary developments could be overseen by the comparison along the original PAZ.

Thus, the PAZ of the original publications are neglected in the following comparison. However, the correlation of the two pollen profiles along a calendar timescale shows that an equation of palynologically defined zones and chronozones across far distances is problematic and, occasionally, misguiding.

Comparison of the pollen profiles

Comparing the synchronised pollen diagram from the Paris Basin and the pollen diagram from the varve counted MFM, some comparable developments but also some differences become apparent.

Some of the differences are independent of the chronological correlation. For instance, in the Paris Basin, juniper pollen are more important than willow, whereas in the MFM record willow is usually more important. Furthermore, birch was the most important arboreal pollen (AP) type in the MFM record, whereas in northern France pine became significantly more important during the upper part of the diagram. Among the non-arboreal pollen (NAP), Artemisia pollen are occasionally more important than the pollen of the true grasses (Poacecae) in the Paris Basin. In the Lateglacial section of the MFM record, Poacecae are always significantly more important than Artemisia.

Perhaps, these differences resulted from climatic influences due to the longitudinal and topographic setting of the profiles. For example, the various types of willow and juniper are relatively comparable in their general climatic and soil requirements[46] but willows usually need more moisture than juniper. Thus, the greater

46 These requirements are considered according to statistical indicator values created for the use in analyses of local conditions (Ellenberg et al. 2001).

importance of willow in the MFM could indicate that this middle range mountain region received more precipitation and/or that the soils could store more water than the sediment at the sites from the relatively level northern France. This impression of a higher moisture is further supported by the supersession of birch by pine in the upper part of the French diagram. Pine is generally more indifferent towards moisture than several birch types which require relatively wet grounds. Thus, with increasing aridity these trees become less frequent. The generally high frequency of Artemisia pollen further sustains the impression of drier grounds in the Paris Basin. Artemisia types require in general more light and less moisture than many true grasses such as *Agrostis* sp., *Poa* sp., or several species of *Festuca* sp. Thus, the catchment area of the northern French pollen diagram appeared to be generally drier than the MFM catchment area. Modern precipitation data also documented a difference in the annual average precipitation between the western Eifel and Ardennes region, the Central Rhineland, and the Paris Basin (Nixon et al. 2003, Map 5.1). The latter two areas receive approximately the same amount of annual rainfall, whereas the western Eifel and the Ardennes region receives clearly more precipitation. This increased precipitation is due to the general atmospheric circulation patterns in Europe. The moist air is transported from the Atlantic onto the continent where the clouds usually pass across the more level regions closer to the Atlantic and along the English Channel but precipitate in the higher altitudes of the Eifel and Ardennes region. Based on the pollen profiles, this climatic sub-area with increased precipitation seemed to have already existed in the Lateglacial.
Besides these general differences, some chronologically different developments can be observed in the two pollen diagrams. Compared to the NGRIP record (**fig. 53**), the Paris Basin profile appears to reflect the climatic changes as revealed in the NGRIP isotope record more instantly than the MFM record. However, this impression is partially due to the correlation of the calibrated ^{14}C ages from the northern French record along the NGRIP isotope record and partially due to the higher resolution of the MFM diagram.
Assuming that the chronologies and the correlations of both records are reliable, pollen preservation in the Paris Basin began approximately 300 years before the onset of the Lateglacial Interstadial, whereas in the MFM only some decades of the Late Pleniglacial were recorded. Thus, pollen were preserved approximately 200 years earlier in northern France than in the MFM profile. Perhaps, increasing moisture and increasing vegetation cover leading to a changing geochemical composition of the sediment as well as decreasing redeposition processes contributed to a better preservation of these microfossils (Bennett/Willis 2002; Lebreton et al. 2010; Tweddle/Edwards 2010). The western upland zone seemed to have a generally moister climate regime than the Paris Basin but the longer duration of frozen grounds and the stronger impact of aeolian activities (see p. 367-370) could have contributed to the later onset of pollen preservation in this area.
In both regions, the relatively short preserved pollen zone of the Late Pleniglacial is dominated by the NAP. In particular, high proportional values of true grasses suggested the presence of widespread grasslands in north-western Europe at this time. However, the pollen concentration remained generally low which further indicated a sparse vegetation cover (Litt 1999, 7). The low AP comprised mainly willow in the Paris Basin and pine in the MFM record. The often high amount of pine pollen but also the occurrence of pollen from thermophilous trees such as oak (*Quercus* sp.) were frequently assumed to represent redeposited material or material from long-distance transport (Litt/Stebich 1999, 7; Cheddadi et al. 2006). Nevertheless, macrobotanical remains have started a discussion about the presence of cryptic northern refugia for some tree species such as pine (Stewart/Lister 2001; Willis/van Andel 2004; Birks/Willis 2008). However, in both pollen diagrams the proportion of pine pollen vanished to insignificance after the first 150-250 years when vegetation covers and conditions of preservation had probably stabilised. This pattern further sustains the impression that the pine pollen originated mainly from redeposited sediments and that with the ceasing redeposition of sediment the values of pine pollen decreased significantly in both regions.

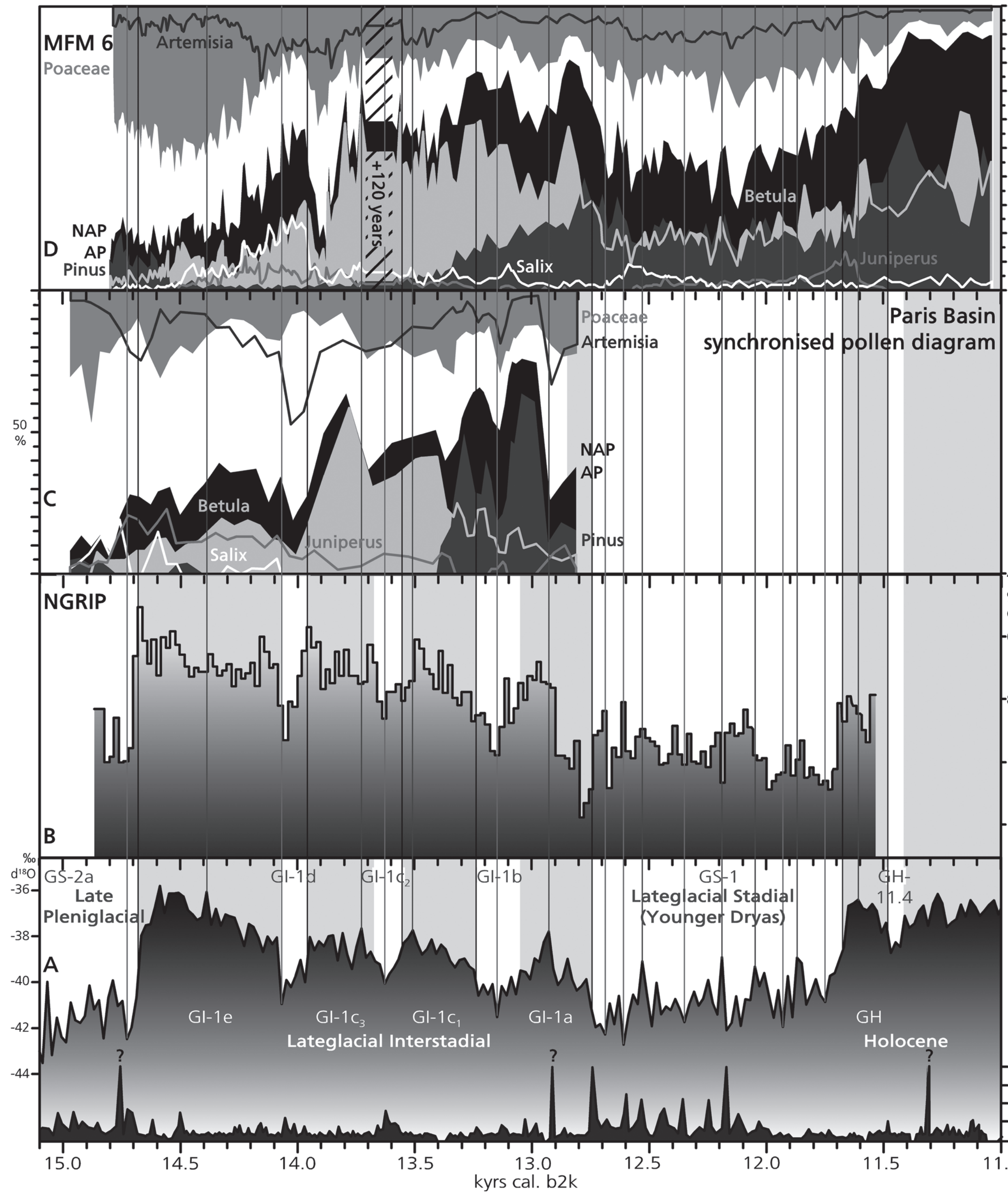


Fig. 53 Comparison of the isotope record from NGRIP and the pollen diagrams used in this project. Grey shaded areas represent events of more interstadial values than the surrounding values in the oxygen isotope record (A). Thin bars given as guide lines (light grey: low; medium grey: high; black: transition). **A** Oxygen isotope record from NGRIP with the Ca^{2+} corrected sulphate content but without associated ash layers (see **fig. 30**). – **B** Deuterium excess record from NGRIP. – **C** synchronised pollen diagram from the Paris Basin, fitted to the calender timescale by the ^{14}C calibration (see **fig. 52**). – **D** simplified Lateglacial pollen diagram from Meerfelder Maar, MFM 6, according to the varve chronology. – **AP** – arboreal pollen. – **NAP** non-arboreal pollen. – For further details see p. 40-48 and text.

Shortly before the onset of the Lateglacial Interstadial, a first peak of AP occurred in both records. In the Paris basin, pine pollen had already vanished from the diagram and the peak was due to a peak of willow (*Salix*. sp.) followed by a peak of juniper (*Juniperus* sp.). In the MFM record, the peak was still formed by pine pollen. The AP pollen in both records decreased around the onset of the Lateglacial Interstadial, only the values of birch (*Betula* sp.) began to increase at this point. When the birch pollen reached a first peak in the French record, juniper and willow pollen formed equally peaks resulting in a first peak of AP in the early Lateglacial Interstadial. In contrast to the French record, the AP remained low at the onset of the Lateglacial Interstadial. Among the AP, pine pollen remained the most abundant species for another 100 years and were then suppressed by birch pollen. From thereon, birch was usually predominated above pine in this archive, only in the transition from the Lateglacial Interstadial to the Lateglacial Stadial and in the early Lateglacial Stadial pine pollen occurred again more abundant than birch pollen.

In the Paris Basin diagram, the first higher AP values again decreased after the GI-1e maximum in the oxygen isotope record of NGRIP and are synchronous with a decline in the deuterium excess record (**fig. 53**). Furthermore, a basaltic ash layer was recorded at this point in the NGRIP record (**fig. 30**) and attributed to the Icelandic Laki volcanic system (Mortensen et al. 2005). Historic eruptions from this volcanic system significantly affected the climate and environment of Central Europe (and beyond) for the following years (Grattan 2006). Since modern atmospheric circulation patterns were in all likelihood already established at the time of the Lateglacial Interstadial, the impact of an eruption in the Laki fissure on Europe was possibly comparable to these historic events. In the French pollen record, the low values of AP were accompanied by higher proportions of pine pollen which probably reflected another short episode of increased introduction of allochtonous material into the stratigraphies. Perhaps, this introduction was related to extreme hot and dry summers followed by spring flooding events which were also quoted as a direct result of a historic Laki eruption (Thordarson / Self 2003). However, if this eruption had affected north-western Europe, crypotephras should be detectable. Therefore, cryptotephra analyses, searching particularly for basaltic ash, could be a considerable help to ascertain chronological correlations within this period and, perhaps, to position archaeological assemblages during this period. This type of findings is particularly important because a longer plateau in the calibration curve makes a precise chronological attribution more difficult. In the MFM diagram a small increase of pine and a decrease of birch was documented around this period but concomitantly a peak of willow occurred which kept the AP values high. However, with the decrease in willow pollen the AP values also decreased so that a low of all AP values, comparable to the French pollen record, occurred some 100 years later in the MFM diagram. Nevertheless, the pollen concentration slowly increased after this point. In the northern French diagram the values of AP began to increase again at this time, in particular due to birch reestablishment, whereas juniper values remained relatively constant. Willow remained undetected after the possible introduction of allochtonous material and reappeared only for a short period towards the end of GI-1e. After a last peak at the onset of GI-1d, willow pollen disappear from the French pollen sequence. In addition, juniper pollen began to gradually decrease at this point.

In the MFM, a significant increase of willow is also accompanied by an increase in AP and birch pollen increase towards the end of GI-1e. However, the steep decline in AP, birch, and willow pollen values in the MFM at the beginning of the Oldest Dryas biozone (Litt / Stebich 1999) correlates, in the present chronology, with the end of GI-1d and occurred again 100 years later than these low values in the French diagram. Without the additional 120 years, the extreme behaviour of the MFM record in the Oldest Dryas zone corresponds to the mid GI-1c_3. Even though a correlation with the cold event GI-1d was usually assumed, the existing chronology cannot confirm this correlation and rather indicates an extreme reaction of the regional vegetation on an event after the onset of the interstadial episode GI-1c_3. A comparable pattern was recently reported from the Weerterbos region, some 150 km north-westwards of the MFM in the southern Netherlands (van

Asch et al. 2013). Previously, combined records of oxygen isotopes and pollen from this region suggested a delayed reaction of the vegetation record to the isotopic cold events GI-1d and GI-1b (Hoek/Bohncke 2001, 1262). Thus, the close correlation of the Paris Basin diagram might be due to the correlation of the chronology with NGRIP (see p. 384-386) and the asynchronic reaction in the MFM could be the more reliable development in the Lateglacial environment. However, in the French diagram, a significant peak of *Artemisia* sp. pollen occurred during the period of low AP values, whereas the true grass values also decreased. This pattern possibly suggests a widespread opening of the landscape because most species of the Artemisia genus require full-light conditions, whereas many species of the various genera within the Poaceae family grow in partially shaded areas. The temperature tolerance of the various genera varies considerably. Thus, the development in the pollen diagram could indicate in analogy to the onset of GS-1 that the impact of a temperature decrease in GI-1d did not affect the environment as severely as aridity and wind breakage (cf. Brauer et al. 2008). However, this combination of low precipitation and high wind activity would also result in an increase of allochtonous material in the records. Indicators for this allochtonous intrusions as suggested by the previous increases of pine pollen were not found in this part of the diagram but in the MFM varve record an increase of varve thickness was documented for this biozone (Brauer/Endres/Negendank 1999). Furthermore, the pollen concentration dropped in this zone to almost Late Pleniglacial values (Litt/Stebich 1999, fig. 4). Moreover, the Artemisia pollen formed only a short peak towards the end of the Oldest Dryas biozone but remained less significant than the Poaceae in this region. Comparable to the Paris Basin, willow and juniper only occurred in small proportions after the onset of this biozone in the MFM.

According to the present correlation, the following steep increase of birch pollen and AP in the MFM occurred quasi-contemporaneously with the same increase in the Paris Basin. In the former, this increase is assumed to correlate with a spread of birch trees and, thus, the spread of first light forests. This interpretation is further sustained by the increase of pollen concentrations to generally higher values. In addition, this peak was accompanied by lower values of juniper, Artemisia, and Poaceae pollen in the French sub-area indicating a decline of an open shrub vegetation. However, the increase in the MFM is not gradual but characterised by extreme fluctuations between high and low AP and birch pollen proportions. This wiggling record is, however, obscured in the synchronised Paris Basin diagram.

After this first increase, a gap due to the slump and turbite deposit followed in the MFM. and In the northern French records, a steep decline of AP and birch values followed and it was accompanied by a slight rise in values of Artemisia and juniper and a peak of Poaceae. This episode in the French diagram correlates with the end of GI-1c_3 and the transition towards the cold event GI-1c_2 in NGRIP. These significant reactions in the French diagrams and the destruction in the MFM within GI-1c_3 can be aligned with the disturbed results from oxygen isotope records in the southern Netherlands (Hoek/Bohncke 2001). This disturbance was assumed to be related to increased groundwater flux due to the final melting of relict ground-ice (Hoek/Bohncke 2001, 1262). However, GI-1c_2 is characterised by a period of higher values in the gypsum corrected sulphate record from NGRIP. Only in the later part of this period a rhyolitic ash layer of possible northern Icelandic origin was detected. The preceding high values of the sulphate could be best explained by globally high volcanic activity, possibly related to the cold but still wet climate event and glaciological developments.

Consequently, the cold event of GI-1d seems to indicate a beginning for approximately 500 years of unstable environmental conditions during which the first shrub vegetation of late GI-1e was replaced for a short period by an open herb steppe followed by the establishment of first light forests in the sub-areas. However, these general developments were accompanied by extreme climatic conditions relating in particular to the water balance and resulting in fluctuating values in the pollen diagrams but also to very differential conditions of preservation.

In the northern French pollen profiles, the AP, birch, and juniper values began increasing again within GI-1c_2, whereas Artemisia continuously decreased and was surpassed by Poaceae. Even though the values did not reach the peak value of GI-1c_3, a widespread light forest with some grass meadows appears to have been established by the onset of GI-1c_1 in the Paris Basin. In the MFM record, the values were still fluctuating, also at a lower level than during GI-1c_3, but the amplitude of the peaks and lows as well as the frequency seemed to decrease indicating a slowly stabilising environment. The Artemisia values remained relatively high in the Eifel, possibly suggesting still more open meadows on higher elevated plateaus of the middle range mountains.

In mid-GI-1c_1 the gypsum corrected sulphate content of NGRIP had its lowest values before the Holocene. In the French record, this low was followed by another sharp decrease of AP, juniper and birch pollen. In contrast, the percentage of pine pollen began increasing. In the MFM diagram, a short peak of AP influenced by an increase in birch followed by willow pollen occurred after the low in the sulphate content. This short AP peak is also followed by a steep decline in AP and birch pollen. The low in AP and birch pollen was accompanied by a peak of Poaceae and a first peak value of pine pollen which surpassed the percentages of willow in this episode. In the Paris Basin, pine became the predominant arboreal genus after this episode, whereas the relative birch concentration decreased gradually. This supersession marked the end of a pioneering phase and the establishment of denser and darker forest covers. This interpretations is further supported by the rather low frequency of Artemisia pollen in the Paris Basin diagram. The importance of pine also increased in the MFM during this period but, as previously mentioned, birch remained the most important arboreal pollen type in this sequence. Thus, at the onset of GI-1b, birch was clearly dominant in the MFM where the AP already presented approximately 75 % of the pollen. In contrast, pine pollen was already dominant among the AP that represented approximately two thirds of all pollen in the synchronised Paris Basin sequence. The values of pine and birch were, in some areas, still close. With the onset of GI-1b the AP values in both diagrams decreased again, whereas Poaceae increased. In the Paris Basin, this increase was accompanied by increasing Artemisia values, although the values of this genus still remained below the Poaceae values. In the second half of GI-1b, willow and juniper pollen had a peak value in the MFM sequence. The juniper peak can also be found in the Paris Basin diagram but began and ended a few decades before the peak in the MFM.

Following the juniper peak, the AP again increased significantly due to a pine peak and accompanied by a steep decrease of Artemisia pollen in the Paris Basin. In contrast, AP and birch pollen began decreasing in the MFM record but comparable to the Paris Basin pine pollen also continued to increase in the MFM. The lowest value of AP and birch occurred before the highest value in GI-1a and corresponds to the onset of PAZ 7 (Younger Dryas) in the Paris Basin diagram. However, this correlation might be due to the lack of reliable correlation points in this part of the French diagram. The sharp decline of pine pollen and AP accompanied by the steep increase of Artemisia pollen which surpass again the Poaceae pollen preceded the decline of oxygen isotopes and the sulphate peak 4 in the NGRIP record and, consequently, the deposit of the LST in the MFM. However, a comparison with the development of the deuterium excess record in NGRIP (**fig. 53**) possibly suggests that the significant alterations of the climate system reflected by this proxy (temperature at source of Greenland precipitation) influenced the vegetation in northern France. Based on the insecure chronology of this part, this hypothesis still requires testing against future stratigraphies. In the MFM region, the AP and birch pollen increased again after the LST to a last peak within the second half of GI-1a. Before the end of GI-1a, the birch values drop sharply and only at this point the pine values increased and surpassed the birch pollen in the MFM. With the first severely low values in NGRIP, the AP record of MFM also decline reflecting the opening of the landscape towards the Younger Dryas. This impression is further sustained by the decline of pollen concentrations. However, the AP values remained on a level comparable to the later part of GI-1e and the pine as well as birch pollen remained relatively high. This pattern suggests that forests might have retreated to more sheltered areas but remained present in north-western Europe during this Lateglacial Stadial.

Evidence from botanical macro-remains

To accomplish a construction of the local environments, directly dated botanical macro-remains (including pieces of charcoal) that were previously determined to species level should supplement the reconstructions based on pollen profiles (Birks 2003; Bennike/Seppänen 2004; Mortensen et al. 2011). This supplement is necessary because of general sources of error with sole reliance on pollen assemblage for past vegetation reconstruction. General sources of error are, for example, the proportional presentation of these diagrams and the disproportional production of pollen as well as the differential effects of the dispersal and of diverse taphonomic processes such as redeposition on the pollen species (Odgaard 1999; Bennett/Willis 2002; de Klerk 2004, 271; Lebreton et al. 2010). These potential errors affect, in particular, environments producing only small sedimentary pollen assemblages (cf. Mortensen et al. 2011, 2535).

In contrast to pollen, macro-remains often make a more precise species determination possible. Moreover, if these specimens are found in environmental archives, a relatively close vicinity of the plant and the deposited remain can be assumed after the exclusion of natural redeposition processes. In contrast, remains from archaeological sites do not necessarily originate from a close vicinity but could be introduced by humans. Yet, these specimen answer, instantly, the archaeological question relating to the general availability and use of a resource. Furthermore, depending on the weight of the macro-remain and the consistency of the sediment, sinking of the remains into softer ground can cause some chronological offset between the sediment and the plant remain. In general, later intrusions due to bioturbation and other post-depositonal processes are possible and, therefore, directly dated plant remains are very useful in the reconstrution of past environments. Directly dated macro-remains can be considered in the form of probability distributions or first and last appearance dates to test the results of the pollen analyses. However, the directly dated and determined macro-remains from the sub-areas of this study are in too low number to be useful in a probability distribution. For instance, from the Central Rhineland only one sample of pine (*Pinus* sp.) was directly dated (Bad Breisig, GrA-17493: 10,840 ± 60 years ^{14}C-BP; see **tab. 75**).

Nevertheless, the presence of determined botanical macro-remains can help in the discussion about the local environment. For example, in the on-going debate about whether small stands of trees or small forests survived in sheltered topographies during the LGM and the Late Pleniglacial, the evidence of macro-remains is one of the essential arguments in favour of their survival (Stewart/Lister 2001; Willis/van Andel 2004; Birks/Willis 2008). The reconstruction of a patchy or mosaic environment during the Late Pleniglacial is of some interest to the palaeontological discussion of non-analogue or disharmonious assemblages (cf. Fahlke 2009; Polly/Eronen 2010) as well as for archaeological considerations about available resources.

For the Late Pleniglacial period, pine and willow charcoal found at Gönnersdorf (Schweingruber 1978), Andernach IV (Holzkämper 2006), and Pincevent (horizon IV; Thiébault 1994; **fig. 54; tab. 72**) should be considered in the reconstruction of the environment. In a more recent microscopic analysis of hearth remains from Pincevent, no pine material was found and only remains attributed to birch (*Betula* sp.) and willow (*Salix* sp.) were determined (Bodu et al. 2009b). At Gönnersdorf, birch was also frequently found and these three typical species (pine, willow, birch) were further supplemented by juniper (*Juniperus* sp.). In Andernach IV, no birch remains were identified but the spectrum was supplemented by a single remain of daphne (*Daphne* sp.). Among the poorly preserved charcoal remains of Étiolles, birch was determined and

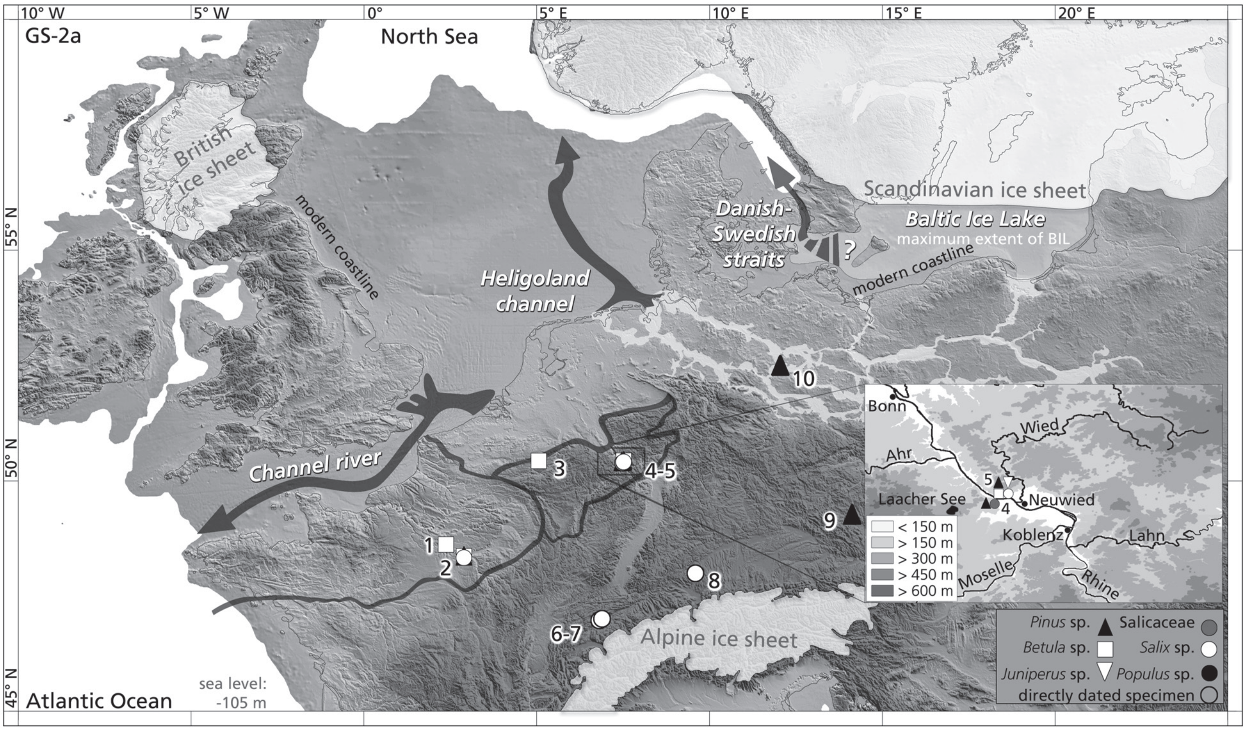


Fig. 54 Map of north-western Europe during GS-2a with sites yielding determined plant macro-remains (within the sub-areas) supplemented by directly dated plant macro-remains (outside the sub-areas). **1** Étiolles; **2** Pincevent; **3** Bois Laiterie; **4** Andernach-Martinsberg; **5** Gönnersdorf; **6** Monruz; **7** Champréveyres; **8** Schussenquelle; **9** Putim; **10** Grieben. – For further details see text.

another piece of the Betulaceae family showed characteristics of the European hornbeam (*Carpinus betulus*; Thiébault 1994). If the determination of the latter is correct, it appeared to represent a younger intrusion and, thus, also the attribution of the birch sample to the Late Pleniglacial can be questioned.

In anthracological analyses of Magdalenian material from the Swiss Lake Neuchâtel, willow (*Salix* sp.) was the dominant species and assumed to originate from the dwarf shrub *Salix retusa* (Leesch et al. 2012). Several directly dated samples confirmed the Late Pleniglacial attribution of this material (Leesch 1997; Bullinger/Leesch/Plumettaz 2006). Besides willow, birch (*Betula* sp.) was again determined. These arboreal species were supplemented with numerous remains of flowers and herbs in the well preserved lower horizon from Monruz (Bullinger/Leesch/Plumettaz 2006). Furthermore, charcoal from the Late Magdalenian Moosbühl site also indicate the typical composition of pine, willow, and birch (Bullinger/Lämmli/Leuzinger-Piccand 1998). However, a convential date made on a sample of birch bark that was found beside a hearth produced an early Lateglacial Interstadial age (B-2316: 12,060 ± 150 years ^{14}C-BP, 14,370-13,570 years cal. b2k; Feustel 1980, 120). Further directly dated charcoal from this site frequently resulted in Holocene ages (Bullinger/Lämmli/Leuzinger-Piccand 1998) suggesting chemical and/or botanical contamination. Further to the north-east, at the Late Magdalenian site of Schussenquelle, a piece of charcoal was determined as willow and also directly dated to the Late Pleniglacial (ETH-6154: 12,630 ± 120 years ^{14}C-BP, 15,600-14,440 years cal. b2k; Schuler 1994). Thus, the presence of willow in north-western Europe during the Late Pleniglacial appears evident. Furthermore, the reliable remains show that besides willow, also pine wood and occasionally birch was available during the Late Magdalenian occupation of northern Europe.

However, these remains may not have originated from tree species because these genera also include small (dwarf) shrub species such as *Pinus mugo*, *Betula nana, Salix polaris*, or *Salix reticulata*. These species would sustain the reconstruction of a steppe-like environment comparable to modern analogues in higher altitudes. In pollen diagrams from north-western Europe, the Late Pleniglacial and early Lateglacial Interstadial

species	Andernach lower horizon IV	Gönnersdorf	Pincevent, horizon IV	Étiolles	Bois Laiterie	Le Closeau	Andernach, upper horizon		Conty	Urbar	Kettig	Niederbieber	Bad Breisig
							2-FMG	3-FMG					
Pinus sp.	**×**	**×**	**×**			**×**	×	**×**	**×**	×		×	×
Saliceae / *Salix* sp. / *Populus* sp.	×	×	**×**				**×**	×		**×**	**×**	**×**	?
Betula sp.		×	×	×	×		×	**×**		×	×	**×**	?
Daphne sp.	×							×					
Juniperus sp.		×											
Carpinus betulus				(?)									
Corylus avellana					(**×**)								
Sambucus sp.							×						
Pomoideae								×					
Prunus sp.								×				?	

Tab. 72 Presence of determined botanical remains (mostly charcoal) on the archaeological sites used in this project (for further details and references see Material-Archaeology, p. 75-133, p. 143-161, p. 163-168, p. 175-179, p. 210-219, and p. 231-237). The most common species are set in bold. Symbols: **×** present; **?** uncertain determination; **()** doubtful association with the archaeological horizon.

presence of birch was usually attributed to the dwarf-shrub *Betula nana* (Lotter 1999; Merkt/Müller 1999; Jones et al. 2002). However, macrofossils of tree birch (*Betula pubescens*) occurred in the MFM and in northern Germany during the early Lateglacial Interstadial (Litt/Stebich 1999; Merkt/Müller 1999) suggesting a rapid expansion at the onset of the Lateglacial Interstadial and/or a survival of small patches in sheltered areas during the Late Pleniglacial. The usually small dimensions of the recovered charcoal material and the high destruction by the firing process did often prohibit further determination but one piece in Gönnersdorf showed characteristics typical for the tree species Scots pine (*Pinus sylvestris*). A review of the evidence for the presence of Scots pine in northern Europe during the Late Weichselian in combination with modern genetic variation among Scots pines suggests that evidence for its presence in northern Europe during GS-2a was almost absent and that this pine dispersed mainly from south-eastern refugia into northern Europe (Cheddadi et al. 2006).

Thus, although a presence of some stands of pine, willow, and/or birch trees or larger shrubs in the flood plains or in sheltered brook valleys cannot be excluded for the Central Rhineland, driftwood from more favourable southern regions as the Upper Rhine rift or possible old wood from gravel deposits washed out during seasonal flooding could have also served as fuel. In the Rhine gravels, remains of Weichselian pines are still being documented (cf. Friedrich et al. 1999; Rosendahl et al. 2006) and sources for fossil material were certainly known among the Magdalenian inhabitants of Gönnersdorf and Andernach as proven by fossil materials identified regularly in the hearth remains from these sites. Therefore, only a direct dating of some determined pieces could help evaluate the presence of Scots pines during the Late Pleniglacial.

A piece of Scots pine from Grieben (Saxony-Anhalt) was dated to the second half of GS-2a (OxA-13284: 12,620 ± 50 years ^{14}C-BP, 15,390-14,870 years cal. b2k; Grünberg 2006). The pine wood served as shaft in a Mesolithic composite tool. If this date is correct, it proves the availability as well as the use of old wood by Mesolithic hunter-gatherers and suggests the availability of larger pines during the Late Pleniglacial in Central Germany. Possibly, this piece originated from a nearby south-western glacial refugium (Cheddadi et al. 2006) and reached this area by river transport. This interpretation was further sustained by a directly dated piece of pine charcoal (GrA-36010: 13,010 ± 60 years ^{14}C-BP, 16,240-15,440 years cal. b2k) from the Magdalenian site at Putim (Verpoorte/Šída 2009) which is located near one of the potential refugia in south-eastern Europe. In addition, a small pine charcoal fragment from the ice wedge cast at Wilcyzce was directly dated and produced a Late Pleniglacial age (Poz-14892: 12,770 ± 120 years ^{14}C-BP, 15,790-14,910 years cal. b2k) which was considered a minimal age due to the amount of material (Fiedorczuk et al. 2007, 120). Besides the pine charcoal, Magdalenian material and a human foetus were found which dated to a comparable age range as the Late Magdalenian remains from Gönnersdorf and Andernach, lower horizon (see p. 466-468; Fiedorczuk et al. 2007; Ginter/Połtowicz 2007; Irish et al. 2008). However, the position near a wide river valley which drained one of the potential Scots pine refugia again made the use of non-primary material possible. Thus far, these pieces are the only determined and directly-dated macro-fossil of pine found in this period.

Comparable with Gönnersdorf and Andernach some macro-botanical remains were dated to GS-2a from their context that must be considered cautiously. For example, the site of Bois Laiterie produced dates comparable to the Grieben specimen and the charcoal remains from this site were determined as birch and hazel (*Corylus avellana*; Pernaud 1997). This latter species is unknown from Lateglacial pollen assemblages but it is well known from Holocene stratigraphies. Therefore, this charcoal can be assumed as a younger intrusion, although the presence of small pioneering patches of hazel and birch during moister and milder episodes might have been possible (cf. Pernaud 1997, 144).

This outline shows how sparse and questionable the direct evidence is for the reconstruction of the Late Pleniglacial vegetation. Additional information can be gathered from few profiles with almost continuously preserved pollen from this period such as La Grande Pile (Beaulieu/Reille 1992). The resolution of this long stratigraphy is relatively low and, thus, the exact chronological attribution of the vegetation to GS-2a was based only on the stratigraphic succession and correlations with Central French biostratigraphies. In general, the impression of the Late Weichselian vegetation developments can be documented from this sequence. The phase approximately correlaties to the GS-2a period and has been described as corresponding »to a crisis of aridity« (Beaulieu/Reille 1992, 435). This impression is further confirmed by pollen records from marine boreholes offshore Europe which registered »higher relative abundance of steppic taxa than during the Last Glacial Maximum« (Fletcher et al. 2010, 2849) in this period and thereby suggests severe cold and dry conditions relating to the Heinrich event 1 (Fletcher et al. 2010).

In contrast to the vegetation records, faunal remains are often better preserved and some faunal species allow for further assumptions on the past vegetation (see p. 412-432). In general, this faunal evidence confirms the picture of a dry and cold steppe environment.

In conclusion, the general picture of a cold and dry grass steppe landscape in the study area during the Late Pleniglacial remains valid but it might be supplemented by grove communities in small refuge areas, particularly in moister low- and middle-range mountain areas and/or sheltered floodplains (cf. Birks/Willis 2008). Even though the presence of these small stands of trees cannot be excluded based on the macro-botanical evidence, it is also not yet proven because the exact source of the macro-botanical material remains uncertain. Besides more sheltered regions, some remains could have originated from dwarf species and/or fossil sources. Therefore, the direct dating of pieces determined to species level from this period is desirable. Nevertheless, the infrequent presence of larger plant material in occasionally good preserved conditions on archaeological sites for this period indicates that wood was a rather scarce resource in north-western Europe during the Late Pleniglacial. However, the presence of wood charcoal in hearths on archaeological sites proves the availability of this material as a resource for fueling fires and suggested the probable availability of this resource for making equipment such as projectile shafts or building constructions such as frames for drying fish or hides. For dwelling constructions or hunting equipment some longer and more solid pieces of wood were required. In the case that no substitute material was available, unsustainable handling of this resource appears very improbable. Wood could have been replaced by faunal material such as prompted by the considerably older, Eastern European mammoth houses (Pidoplichko 1998) or the mammoth femur in the hearth construction of Gönnersdorf (Street et al. 2006). Furthermore, wood could have originated from other arboreal species such as *Juniperus communis*. Although juniper is usually only of a small shrub size, it can occasionally become larger. However, these longer woody parts are usually not straight but rather distorted, which is useless for hunting equipment but could serve in dwelling constructions. Thus, for the hunting equipment, the scarcer straight offshoots of shrubs and trees must have been used. Based on the assumed scarcity of this material, some questions about the handling of this resource arise such as: Were the composite techniques, which are known for lithic and (faunal) organic artefacts, extended to a wooden shaft part? Or were the constructions designed with predetermined breaking points allowing rather a loss or fracturing of the lithic and/or faunal material? The composite technique of wooden shafts was observed in the Ahrensburgian arrows from Stellmoor (Rust 1943) and possibly the result from a longer tradition of composite projectiles intended for a sustainable handling of scarce resources (Bokelmann 1991).

For the Lateglacial Interstadial, pollen profiles are better preserved and the number of sites producing determinable wood charcoal also increases (**tab. 72; fig. 55**). However, a plateau in the calibration record spreads the calibrated age ranges across the final Late Pleniglacial period and the first half of the Lateglacial Interstadial and makes a precise attribution to this early part, based only on radiocarbon dating difficult, in particular for dates with larger standard deviations. Moreover, the developments observed in the pollen

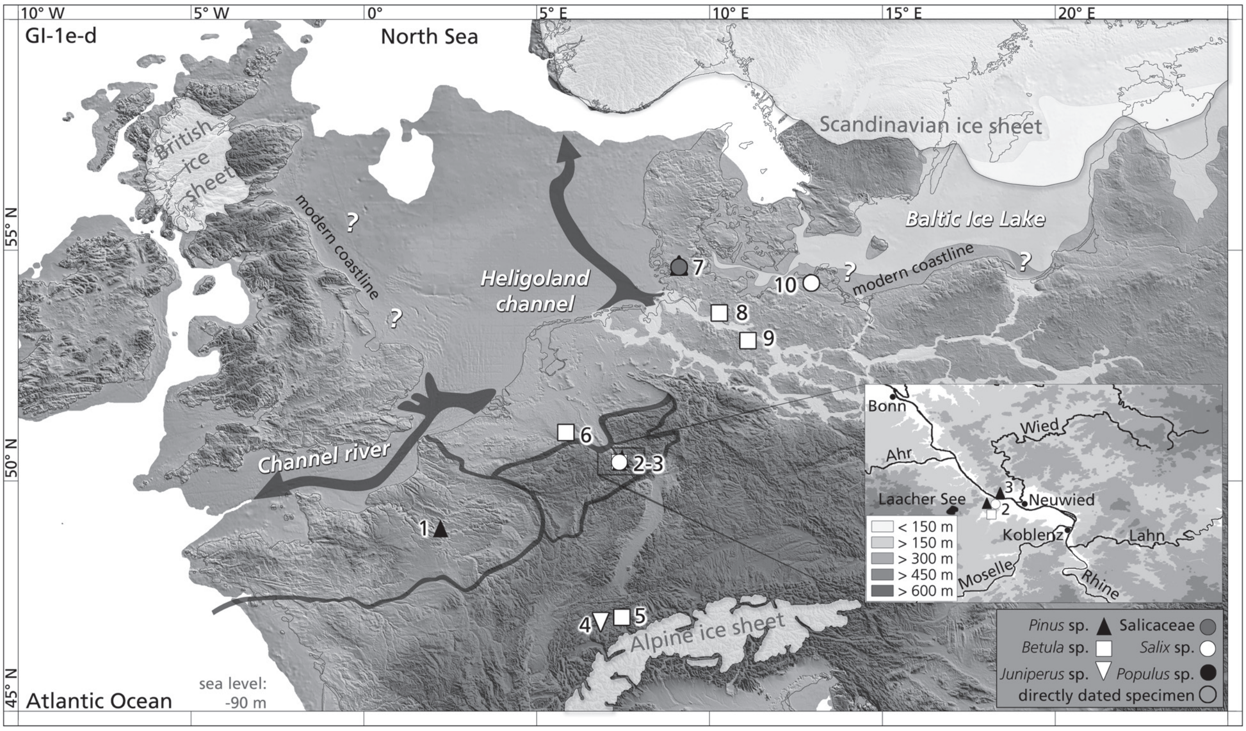


Fig. 55 Map of north-western Europe during GI-1e-d with sites yielding determined plant macro-remains (within the sub-areas) supplemented by directly dated plant macro-remains (outside the sub-areas). **1** Le Closeau; **2** Andernach-Martinsberg; **3** Gönnersdorf; **4** Monruz; **5** Moosbühl; **6** Gulickshof; **7** Ahrenshöft LA 73; **8** Poggenwisch; **9** Grabow 15; **10** Endingen Horst VI. – For further details see text.

records for the period corresponding to GI-1e to GI-1c_3 cannot be evaluated in greater detail based on the macro-remains due to this lack of precision. In fact, some material was attributed to this early period based on sedimentology, approximate vegetation development in the region (from pollen profiles), and the associated archaeological material. Thus, vegetation reconstruction for this period occasionally suffered from problems related to chronology and circular arguments.

For example, the calibrated age range of the material from Pincevent, horizon IV and Étiolles spread into the Lateglacial Interstadial but due to the assumed relation with the archaeological material, the material including the wood charcoal should be attributed to the Late Pleniglacial. However, younger intrusions of charcoal and/or a continued occupation into the early Lateglacial Interstadial cannot be excluded. Thus, the age range of the calibrated ^{14}C dates could be reliable and, thus, also date the presence of the botanical macro-remains. This consideration applies equally to the remains from Bois Laiterie. These possible early Lateglacial Interstadial remains were supplemented by the pine charcoal from Le Closeau. The range of directly dated samples attributed this species only to the late Lateglacial Interstadial (GI-1b and GI-1a). However, pine charcoal found in hearths associated with the lower horizon could be, indirectly, attributed to the early Lateglacial Interstadial. In fact, the dates on bones also spread into the later part of the Late Pleniglacial but the complex stratigraphy suggested that the horizon from which the material originated post-dated the Late Pleniglacial. As long as the dated remains and/or the associated macro-fossils were not moved stratigraphically upwards, this part of the age range can, consequently, be neglected. However, the presence of pine in the Paris Basin must still be questioned for the early Lateglacial Interstadial because of the unclear associations and the remaining uncertainty about the origin of the botanical material.

The same uncertainty about the association of the macro-botanical material with dated material applies to the pine charcoal found in the south-western area of Gönnersdorf and the pine, willow, and birch charcoal associated with the FMG concentrations in Andernach 2. The macro-botanical remains on archaeological sites from the sub-areas are usually only indirectly attributed to GI-1e and GI-1d or falls into the date range due to the calibration plateau (Bois Laiterie).

However, some material outside the sub-areas could be attributed to this early part of the Lateglacial Interstadial with some certainty.

Four directly dated samples of juniper from Monruz (sector 1 and sector 2, south) were associated with the younger, Azilian horizon and yielded calibrated ages which scattered between the final Late Pleniglacial and the early Lateglacial Interstadial (Leesch / Cattin / Müller 2004, 167. 183). One of these samples came from a disturbed area (hearth B11) and produced an almost entirely Late Pleniglacial age (ETH-23271: 12,570 ± 90 years ^{14}C-BP, 15,450-14,450 years cal. b2k; Leesch / Cattin / Müller 2004, 183). Thus, these age ranges suggest the use of juniper in a very early Lateglacial Interstadial context. Besides juniper, willow and pine were associated with the Azilian hearths from Monruz, sector 2-South (Leesch / Cattin / Müller 2004) but due to some disturbances the association of these species with a younger occupation phase remains uncertain. However, pine from an organic layer was directly dated and the calibrated age range encompasses the late GI-1e and GI-1d (Leesch / Cattin / Müller 2004). Based on the stratigraphic position, above the upper (Azilian) horizon, and due to the organic composition of the layer, an attribution to the mid-Lateglacial Interstadial appears more plausible. Nevertheless, the Central European pine chronologies reached into this period and, consequently, some groves of Scots pines were already growing at the end of GI-1e in Switzerland (Kaiser et al. 2012). Thus, the organic deposit could also originate from the latest part of GI-1e. This attribution would further emphasise that the Azilian occupation occurred in the very early Lateglacial Interstadial.

Even though charcoal samples were not yet dated directly to this period in Champréveyres, the Azilian material consisting of willow, juniper, and birch probably of comparable dates to the material from Monruz. A previously mentioned date was made on birch bark from the Moosbühl site. This date, perhaps, suggests a short reoccupation of this site comparable to the south-western area of Gönnersdorf. This indication could be further sustained by the occurrence of possible *Federmesser* and triangles (Bullinger / Lämmli / Leuzinger-Piccand 1998) as well as the presence of Baltic amber material (Schwab 1985) comparable to the Champréveyres site (Leesch 1997). However, the sampled material could also represent a natural intrusion that only indicates the presence of birch wood at this site during the early Lateglacial Interstadial but was not related to the archaeology. Furthermore, juniper seemed of some importance in the Alpine foothills region (cf. Lotter et al. 1992; Magny et al. 2006).

The increasing importance of birch, as indicated by pollen profiles, is also documented by directly dated macro-fossils (**fig. 55**). Evidence for this increasing importance usually comes from sites in the vicinity of major river systems such as Gulickshof (Hoek et al. 1999), Poggenwisch (Tromnau 1992; Lanting / van der Plicht 1996; cf. Grimm / Weber 2008), and Grabow 15 (Tolksdorf et al. 2013). As well as providing expansion routes along the drainage channels, this pattern indicates the preference of this genus to grow on well-watered grounds.

At the onset of the Lateglacial Interstadial, the increasing importance of birch was probably related to dwarf birch (*Betula nana*). Directly dated leaves of this species found in Gulickshof, southern Netherlands, produced a date at the transition between the Late Pleniglacial and the early Lateglacial Interstadial (Hoek et al. 1999). Dwarf birch was also observed in early GI-1e in the north-western English stratigraphy from Hawes Water where it was replaced by European white birch (*Betula pubescens*) around the end of GI-1e and within GI-1d according to comparisons with the oxygen isotope record (Jones et al. 2002). In addition, the first macro-fossils of European white birches occurred in the MFM sequence at the end of the Meiendorf biozone which corresponded approximately to the end of GI-1d (Litt / Stebich 1999). Thus, the expansion of birch trees across north-western Europe had occurred during the very early part of the Lateglacial Intersta-

dial with first communities established before the first significant increase recorded in the pollen diagrams. However, evidence from the Danish Slotseng site indicated a much later transition from open tundra-like environments reflected by the presence of *Betula nana* and *Dryas octopetala* to light forests with European white birches (Mortensen et al. 2011). Presumably, this delayed reaction showed the persistent influence of the Scandinavian ice sheet and the glacial meltwaters in the region around the modern Baltic Sea.
The numerous indications of Saliceae are possibly related to the return of colder conditions. A piece of charcoal from a hearth at Ahrenshöft LA 73 (classic Hamburgian horizon) was attributed to *Salix* sp. or *Populus* sp. and another fragment from an upper horizon (Havelte Group) was determined as pine (Clausen 1998). These specimens were directly dated and produced statistically identical ^{14}C ages which attributed the occupation of the site towards the end of GI-1e, GI-1d, and the early GI-1c$_3$ (Grimm/Weber 2008). A charcoal fragment determined as *Salix* sp. or *Populus* sp. found in Reichwalde resulted in a comparable date (KIA-13412: 12,193 ± 58 years ^{14}C-BP, 14,250-13,890 years cal. b2k; Vollbrecht 2005). This date was younger than dates made on calcined bones from the same archaeological feature. However, the latter material was shown elsewhere to be affected by some type of contamination in the Lateglacial (Lanting/Niekus/Stapert 2002). Besides the dated material, wood remains of birch, willow, and pine were preserved in this gravel pit reflecting a Lateglacial forest community (Friedrich et al. 2001a). However, the precise relation of the archaeological charcoal material and these environmental finds remains uncertain due to the large area and the complex stratigraphy. A piece of willow wood found in a test pit near the Final Palaeolithic site Endingen (Terberger 1996; Street 1996) was stratigraphically attributed to the first cold phase in the Lateglacial Interstadial (GI-1d, early Dryas; Kaiser/de Klerk/Terberger 1999). Due to a large standard deviation and the calibration plateau, the conventional date made of this sample was absolutely consistent with this attribution (Hv-20987: 12,360 ± 245 years ^{14}C-BP, 15,540-13,620 years cal. b2k; Kaiser/de Klerk/Terberger 1999).
This compilation indicates that with the return of colder conditions (GI-1d) birch material was presumably substituted with more readily available material such as willow.

After GI-1d, the pollen diagrams document a significant increase in arboreal pollen that was assumed to reflect the spread of light forest environments. However, some disturbances were also observed during the following mid-Lateglacial Interstadial period (GI-1c$_{3\ \mathrm{and}\ 2}$; see p. 378-380). Based on the directly dated botanical macro-fossils this period, in particular GI-1c$_2$, appears as a transition between the early Lateglacial Interstadial and the late Lateglacial Interstadial. The early Lateglacial Interstadial was still characterised by a relatively open environment with shrub communities, light forests, and a significant amount of meadows, whereas in the late Lateglacial Interstadial the forest communities predominate the reconstruction. Depending on the locality, the tempo of the development varied. For instance, more open communities persisted into this intermediate phase in some more exposed areas, whereas in sheltered areas such as the Seine valley a denser forest developed.
Partially, this impression is due to the calibration curve that becomes more reliable for this period due to the increasing evidence but also due the plateau encompassing the late Late Pleniglacial and the early Lateglacial Interstadial ending within GI-1d. Thus, more precise chronological attributions became possible after the end of the plateau. Consequently, this period, particularly the early part (GI-1c$_3$), provides the end point for the calibrated age range of many of the previously mentioned dated material.
In addition, some material that produced a longer dated age range towards the late Lateglacial Interstadial could not often be attributed more precisely. This imprecision was because many of the associated biostratigraphies distinguished only between a first pioneer episode and a last forested episode separated by a cold interval in the Lateglacial Interstadial. Usually, the first phase was equivalent to the early Lateglacial Interstadial (GI-1e-d), whereas for the later phase the attribution was occasionally difficult to distinguish

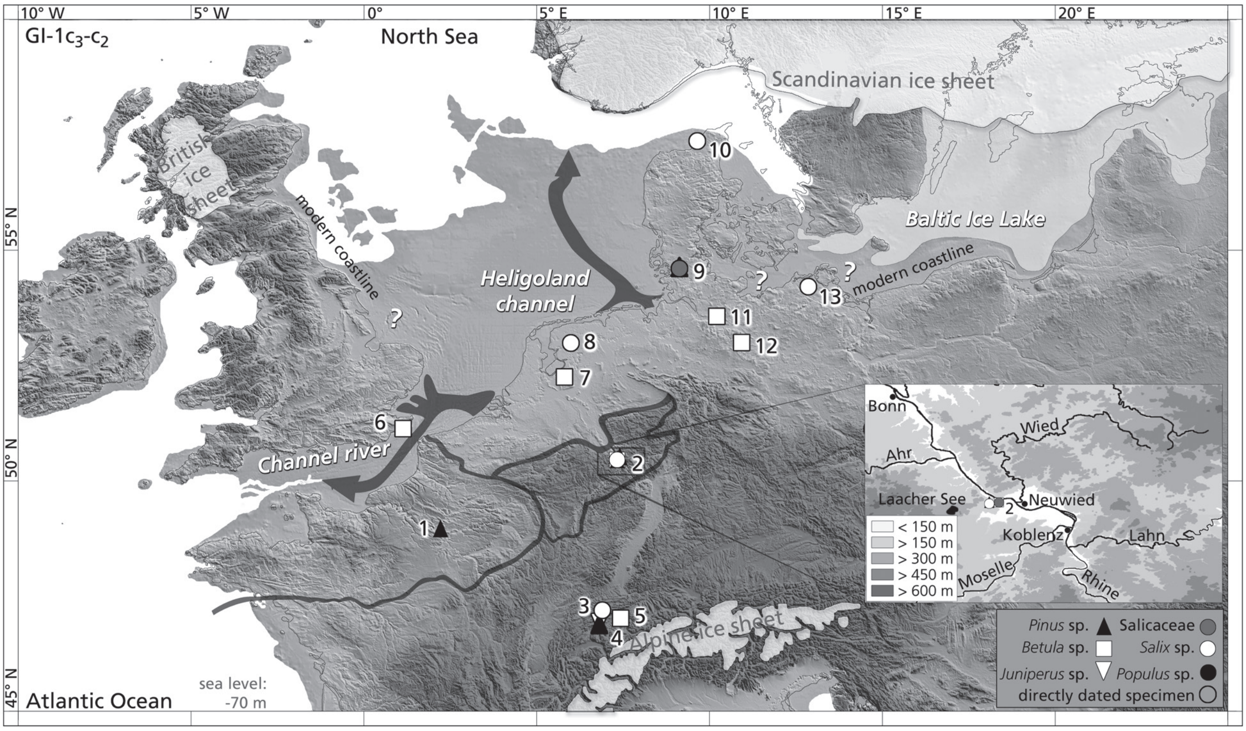


Fig. 56 Map of north-western Europe during GI-1c$_{3-2}$ with sites yielding determined plant macro-remains (within the sub-areas) supplemented by directly dated plant macro-remains (outside the sub-areas). **1** Le Closeau; **2** Andernach-Martinsberg; **3** Grotte du Bichon; **4** Monruz; **5** Moosbühl; **6** Holywell Coombe; **7** Usselo; **8** Oldeholtwolde; **9** Ahrenshöft LA 73; **10** Nørre Lyngby; **11** Poggenwisch; **12** Grabow 15; **13** Endingen Horst VI. – For further details see text.

whether it represented a preserved mid-Lateglacial Interstadial (GI-1c) or formed only the onset of this last forested episode (GI-1c-a). Consequently, the attribution of dated macro-fossils from the onset of this type of later forested period could relate to the mid-Lateglacial Interstadial as well as to the onset of the late Lateglacial Interstadial.

In the sub-areas, ^{14}C dates made on bones from the lower horizon of Le Closeau helped to date the pine charcoal on this site. These dates ended during the early part of this period (**fig. 56**). Furthermore, the FMG material from Andernach 2 could also originate from this period. Both attributions are vague and, consequently, the vegetation development of this period is poorly documented in the sub-areas.

Outside the sub-areas, most of the previously mentioned directly dated material from northern and eastern Germany but also the juniper material from Monruz and the birch bark from Moosbühl ranged up to this period and ended in it. Only the pine charcoal from the organic layer at Lake Neuchâtel probably dated to this period. In addition, the sites contributing material to the various dendrochronologies became more numerous around this time (Kaiser et al. 2012) indicating the presence of small groves of pines, at least in favourable places in Switzerland and eastern France, as well as in the Danube valley and eastern Germany. However, birch and willow seem, in general, to remain the predominant species. For instance, the calibrated age range of some directly dated willow remains from the new investigations at Nørre Lyngby (Aaris-Sørensen 1995) began in this period and spread into the late Lateglacial Interstadial. This range could suggest a continuous patch of willows in this area in the second half of the Lateglacial Interstadial. This onset of a shrub vegetation in northern Denmark is consistent with the first indications of light forests in Central Denmark (cf. Mortensen et al. 2011).

In addition, a fragment of willow charcoal that was recovered in the Swiss cave Le Bichon also produced a date which ranged from this period into the late Lateglacial Interstadial (ETH-4246: 11,680 ± 120 years ^{14}C-

BP, 13,790-13,230 years cal. b2k; Morel 1993). The cave bear and the human remains which were related with the charcoal yielded comparable results. Only a second fragment of charcoal produced a younger date, possibly due to contamination.

The calibrated age range for several pieces of willow charcoal found at the northern Dutch site of Oldeholtwolde (Johansen/Stapert 2004) also began in this period. Besides the several pieces of willow, a piece of pine charcoal was directly dated and produced a younger date suggesting a late Lateglacial Interstadial presence. According to the general succession known from the pollen profiles (Hoek 1997), these attributions seemed possible but the stratigraphic position and the archaeological context of the material were contradictory (Grimm/Weber 2008). If the dates were reliable, they would indicate the presence of willow in the northern Netherlands during the mid-Lateglacial Interstadial. Nevertheless, sample contamination is a possible reason for the relatively young results. Therefore, the remains from Oldeholtwolde have to be considered cautiously when discussing the development of the Lateglacial vegetation.

In addition, a birch sample recovered in a peat during excavations of the well-known Usselo site (Stapert/Veenstra 1988; van Geel/Coope/van der Hammen 1989) produced a vague age which after calibration spread across almost the entire Lateglacial Interstadial (R-106: 11,800 ± 280 years ^{14}C-BP, 14,390-13,030 years cal. b2k; Alessio/Bella/Cortesi 1964). However, according to the correlation of the peat with the pollen stratigraphy of the site, the sample originated probably from a period equivalent to GI-1c_3.

Directly dated birch samples from the biostratigraphy at Holywell Coombe yielded some results of mid- to late Lateglacial Interstadial age (Hedges et al. 1993a). One fragment from a lower section was considerably older stretching into the Late Pleniglacial. This attribution could be explained by the setting of the site near the English Channel river and an early expansion of dwarf birches along these favourable watercourses but the date remained doubtful and was therefore not used in this study.

Even though the calibration possibilities are relatively good, only a few directly dated macro-fossils can be attributed, unambiguously, to this period. Perhaps, the disturbance observed in the pollen diagrams during this period also had a negative effect on the preservation of macro-fossil material.

This poverty is set in clear contrast to the late Lateglacial Interstadial from which considerably more material was preserved. In particular, in the Central Rhineland, this better preservation was due to the cover of the LST that created an exceptional environmental archive.

In particular, the directly dated results of charcoal of poplars (*Populus* sp.) from Miesenheim 2 and the Brohl valley ranged from the onset of this period to the LSE but also the birch remains found at Thür encompassed the complete period until the LSE (**fig. 57**; Street 1986; Hedges et al. 1993b; Baales et al. 2002). Besides individual pieces of occupation evidence from Andernach 2, the Andernach 3 location was attributed to this period by the ^{14}C dates (Kegler 2002). The charcoal from this site comprised birch, willow, poplar, as well as Saliceae and singular specimens of a drupe tree (*Prunus* sp.), an apple tree (Maloideae), and again daphne (Kegler 1999, 14). According to the dated material, the other FMG sites in the Central Rhineland were also settled during this period (see **tab. 20**, p. 143-162, and p. 466-473). The species determined from these sites consisted of pine, willow, poplar, and birch. In Niederbieber, a possible drupe tree (*Prunus* sp.) was identified. Thus, temperate, light forest communities had certainly established in the Central Rhineland by this period.

Furthermore, imprints of leaves, flowers, and fruits of various taxa were preserved in the LST. Among many other plants, these imprints proved the presence of bird cherry (*Prunus padus*), European white birch (*Betula pubescens*), which was also present in a smaller arctic variety (subsp. *tortuosa*), silver birch (*Betula pendula*), European common aspen (*Populus tremula*), the shrub-sized *Salix caprea* and *Salix pentandra* as well as elder (*Sambucus nigra*, Baales et al. 2002). In comparison with the pollen profiles, this exceptional archive proved the variety within single genera and further showed that genera which were recorded sparsely in

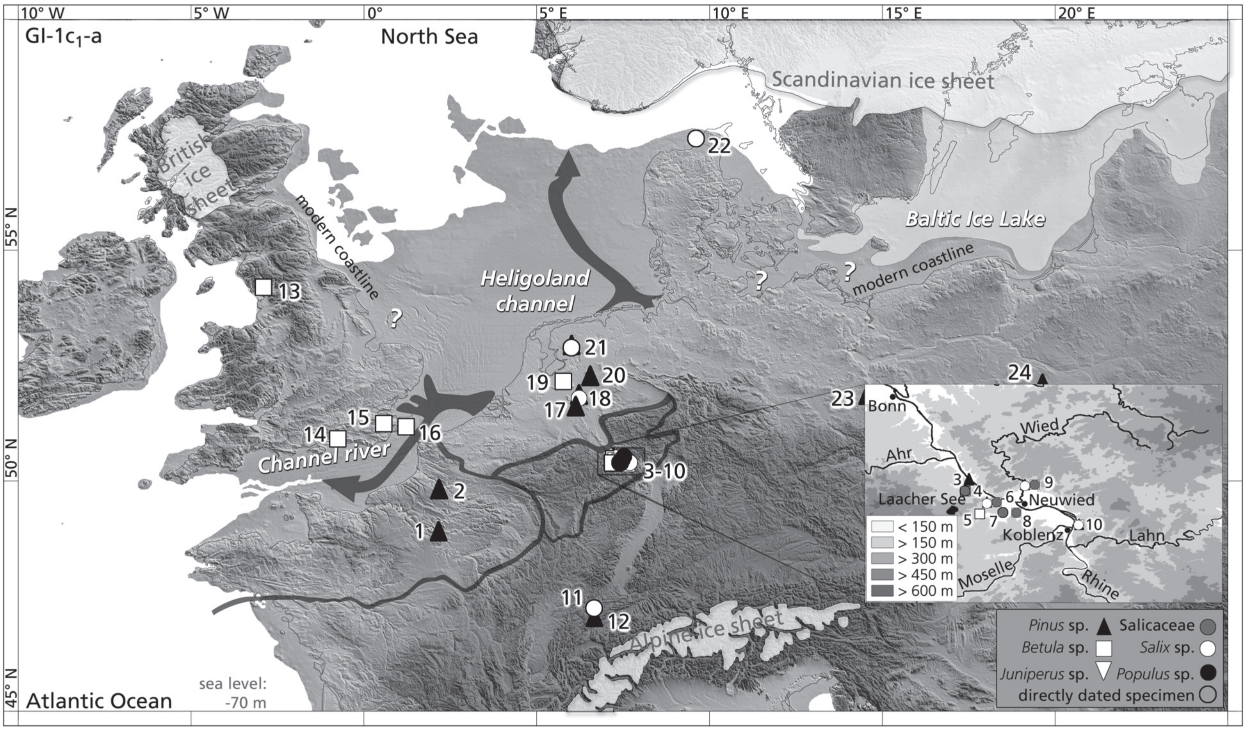


Fig. 57 Map of north-western Europe during GI-1c$_1$-a with sites yielding determined plant macro-remains (within the sub-areas) supplemented by directly dated plant macro-remains (outside the sub-areas). **1** Le Closeau; **2** Conty; **3** Bad Breisig; **4** Brohl Valley; **5** Thür; **6** Andernach-Martinsberg; **7** Miesenheim 2; **8** Kettig; **9** Niederbieber; **10** Urbar; **11** Grotte du Bichon; **12** Monruz; **13** Hawes Water; **14** Westhampnett; **15** Cherry Garden Hill; **16** Holywell Coombe; **17** Hülm; **18** Doetinchem; **19** Usselo; **20** Wierden Enterse-Akkers HS; **21** Oldeholtwolde; **22** Nørre Lyngby; **23** Groß Lieskow; **24** Witów (1-P, layer 4a). – For further details see text.

the pollen record such as willow could still occur numerously in favourable locations. Furthermore, the scarcity of pine charcoal as well as the rarely determined imprints of pine are consistent with the MFM pollen diagram where deciduous trees, in particular birch, remained more important than pine until the very end of the Lateglacial Interstadial.

For the remaining centuries of the Lateglacial Interstadial, the record from the Central Rhineland is almost absent which was tempting to interpret as a significant environmental hazard in this region. However, the pollen diagram from the MFM but also from other sites in Central Europe proved that the vegetation cover reestablished shortly after the LSE and prior to the onset of the Lateglacial Stadial (Merkt/Müller 1999; Litt/Schmincke/Kromer 2003). Directly dated macro-fossils are again very sparse and due to a small plateau and/or a very gradual decline in the calibration curve around the LSE, the attribution of the material to before or after the LSE remains a matter of speculation without a tephra layer in the stratigraphy. In the Central Rhineland the material from the Bad Breisig sites was found on top of the volcanic deposits and suggested that pines began growing again in the floodplains before the onset of the Lateglacial Stadial. This finding is consistent with the short dominance of pine pollen in the MFM sequence at the end of the Lateglacial Interstadial.

In the northern French sub-area, pine bark found in the stratigraphy of Conty is dated to the first part of this period (Ly-284: 11,540 ± 80 years ^{14}C-BP, 13,560-13,200 years cal. b2k; Ponel et al. 2005). This spread of pine in northern France is further sustained by the evidence from the intermediate and upper horizon of Le Closeau which produced also remains of pine charcoal (see **tab. 44** and p. 215). Presumably, some of this charcoal originated from natural fires (cf. Bodu 1998, 49). Nevertheless, these remains indicate widespread pine groves in the northern French river valleys during the late Lateglacial Interstadial. According to the directly dated specimens from Le Closeau, some pines remained growing in this location until the early Lateglacial Stadial when this type of floodplain forest first seemed to spread into the Central Rhineland.

On the British Isles, directly dated evidence for birch becomes more numerous suggesting the spread of more deciduous light forests in this region (Hedges et al. 1993a; Bronk Ramsey et al. 2000; Jones et al. 2002). Besides the macro-fossils, the pollen diagrams from the British Isles also indicated that pine was generally of minor importance on the British Isles during the Lateglacial (e. g. Walker/Coope/Lowe 1993; Brooks/Mayle/Lowe 1997; Jones et al. 2002; Walker et al. 2003).

In contrast, the observation of a spread of denser, pine dominated forests into sheltered valleys of mainland Europe during the early part of this period was further sustained by the available dendrochronological material which became more abundant in regard to the number of sites as well as the number of trees on a single site during this period (Kaiser et al. 2012). In addition, directly dated pine charcoal from Oldeholtwolde which originated from the so-called Usselo soil dated to this period (Johansen/Stapert 2004) and, thus, dated comparable to other material from this marker horizon (van der Hammen/van Geel 2008; Kaiser et al. 2009). Besides confirming the presence of wild fires, the numerous charcoal particles from this horizon further sustain the picture of widespread forests during this period. However, the pine material from Monruz is possibly dated to the onset of this period but the attribution to the later part of this period (GI-1b-a) was increasingly unreliable.

Nevertheless, numerous further directly dated pine specimens from northern sites further contributed to the picture of the previously observed expansion of pine forests in the floodplains after the LST. For instance, a pine cone from Hülm produced an age that fell into the plateau around the LST and the onset of GS-1 (GrA-23744: 11,080 ± 50 years ^{14}C-BP, 13,110-12,740 years cal. b2k; Kasse et al. 2005). Another directly dated charcoal fragment determined as Scots pine from the Dutch site Doetinchem was also attributed to the very end of the Lateglacial Interstadial and the transition to the early Lateglacial Stadial (GrA-13686: 10,870 ± 50 years ^{14}C-BP, 12,860-12,660 years cal. b2k; Niekus/Stapert/Johansen 1998; Johansen et al. 2000). In the eastern part of the North European Plain, this increasing predominance of pine became apparent a bit early within the cold event of GI-1b as suggested by the material from Groß Lieskow (Bittmann/Pasda 1999) and Witów (Tauber 1966).

Moreover, these pine forests did not presumably retreat completely during the Lateglacial Stadial, even though a clear decline occurred which resulted in the gap in the dendrochronological material. Nevertheless, a pine charcoal fragment from a hearth at the site Geldrop Mie Peels resulted in an early Lateglacial Stadial age (OxA-2563: 10,610 ± 100 years ^{14}C-BP, 12,760-12,320 years cal. b2k; Hedges et al. 1992) and indicated a continued presence of pines in the Netherlands (**fig. 58**). Comparably, a fragment of Scots pine charcoal was recovered at the northern German site of Melbeck and the date (Hv-17306: 10,515 ± 95 years ^{14}C-BP, 12,730-12,130 years cal. b2k; Richter 1992) also proved the availability of pine material during the early to mid-Lateglacial Stadial in this northern area. Furthermore, in a fluvial context at Wustermark 22 a pine branch from the mid-Lateglacial Stadial was preserved (unpublished lab. no.: 10,389 ± 57 years ^{14}C-BP, 12,520-12,040 years cal. b2k; Hanik 2009).

Consequently, even though pollen profiles, in particular, from northern Europe, document a significant decline in arboreal pollen during the Lateglacial Stadial, the sparse macro-botanical evidence suggest the continued presence of pine groves and, thus, indicated a more taiga-like environment in these areas during the Lateglacial Stadial. In the north-west, pines remained absent but single birch and willow remains were found (**fig. 58**). The limited contribution of sandy and loessic areas to fluvial sediments in northern France suggested in addition to the macro-remains that the ground cover was sufficient in this period to prevent erosional processes (Pastre et al. 2003, 2184). However, further to the north where permafrost conditions temporarily returned vegetation changed again to a more tundra-like habitat (cf. Mortensen et al. 2011).

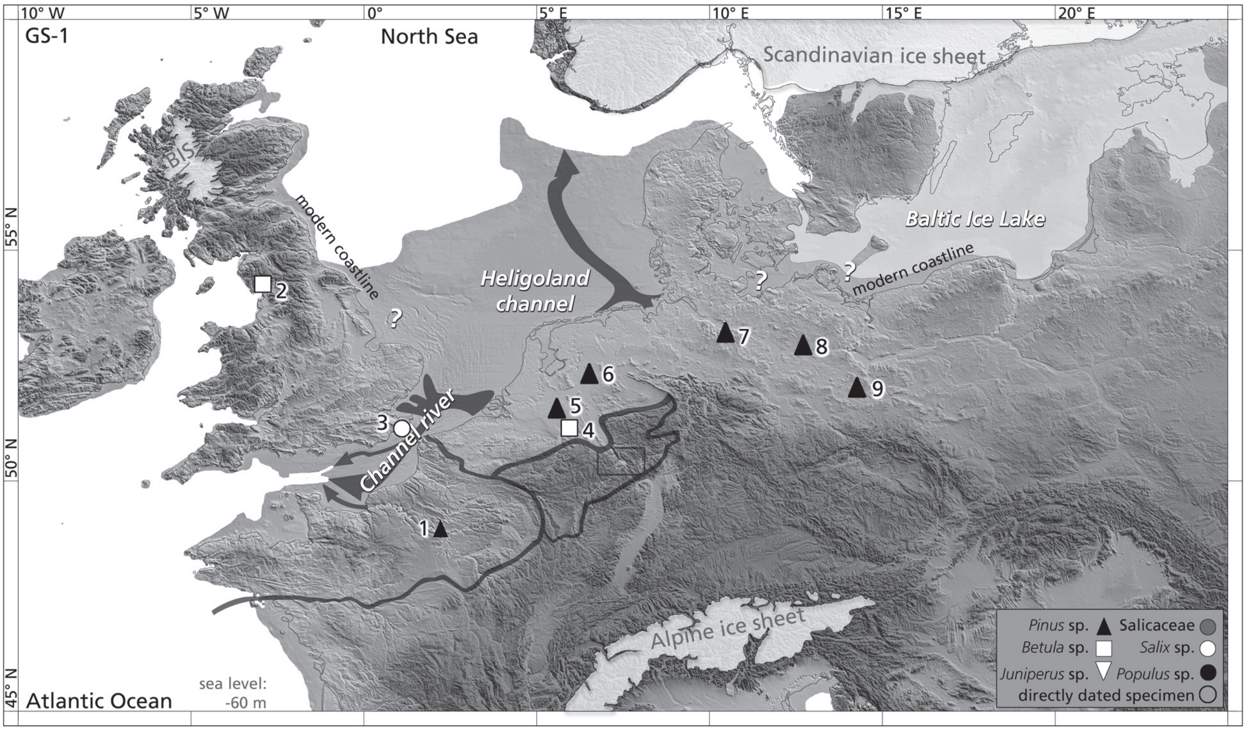


Fig. 58 Map of north-western Europe during GS-1 with sites yielding determined plant macro-remains (within the sub-areas) supplemented by directly dated plant macro-remains (outside the sub-areas; see **tab. 73**). **1** Le Closeau; **2** Hawes Water; **3** Holywell Coombe; **4** Gulickshof; **5** Geldrop Mie Peels; **6** Wierden Enterse-Akkers HS; **7** Melbeck; **8** Wustermark 22; **9** Groß Lieskow. – For further details see text.

Moreover, the number of sites producing macro-remains decreased significantly which was possibly due to a decline in conditions of preservation such as due to increasing deposit of acidic coversands, increasing taphonomic disturbances such as intensified high flood events in areas of frozen grounds, opening of vegetation covers, or a combination of these possibilities (cf. Weber/Grimm/Baales 2011).

In summary, the pollen profiles and the botanical macro-fossils reveal the following vegetation development in the Lateglacial (**fig. 59**):
During the Late Pleniglacial period, the landscape was characterised by a sparse grass steppe vegetation that was possibly supplemented by some stands of shrubs and trees in sheltered and moist areas. This light shrub vegetation expanded at the onset of the Lateglacial Interstadial. The first expansion of light forest communities into sheltered areas could only be proven for the latter part of GI-1e in north-western Europe. Pioneer forests began to spread in the mid-Lateglacial Interstadial (GI-1c_3). However, this period appeared characterised by inconstant climatic conditions resulting in unstable grounds and, thus, the expansion of the light forests communities appeared as a more vibrant development. Furthermore, this instability seemed to have affected the conditions of preservation at palaobotanical as well as archaeological sites and, consequently, the reliable evidence for the vegetation development from this time is particularly sparse. At the end of this period, the environment had shifted from the still relatively open landscapes to a landscape dominated by light forests. In some drier and more sheltered areas, these forests were already darker and dominated by groves of pines, in particular Scots pine. These darker forests increasingly became more dominant and by the end of the Lateglacial Interstadial pine dominated forests formed the main vegetation community in north-western Europe. These communities were so well established that they seemed to persist as groves in favourable areas throughout the Lateglacial Stadial. With the onset of the Holocene the conifer dominated forests established quickly over wide parts of the study area.

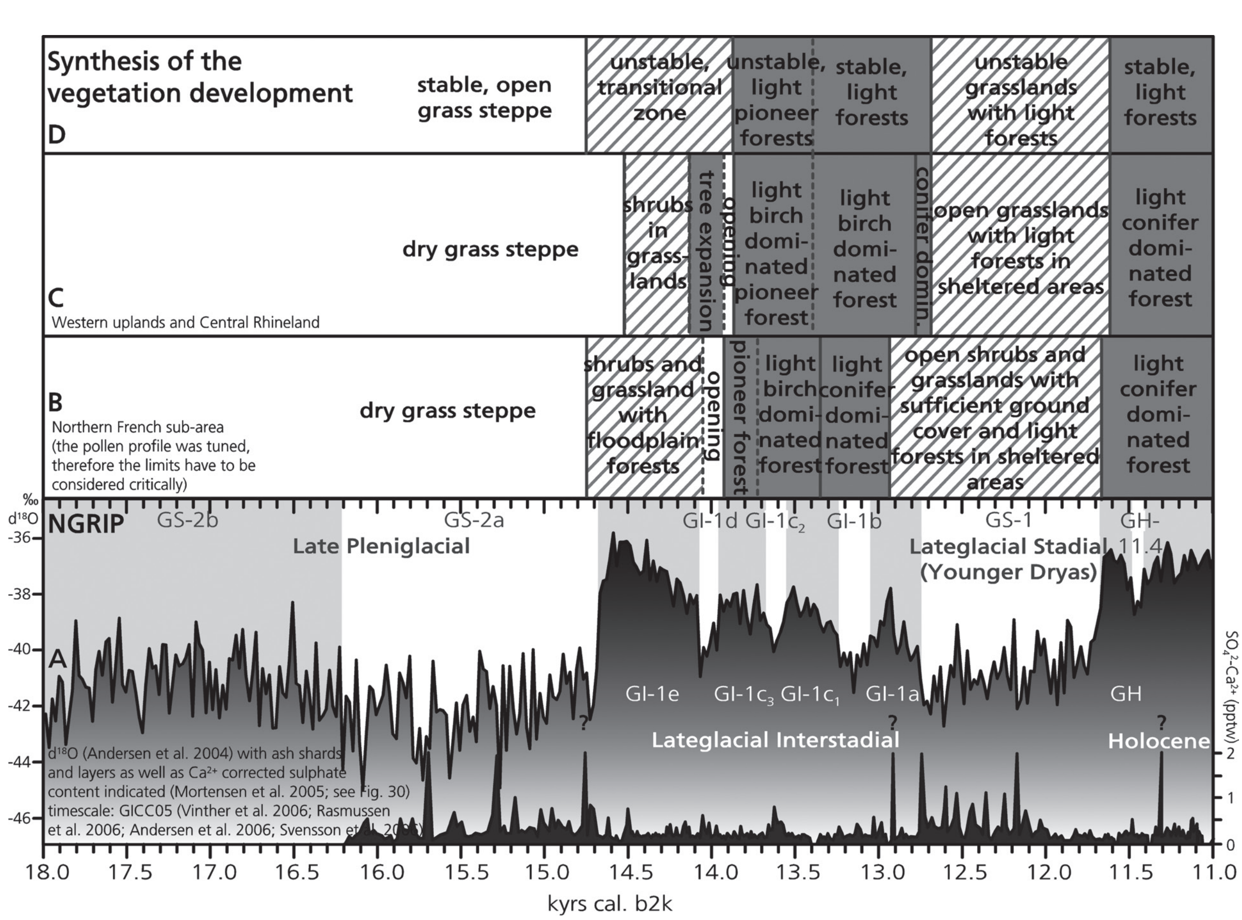


Fig. 59 Synthesis of the vegetation development in the sub-areas of this study (see **figs 53-58**). White backgrounds: cold and open environments; hatched background: transitional environments; grey shaded background: temperate forest environments.

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
pine (*Pinus* sp.), n=29								
Groß Lieskow, Brandenburg (D)	*LZ-1346*	*18,960*	*180*	charcoal/ sediment	*Pinus* sp.	archaeological horizon; PROBLEMATIC: big pieces of charcoal mixed with sand; REJECT: too high concentration of sand?	×	1
Mannheim-Vogelstang, Baden-Württemberg (D)	*GrA-*	*14,680*	*70*	wood	*Pinus sylvestris*	modified; bow fragment? REJECT: long storage, too low amount of material	×	2
Putim, Jihočeský (CZ)	GrA-36010	13,010	60	charcoal	*Pinus* sp.		16,240-15,440	3
Wilczyce, Świętokrzyskie (PL)	Poz-14892	12,770	120	charcoal	*Pinus* sp.	from ice wedge cast; PROBLEMATIC: »minuscule fragment…and, therefore, is considered … as of minimal age.« (Fiedorczuk et al. 2007, fig. 5)	15,790-14,910	4
Grieben, Saxony-Anhalt (D)	OxA-13284	12,620	50	wood	*Pinus sylvestris*	haft of coarse Mesolithic stone hatchet; PROBLEMATIC: long storage, use of old wood	15,390-14,870	5-6
Ahrenshöft LA 73 south, Schleswig-Holstein (D)	KIA-3605	12,200	60	charcoal	*Pinus* sp.	horizon 1	14,260-15,440	7
Monruz, sect. 2, Neuchâtel (CH)	ETH-17108	11,945	95	charcoal	*Pinus* sp.	possibly a cone was within the sample, above archaeological horizons	14,020-13,580	8
Monruz, sect. 1, Neuchâtel (CH)	ETH-20726	11,610	80	charcoal	*Pinus* sp.	above archaeological horizons	13,610-13,250	8
Oldeholtwolde, Friesland (NL)	OxA-2560	11,300	110	charcoal	*Pinus* sp.	from Usselo soil; no association to archaeology	13,350-12,950	9
Hülm, Nordrhein-Westfalen (D)	GrA-23744	11,080	50	cone	*Pinus* sp.		13,100-12,740	10
Wierden-Enterse Akkers HS, Overijssel (NL)	GrA-25906	11,070	60	charcoal	*Pinus* sp.		13,090-12,730	11
Witów (1-P), horizon 4a, Łódzkie (PL)	K-952	11,020	170	charcoal	*Pinus* sp.		13,190-12,630	12
Groß Lieskow, Brandenburg (D)	LZ-1350	11,000	110	charcoal	*Pinus* sp.	archaeological horizon; PROBLEMATIC: big pieces of charcoal mixed with sand	13,080-12,680	1
Groß Lieskow, Brandenburg (D)	LZ-1349 (or -1348?)	10,970	80	charcoal	*Pinus* sp.	archaeological horizon; PROBLEMATIC: big pieces of charcoal mixed with sand	13,040-12,680	1
Groß Lieskow, Brandenburg (D)	LZ-1352	10,960	80	charcoal	*Pinus* sp.	archaeological horizon; PROBLEMATIC: big pieces of charcoal mixed with sand	13,030-12,670	1
Groß Lieskow, Brandenburg (D)	LZ-1347	10,870	105	charcoal	*Pinus* sp.	archaeological horizon; PROBLEMATIC: big pieces of charcoal mixed with sand	13,010-12,610	1
Usselo, Overijssel (NL)	*Y-139-2*	*10,880*	*160*	sediment/ charcoal?	*Pinus* sp.	REJECT: material, mainly sandy peat?	×	13

Tab. 73 ^{14}C dates from selected plant samples in north-western Europe outside the study area. If the sub-assemblage is known from which the sample originated, the sub-assemblage is given behind the site name. Otherwise the province and the country is given. **?** (behind the species) uncertain species determination. Doubtful dates are shaded grey. Rejected dates are shaded grey and set in italics and, in addition, the main reason for rejection is given in comment. For further details see p. 259-263, p. 265-269, and p. 412-429. The dates were calibrated with the calibration curve of the present study (see p. 358-364) and the calibration program CalPal (Weninger/Jöris/Danzeglocke 2007). The result range of 95 % confidence is given for the calibrated ages (years cal. b2k). – References (ref.): **1** Bittmann/Pasda 1999; **2** Rosendahl et al. 2006; **3** Verpoorte/Šída 2009; **4** Fiedorczuk et al. 2007; **5** Grünberg 2006; **6** Higham et al. 2007; **7** Clausen 1998; **8** Leesch/Cattin/Müller 2004, 167. 183; **9** Johansen/Stapert 2004; **10** Kasse et al. 2005; **11** Deeben et al. 2006; **12** Tauber 1966; **13** Barendsen/Deevey/Gralenski 1957; **14** Johansen et al. 2000; **15** Hedges et al. 1992; **16** Lanting/van der Plicht 1996; **17** Hanik 2009; **18** Gob 1990; **19** Leesch 1997, 21. 199; **20** Bullinger/Leesch/Plumettaz 2006; **21** Schuler 1994; **22** Kaiser/de Klerk/Terberger 1999; **23** Vollbrecht 2005; **24** Otlet/Slade 1974; **25** Morel 1993; **26** Aaris-Sørensen 1995; **27** Kabaciński/Schild 2005; **28** Hedges et al. 1993a; **29** Hoek et al. 1999; **30** Tromnau 1992; **31** Tolksdorf et al. 2013; **32** Barr 1975; **33** Hedges et al. 1995; **34** Alessio/Bella/Cortesi 1964; **35** Jones et al. 2002; **36** Bronk Ramsey et al. 2000; **37** Niekus 2006.

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Doetinchem, Gelderland (NL)	GrA-13686	10,870	50	charcoal	*Pinus* sp.		12,860-12,660	14
Monruz, sect. 1, Neuchâtel (CH)	ETH-20725	10,800	75	charcoal	*Pinus* sp.	above archaeological horizons	12,800-12,640	8
Groß Lieskow, Brandenburg (D)	LZ-1349 (or -1348?)	10,660	80	charcoal	*Pinus* sp.	archaeological horizon; PROBLEMATIC: big pieces of charcoal mixed with sand; below aeolian sands – intrusion of these sands?	12,760-12,440	1
Geldrop Mie Peels, Noord Brabant (NL)	OxA-2563	10,610	100	charcoal	*Pinus* sp.	hearth	12,760-12,320	15; 16
Wierden-Enterse Akkers HS, Overijssel (NL)	GrA-24580	10,610	60	charcoal	*Pinus* sp.		12,720-12,440	11
Groß Lieskow, Brandenburg (D)	LZ-1351	10,520	100	charcoal	*Pinus* sp.	archaeological horizon; PROBLEMATIC: big pieces of charcoal mixed with sand; below aeolian sands – intrusion of these sands?	12750-12,110	1
Groß Lieskow, Brandenburg (D)	LZ-1353	10,420	100	charcoal	*Pinus* sp.	archaeological horizon; PROBLEMATIC: big pieces of charcoal mixed with sand; below aeolian sands – intrusion of these sands?	12,660-11,980	1
Wustermark 22, Brandenburg (D)	?	10,389	57	branch	*Pinus* sp.	fluvial accumulation	12,520-12,040	17
Wierden-Enterse Akkers HS, Overijssel (NL)	*GrA-23937*	*10,350*	*60*	charcoal	*Pinus* sp.	REJECT: too small amount of material	×	11
Groß Lieskow, Brandenburg (D)	LZ-1345	9,780	75	charcoal	*Pinus* sp.	PROBLEMATIC: big pieces of charcoal mixed with sand; REJECT: Holocene age but found below aeolian sands – intrusion of these sands?	×	1
Elsloo-Tronde, Friesland (NL)	*GrN-4869*	*7,790*	*95*	charcoal	*Pinus* sp.	from hearth; REJECT: Holocene intrusion / Mesolithic feature?	×	18
Meer IV, Antwerp (B)	*GrA-10290*	*5,940*	*180*	charcoal	*Pinus sylvestris*	from hearth; REJECT: Holocene intrusion?	×	16
willow family (*Saliceae*) / willow (*Salix* sp.) / poplar (*Populus* sp.), n = 42								
Champréveyres, sect. 1, Neuchâtel (CH)	UCLA-2760	17,695	210	charcoal	*Salix* sp.	from hearth in lower horizon; PROBLEMATIC: too old for stratigraphy but dated twice with comparable results; old wood?	21,800-20,600	19
Monruz, sect. 1, Neuchâtel (CH)	ETH-6413	13,330	110	charcoal	*Salix* sp.	from hearth in lower horizon	16,730-15,490	19-20
Monruz, sect. 2, north, Neuchâtel (CH)	ETH-6421	13,140	120	charcoal	*Salix* sp.	from hearth	17,000-16,000	8; 19
Monruz, sect. 1, Neuchâtel (CH)	ETH-6420	13,120	120	charcoal	*Salix* sp.	from hearth in lower horizon	16,700-15,460	19-20
Monruz, sect. 1, Neuchâtel (CH)	ETH-6416	13,070	130	charcoal	*Salix* sp.	from hearth lower horizon	16,640-15,360	19-20
Champréveyres, sect. 1, Neuchâtel (CH)	UZ-2285	13,050	155	charcoal	*Salix* sp.	from hearth in lower horizon	16,680-15,280	19
Monruz, sect. 1, Neuchâtel (CH)	ETH-6417	13,030	120	charcoal	*Salix* sp.	from hearth in lower horizon	16,500-15,340	19-20
Monruz, sect. 1, Neuchâtel (CH)	ETH-6412	12,970	110	charcoal	*Salix* sp.	from hearth in lower horizon; PROBLEMATIC: the $\delta^{13}C$ value is surprisingly high	16,340-15,260	19-20
Champréveyres, sect. 1, Neuchâtel (CH)	UZ-2283	12,950	155	charcoal	*Salix* sp.	from hearth in lower horizon	16,470-15,110	19
Monruz, sect. 1, Neuchâtel (CH)	ETH-6415	12,900	120	charcoal	*Salix* sp.	from hearth in lower horizon	16,190-15,150	19-20
Monruz, sect. 1, Neuchâtel (CH)	ETH-6419	12,880	120	charcoal	*Salix* sp.	from hearth in lower horizon	16,100-15,140	19-20
Champréveyres, sect. 1, Neuchâtel (CH)	UZ-2286	12,870	135	charcoal	*Salix* sp.	from hearth in lower horizon	16,160-15,080	19

Tab. 73 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Monruz, sect. 1, Neuchâtel (CH)	ETH-6414	12,840	120	charcoal	*Salix* sp.	from hearth in lower horizon; PROBLEMATIC: the δ^{13}C value is surprisingly low	15,910-15,110	19-20
Champréveyres, sect. 1, Neuchâtel (CH)	UZ-2171	12,730	135	charcoal	*Salix* sp.	from hearth in lower horizon	15,790-14,670	19
Champréveyres, sect. 1, Neuchâtel (CH)	UZ-2175	12,630	130	charcoal	*Salix* sp.	from hearth in lower horizon	15,630-14,390	19
Schussenquelle I, Baden-Württemberg (D)	ETH-6154	12,630	120	charcoal	*Salix* sp.	lower horizon	15,600-14,440	21
Champréveyres, sect. 1, Neuchâtel (CH)	UZ-2172	12,620	145	charcoal	*Salix* sp.	from hearth in lower horizon	15,660-14,300	19
Champréveyres, sect. 1, Neuchâtel (CH)	UZ-2177	12,600	145	charcoal	*Salix* sp.	from hearth in lower horizon	15,630-14,230	19
Ahrenshöft LA 73 south, Schleswig-Holstein (D)	*KIA-3606*	*12,550*	*+1,170 / -1,020*	charcoal	*Salix* sp./ *Populus* sp.	horizon I; REJECT: too low amount of carbon	×	7
Champréveyres, sect. 1, Neuchâtel (CH)	UZ-2173	12,540	140	charcoal	*Salix* sp.	from hearth in lower horizon	15,560-14,080	19
Champréveyres, sect. 1, Neuchâtel (CH)	UZ-2174	12,510	130	charcoal	*Salix* sp.	from hearth in lower horizon	15,470-14,070	19
Champréveyres, sect. 2, Neuchâtel (CH)	UZ-2287	12,500	145	charcoal	*Salix* sp.		15,500-14,020	8; 19
Endingen, Horst VI, Mecklenburg-Vorpommern (D)	Hv-20987	12,360	245	wood	*Salix* sp.		15,540-13,620	22
Reichwalde 5055, Sachsen (D)	KIA-13412	12,193	58	charcoal	*Salix* sp./ *Populus* sp.		14,250-13,890	23
Ahrenshöft LA 73 north, Schleswig-Holstein (D)	KIA-3833	12,130	60	charcoal	*Salix* sp./ *Populus* sp.	horizon II	14,180-13,780	7
Sproughton, Devil's Wood Pit, Suffolk/England (GB)	HAR-260	11,940	180	branch	*Salix* sp.	PROBLEMATIC: not associated with archaeology; uncertain sedimentation	14,260-13,380	24
Oldeholtwolde, Friesland (NL)	OxA-2558	11,810	110	charcoal	*Salix* sp.	PROBLEMATIC: stratigraphic position and archaeology in contrast to date	13,860-13,420	9; 15
Ahrenshöft LA 73 south, Schleswig-Holstein (D)	KIA-3606	11,750	60	charcoal	*Salix* sp./ *Populus* sp.	horizon I	13,740-13,460	7
Oldeholtwolde, Friesland (NL)	OxA-2561	11,680	120	charcoal	*Salix* sp.	PROBLEMATIC: stratigraphic position and archaeology in contrast to date	13,790-13,230	9; 15
Grotte du Bichon, Neuchâtel (CH)	ETH-4246 (UZ-2423)	11,680	120	charcoal	*Salix* sp.		13,790-13,230	25
Nørre Lyngby, Nordjylland (DK)	AAR-1509	11,590	130	wood	*Salix* sp.		13,710-13,150	26
Oldeholtwolde, Friesland (NL)	GrN-10274	11,540	270	charcoal	*Salix* sp.	PROBLEMATIC: stratigraphic position and archaeology in contrast to date	13,920-12,880	9; 16
Oldeholtwolde, Friesland (NL)	OxA-2559	11,470	110	charcoal	*Salix* sp.	PROBLEMATIC: stratigraphic position and archaeology in contrast to date	13,540-13,100	15
Nørre Lyngby, Nordjylland (DK)	AAR-1507	11,340	120	wood	*Salix* sp.		13,410-12,970	26
Nørre Lyngby, Nordjylland (DK)	AAR-1508	11,260	120	wood	*Salix* sp.		13,330-12,890	26
Nørre Lyngby, Nordjylland (DK)	AAR-1510	11,230	150	wood	*Salix* sp.		13,370-12,770	26
Oldeholtwolde, Friesland (NL)	GrN-12280	11,080	280	charcoal	*Salix* sp.	no relation with archaeology	13,450-12,490	9; 16
Grotte du Bichon, Neuchâtel (CH)	ETH-4245 (UZ-2422)	10,950	180	charcoal	*Salix* sp.	PROBLEMATIC: age significantly younger than other ages from the site	13,150-12,590	25
Mirkowice 33, Wielkopolskie (PL)	UtC-8617	10,210	120	leaf	*Salix* cf. *polaris*	PROBLEMATIC: association uncertain	12,420-11,420	27

Tab. 73 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Holywell Coombe, Kent/England (GB)	OxA-2608	10,160	110	wood	*Salix* sp.		12,290-11,330	28
Holywell Coombe, Kent/England (GB)	OxA-2606	9,900	100	wood	*Salix* sp.		11,800-11,120	28
Sproughton, Devil's Wood Pit, Suffolk/England (GB)	*HAR-259*	*9,880*	*120*	macro remains	*Salix* sp.	REJECT: not associated with archaeology; bulked sample; uncertain sedimentation	×	24
birch (*Betula* sp.), n=17								
Holywell Coombe, Kent/England (GB)	OxA-1751	13,160	400	fruits, cone scales	*Betula* sp.		17,360-14,600	28
Gulickshof, Limburg (NL)	UtC-3196	12,480	90	leaves	*Betula nana*		15,320-14,120	29
Poggenwisch, Schleswig-Holstein (D)	GrN-11254	12,460	60	wood	*Betula* sp.		15,210-14,170	30
Grabow 15, Niedersachsen (D)	KIA-41862	12,125	50	charcoal	*Betula* sp.	from archaeological feature	14,160-13,800	31
Moosbühl, Bern (CH)	B-2316	12,060	150	bark	*Betula* sp.	found *in situ* beside hearth	14,370-13,570	32
Holywell Coombe, Kent/England (GB)	OxA-1974	11,830	140	fruits, cone scales	*Betula* sp.		13,970-13,370	28
Krumpa, Sachsen-Anhalt (D)	OxA-4499	11,810	100	fruits, cone scales	*Betula pendula / pubescens* (previously: *alba*)		13,830-13,430	33
Usselo, Overijssel (NL)	R-106	11,800	280	wood	*Betula* sp.	PROBLEMATIC: found in peat; association to archaeology uncertain	14,390-13,030	34
Krumpa, Sachsen-Anhalt (D)	OxA-4498	11,660	100	fruits, cone scales	*Betula pendula / pubescens* (previously: *alba*)		13,760-13,240	33
Holywell Coombe, Kent/England (GB)	OxA-2352	11,600	100	charcoal	*Betula* sp.	PROBLEMATIC: the δ^{13}C value is surprisingly low	13,650-13,210	28
Cherry Garden Hill, Kent/England (GB)	OxA-2242	11,580	100	charcoal	*Betula* sp.		13,610-13,210	28
Holywell Coombe, Kent/England (GB)	OxA-2353	11,520	90	charcoal	*Betula* sp.		13,540-13,180	28
Hawes Water, Lancashire/England (GB)	NERC-32069	10,980	60	fruit	*Betula* sp.		13,020-12,700	35
Westhampnett, West Sussex/England (GB)	OxA-4166	10,880	110	charcoal	*Betula* sp.		13,020-12,620	36
Gulickshof, Limburg (NL)	GrA-4309	10,800	90	leaves, fruits	*Betula* sp.		12,850-12,610	29
Hawes Water, Lancashire/England (GB)	CAMS-45852	10,160	220	fruit	*Betula* sp.		12,620-11,100	35
Vledder, Drenthe (NL)	*GrA-10938*	*6,150*	*60*	charcoal	*Betula* sp.	REJECT: Holocene intrusion in sand?	×	37
juniper (*Juniperus* sp.), n=5								
Monruz, sect. 2 south, Neuchâtel (CH)	ETH-23271	12,570	90	charcoal	*Juniperus* sp.	from hearth	15,450-14,450	8
Monruz, sect. 1, Neuchâtel (CH)	ETH-17974	12,370	110	charcoal	*Juniperus* sp.	from hearth in upper horizon	15,190-13,910	8
Monruz, sect. 2 south, Neuchâtel (CH)	ETH-23272	12,355	85	charcoal	*Juniperus* sp.	from hearth	14,980-13,980	8
Monruz, sect. 1, Neuchâtel (CH)	ETH-17973	12,165	130	charcoal	*Juniperus* sp.	from hearth in upper horizon	14,660-13,620	8
Holywell Coombe, Kent/England (GB)	OxA-2346	9,820	90	fruits	*Juniperus communis*		11,530-11,090	28

Tab. 73 (continued)

Lateglacial faunal successions in the study areas

The presence of selected faunal species is established by the frequency of directly ^{14}C-dated samples of these species and by the geographic distribution of the faunal remains, in particular on the archaeological sites.

The probability distributions

For the sub-areas, the total numbers of ^{14}C dates from the relevant species are in general small (see **tabs 74-76**) and during the Late Pleniglacial clearly biased by the preference for hunting horse which consequently provided a large quantity of datable material. Thus, the probability distributions of ^{14}C dates from the sub-areas (**figs 60-61**) indicate several problems previously discussed regarding the interpretation of these distributions (see p. 263 f.).

According to the probability distribution of the Central Rhineland and the western uplands (**fig. 60**), a major change in the selected fauna composition occurred at the onset of GI-1d. In contrast, a comparable change occurred in the Paris Basin considerably later, during GI-1c_3 (**fig. 61**). In both areas, this change seemed to correlate with a significant increase of arboreal and particularly birch tree pollen.

The probability distribution of the Lateglacial fauna from the Central Rhineland and the western uplands can be subdivided in a total of four sections numbered stratigraphically from top to base. The second and the fourth can be further divided into two sub-units. The sections 4 and 3 occurred before the major change in the fauna composition and section 1 and 2 were identified afterwards. The oldest section (4) relates to the Late Pleniglacial and ended at the onset of the Lateglacial Interstadial. The following section 3 comprised the early Lateglacial Interstadial. After the major change, section 2 related to the mid- and late Lateglacial Interstadial and, finally, the section 1 occurred in the LateglacialStadial.

Section 4 was dominated by numerous directly dated horse (*Equus* sp.) remains. Furthermore, this section can be bisected in an earlier part in which reindeer (*Rangifer tarandus*) dates were also frequent and a later part in which more horse remains were dated but no more reindeer material. In the latter, directly dated musk ox (*Ovibos moschatus*) remains appeared in some Belgian sites (see **tab. 74**), whereas the steppe wisent (*Bison priscus*) from Gönnersdorf was dated to the earlier part of this sub-unit (see **tab. 75**).

Reindeer and musk ox are considered as a typical representative of cold, arctic conditions, whereas steppe wisent seemed in general more common in arid steppe environments (von Koenigswald 1999) and horse usually inhabits grasslands. Thus, to interpret this distribution in a successive climatic and environmental way is tempting but this interpretation is only possible within a more complete faunal context. For instance, musk ox seemed to be avoided by Late Weichselian hunters (Pushkina / Raia 2008). Thus, material was only found in the Belgian Late Magdalenian sites but not in comparable sites in the Paris Basin or the Central Rhineland. Perhaps, this distribution was due to the range area of the presumably small remaining population of this species in Europe after the LGM (Campos et al. 2010). Consequently, the presence of musk ox in this area could indicate the presence of more intense arctic conditions in the north-western part of the western uplands and a regression of these conditions in the Central Rhineland as suggested by the decreasing number of reindeer dates. Moreover, the probability distribution of reindeer in Central Rhineland could suggest that the presence of these animals was more probable in a younger phase of the Magdalenian occupation of Gönnersdorf. In additon, a retreat of steppe wisent during this younger sub-unit could be interpreted as reflecting increasingly moist conditions.

However, this temptation reveals the problems of interpreting probability distributions without the context of the dated specimens because the distribution of reindeer remains at Gönnersdorf was not noticeably differ-

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
pine (*Pinus* sp.), n=0								
willow family (*Saliceae*) / willow (*Salix* sp.) / poplar (*Populus* sp.), n=0								
birch (*Betula* sp.), n=0								
reindeer (*Rangifer tarandus*), n=21								
Trou des Blaireaux (Vaucelles)	Lv-1385	16,270	230	antler	*Rangifer tarandus*	FAD reindeer in western uplands; PROBLEMATIC: bulked sample	20,160-18,880	1
Trou des Blaireaux (Vaucelles)	Lv-1558	16,130	250	antler	*Rangifer tarandus*	PROBLEMATIC: bulked sample	19,940-18,780	1
Schlaederbach valley/Plateau Haed (Oetrange, LUX)	Lv-466	16,070	450	antler	*Rangifer tarandus*		20,370-18,450	2
Trou des Blaireaux (Vaucelles)	Lv-1433	13,930	120	antler	*Rangifer tarandus*	PROBLEMATIC: bulked sample of female antlers	17,540-16,900	1
Trou des Blaireaux (Vaucelles)	Lv-1309D	13,850	335	antler	*Rangifer tarandus*	PROBLEMATIC: bulked sample	17,920-16,160	1
Trou des Blaireaux (Vaucelles)	Lv-1314	13,790	150	antler	*Rangifer tarandus*	PROBLEMATIC: bulked sample	17,210-16,850	1
Trou des Blaireaux (Vaucelles)	Lv-1434D	13,730	400	antler	*Rangifer tarandus*	PROBLEMATIC: bulked sample of female antlers	17,970-15,570	1
Saint Mihiel	Lv-2096	13,160	110	antler	*Rangifer tarandus*	PROBLEMATIC: bulked sample	16,740-15,540	3
Bois Laiterie	OxA-4198*	12,660	140	antler	*Rangifer tarandus*	double bevelled point, YSS	15,690-14,410	1; 4
Coléoptère (Bomal-sur-Ourthe), lower horizon	Lv-717	12,400	110	bone	*Rangifer tarandus*		15,230-13,950	5
Trou da Somme (Waulsort)	OxA-4199*	12,240	130	antler point	*Rangifer tarandus*	artefact	14,880-13,720	4
Remouchamps	OxA-4191*	10,800	110	metacarpus	*Rangifer tarandus*	cut-marks	12,940-12,540	5
Remouchamps	Lv-535	10,380	170	bone fragments	*Rangifer tarandus*	PROBLEMATIC: bulked sample	12,770-11,610	6
Remouchamps	OxA-3634*	10,320	80	maxilla	*Rangifer tarandus*	cut-marks; PROBLEMATIC: the δ^{13}C value is surprisingly high (cf. OxA-9031)	12,510-11,870	5
Kartstein (Mechernich)	OxA-9031	10,220	75	femur	*Rangifer tarandus*	PROBLEMATIC: »the δ^{13}C value is surprisingly high« (M. Baales / O. Jöris / B. Weninger in Bronk Ramsey et al. 2002, 31)	12,260-11,660	7

Tab. 74 ^{14}C dates from selected plant and faunal samples from the western upland areas. ***** dates which were pretreated by the use of ion-exchanged gelatin (Lab.code: AI) in the Oxford series (cf. Jacobi/Higham 2009, 1896). Rejected date is shaded grey and set in italics and, in addition, the main reason for rejection is given in comment. For further details see p. 259-263, p. 265-269, and p. 412-429. The dates were calibrated with the calibration curve of the present study (see p. 358-364) and the calibration program CalPal (Weninger/Jöris/Danzeglocke 2007). The result range of 95 % confidence is given for the calibrated ages (years cal. b2k). – References (ref.): **1** Charles 1996; **2** Gilot 1970; **3** Stocker et al. 2006; **4** Hedges et al. 1994; **5** Hedges et al. 1993b; **6** Gob 1990; **7** Bronk Ramsey et al. 2002; **8** Baales 1996, 42; **9** Léotard 1993; **10** Stevens et al. 2009a; **11** Hedges et al. 1993a; **12** Stevens/Hedges 2004; **13** Germonpré 1997; **14** Hedges et al. 1988b; **15** Charles 1997a.

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Kartstein (Mechernich)	KN-4254A	10,030	60	shaft fragments	cf. *Rangifer tarandus*	PROBLEMATIC: bulked sample	11,880-11,280	7
Kartstein (Mechernich)	KN-4252	10,000	50	shaft fragments	cf. *Rangifer tarandus*	PROBLEMATIC: bulked sample	11,790-11,270	7
Kartstein (Mechernich)	*KN-4254B*	*9,900*	*45*	shaft fragments	cf. *Rangifer tarandus*	PROBLEMATIC: bulked sample; REJECT: probably different fraction of KN-4254	11,480-11,240	7
Kartstein (Mechernich)	*KN-4254C*	*9,685*	*50*	shaft fragments	cf. *Rangifer tarandus*	PROBLEMATIC: bulked sample; REJECT: probably same as KN-4254 but other fraction	11,360-10,800	7
Kartstein (Mechernich)	KN-4072	9,550	90	bone fragments	cf. *Rangifer tarandus*	PROBLEMATIC: bulked sample	11,270-10,630	7-8
Kartstein (Mechernich)	KN-4073	9,530	90	shaft fragments	cf. *Rangifer tarandus*	PROBLEMATIC: bulked sample	11,270-10,590	7-8
horse (*Equus* sp.), n = 14								
Trou des Blaireaux (Vaucelles)	OxA-4200*	13,330	160	ulna	*Equus* sp.	possible cut-marks	17,110-15,710	4
Trou du Frontal (Furfooz)	*Lv-1750*	*13,130*	*170*	»cut bone splinters«	*Equus* sp. (and/or *Canis lupus*)	PROBLEMATIC: bulked sample; REJECT: species attribution unclear	16,870-15,350	1; 9
Trou du Frontal (Furfooz)	Lv-1749	12,950	170	»cut bone splinters«	*Equus* sp.	PROBLEMATIC: bulked sample	16,520-15,080	1; 9
Trou de Chaleux (Hulsonniaux)	OxA-3633*	12,880	100	bone	*Equus* sp.	cut-marks	15,920-15,240	10-12
Coléoptère (Bomal-sur-Ourthe), lower horizon	OxA-3635*	12,870	95	phalange	*Equus* sp.	cut-marks; PROBLEMATIC: the δ^{13}C value is surprisingly high	15,850-15,250	5
Sy Verlaine-sur-Ourthe	OxA-4014*	12,870	110	pisiform	*Equus* sp.	possible cut-marks	15,950-15,190	4
Trou de Frontal (Furfooz)	OxA-4197*	12,800	130	bone	*Equus* sp.		15,870-14,950	12
Trou de Chaleux (Hulsonniaux)	OxA-3632*	12,790	100	bone	*Equus* sp.	cut-marks	15,720-15,080	10-11
Goyet, 3rd cave, horizon 1	OxA-V-2223-48	12,775	55	bone	*Equus* sp.		15,580-15,220	10
Goyet, 3rd cave, horizon 1	GrA-3237	12,770	90	bone	*Equus* sp.	cut-marks, coloured by ochre	15,670-15,070	10; 13
Trou des Nutons (Furfooz)	OxA-4195*	12,630	140	phalange	*Equus* sp.	cut-marks	15,660-14,340	4
Trou de Chaleux (Hulsonniaux)	OxA-V-2216-45	12,630	55	bone	*Equus* sp.	cut-marks	15,400-14,880	10
Goyet, 3rd cave, horizon 1	Utc-8957	12,560	50	bone	*Equus* sp.		15,380-14,540	10
Trou de Chaleux (Hulsonniaux)	OxA-V-2216-44	12,375	50	bone	*Equus* sp.	cut-marks	14,810-14,090	10

Tab. 74 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
elk (*Alces alces*), n=0								
wild boar (*Sus scrofa*), n=1								
Trou de Chaleux (Hulsonniaux)	*OxA-4193**	*3,060*	*85*	humerus	*Sus scrofa*	cut-marks; REJECT: too young; intrusion	×	4
red deer (*Cervus elaphus*), n=2								
Presles, uncertain cave	OxA-1344	10,950	200	mandible	*Cervus elaphus*	unmodified	13,190-12,550	14-15
Trou des Nutons (Furfooz)	*OxA-4194**	*2,210*	*80*	naviculo-cuboid	*Cervus elaphus*	cut-marks; REJECT: too young / younger intrusion?	×	4
large bovids (*Bison priscus* / *Bos* sp. / *Bos primigenius*), n=0								
others, n=5								
Trou de Chaleux (Hulsonniaux)	OxA-4192*	12,860	140	bone	*Ovibos moschatus*	cut-marks	16,150-15,030	4; 10
Trou da Somme (Waulsort)	OxA-8308	12,815	75	bone	*Ovibos moschatus*		15,680-15,240	7; 10
Goyet, 3rd cave, horizon 1	OxA-12121	12,775	50	bone	*Ovibos moschatus*		15,580-15,220	10
Goyet, 3rd cave, horizon 1	GrA-3238	12,620	90	bone	*Ovibos moschatus*	cut-marks	15,520-14,520	10; 13
Goyet, 3rd cave, horizon 2	KIA-22275	12,380	60	bone	*Alopex lagopus*		15,520-14,520	10

Tab. 74 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
pine (*Pinus* sp.), n=1								
Bad Breisig	GrA-17493	10,840	60	charcoal	*Pinus* sp.	from the hearth	12,820-12,660	1
willow family (*Saliceae*) / willow (*Salix* sp.) / poplar (*Populus* sp.), n=17								
Brohl valley 1	KN-3803	11,510	90	wood	*Populus* sp.	within LST	13,530-13170	2-3
Miesenheim 2	KN-3533	11,460	90	wood, root	*Populus* sp.	PROBLEMATIC: root material	13,510-13,110	4
Miesenheim 2	KN-3531	11,460	100	wood, trunk	*Populus* sp.		13,530-13,090	4
Miesenheim 2	KN-3532	11,390	90	wood, root	*Populus* sp.	PROBLEMATIC: root material	13,410-13,050	4
Miesenheim 2	KN-3534	11,360	110	wood, root	*Populus* sp.	PROBLEMATIC: root material	13,430-12,990	4
Miesenheim 2	KN-3517	11,290	95	wood, root	*Populus* sp.	PROBLEMATIC: root material	13,300-12,980	4
Brohl valley 1	KN-3802	11,280	100	charcoal	*Populus* sp.	within LST	13,310-12,950	2-3
Brohl valley 1	KN-3801	11,260	95	wood	*Populus* sp.	within LST	13,280-12,960	2-3
Brohl valley 1	KN-3800	11,240	110	wood	*Populus* sp.	within LST	13,300-12,900	2-3
Miesenheim 2	KN-3516	11,230	95	wood, root	*Populus* sp.	PROBLEMATIC: root material	13,270-12,910	4
Miesenheim 2	KN-3518	11,080	220	wood, bark	*Populus* sp.		13,350-12,590	4
Miesenheim 2	KN-3520	11,070	100	wood	*Populus* sp.		13,140-12,700	4
Miesenheim 2	KN-3519	11,040	220	wood, bark	*Populus* sp.		13,300-12,580	4
Miesenheim 2	OxA-2611	11,030	110	wood	*Populus* sp.		13,120-12,680	5
Miesenheim 2	OxA-2609	10,960	110	wood	*Populus* sp.		13,060-12,660	5
Miesenheim 2	OxA-2610	10,960	110	wood	*Populus* sp.		13,060-12,660	5
Miesenheim 2	*ETH-*	*10,840*	*195*	wood	*Populus* sp.	REJECT: post-LSE date	×	2
birch (*Betula* sp.), n=4								
Thür	KN-2870	11,250	95	wood	*Betula* sp.		13,270-12,950	2
Thür	KN-2869	11,110	90	wood	*Betula* sp.		13,170-12,730	2
Brohl valley	unknown	11,085	90	wood	*Betula* sp.	within LST	13,150-12,710	2-3
Thür	KN-2868	11,050	120	wood	*Betula* sp.		13,150-12,670	2
reindeer (*Rangifer tarandus*), n=5								
Gönnersdorf III	OxA-V-2223-43	13,075	55	metapodial	*Rangifer tarandus*		16,330-15,570	6
Gönnersdorf III	OxA-15295	13,060	60	metapodial	*Rangifer tarandus*	marrow fractured	16,310-15,550	6-7

Tab. 75 ^{14}C dates of selected plant and faunal samples from the Central Rhineland. If the sub-assemblage is known from which the sample originated, the sub-assemblage is given behind the site name. ***** dates which were pretreated by the use of ion-exchanged gelatin (Lab.code: AI) in the Oxford series (cf. Jacobi/Higham 2009, 1896); ****** dates which might be contaminated due to the use of a method leaving traces of a humectant in the collagen (Lab.code: AF*) in the Oxford series (cf. Higham et al. 2007, S55 & S2); **LSE** Laacher See (Volcanic) Eruption; **LST** Laacher See tephra. Doubtful dates are shaded grey. Rejected dates are shaded grey and set in italics and, in addition, the main reason for rejection is given in comment. For further details see p. 259-263, p. 265-269, and p. 412-429. The dates were calibrated with the calibration curve of the present study (see p. 358-364) and the calibration program CalPal (Weninger/Jöris/Danzeglocke 2007). The result range of 95 % confidence is given for the calibrated ages (years cal. b2k). – References (ref.): **1** Baales/Grimm/Jöris 2001; **2** Baales et al. 2002; **3** Street/Baales/Weninger 1994; **4** Street 1986; **5** Hedges et al. 1993b; **6** Stevens et al. 2009b; **7** Higham et al. 2007; **8** Higham et al. 2011; **9** Bronk Ramsey et al. 2002; **10** Stevens/Hedges 2004; **11** Street/Terberger 2004; **12** Hedges et al. 1987; **13** Hedges et al. 1998b; **14** Evin/Marien/Pachiaudi 1975; **15** Evin/Marien/Pachiaudi 1978; **16** Baales 2002, 11 f. 40-45; **17** Kegler 2002; **18** Gowlett et al. 1987; **19** Street 1993; **20** Baales/Mewis/Street 1998; **21** kind permission of Stefan Wenzel.

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Gönnersdorf II	OxA-V-2223-31	13,010	55	metatarsal	*Rangifer tarandus*		16,220-15,460	6
Gönnersdorf I	OxA-V-2223-42	12,990	55	metatarsal	*Rangifer tarandus*		16,180-15,420	6
Wildweiberlei	OxA-18410**	12,835	55	antler	*Rangifer tarandus*	modified; (Lab.code: AF*, but dated after recognition of possible contamination)	15,660-15,300	8
horse (*Equus* sp.), n=24								
Andernach, lower horizon III (?)	*OxA-10492***	*13,500*	*90*	rib	*Equus* sp.	cut-marks; REJECT: redating available	×	6; 9-11
Andernach, lower horizon III (?)	*OxA-10651***	*13,270*	*180*	phalanx	*Equus* sp.	REJECT: relatively high C/N ratio and relatively high $\delta^{15}N$	×	6; 9-11
Gönnersdorf I	OxA-V-2223-39	13,270	55	metatarsal	*Equus* sp.		16,810-16,090	6
Andernach, lower horizon II	OxA-1128	13,200	140	rib	*Equus* sp.	sample from pit	16,920-15,520	6; 11-12
Andernach, lower horizon III (?)	OxA-10493**	13,185	80	rib	*Equus* sp.	cut-marks	16,720-15,640	6; 9-11
Gönnersdorf II	OxA-V-2223-40	13,165	55	metatarsal	*Equus* sp.		16,600-15,680	6
Andernach, lower horizon I	OxA-V-2216-43	13,135	55	humerus	*Equus* sp.		16,540-15,620	6
Andernach, lower horizon II	OxA-V-2218-40	13,110	50	humerus	*Equus* sp.		16,390-15,630	6
Andernach, lower horizon II	OxA-1129	13,090	130	fragments	*Equus* sp.	sample from pit	16,680-15,400	6; 11-12
Andernach, lower horizon III (?)	OxA-18409**	13,025	50	rib	*Equus* sp.	cut-marks; redating of OxA-10492; (Lab.code: AF*, but dated after recognition of possible contamination)	16,220-15,500	6; 8
Andernach, lower horizon I	OxA-V-2218-38	13,015	50	metatarsus	*Equus* sp.		16,210-15,490	6
Andernach, lower horizon III	OxA-1130	12,950	140	bone fragments	*Equus* sp.	sample from pit	16,410-15,170	6; 11-12
Andernach, lower horizon I	OxA-1125	12,930	180	bone fragments	*Equus* sp.	sample from pit	16,530-15,010	6; 11-12
Gönnersdorf I	OxA-5729*	12,910	130	rib fragments	*Equus* sp.		16,290-15,130	6; 11; 13
Andernach, lower horizon I	OxA-1126	12,890	140	rib	*Equus* sp.	sample from pit	16,270-15,070	6; 11-12
Andernach, lower horizon II	OxA-1127	12,820	130	bone fragments	*Equus* sp.	sample from pit	15,920-15,000	6; 11-12

Tab. 75 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Gönnersdorf I	OxA-5730*	12,790	120	rib fragments	*Equus* sp.		15,810-14,970	6; 11; 13
Gönnersdorf I	OxA-5728*	12,730	130	rib fragments	*Equus* sp.		15,760-14,720	6; 11; 13
Andernach, lower horizon III	OxA-V-2223-37	12,675	55	humerus	*Equus* sp.	sample from pit	15,440-15,000	6
Gönnersdorf	Ly-1172	12,660	370	mainly rib fragments	*Equus* sp.?	PROBLEMATIC: bulked sample	16,680-13,600	6; 14
Andernach, upper horizon 2	OxA-V-2218-39	12,270	50	femur	*Equus* sp.		14,560-13,960	6
Gönnersdorf	Ly-1173	11,100	650	mainly rib fragments	*Equus* sp.?	PROBLEMATIC: bulked sample	14,520-11,280	6; 15
Niederbieber 3	OxA-1135	11,130	130	astralagus	*Equus* sp.	PROBLEMATIC: uncertain association	13,260-12,700	11; 16
Niederbieber 2 (19)	*OxA-1134*	*6,250*	*130*	tooth	*Equus* sp.	REJECT: post-LSE date	×	11; 16
elk (*Alces alces*), n = 6								
Gönnersdorf V	OxA-15296	12,385	65	radius	*Alces alces*		15,010-14,050	7
Miesenheim 4	OxA-3585*	11,310	95	rib	*Alces alces*		13,340-12,980	5; 11
Miesenheim 4	OxA-3584*	11,190	90	rib	*Alces alces*		13,230-12,870	5; 11
Miesenheim 4	OxA-3586*	11,190	100	rib	*Alces alces*		13270-12,830	5; 11
Niederbieber 2 (19)	OxA-2066	11,110	110	bone	*Alces alces*		13,210-12,690	11; 16
Niederbieber 2 (19)	*OxA-1133*	*9,750*	*240*	bone	*Alces alces*?	REJECT: post-LSE date	×	11; 16
wild boar (*Sus scrofa*), n = 0								
red deer (*Cervus elaphus*), n = 13								
Andernach, lower horizon I / upper horizon 2	GrA-16986	13,180	70	shaft fragment	*Cervus elaphus*	impact scar	16,670-15,670	17
Andernach, lower horizon I / upper horizon 2	GrA-16985	13,110	80	shaft fragment	*Cervus elaphus?*		16,550-15,550	17
Andernach, upper horizon 2	*OxA-999*	*12,500*	*500*	shaft fragments	*Cervus elaphus*	REJECT: redating available	×	6; 11; 18
Andernach, upper horizon 2	GrA-16989	11,960	70	metatarsal fragment	*Cervus elaphus*		13,980-13,660	6; 17
Andernach, upper horizon 2	OxA-984	11,950	250	shaft fragments	*Cervus elaphus*	re-dating of OxA-999	14,670-13,190	6; 11; 18
Andernach, upper horizon 2	OxA-1924	11,890	120	bone	*Cervus elaphus*		14,030-13,430	6; 11; 19

Tab. 75 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Andernach, upper horizon 2	OxA-997	11,800	160	bone	*Cervus elaphus*		13,980-13,300	6; 11; 18
Urbar	OxA-1137	11,350	120	bone	*Cervus elaphus*		13,440-12,960	11; 15; 20
Kettig	Hd-18123	11,314	50	bone	cf. *Cervus elaphus*	PROBLEMATIC: bulked material	13,280-13,040	16
Boppard	KIA-26644	11,095	55	metapodial	*Cervus elaphus*		13,110-12,750	21
Niederbieber 1	*OxA-1132*	*10,700*	*130*	bone	*Cervus elaphus*	REJECT: post-LSE date	×	11; 16
Niederbieber 4	*OxA-1136*	*10,480*	*130*	shaft fragment	*Cervus elaphus*	REJECT: post-LSE date	×	11; 16
Niederbieber 7	*OxA-2067*	*10,390*	*100*	bone	*Cervus elaphus?*	REJECT: post-LSE date	×	11; 16
large bovids (*Bison priscus* / *Bos* sp. / *Bos primigenius*), n = 3								
Gönnersdorf II	OxA-V-2223-41	13,095	55	scapula	*Bison* sp.		16,360-15,600	6
Andernach, upper horizon 2	GrA-16991	12,040	70	shaft fragment	*Bos* sp./ *Bison* sp.		14,090-13,690	6; 18
Andernach, upper horizon 2	OxA-998	11,370	160	bone	*Bos* sp./ *Bison* sp.		13,550-12,910	6; 11; 18
others, n = 3								
Kettig	*GrA-14762*	*11,210*	*60*	metacarpal	*Capreolus capreolus*	REJECT: calcined bone	×	16
Miesenheim 2	*OxA-2608*	*10,820*	*110*	bone	*Capreolus capreolus*	REJECT: post-LSE date	×	11
Andernach, upper horizon 2	GrA-16987	12,050	70	scapula	*Castor fiber*		14,100-13,700	6; 17

Tab. 75 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
pine (*Pinus* sp.), n=3								
Conty	Ly-284	11,540	80	bark	*Pinus* sp.	PROBLEMATIC: reworked material?	13,560-13,200	1
Le Closeau, top horizon, *locus* 25	Ly-564	10,885	85	charcoal	*Pinus* sp.	PROBLEMATIC: uncertain association	12,990-12,630	2
Le Closeau, top horizon, *locus* 25	Ly-563	10,755	90	charcoal	*Pinus* sp.	PROBLEMATIC: uncertain association	12,800-12,560	2
willow family (*Saliceae*) / willow (*Salix* sp.) / poplar (*Populus* sp.), n=0								
birch (*Betula* sp.), n=0								
reindeer (*Rangifer tarandus*), n=14								
Thèmes-Ferme de la Bouvière, Yonne/Bourgogne	OxA-7342	14,340	130	tooth	*Rangifer tarandus*	PROBLEMATIC: palimpsest or contaminated samples?	17,970-17,090	3
Rinxent	OxA-1343	13,030	120	antler	*Rangifer tarandus*		16,500-15,340	4-5
Le Grand Canton, sector 2, upper horizon	Gif-9608	12,880	80	bone	*Rangifer tarandus*		15,810-15,290	5-7
Étigny-Le Brassot, southern *locus*	OxA-10096	12,630	90	bone	*Rangifer tarandus*		15,540-14,540	5; 8-9
Pincevent level IV.20, section 27	OxA-148	12,600	200	bone	*Rangifer tarandus*		15,800-14,000	5; 10
Pincevent level IV.21.3, section 25	OxA-149	12,400	200	bone	*Rangifer tarandus*		15,480-13,760	5; 10
Pincevent level IV.21.3, section 25	OxA-177	12,300	220	bone	*Rangifer tarandus*		15,390-13,590	5; 10
Pincevent level IV, habitation 1	Erl-6786	12,277	96	bone	*Rangifer tarandus*		14,810-13,850	5; 10-11
Marsangy, conc. D14	OxA-740	12,120	200	tooth	*Rangifer tarandus*	found in C14	14,920-13,440	5; 12
Pincevent level IV.21.3, section 25	OxA-176	12,000	220	bone	*Rangifer tarandus*		14,640-13,320	5; 10
Marsangy, conc. N19	OxA-178	11,600	200	antler	*Rangifer tarandus*	found in P16; PROBLEMATIC: reindeer in France?	13,850-13,050	5; 13
Le Tureau des Gardes, *locus* 6	Ly-6989	11,560	100	bone	*Rangifer tarandus*	attributed to the Late Magdalenian; PROBLEMATIC: reindeer in France?	13,590-13,190	5-6
Marsangy, conc. D14	*OxA-505*	*9,770*	*180*	bone	*Rangifer tarandus*	found in B12, REJECT: insufficient collagen	×	5; 12

Tab. 76 ^{14}C dates from selected plant and faunal samples from northern France. If the sub-assemblage is known from which the sample originated, the sub-assemblage is given behind the site name. * dates which were pretreated by the use of ion-exchanged gelatin (Lab.code: AI) in the Oxford series (cf. Jacobi/Higham 2009, 1896); ** dates which might be contaminated due to the use of a method leaving traces of a humectant in the collagen (Lab.code: AF*) in the Oxford series (cf. Higham et al. 2007, S55 & S2). Doubtful dates are shaded grey. Rejected dates are shaded grey and set in italics and, in addition, the main reason for rejection is given in comment. For further details see p. 259-263, p. 265-269, and p. 412-429. The dates were calibrated with the calibration curve of the present study (see p. 358-364) and the calibration program CalPal (Weninger/Jöris/Danzeglocke 2007). The result range of 95 % confidence is given for the calibrated ages (years cal. b2k). – References (ref.): **1** Ponel et al. 2005; **2** Bodu 2004; **3** Higham et al. 2007; **4** Hedges et al. 1988a; **5** Fagnart 1997; **6** Lang 1998; **7** Hedges et al. 1993b; **8** Stevens/Hedges 2004; **9** Lhomme et al. 2004, 732; **10** Bodu et al. 2009b; **11** Leroi-Gourhan/Brézillon 1966; **12** Gowlett et al. 1986b; **13** Gowlett et al. 1986a; **14** Gilot 1997; **15** Deloze et al. 1999, 38; **16** Bignon 2006; **17** Bodu/Debout/Bignon 2006; **18** Hedges et al. 1997; **19** Stevens/Hedges 2004; **20** Bodu/Valentin 1997, 343; **21** Coudret/Fagnart 2004; **22** Fagnart/Coudret 2001.

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Marsangy	*Lv-1215*	*5,000*	*350*	antler	*Rangifer tarandus*	REJECT: contamination?	×	14
horse (*Equus* sp.), n=22								
Le Grand Canton, sector 1	OxA-3139*	12,650	130	phalange	*Equus* sp.	same sample as OxA-3671	15,660-14,420	5-7; 15
Le Tureau des Gardes, *locus* 10	AA-44216	12,520	130	radius	*Equus* sp.		15,510-14,070	5; 16
Le Closeau, lower horizon, *locus* 33	GrA-18860	12,510	80	diaphyse of longbone	*Equus* sp.		15,340-14,260	5; 17
Le Closeau, lower horizon, *locus* 46	GrA-11664 (Ly-789)	12,350	60	tibia	*Equus* sp.		14,800-14,040	5; 17
Le Tureau des Gardes, *locus* 6	Ly-6988	12,290	90	bone	*Equus* sp.	attributed to the Late Magdalenian	14,810-13,890	5-6; 16
Étiolles	OxA-5995*	12,250	100	bone	*Equus* sp.	from horse concentration A17?	14,790-13,790	5; 18
Le Grand Canton, sector 2, lower horizon	Gif-9606	12,195	130	bone	*Equus* sp.	attributed to the Late Magdalenian	14,800-13,640	5-6; 15
Le Tureau des Gardes, *locus* 10	AA-44214	12,170	130	phalange	*Equus* sp.		14,680-13,640	5; 16
Le Tureau des Gardes, *locus* 10	AA-44215	12,160	120	humerus	*Equus* sp.		14,540-13,660	5; 16
Marsangy, conc. N19	OxA-8453	12,140	75	tooth	*Equus* sp.	found in M16	14,220-13,780	5; 19
Le Closeau, lower horizon, *locus* 4	OxA-5680* (Ly-166)	12,090	90	diaphyse	*Equus* sp.		14,180-13,700	5; 17; 19-20
Le Grand Canton, sector 2, upper horizon	Gif-9607	12,080	115	bone	*Equus* sp.		14,250-13,650	5-6; 15
Le Grand Canton, sector 2, upper horizon	*Gif-9609*	*11,420*	*100*	bone	*Equus* sp.	REJECT: low collagen content	×	5-6; 15
Le Grand Canton, sector 1	*OxA-3671**	*11,030*	*105*	phalange, protein	*Equus* sp.	REJECT: fraction; same sample as OxA-3139	×	5-7; 15
Belloy-sur-Somme, upper horizon, north	OxA-724	10,260	160	tooth	*Equus* sp.		12,650-11,370	12
Belloy-sur-Somme, upper horizon, north	OxA-722	10,110	130	tooth	*Equus* sp.	re-dating of OxA-461	12,260-11,220	12
Belloy-sur-Somme, upper horizon, north	OxA-723	9,890	150	tooth	*Equus* sp.		11,960-11,000	12
Conty, lower horizon	OxA-7653	9,815	60	bone	*Equus* sp.	PROBLEMATIC: origin – top horizon?	11,380-11,180	19
Belloy-sur-Somme, upper horizon, north	OxA-462	9,720	130	tooth	*Equus* sp.		11,470-10,710	12
Le Closeau, upper horizon, *locus* 26	*GrA-10886*	*9,070*	*70*	jugale	*Equus* sp.	REJECT: younger intrusion?	×	5
Belloy-sur-Somme, upper horizon, north	*OxA-461*	*8,010*	*110*	tooth	*Equus* sp.	REJECT: low collagen content; redating available (OxA-722)	×	12
Le Closeau, upper horizon, *locus* 26	*GrA-10885*	*5,290*	*90*	jugale	*Equus* sp.	REJECT: younger intrusion?	×	5
elk (*Alces alces*), n=0								
wild boar (*Sus scrofa*), n=6								
Le Closeau, lower horizon, *locus* 46	AA-41881	12,423	67		*Sus scrofa*		15,160-14,080	5; 16; 20
Le Closeau, lower horizon, *locus* 46	GrA-18816	12,350	70	femur	*Sus scrofa*		14,830-14,030	5; 16-17; 20
Le Closeau, lower horizon, *locus* 4	GrA-18762	11,640	70	diaphyse	*Sus scrofa*	PROBLEMATIC: association doubtful	13,670-13,270	5; 17
Le Closeau, lower horizon, *locus* 4	GrA-18697	10,240	150	phalange	*Sus scrofa*	PROBLEMATIC: association doubtful	12,600-11,360	5; 17
Le Closeau, lower horizon, *locus* 46	*GrA-18763*	*6,420*	*110*	femur	*Sus scrofa*	REJECT: younger intrusion?	×	5; 17

Tab. 76 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Le Closeau, lower horizon, *locus* 4	*GrA-18701*	*5,380*	*100*	phalange	*Sus scrofa*	REJECT: association doubtful; younger intrusion?	×	5; 17
red deer (*Cervus elaphus*), n = 4								
Le Closeau, lower horizon, *locus* 46	*GrA-11665 (Ly-790)*	*12,360*	*60*	femur	Cervidae	REJECT: species determination unclear	14,820-14,060	2; 17
Le Closeau, lower horizon, *locus* 56	*GrA-18819*	*12,340*	*70*	radius	Cervidae	REJECT: species determination unclear	14,810-14,010	2; 17
Conty, palaeontological sample	OxA-6257* (Ly-286)	12,300	120	antler	*Cervus elaphus*		14,990-13,830	1
Saleux, trench A17	Beta-170494	11,180	50	diaphyse	*Cervus elaphus*		13,180-12,940	21
large bovids (*Bison priscus* / *Bos* sp. / *Bos primigenius*), n = 14								
Thèmes-Ferme de la Bouvière	OxA-8049	13,580	180		bovid	PROBLEMATIC: palimpsest or contaminated samples?	17,210-16,290	3
Conty, lower horizon	OxA-6151* (Ly-260)	11,890	90	metacarpal	*Bos primigenius*		13,960-13,480	1; 5
Hangest-sur-Somme III.1, lower horizon	*OxA-4432* (Ly-22)*	*11,660*	*110*	molars	*Bos primigenius* / *Equus* sp.?	REJECT: species attribution unclear	13,760-13,240	5
Saleux-Les Baquets (244)	GrA-18832 (Ly-1566)	11,640	70	metapodial	*Bos primigenius*		13,670-13,270	22
Hangest-sur-Somme III.1, lower horizon	*OxA-4936* (Ly-86)*	*11,630*	*90*	molars	*Bos primigenius* / *Equus* sp.?	REJECT: species attribution unclear	13,700-13,220	5
Conty, lower horizon	OxA-6148* (Ly-257)	11,620	90	diaphysis	*Bos primigenius*		13,670-13,230	1; 5
Conty, lower horizon	OxA-6149* (Ly-258)	11,560	90	diaphysis	*Bos primigenius*		13,570-13,210	1; 5
Conty, lower horizon	OxA-6150* (Ly-259)	11,410	80	tibia	*Bos primigenius*		13,440-13,080	1; 5
Saleux-Les Baquets (234)	GrA-15945 (Ly-1141)	11,200	70	femur	*Bos primigenius*		13,210-12,930	21
Saleux-Les Baquets (234)	GrA-15946 (Ly-1142)	11,160	70	M2 inf.	*Bos primigenius*		13,190-12,870	21
Saleux-La Vierge Catherine (114)	OxA-4932* (Ly-81)	11,010	80	diaphyse	*Bos primigenius*		13,060-12,700	5; 21
Hangest-sur-Somme III.1, upper horizon	OxA-4935* (Ly-85)	10,920	90	vertebra	*Bos primigenius*	PROBLEMATIC: the δ^{13}C value is surprisingly low	13,010-12,650	5
Saleux-La Vierge Catherine (114)	OxA-4933* (Ly-82)	10,800	140	diaphyse	*Bos primigenius*		13,030-12,470	5; 21
Hangest-sur-Somme II.1, lower horizon	Gif-9355	10,140	110	bone fragments	*Bos primigenius*		12,260-11,300	5
others, n = 0								

Tab. 76 (continued)

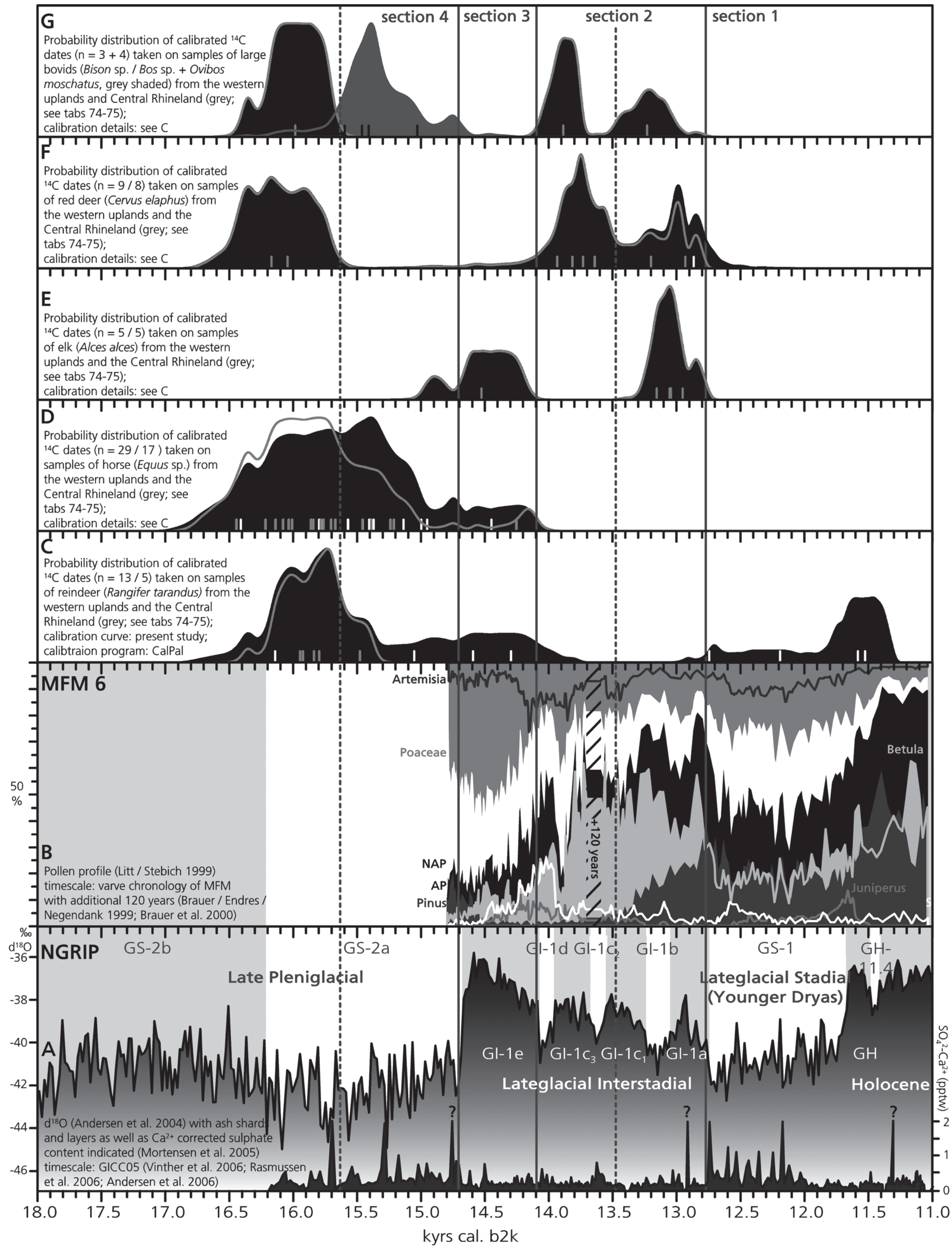


Fig. 60 Probability distribution of ^{14}C dates made on samples of the selected fauna species (**C-G**) from the western uplands (see **tab. 74**) and, in particular, the Central Rhineland (grey lines; see **tab. 75**) in comparison to the pollen diagram from the Meerfelder Maar (**B**) and the oxygen isotope record as well as the gypsum corrected sulphate content of NGRIP (**A**; see **fig. 53**). **G** grey shaded area represents the probability distribution for the arctic species musk ox (*Ovibos moschatus*).

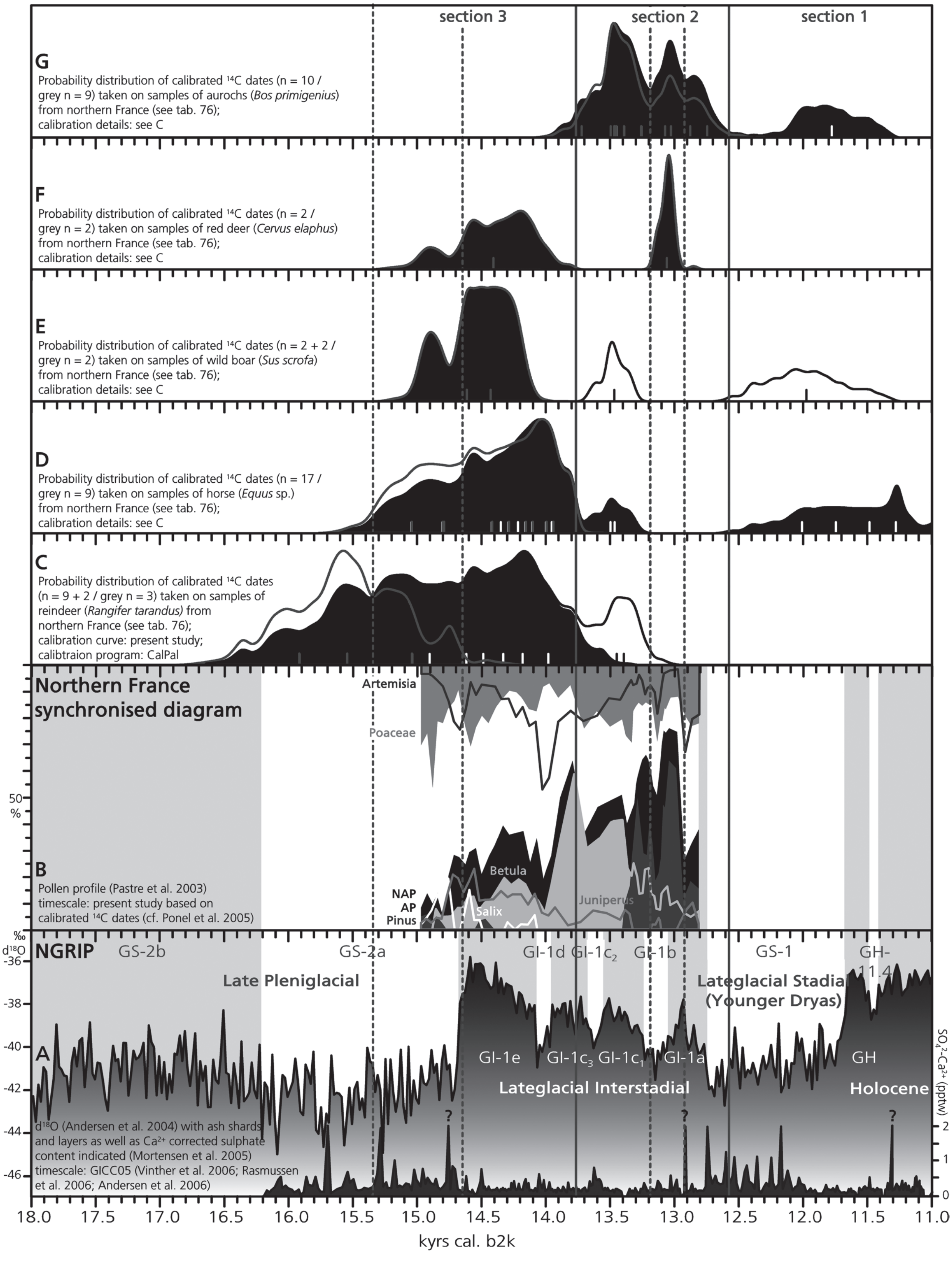


Fig. 61 Probability distribution of ^{14}C dates made on samples of the selected fauna species (**C-G**) from the Paris Basin (see **tab. 76**) in comparison to the pollen diagram from the Paris Basin (**B**) and the oxygen isotope record as well as the gypsum corrected sulphate content of NGRIP (**A**; see **fig. 53**). In **C-G** black lines with white background refer to problematic material and grey lines refer to more recently made, reliable dates (see text).

ent from the distribution of horses. This spatial context suggested no chronologically younger phase related to the presence of reindeer. Moreover, the Belgian faunal assemblages yielded, besides musk ox, remains from steppe wisent and aurochs (*Bos primigenius*; Germonpré / Sablin 2002) which prefers more forested habitats. The remains of steppe wisent and aurochs from the Belgian assemblages were not directly dated but according to the stratigraphic evidence these species occurred in the western uplands quasi-contemporaneously with musk ox. However, the directly dated examples from the Central Rhineland yielded distinct results for steppe wisent and aurochs and both species were never found together in a single assemblage. Therefore, direct dates from the western uplands on these large bovid species could help to determine further the reliability of these collections and / or the possibility of more varied environment in the western upland zone. Thus, these direct dates could alter the probability distribution of large bovids from the western uplands and, consequently, change this criterion for a bisection of the Late Pleniglacial unit.
Furthermore, the bisection of section 4 was also established based on the distribution of red deer (*Cervus elaphus*) remains because material from Andernach was dated to the early part of this section. However, a presence of red deer was not necessarily proven by the dated remains because the relation of the dated bones with the Late Magdalenian occupation remained uncertain and, therefore, a contamination of the samples could not be excluded. Furthermore, the ascertained Late Magdalenian material consisted mainly of dental material which was considered as jewellery material and, thus, during the Late Pleniglacial red deer was possibly not present in the Central Rhineland (Sommer et al. 2008, 720-723).These problems arose when the probability distributions are interpreted without considering the context of the sampled material. In contrast, at the transition to section 3, problems relating to calibration relics occurred in the probability distributions. Extra-fluctuations suggested a possible earlier appearance of elk (*Alces alces*) and / or a continued presence of large bovids and horses. These additional peaks were due to the plateau in the calibration curve. Thus, these deflections demonstrate methodological problems which are due to the dependence on the calibration curve.
Section 3 represented a transitional faunal composition in which some dates of reindeer and horse occurred, supplemented by elk in the Central Rhineland. Directly dated material from red deer and larger bovids is unknown from this period. However, the total number of directly dated specimens as well as of ascertained archaeological sites decreased significantly in this period making a reliable discussion about the fauna of this period difficult. Besides the elk remains from the south-western area of Gönnersdorf, single horse remains from the Trou de Chaleux (Stevens et al. 2009a) and Andernach (Stevens et al. 2009b) as well as single reindeer remains from the Trou da Somme (Hedges et al. 1994; Lanting / van der Plicht 1996) and the Grotte du Coléoptère (Hedges et al. 1993b; Lanting / van der Plicht 1996) were dated to this transitional section. The material from the Trou da Somme including an antler point was dated at the Oxford laboratory during the use ion-exchanged gelatin (lab. code: AI) which could cause some contamintation (Burky et al. 1998; Higham / Jacobi / Bronk Ramsey 2006). Thus, besides a potentially contamintated date, the material could have been introduced to this region from elsewhere due to the artefact character of the piece. Moreover, post-depositional disturbances at this site make a reliable stratigraphic attribution impossible (Miller / Noiret 2009). The remaining reindeer date was made again on antler and, thus, the presence of the species near the site can be questioned. The date fell onto the calibration plateau at the transition from GS-2a to GI-1e and, consequently, this reindeer material is dated probably to the end of section 4. Two further dates from this horizon proded an older and a younger result. The younger date was produced from bone splinters that could indicate that either material was relocated in the cave sediments and / or disturbed during excavations in the early 20th century. The older date was from a horse bone that bore cut marks and, thus, represented a reliable indicator of the Late Magdalenian occupation. Thus, the presence of reindeer in the western uplands during the period of section 3 still remains to be ascertained. The dates on

the horse bones were made during a project by Rhiannon Stevens about the nitrogen and carbon isotopic signatures of horse bones in order to reconstruct the local environment (Stevens et al. 2009b; Stevens et al. 2009a). Thus, they were thoroughly analysed and both samples were of a different isotopic signature than the Late Magdalenian samples. The isotopic composition of the piece in Chaleux suggested that this horse relied on a more mixed diet than the other horse remains in this assemblage. Consequently, the authors assumed that the horses which yielded the younger samples lived in a different environment and considered, for both sites, a younger episode as a possible explanation (Stevens et al. 2009b, 143f.; Stevens et al. 2009a, 661).

However, these later episodes have remained, thus far, undetected in both archaeological assemblages. Therefore, another possible explanation involves undetected contamination of the samples. Without further samples of comparable age and/or comparable isotopic signature, these intermediate phases cannot be verified. Consequently, the elk from Gönnersdorf remains the only reliably dated species for this section in the Central Rhineland and the western uplands. Thus, this section appears more like a gap of data than an actual transitional period. This gap in the record is not clearly shown by the probability distribution but no assemblage from the Central Rhineland or the western uplands was attributed unambiguously to GI-1d. Only the calibrated age range of the single date on horse from Andernach 2 could indicate human presence in the Central Rhineland across this period. However, this single date remains doubtful. In the western uplands, the calibrated age range of the Trou da Somme specimen encompassed this period but apart from this material, no other assemblage was attributed to this or the immediately following period. A directly dated red deer mandible from Presle (Hedges et al. 1988b) which was calibrated to the transition towards the Lateglacial Stadial is the further evidence of faunal development in this area. Hence, the temporal classification of the directly dated faunal remains from the western upland zone revealed a gap of directly dated specimens during the mid-to late Lateglacial Interstadial (GI-1c_2, GI-1c_1, and GI-1b) and the dates for an occupation during the early Lateglacial Interstadial (GI-1e and GI-1d) were also sparse. Consequently, the process of faunal change remains poorly understood for this area.

However, the major change in the probability distributions is observable in the following section 2 which can be further sub-divided in an earlier and a later part. Already during the earlier phase, no dates for the previously dominant species, reindeer and horse, were recorded. Instead, dates of red deer and large bovids, usually determined as aurochs, become frequent. These species indicate a light forest environment. Thus, the cold event GI-1d marked the end of a steppe landscape in the eastern sub-area and section 2 represented a fully established Lateglacial Interstadial environment. In general, the number of dated specimens increased in this section but the number of archaeological sites remained low in this earlier part. Only from the upper horizon of Andernach 2 were directly dated samples obtained, proving human occupation in this early phase after the faunal exchange.

In the later part of section 2, the total number of ^{14}C dates increased only gradually but the number of assemblages attributed to this period increased significantly. This younger sub-unit of the Lateglacial Interstadial section was related to the stabilisation of the climate and a forested environment in the western upland zone (**fig. 60B**). The red deer and aurochs dates were supplemented by directly dated elk remains. However, elk was also determined in the material of the upper horizon from Andernach 2 but not dated. Thus, even though a continued presence of elk in the Central Rhineland and the western uplands since the onset of the Lateglacial Interstadial remains a matter of discussion, due to the scarcity of data attributed to the early Lateglacial Interstadial, it had been regularly present in the Central Rhineland since the onset of the mid-Lateglacial Interstadial.

Section 2 of the probability distributions ended at the onset of the Lateglacial Stadial but in the Central Rhineland the preservation of organic remains decreased significantly with the absence of the LST. Only at

Bad Breisig were calcined remains of red deer, roe deer, and horse recovered. No Lateglacial faunal material younger than this assemblage, from the transition of the Lateglacial Interstadial to the Lateglacial Stadial, has been recovered in the Central Rhineland. Also, in the western uplands, reliably dated archaeological assemblages vanished almost completely at the transition to the Lateglacial Stadial but several Ahrensburgian assemblages such as Remouchamps and Kartstein were attributed to the younger half of Lateglacial Stadial. However, some of the directly dated reindeer remains from Remouchamps yielded some early Lateglacial Stadial ages. Besides reindeer, horse was also identified in this assemblage and also in the other, unambiguously later Ahrensburgian assemblages. These remains suggested the presence of some open grasslands. Furthermore, in some of these assemblages arctic fox (*Alopex lagopus*) was present indicating cold climatic conditions. From the Hohlen Stein in Kallenhardt a mixed assemblage was recovered that contained, alongside these three species also aurochs, wild boar, elk, beaver, red deer, and roe deer (Baales 1996). These species indicate that moist and forested areas were also found, occasionally, in the Belgian Ahrensburgian assemblages such as the beaver in the horizon 6B of the Grotte du Coléoptère or the wild boar in Fonds de Forêt (Dewez 1987). André Thévenin considered the presence of these species as an indication of the late Lateglacial Stadial to early Holocene age of these assemblages (Thévenin 1990), whereas Michael Baales assumed these species as Holocene intrusions (Baales 1996). A Holocene age for the wild boar from the Magdalenian collection of the Trou de Chaleux indicates that Holocene admixtures in these cave collections were possible (Hedges et al. 1994). Nevertheless, the detailed environmental study from the Kartstein and also the small mammal fauna from Coléoptère demonstrates the variability of the landscapes in the middle-range mountain areas during the Younger Dryas. This variability, due to topography, was also suggested for the same period in Britain (Price 2003). Thus, without direct dates of samples from the questionable species, their presence cannot be excluded, in particular due to the increasing indications for a return of moist and forested conditions to the western uplands during the younger half of the Lateglacial Stadial. The Holocene faunal development was not considered in the present study.

In the Paris Basin, three sections were established in the probability distribution.
The oldest section 3 and the intermediate section 2 were further sub-divided into three sub-sections.
Section 3 is dominated by horse and reindeer dates. Only a few direct dates of reindeer were attributed to the oldest sub-section. In the intermediate sub-section, horse supplemented the reindeer material, and the youngest sub-section correlates approximately with the section 3 in the western uplands. In contrast to the eastern sub-area, dates of wild boar and red deer supplemented horse and reindeer material during this period in the Paris Basin. The onset of this sub-section corresponds to the onset of the Lateglacial Interstadial and follows on an increase in the arboreal pollen that was due to increases in juniper, willow, and, later, birch pollen. Direct dates of the supplementary fauna species vanished with a decrease in the arboreal pollen and an increase in Artemisia, whereas the probability of horse dates increased. The end of this section correlated to a significant increase of the arboreal pollen and particularly the birch pollen and, thus, this environmental position is comparable to the onset of section 2 in the Central Rhineland.
Section 2 corresponds to the forested phase and was dominated by dated aurochs material in the northern French records. Thus, the major change in the faunal composition also occurred between the sections 3 and 2 in the Paris Basin. However, in northern France this transition occurred in the mid-Lateglacial Interstadial and, thus, 350 years later than in the Central Rhineland. In the oldest sub-section, the dated aurochs material was supplemented by some dates on horse and in the intermediate sub-section by red deer. In the youngest sub-section of section 2, direct dates were only made on aurochs remains.
Section 1 again corresponds to the fauna of the Lateglacial Stadial which consisted of horse and aurochs in the Paris Basin.

Nevertheless, possible problems with the quality of the ^{14}C dates on bones from the Paris Basin and in particular from the area near Marolles-sur-Seine makes this probability distribution problematic. Results were often younger than considered possible based on the stratigraphic and environmental evidence but thus far no consistent problem has been identified. However, direct comparison with the synchronised pollen diagram from the Paris Basin (fig. 61B) suggests that the probability distributions could be explained by the development of a denser plant environment. Since the synchronised pollen diagram from the Paris Basin was correlated to the NGRIP record also by using calibrated age ranges, the probability distributions and the pollen diagram are subject to the same methodological problems. Consequently, potential offsets resulting from methodological reasons are negligible. Thus, if contamination of the material is excluded, the comparable developments in the plant and the faunal environment indicate probable interrelations.

Nevertheless, the botanical macro-remains suggested a denser environment in most parts of northern France than in the Central Rhineland. Thus, even though correlation with the pollen diagram could explain the long persistence of a cold grass steppe adapted fauna, the previously outlined climatic and environmental development of the western sub-area clearly contradicts this longer presence. Furthermore, reliable dates on the mainly forest adapted fauna from the lower horizon in Le Closeau were older than many faunal remains from unambiguously Late Magdalenian assemblages. Considering the general vicinity, for example, of Étiolles and Le Closeau as well as the environmental indications from these sites (Rodriguez 1994; Olive 2004; Bignon 2009), a quasi-contemporaneity is improbable because of the numerous differences. Therefore, contamination of several ^{14}C-dated samples seems worth considering.

Possibly, the deposition in alluvial plains and, thus, the interaction with groundwater resulted in undetected diagenetic alterations of faunal material (Hedges/Millard 1995; Hedges/Millard/Pike 1995; Hedges 2002). These possible alterations have resulted in the younger ages. However, if dates made on potentially contaminated bulked samples or made in the early days of AMS, possibly with an insufficient pretreatment protocol, were rejected in general from the list, very few dates remained to develop the probability distributions (fig. 61, grey lines). However, the general sub-division would remain the same except for numerous dates on reindeer being rejected. According to this reduced list of dates, reindeer seemed to have vanished from the Paris Basin already with the first increase of arboreal pollen (fig. 61C). This final decrease of the probability distribution corresponded approximately to the decrease of reindeer dates in the Central Rhineland.

According to this observation, reindeer might have shifted its range areas further northwards in the final phase of the Late Pleniglacial. Moreover, with the disappearance of reindeer herds, horse became more important but with the spread of light forests probably also on the higher plateaus during the mid-Lateglacial Interstadial. The subsequent importance in the probability distributions speaks in favour of a diachronic model of the occupation in the Paris Basin with horse dominated assemblages following on sites where mainly reindeer was hunted (Enloe 2000). However, the stratigraphic, environmental, and archaeological comparison of several sites such as Verberie, Étiolles, and various concentrations of Pincevent IV (Roblin-Jouve 1994; Rodriguez 1994; Bignon 2006) suggested that several of the assemblages dominated by reindeer or by horse as well as sites dominated by both species were deposited in the same period. Thus, a synchronic settlement with a complementary subsistence system appears probable during the Late Plenigacial in the Paris Basin (Bignon 2006). In addition, this contemporaneity suggests at least the occasional presence of reindeer also in the final part of the Late Pleniglacial. Moreover, the various comparisons singled out Marsangy as a clearly younger settlement episode. In the small faunal inventory from this site, reindeer was found besides horse and red deer remains indicating a more continued presence of single reindeer in this region into the early Lateglacial Interstadial. This scenario for the Paris Basin is comparable to the more continued, though sporadic indication of reindeer in the western uplands. In contrast to the Belgian cave sites, reindeer bones were found besides antler sustaining the presence of these animals as potential prey in northern France.

In summary, this detailed comparison of the probability distributions of the selected fauna species from the sub-areas with the contextual evidence of the species and the pollen diagram from the same areas helped to visualise relations between the faunal and the plant environment but a cautious interpretation of the distributions as well as the relations. In particular, small numbers of dated specimens from a few selected assemblages and/or the few selected species bias the outcome of these probability distributions significantly. Differential conditions of preservation due to the bone structure of the species, the taphonomic processes at the sites as well as in different climates and environments further influence the outcome of the distributions. Therefore, probability distributions of ^{14}C dates should not be interpreted without additional information such as the first and last appearance dates and/or supplementary analysis such as maps showing the distribution of the species. These supplementary information make an evaluation of the absence or presence of a species in the studied areas based on the development in surrounding areas possible. A combination of these data allows for a well rounded interpretation of the presence of selected fauna species in the study area.

Supplementary information on the presence of selected faunal species

In general, the ^{14}C dates used in this study represent the first appearance dates (FAD) of the selected species in the sub-areas after the LGM (GS-3, *c.* 27,550-23,350 years cal. b2k, *c.* 23,000-19,600 years ^{14}C-BP). The LGM was followed by a short-termed interstadial (GI-2, *c.* 23,350-22,900 years cal. b2k; *c.* 19,600-18,800 years ^{14}C-BP) and the tri-parted GS-2 (GS-2c: 22,900-20,900 years cal. b2k and *c.* 18,800-17,800 years ^{14}C-BP; GS-2b: 20,900-16,230 years cal. b2k and *c.* 17,800-13,200 years ^{14}C-BP; GS-2a: 16,230-14,687 years cal. b2k and *c.* 13,200-12,400 years ^{14}C-BP; Lowe et al. 2008; Rasmussen et al. 2008; Weninger/Jöris 2008). For horse and reindeer were older dates than those given for the presented sites known in or close to the sub-areas. Besides the FAD, the collection of dates (**tabs 74-76**) also provided last appearance dates (LAD) in the sub-areas for some of the glacial species such as reindeer, musk ox, or steppe wisent. In contrast, many of the species indicate temperate forest environments such as wild boar, beaver, aurochs, red deer, and roe deer, and inhabited the forests of the sub-areas until historic times (Ziswiler 1965; von Koenigswald 2004). Consequently, no LAD for these species are given by the present project.

In contrast to the probability distributions, the use of FADs and LADs does not allow for detecting short phases of absence for a species in the analysed areas (cf. Aaris-Sørensen 2009, 7). Therefore, tables of potential presence were made per the sub-area also including the indirectly dated material (**tabs 77-79**). These tables revealed a clear gap in the data from the western uplands during the mid- to late Lateglacial Interstadial. Furthermore, in the French record several species were not found suggesting biased preservation either due to the absence of the species, the different preservation properties of faunal remains, a selection of the prey and a better preservation or more probable determination in an archaeological assemblage, or a combination of these factors. In particular, species indicating very arctic conditions such as musk ox as well as indicators of very moist environments such as elk were missing. The latter is consistent with the assumptions based on the general comparison of the pollen profiles.

Supplementary information by further faunal indicators

Besides the selected fauna, further animal species can help to reconstruct the past environments. In particular, chironomid, malacological, and coleopteran data provide insights in the local micro-climate and vegetation (Rodriguez 1994; Lotter et al. 1997; Meyrick 2001; Ponel et al. 2005). Some of these analyses were

species	pre-GS-2a	GS-2a$_3$	GS-2a$_2$	GS-2a$_1$	GI-1e	GI-1d	GI-1c$_3$	GI-1c$_2$	GI-1c$_1$	GI-1b	GI-1a	GS-1b	GS-1a	GH
Rangifer tarandus	S	^{14}C / S	^{14}C / S	S / nd	nd	nd						nd	nd	nd
Equus sp.	^{14}C / S	^{14}C / S	^{14}C / S	S / nd	^{14}C / nd	^{14}C / nd	^{14}C	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	S / nd	nd	nd
Alces alces				^{14}C / nd	^{14}C / S	^{14}C / nd	S	S	^{14}C / S	^{14}C / S	^{14}C / S	nd	nd	nd
Sus scrofa		S	S	S / nd	nd	nd		S	S	S	S	S / nd	nd	nd
Cervus elaphus	S	^{14}C / S	S	S/ nd	S / nd	^{14}C / nd	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	nd	nd
Bison sp. / *Bison priscus*	S	^{14}C / S	S	nd	nd	nd						nd	nd	nd
Bison sp. / *Bos* sp.				S / nd	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	nd	nd	nd
Bos sp. / *Bos primigenius*				nd	nd	nd			S	S	S	nd	nd	nd
Ovibos moschatus				nd	nd	nd						nd	nd	nd
Alopex lagopus	S	S	S	S / nd	nd	nd						nd	nd	nd
Lepus timidus	S	S	S	nd	nd	nd						nd	nd	nd
Saiga tatarica		S	S	nd	nd	nd						nd	nd	nd
Capreolus capreolus				nd	S / nd	S / nd	S	S	^{14}C / S	^{14}C / S	^{14}C / S	S / nd	nd	nd
Castor fiber				nd	nd	^{14}C / nd	^{14}C / S	^{14}C / S	S	S	S	nd	nd	nd

Tab. 77 Presence of selected fauna and indicator species in the Central Rhineland. **^{14}C** directly dated specimens; **S** stratigraphic attribution and / or other species in the assemblage were ^{14}C-dated to this period; **nd** no or very sparse data from this period. Dark grey shaded: reliable presence; light grey shaded: possible presence. For Greenland events see **tab. 64**, additional sub-divisions were made: **pre-GS-2a** LGM to onset GS-2a (< 16,230 years cal. b2k / *c.* 13,400 ^{14}C-BP); **GS-2a$_3$** first part of GS-2a with generally lower oxygen isotope values (16,230 – *c.* 15,400 years cal. b2k / *c.* 13,400-12,900 ^{14}C-BP); **GS-2a$_2$** intermediate phase of GS-2a with fluctuating oxygen isotope values (*c.* 15,400-15,000 years cal. b2k / *c.* 12,900-12,600 ^{14}C-BP); **GS-2a$_1$** last phase of GS-2a with generally higher oxygen isotope values (*c.* 15,000 > years cal. b2k / *c.* 12,600 > ^{14}C-BP); **GS-1b** pre-Vedde Ash or mid-GS-1 (*c.* 12,770-12,170 years cal. b2k); **GS-1a** post-Vedde Ash or mid-GS-1 (*c.* 12,170-11,670 years cal. b2k).

regularly carried out on archaeological sites but often suffered from poor conditions of preservation for this type of material. However, due to the very local nature, most results from palaeoecological stratigraphies are not relevant for the present study except for the discussion on the patchiness of the landscape. The mollusc assemblages from the Late Magdalenian assemblages in the Paris Basin suggests partially temperate forested areas (Étiolles) and partially cold steppic environments (Pincevent, Marsangy; Rodriguez 1994). However, the Late Magdalenian occupation was associated at all sites with very low proportions or absence of aquatic species, also in otherwise moist areas. Thus, the malacological data also pointed to the significant aridity of this period. Nevertheless, the diversity of vegetation indicated by the molluscs increased at many of the Late Magdalenian sites suggesting that in the floodplain of sheltered river valleys the first shrub communities or light forests could develop. In the Central Rhineland, a malacological study at Gönnersdorf provided indications for a ground covering vegetation with rare mesophile elements and single species inhabiting steppe, hygrophile, or semi-forested habitats (Puisségur 1978). In general, the results were comparable to those from the French sites but various ground movements such as bioturbation, sediment flows, or hydrological infiltration at the site could have caused an admixture of diachronic elements.

In addition, some mammals and particularly small mammals allowed for further assumptions on the regional development of the climate and the vegetation (Cordy 1991; Rabenstein 1991; cf. Price 2003; Hernández Fernández / Peláez-Campomanes 2005; Fahlke 2009). Comparable to the plant material, these remains suffered in the Lateglacial Interstadial from dating uncertainties. However, the lack of directly dated plant

species	pre-GS-2a	GS-2a$_3$	GS-2a$_2$	GS-2a$_1$	GI-1e	GI-1d	GI-1c$_3$	GI-1c$_2$	GI-1c$_1$	GI-1b	GI-1a	GS-1b	GS-1a	GH
Rangifer tarandus	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / nd	^{14}C / nd	nd	nd	^{14}C	^{14}C / S	^{14}C / S	^{14}C
Equus sp.	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	S / nd	S / nd	nd	nd	S	S	S	S
Alces alces			S	S	S		nd	nd	nd	nd		S	S	S
Sus scrofa		S	S	S	S		nd	nd	nd	nd		S	S	^{14}C / S
Cervus elaphus		S	S	S	S	S	nd	nd	nd	^{14}C / nd	^{14}C	^{14}C / S	S	S
Bison sp. / *Bison priscus*		S	S	S	S	S	nd	nd	nd	nd				
Bison sp. / *Bos* sp.			S	S	S	S	S / nd	S / nd	nd	nd				
Bos sp. / *Bos primigenius*		S	S	S	S	S	nd	nd	nd	nd		S	S	S
Ovibos moschatus		^{14}C / S	^{14}C / S	^{14}C / S	^{14}C		nd	nd	nd	nd				
Alopex lagopus		S	S	^{14}C / S	^{14}C / S	^{14}C / S	nd	nd	nd	nd		S	S	S
Lepus timidus							nd	nd	nd	nd	S	S	S	S
Saiga tatarica		S	S	S	S	S	nd	nd	nd	nd				
Capreolus capreolus		S	S	S	S	S	nd	nd	nd	nd		S	S	S
Castor fiber		S	S	S	S	S	nd	nd	nd	nd		S	S	S

Tab. 78 Presence of selected fauna and indicator species in the western uplands. **^{14}C** directly dated specimens; **S** stratigraphic attribution and/or other species in the assemblage were ^{14}C-dated to this period; **nd** no or very sparse data from this period. Dark grey shaded: reliable presence; light grey shaded: possible presence. For Greenland events see **tab. 64** and for the additional sub-divisions see **tab. 77**.

species	pre-GS-2a	GS-2a$_3$	GS-2a$_2$	GS-2a$_1$	GI-1e	GI-1d	GI-1c$_3$	GI-1c$_2$	GI-1c$_1$	GI-1b	GI-1a	GS-1b	GS-1a	GH
Rangifer tarandus	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	S				nd	nd	
Equus sp.	S	S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C	^{14}C / S	^{14}C / S	S	S	^{14}C / S	^{14}C / S	^{14}C / S
Alces alces												nd	nd	
Sus scrofa	S	S	S	^{14}C / S	^{14}C / S	^{14}C / S	S	S		S	S	S / nd	nd	^{14}C / S
Cervus elaphus	S	S	S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	S	S	^{14}C / S	^{14}C / S	S / nd	S / nd	S
Bison sp. / *Bison priscus*		S	S	S	S	S	S					nd	nd	
Bison sp. / *Bos* sp.	^{14}C / S	S	S	S	S	S	S	S				nd	nd	
Bos sp. / *Bos primigenius*			S	S	S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	^{14}C / S	S / nd	S
Ovibos moschatus												nd	nd	
Alopex lagopus												nd	nd	
Lepus timidus			S	S	S	S	S					nd	nd	
Saiga tatarica												nd	nd	
Capreolus capreolus					S	S	S	S	S	S	S	nd	nd	
Castor fiber												nd	nd	

Tab. 79 Presence of selected fauna and indicator species in the Paris Basin. **^{14}C** directly dated specimens; **S** stratigraphic attribution and/or other species in the assemblage were ^{14}C-dated to this period; **nd** no or very sparse data from this period. Dark grey shaded: reliable presence; light grey shaded: possible presence. For Greenland events see **tab. 64** and for the additional sub-divisions see **tab. 77**.

remains and preserved pollen deposits affected in particular the Late Pleniglacial period from which some well dated faunal assemblages were preserved.
Some of the species in these assemblages help to qualify the surrounding landscape such as steppe pika (*Ochotona pusilla*) and saiga antelope (*Saiga tatarica*) which inhabit arid, continental steppe regions or collared lemmings (*Dicrostonyx* sp.) and arctic fox *(Alopex lagopus*) which are circumpolar species indicating glacial habitats (van Kolfschoten 1995). In contrast, beaver (*Castor fiber*) requires significant wetland conditions and roe deer (*Capreolus capreolus*) is a representative of forest communities. Directly dated samples from these specimens are sparse. In particular, the small mammal species were dated only on singular samples in Britain (Hedges et al. 1998a; Bronk Ramsey et al. 2002; cf. Price 2003). These samples produced age ranges from the Lateglacial Stadial to the Holocene and, thus, are not useful in the present study. Some medium to large sized mammals can be used for a comparison between the sub-areas.
However, none of the indicator species detailed above was dated directly in the French sub-area and, in fact, only roe deer was determined within the archaeological assemblages of the Grotte du Gouy and Conty. For many northern French sites, this absence could reflect the poor preservation but also on the sites with relatively good preservation, such as Pincevent, these species are absent and the species lists are in general not short. Thus, the limited diversity of the species in the French sub-area is partially due to a human prey selection bias (cf. Gaudzinski / Street 2003) and partially due to the absence of extreme conditions such as high arctic or very arid climates. The absence of beaver can perhaps be explained by poorer conditions of preservation for this smaller mammal in a more temperate environment with more intense pedogenetic processes and possibly due to the position of most sites along the Seine or Somme and at some distance to more suitable habitats for beavers such as smaller streams, brooks, or limnic environments. In contrast, several specimens were found and dated in the western uplands and the Central Rhineland and can be included in the following outline of the faunal development.

Development of the selected species in the sub-areas

In the following, the presence of the selected fauna species and also the FADs after the LGM and the LADs in the Lateglacial for these species are considered per sub-area. Moreover, directly dated specimens in the surrounding areas of Central Europe are also reckoned to understand the distribution of these species after the LGM.
Thus far, no indications were found for the presence of faunal species in the study area during the LGM and immediately after. However, some evidence for the presence of animal in north-western Europe during this period were found outside the study area (**fig. 62**). For instance, a FAD for horse and reindeer came from Wiesbaden-Igstadt which is located only a few kilometres south of the southern limit of the western upland zone. Horse remains from this assemblage were dated approximately to the end of the LGM with an oldest date of 19,320 ± 240 years ^{14}C-BP (OxA-7502; 23,610-22,450 years cal. b2k; Hedges et al. 1998a; cf. Street / Terberger 2004). Reindeer remains were also dated at the site but yielded younger results (**tab. 73**), even though the material was considered as quasi-contemporaneous with the horse remains according to the spatial distribution (Street / Terberger 1999, 264 f.). In fact, the calibrated age ranges overlapped significantly (**fig. 63**). The older dates were congruent with dates on reindeer remains from the middle horizon of the Swiss Kastelhöhle-Nord (Street / Terberger 2004) and dated to the late GS-3 and early GI-2 (approximately 24,000 to 22,350 years cal. b2k). The younger dates made on reindeer from Wiesbaden-Igstadt are congruent with two dates made on human remains from the Mittlere Klause and fall calibrated to GI-2 (*c.* 23,050 to 21,350 years cal. b2k), a less rigid period (Street / Terberger / Orschiedt 2006; cf. Sánchez

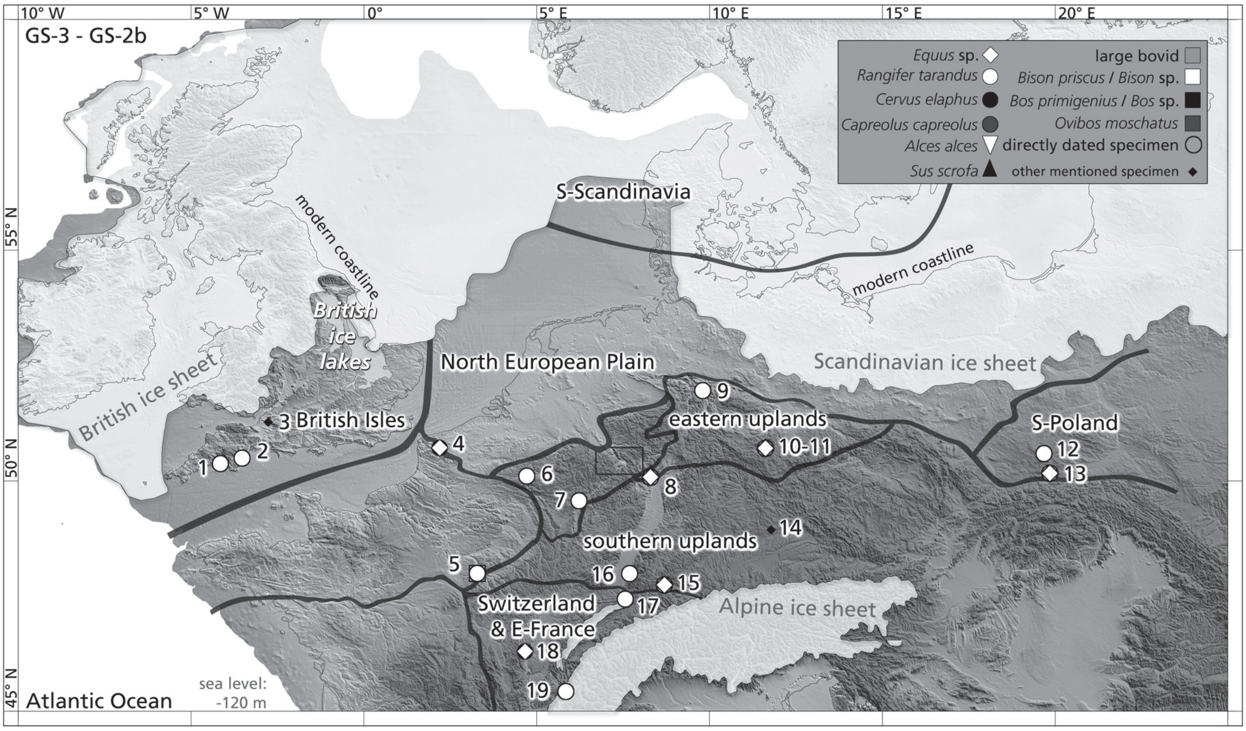


Fig. 62 Map of sites yielding material of selected fauna species during the late LGM and post-LGM to pre-GS-2a and sub-areas outside the study area. **1** Reindeer Rift; **2** Kent's Cavern; **3** Soldier's Hole; **4** Hallines; **5** Thèmes-Ferme de la Bouvière; **6** Trou des Blaireaux; **7** Schlaederbach valley; **8** Wiesbaden-Igstadt; **9** Aschenstein; **10** Ranis-Ilsenhöhle; **11** Kniegrotte; **12** Maszycka Cave; **13** Deszczowa Cave; **14** Mittlere Klause; **15** Kesslerloch; **16** Munzingen; **17** Kastelhöhle-Nord; **18** Solutré; **19** Abri de la Fru. – For further details see text.

Goñi 1991; Delpech 2012). The Mittlere Klause material, the archaeological assemblages from Wiesbaden-Igstadt (Street/Terberger 1999) and Kastelhöhle-Nord (Terberger/Street 2002) provided the evidence of a first return of human hunters into Central Europe after the LGM, presumably during a milder interstadial period. Moreover, these dates indicated that animals such as reindeer and horse could range in western Central Europe around GI-2.

A single date made by the Zürich laboratory on an indeterminate bone from Wiesbaden-Igstadt produced a somewhat younger date (UZ-3768/ETH-13380: 17,210 ± 135 years ^{14}C-BP; Street/Terberger 1999). When calibrated, this date fell to approximately GS-2c (21,090-20,290 years cal. b2k). Though similar to the reindeer dates from the site, the date was younger and not congruent with the group of Oxford dates. Since it is a single result and contamination was considered a possible source of error at the site (Street/Terberger 1999, 267), this date is considered a doubtful outlier in this study.

Besides these archaeological materials, unmodified reindeer remains from the Aschenstein assemblage east of the western upland zone dated to this late LGM and GI-2 period (Terberger et al. 2009). Furthermore, a red deer calcaneum from the French site Solutré (Pestle/Colvard/Pettitt 2006), a cow (*Bos* sp.) tibia from the British Soldier's Hole (Gowlett et al. 1986b), and a reindeer antler from the Polish Deszczowa Cave (Cyrek et al. 2000) were also dated to this period.

In the Aschenstein collection, further reindeer material with traces of human use was dated to the transition from the Late Pleniglacial to the early Lateglacial Interstadial (Terberger et al. 2009). The assemblage originated from a mid-20th century excavation and the spatial and stratigraphic position of the material was not documented. Therefore, the attribution of further material, also from other species such as horse, steppe wisent, musk ox, mammoth, arctic fox, arctic hare, and several bird species found at the site remained un-

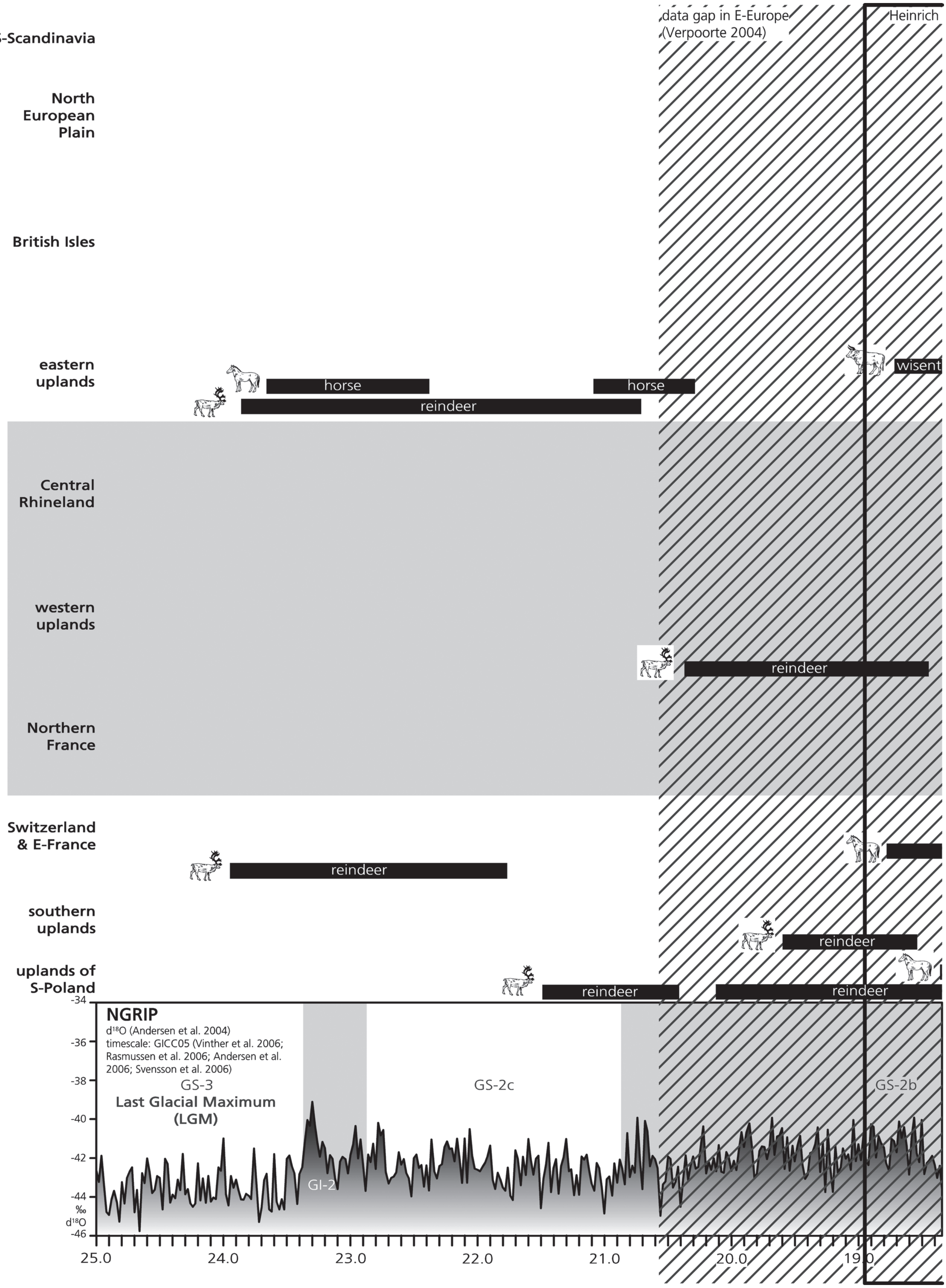
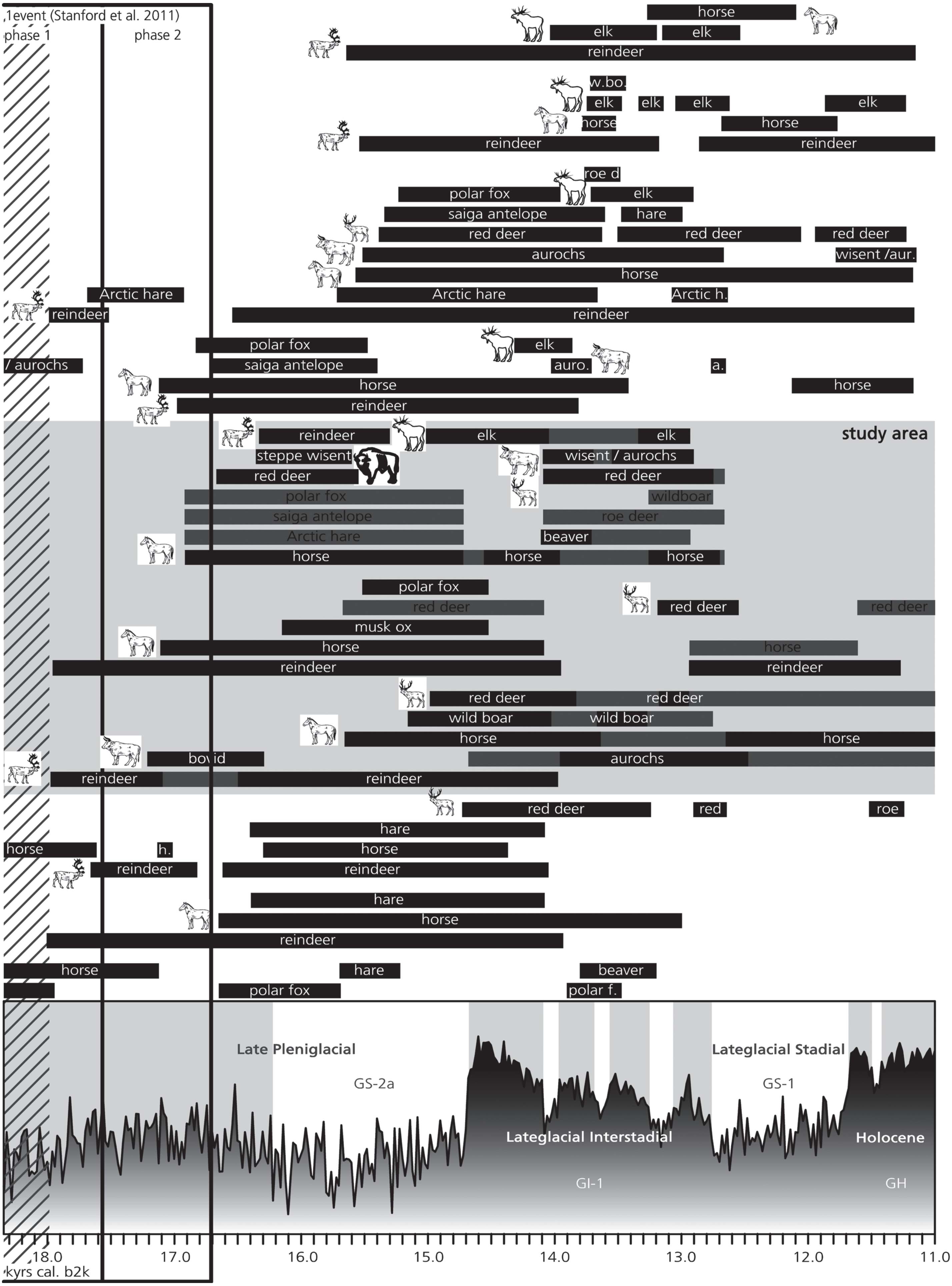


Fig. 63 Presence of selected fauna species in north-western Europe based on calibrated ^{14}C dates (black background) and indirect evidence (grey background; only in study area) in relation to the oxygen isotope record of NGRIP (see **fig. 53**).Grey shaded areas represent periods of more interstadial values than the surrounding values (for instance, the values in GS-2b are more interstadial than in GS-2a but



still these values are as stadial as the values in GS-1). The event limits are set according to **fig. 29** and Blockley et al. 2012, fig. 1. Note that some calibrated age ranges were capped due to the additional stratigraphic evidence such as the cover by the LST. – For further details see text.

certain. However, many pieces appeared to represent natural intrusions which were deposited during the LGM to the Late Pleniglacial and some remains such as the ones of roe deer were probably even younger elements (Terberger et al. 2009). Consequently, only reindeer can thus far be ascertained for the late LGM to early post-LGM period at this site.

The reliability of the Solutré specimen is, for various reasons, difficult to estimate: The sample was dated at the Oxford laboratory in the period in which some contamination in the ultra-filtration process still occurred but the date is congruent with previous dates from the Solutrean deposits (Montet-White/Evin/Stafford 2002). However, the piece was found in a collection from the 19th century and a relation to one of the hearths from the reindeer age was noted, although this hearth may not necessarily be equivalent to the Solutrean. Furthermore, the small faunal assemblage from the Solutrean was poorly preserved and in a previous examination, no red deer remains were determined (Olsen 1989). Thus, the sample might represent a single piece which could have reached the site as an element of the provision brought to the site from elsewhere, for example from a south-western French refuge (cf. Sommer et al. 2008). Therefore, the context of this single evidence has to be ascertained before it can be accepted as evidence for the presence of red deer in this area during this period.

The specimen from Soldier's Hole was found in a lower deposit (unit 4, spit 16) at the site and the date was made on amino acids in an early phase of the Oxford accelerator unit (cf. Burleigh 1986). Other samples from this unit produced considerably older ages suggesting a pre-LGM accumulation. An admixture of material from different periods could be a possible explanation but a contamination of the sample cannot be entirely excluded. However, the Cheddar Gorge where the Soldier's Hole was located (fig. 62) was only at a distance of some 35 km south-east of the maximum extent of the British glaciers during the LGM. If a fast regression of the ice sheet and the surrounding permafrost zone was considered possible in this area a reestablishment of the environment to provide a suitable habitat for large grazers such as red deer still appears improbable. Therefore, this evidence is doubted in this project.

The reindeer antler from horizon VIII in the southern Polish Deszczowa Cave produced the following date: Gd-10212: 17,480 ± 150 years ^{14}C-BP; 21,490-20,410 years cal. b2k (Cyrek et al. 2000; Wojtal 2007). This result is comparable in age to the doubted date from Wiesbaden-Igstadt. In contrast, a reindeer long bone from the same deposit produced a younger date and increased the age range of this deposit into GS-2b (Gd-9464: 16,150 ± 280 years ^{14}C-BP; 20,120-18,720 years cal. b2k; Cyrek et al. 2000; Wojtal 2007). Furthermore, dates on bones of woolly rhinoceros (*Coelodonta antiquitatis*; Nadachowski et al. 2009) and willow ptarmigan (*Lagopus lagopus*; Lorenc 2006) produced LGM results. Presumably, the position of the samples within the thick horizon as well as the location of the samples on the site (inside or outside the cave) could explain some discrepancy (Lorenc 2006, 47 f.). Even though the antler was found near a structure interpreted as hearth, it was unmodified and not unambiguously related to human activity. Nevertheless, besides the younger horse date from Wiesbaden, this date represents the only possible result determined to species in western Central Europe for the period between 17,500 and 16,500 years ^{14}C-BP (*c.* 21,250-19,500 years cal. b2k). Calibrated, this period relates to the transition from GS-2c to GS-2b. Within GS-2b a rapid rise in sea-level occurred and also the onset of the Heinrich 1 event in the broad sense is related to this event (cf. Stanford et al. 2011b, fig. 5).

In Eastern Europe, a period of particularly sparse evidence for human settlement followed the LGM dating between 17,000 and 15,000 years ^{14}C-BP (Verpoorte 2004). This period did not correlate to the onset of Heinrich 1 event as could be suggested but occurred shortly after the onset of GS-2b. Due to significant loess deposition, the reduced river activities, and the decreasing vegetation cover (cf. Fletcher et al. 2010), Alexander Verpoorte suggested that the decreasing evidence relates to a retreat of humans triggered by an increase in aridity (Verpoorte 2004, 263). Besides the aridity, seasonality and wind intensity could have been additionally limiting factors (cf. Dietrich / Seelos 2009) that could have had different effects in Western and in Eastern Europe.

However, the most significant aridity in Europe was assumed to relate to the main phase of the Heinrich 1 event dated between 15,000 and 13,500 years ^{14}C-BP (McCabe / Clark / Clark 2005; Stanford et al. 2011b). Thus, from this period no data should be available if the general aridity on the continent was the major limiting factor for the dispersal of vegetation and fauna and, consequently, humans into northern Europe.

In fact, comparable to Eastern Europe only very few dates from the period between approximately 17,000 and 15,000 years ^{14}C-BP have been achieved in north-western Europe. However, the first results from the studied sub-areas of this project appeared after the onset of GS-2b. These were made on several reindeer remains from the horizon III in the Trou des Blaireaux (**tab. 74**) and provided the FAD for this species in the western uplands. Two dates from the base of the stratigraphy provided results from the period between 16,500 and 15,800 years ^{14}C-BP (*c.* 20,200-18,750 years cal. b2k) and three dates from an intermediate concentration and one date from an upper concentration in this horizon III produced results between 14,000 and 13,300 years ^{14}C-BP (*c.* 17,550-15,550 years cal. b2k; Charles 1996). Thus, a gap of approximately 1,200 radiocarbon years occurred in the data series from Trou des Blaireaux between 15,800 and 14,000 years ^{14}C-BP.

The older set of dates was supplemented by a reindeer antler found in the Schlaederbach valley at the foot of the Plateau Haed in Oetrange (Luxembourg) which was dated to the period between 16,500 and 15,600 years ^{14}C-BP (20,370-18,450 years cal. b2k; Gilot 1970). This older series was not related to human occupation (Charles 1996; Housley et al. 1997) and indicated only the presence of reindeer in this area during this part of the Late Pleniglacial. The ^{14}C results from Trou des Blaireaux and the Schlaederbach valley were dated with the conventional method in the 1970s and 1980s and except the Schlaederbach valley specimen, these dates were made on bulked antler samples. Thus, the dates on bulked samples at the base of the Trou Blaireaux sequence could also be the result of material of different ages being dated. A redating of single specimens is desirable to ascertain the presence of reindeer in Central Europe during this period of generally sparse evidence. Nevertheless, since several old dates originated from the site and the general stratigraphic succession seems to confirm the results, the dates from horizon III of the Trou des Blaireaux in combination with the Schlaederbach valley date are considered as the FAD of reindeer in the western uplands.

In addition to the older series from the western uplands, the dated mammoth vertebrae from the upper horizon in Hallines resulted in an age around 16,000 years ^{14}C-BP but the association of this piece with the archaeology remains uncertain (Fagnart 1997, 42). A horse tooth and a red deer rib were also found in this horizon but if the mammoth material represents fossil material the horse and red deer remains as well as the archaeology could be considerably younger. In fact, the small mammal and the mollusc assemblages found in this deposit indicated a Late Pleniglacial age comparable to Gönnersdorf. Moreover, the archaeological material was also similar to the Late Magdalenian and, thus, the mammoth remains were probably fossil. Whether the mammoth died in the vicinity of the site or the material was brought to the site by Lateglacial hunters for further use remains to be examined for example by isotope analysis.

However, a series of dates made on reindeer material from the southern German site Munzingen produced comparable results to the ones from the western uplands (between 16,200 and 15,250 years ^{14}C-BP, approximately 19,600-18,550 years cal. b2k) and was considered among the earliest evidences of Magdalenian remains in Central Europe (Pasda 1998; Kozłowski et al. 2012; Street / Jöris / Turner 2012). The end of the date range from Munzingen is correlated with a period of particularly low values in the oxygen isotope record reflecting the first indications of the Heinrich 1 event (Stanford et al. 2011b). The faunal assemblage recovered in the 1976-1977 excavation of the site was poorly preserved and only reindeer was determined (Pasda 1994). In contrast, several campaigns between 1914 and 1960 yielded beside reindeer material, remains of horse, woolly rhinoceros, arctic hare, and wolverine (*Gulo gulo*) as well as teeth of red fox (*Vulpes vulpes*) and mammoth ivory. Due to patchy documentation, the exact relation of these remains and whether they are representatives of a contemporary biome cannot be evaluated. However, the species reflect a cold environment comparable to the previously described assemblages.

Calibrated ages made on samples of human, horse, and reindeer remains from the Polish Maszycka Cave (approximately 15,800-14,280 years ^{14}C-BP; *c.* 19,470-17,120 years cal. b2k; Kozłowski et al. 2012) also fell in this part of low values during GS-2b. Although the ^{14}C date on the horse sample appeared a bit younger than the other dates, it was consistent with the rest of the series after the calibration. Besides reindeer and horse, the collection contained mammoth ivory and remains of woolly rhinoceros, saiga antelope, red deer, brown bear as well as cave bear (*Ursus spelaeus*) and remains determined as wisent (*Bison* sp.) as well as some attributed to cattle (*Bos* sp.; Kozłowski et al. 1995). The rich organic artefact inventory from the site was comparable to the Munzingen assemblage attributed to a middle Magdalenian (Kozłowski et al. 1995). The variety of faunal species seemed likewise in Munzingen increased but since some material originated from a late 19th century collection, the integrity of the assemblage remained again uncertain.

Three dates made on horse samples from Solutré also produced results which fell calibrated to the period of lowered values in GS-2b between 15,210 and 14,505 years ^{14}C-BP (Hedges et al. 1997; Pestle / Colvard / Pettitt 2006). These dates were also assumed to relate to a Magdalenian assemblage of the site (Montet-White / Evin / Stafford 2002; Pestle / Colvard / Pettitt 2006).

At the southern limit of the French sub-area, a single direct date on a reindeer bone from Thèmes-Ferme de la Bouvière fell also into the period after 15,000 years ^{14}C-BP (Higham et al. 2007). However, the reliability of this date was questioned because two further dates from this assemblage produced significantly younger results and the archaeological assemblage suggested an early Upper Palaeolithic age.

A humerus from a large bovid (*Bison* sp. / *Bos* sp.) found in the Thuringian Ranis-Ilsenhöhle also resulted in a date from this early Heinrich 1 event period (Higham et al. 2007). This sample came from a yellow layer (horizon 4) which was also related to a middle Magdalenian (Grünberg 2006). The δ^{13}C value of the specimen was surprisingly low but, perhaps, this value could be explained by depletion due to the nutritional intake. However, a horse bone from the same stratigraphic unit yielded a pre-LGM date. In fact, this series for the Ilsenhöhle showed some disturbances in the stratigraphic integrity of this cave site. Moreover, this date series was made during a period in which still some problems in the ultra-filtration process occurred. Therefore, this result remains doubtful.

Thus, although no gap can be identified in the date series for north-western Europe between the LGM and the onset of the Heinrich 1 event, the indications for human and faunal presence in this period are very scattered and occasionally still uncertain. The few determined samples indicate only species inhabiting cold to arctic habitats such as reindeer or woolly rhinoceros. These species were supplemented by horse during milder episodes (**fig. 63**). Possibly, the variety of preserved species in the assemblages increased with the first indications of the Heinrich 1 event. After the period of particularly sparse data, an arctic fauna with reindeer was found in most parts of north-western Europe. For example, the first reliable results of reindeer from south-western England (Kent's Cavern, Reindeer Rift) and a possible evidence of arctic hare in western England (Pin Hole) dated to this period. However, during the main phase (phase 2) of the Heinrich 1 event (Stanford et al. 2011b), these northern ranges seemed to be abandoned again.

After the younger set of dates from the Trou des Blaireaux, the next youngest date for reindeer in the western sub-areas is the dated specimen from Saint Mihiel followed by dates from Gönnersdorf. Due to the relatively large standard deviations no gap in the reindeer dates from the western uplands can be identified, although the few finds suggested that during the most intense period during the first part of the main

phase of Heinrich 1 evidence from the western uplands could be lacking. However, since the end of this phase 2 of the Heinrich event, a regular presence of reindeer in this eastern sub-area was attested.
In contrast to the reindeer dates, an AMS date on horse from horizon II of the Trou des Blaireaux resulted in an age of 13,330 ± 160 years ^{14}C-BP (OxA-4200; 17,110-15,710 years cal. b2k; Hedges et al. 1994) and indicate the general reliability of the stratigraphic sequence. Nevertheless, this date was made in the series with the ion-exchange pretreatment (lab. Code: AI) which could cause some contamination and, in fact, a bone of brown bear (*Ursus arctos*) from the same horizon resulted in a considerably younger age (Lv-1386: 12,440 ± 180 years ^{14}C-BP; 15,490-13,850 years cal. b2k; Charles 1996; Lanting/van der Plicht 1996). Moreover, the distribution of lithic material suggested some admixture within this assemblage, probably due to animal burrows (Charles 1996; Housley et al. 1997). However, dates of horse from Gönnersdorf and the lower horizon in Andernach were only slightly younger than this sample from the Trou des Blaireaux. Consequently, a major dispersal of horse into the sub-areas can only be proven for the transition from GS-2b to GS-2a and, thus, the period after the main phase of Heinrich 1. Although horse was present at Wiesbaden-Igstadt in approximately GI-2, no remain of this species was directly dated between 17,000 and 15,000 years ^{14}C-BP and a regular occurrence in north-western Europe was only proven after 14,000 years ^{14}C-BP. Therefore, these later dates represented the FADs of horse in the western upland zone and the Central Rhineland respectively.
With the end of the main phase of the Heinrich 1 event, a spread of the late Magdalenian into the middle-range mountain ranges and a significant increase in preserved faunal material can be noted (**fig. 63**). This increase further intensified with the onset of GS-2a. Besides reindeer and horse, hare and arctic fox were frequently identified and dated. This spread can be observed in the western uplands as well as in the Central Rhineland but northern France appeared comparable to the British Isles and the North European Plain still unaffected by this spread. Only a date of reindeer from Rinxent also indicates the presence of this species in northern France at the onset of GS-2a. The climatic harshness of this period is reflected by the occasional presence of saïga antelope in the eastern upland zone and the Central Rhineland and the occurrence of musk ox at the northern limit of the western upland zone.
Saïga antelope was found in some Magdalenian assemblages such as Gönnersdorf, Saint Mihiel, Trou de Chaleux (Charles 1998), or Kniegrotte (Feustel 1974; Hedges et al. 1998a; Höck 2000) but also in faunal assemblages from Creswellian sites such as Soldier's Hole and Gough's Cave (Jacobi 1980; Currant 1991; Jacobi 2004). Remains from the latter three sites were directly dated and produced calibrated age ranges from the Late Pleniglacial to the mid-Lateglacial Interstadial (see **tab. 73**). Thus, the last appearance date (LAD) for this species in Central Germany was in the Late Pleniglacial and on the British Isles the LAD fell to the early Lateglacial Interstadial. Possibly, this late appearance was related to the return of arid and glacial conditions in Britain during GI-1d. Even though only a few pieces of saïga material were determined at the British sites, the number of sites (n = 5) indicate a relatively frequent occurrence of this species in southern England and, in particular in the Cheddar region during this period (Currant 1987).
Musk ox remains were only identified in cave sediments from the northern limit of the western uplands. Since many of these remains originated from early collections the integrity was questioned and some specimens from the Grotte du Goyet, Trou da Somme, and Trou de Chaleux were directly dated (see **tab. 74**). Two pieces were cut-marked and indicated the human influence (Stevens 2009). The resulting dates were congruent and suggested a time of death during GS-2a.
The harsh climatic conditions of GS-2a were also indicated by the environmental data from some Late Magdalenian Paris Basin sites such as Verberie and most of the horizon IV assemblages at Pincevent (Taborin 1994). However, the radiometric results usually indicated an attribution to the second half of GS-2a or even to the early Lateglacial Interstadial. For example, the horse remains from Le Grand Canton and Le Tureau des

Gardes represented the FAD of this species in northern France and date comparable to Bois Laiterie (Krueger 1997). According to techno-typological analyses, the archaeological material found in these different sites also was comparable (Julien/Rieu 1999; Weber 2006; Valentin 2008a; Sano/Maier/Heidenreich 2011). ^{14}C dates from the Late Magdalenian concentrations of Verberie provided comparable results but many of the results from the Late Magdalenian of Pincevent produced even older dates (Bodu 2004; Débout et al. 2012). Thus, the Late Magdalenian occurred contemporaneously with the so-called faciès Cepoy-Marsangy or the dates from these Late Magdalenian assemblages were too young (see p. 474-481). If these dates were to young and the assemblages were, dated according to the archaeological evidence, comparable to the Central Rhineland and the Belgian sites, horse and, in particular, reindeer were regularly present in northern France at the onset of GS-2a.

In contrast, red deer remains were regularly found in the Belgian cave collections and in Gönnersdorf and the lower horizon of Andernach. From the latter two sites, these remains were identified as special items such as jewellery teeth (Street et al. 2006; Street/Turner 2013) which can be considered as imports from elsewhere. Comparably, in the Belgian assemblages remains of this species represented either special goods or represented Holocene intrusions (Hedges et al. 1994). Thus, red deer was probably still not present in the northern range of the uplands during GS-2a (cf. Sommer et al. 2008).

However, in the second half of GS-2a a gradual amelioration of the climate led to an increasing suitability for faunal expansions into the northern landscapes. Many of the selected species were present on the British Isles during this period (**fig. 63; tab. 80**) and also the first arctic indicatiors from the North European Plain fall into this transitional period between the Late Pleniglacial and the early Lateglacial Interstadial (Mortensen 2007; Grimm/Weber 2008).

The appearance of species indicating a different habitat to the arctic tundra and the grass steppe appeared in the study area at the transition from GS-2a to the early Lateglacial Stadial closely following on the expansion of many arctic species into these northern areas. Thus, a northward shift of the different habitat limits began around the end of the Late Pleniglacial.

For example, remains of wild boar occurred infrequently in assemblages attributed to the Late Pleniglacial such as in the Late Magdalenian horizon V of the Wildscheuer cave at the eastern limit of the Central Rhineland (Terberger 1993), in Rinxent, Abri du Mammouth, Bonnières-sur-Seine, Trou des Nutons, Trou de Frontal, and Grotte de Sy Verlaine (Charles 1996). Probably, these remains represented intrusions and/or admixtures from younger deposits because most of these sites were disturbed during 19th and early 20th century excavations of the sites.

However, directly dated material from the lower horizon of Le Closeau proved the presence of wild boar in the Seine valley during the transition of the Late Pleniglacial to the Lateglacial Interstadial (Bodu/Debout/Bignon 2006). These dates represent the FADs for wild boar in the northern French sub-area. Directly dated specimens from the other sub-areas resulted only in Holocene age and, therefore, a FAD is not given although this species appeared at least in the Central Rhineland during the Lateglacial (see p. 443). Younger material of wild boar found in the *loci* 4 and 46 were considered as Mesolithic intrusions or suggested possible contamination. The former is possible in some parts of the site due to the complex stratigraphy.

In addition, elk also occurred during this first faunal transition period. During the Lateglacial, this species was only found in the eastern sub-area and directly dated specimens come only from the Central Rhineland. Thus, the elk from Gönnerdorf south-west provided the FAD in the Central Rhineland. However, remains of a possible female elk were also determined within the faunal assemblage from the Magdalenian horizons of Bois Laiterie (Gautier 1997). This determination was mainly based on the size of the remains but also on a morphological dental feature. A recent reanalysis of the lithic inventory from the site revealed some technical differences in comparison to typical Late Magdalenian assemblages but also came to the conclusion of a single episode inventory (Sano/Maier/Heidenreich 2011; cf. Straus/Orphal 1997). Thus, if the elk was related to the archaeology because it was found within the archaeological horizon, it represented the oldest indirectly dated evidence of elk presence in the western uplands. This indirect date would date the expansion of elk into the mid to late GS-2a. However, the remains were not directly dated and, thus, a somewhat younger admixture comparable to the elk in Gönnersdorf cannot be excluded completely. Yet, the Gönnersdorf results proved the presence of elk in this area at the onset of the Lateglacial Interstadial.

Besides these two species, red deer expanded its range into Western Europe during this early phase of the Lateglacial Interstadial. The Late Weichselian expansion of red deer was recently described based on ^{14}C dates, stratigraphic and spatial distributions as well as genetic evidence (Sommer et al. 2008). Its presence in western Europe was proven by several dates from the British Isles (Jacobi 2004; Jacobi/Higham 2009) and a palaeontological sample from Conty produced an age from the Late Pleniglacial to Lateglacial Interstadial transition (OxA-6257: 12,300 ± 120 years ^{14}C-BP, 14,990-13,830 years cal. b2k; Ponel et al. 2005). Even though this date was made in the problematic series with ion-exchange pretreatment (lab. code: AI) which could cause contamination of the sample, this type of problem was not indicated by additional signature values. Furthermore, the stratigraphic position was in accordance. Since this period, red deer had been found regularly in the archaeological assemblages of the northern French sub-area. Two further bones of a cervid were dated from the lower horizon of Le Closeau and resulted in almost identical ages as the Conty specimen. However, these pieces were not determined to species level. Although red deer appeared the more probable species, they might also reflect the presence of reindeer in the assemblage. A date of a red deer calcaneum from the Swiss Kesslerloch equally yielded a date from this transition period (KIA-33351: 12,335 ± 45 years ^{14}C-BP, 14,730-14,050 years cal. b2k; Napierala 2008a) and suggested a reoccupation of this site comparable to the south-western area of Gönnersdorf. Since the position of dated skeletal material from the lower horizon of Andernach remained ambiguous, these dates are not used as FAD for the presence of red deer in the Central Rhineland. Although red deer occurred in several assemblages in the western uplands, the uncertainty of the relation with the Late Pleniglacial material remained comparable to the Andernach material. Furthermore, admixture of this species into the Belgian assemblages was considered possible because several of the faunal collections originated from 19th and early 20th century excavations. This doubt was further sustained when a bone from the Trou des Nutons was dated to the mid-Holocene (Hedges et al. 1994). Thus, the presence of red deer in the western upland zone and particularly in the Central Rhineland remains questionable for the Late Pleniglacial. Moreover, no data of red deer could be attributed to the early Lateglacial Interstadial with some certainty in the eastern sub-areas. Possibly, red deer remains found in a stratigraphic higher position at Gönnersdorf could date comparable to the elk from the south-western area but these pieces were not yet directly dated. In the western upland zone, no assemblage from the mid-Lateglacial Interstadial is known and, thus, the very late appearance of red deer seems unsurprising.

Thus, in the west, wild boar and red deer supplemented the cold and open fauna of, predominantly, horse during the transition from the Late Pleniglacial to the Lateglacial Interstadial. In the eastern sub-areas the reliable assemblages are very few but the directly dated material also suggested the continued presence of horse (Stevens et al. 2009a; Stevens et al. 2009b) but supplemented by elk.

The relatively late reindeer dates in northern France and the LADs of reindeer were already discussed within the probability distributions (see p. 428). However, the question which ^{14}C date is the last reliable could be further discussed but clearly reindeer occurred in the northern French sub-area until the cold event in the early Lateglacial Interstadial as suggested by the evidence from Marsangy. According to this LAD in GI-1d, the data confirmed the previous suggestion that reindeer left France around GI-1d (Lang 1998, 85). This last appearance of reindeer in northern France co-occurred with the disappearance of reindeer in the French

Jura (Drucker/Bridault/Cupillard 2012). In the Central Rhineland, reindeer had already disappeared after the Late Magdalenian settlement of Gönnersdorf and the Wildweiberlei, whereas a few indications for a survival into the early Lateglacial Interstadial comparable to the Northern French evidence also exist in the western uplands.

LADs for horses are not given since single specimen occur throughout the Lateglacial Interstadial and it represented one of the most common species among the material from the late Lateglacial Stadial to early Holocene transition in northern France (Fagnart 1997) and also occurred occasionally in the northern Rhineland (Street 1991). Moreover, the colonisation history of this species seemed related to open landscapes and as a result of the human change of the landscape, the range patterns of horses were complex during the Holocene (Sommer et al. 2011). However, a significant decrease in the presence of horse can be recorded around the disappearance of reindeer in the northern French assemlages around GI-1d. Also in the Central Rhineland sites, horses were only found singularly from the mid-Lateglacial onwards.

In contrast, red deer occurred during this period regularly in the assemblages from the Central Rhineland and it often formed the dominant species in the archaeological assemblages (see **tab. 15**). Furthermore, the faunal composition changed significantly in this period. Besides elk that occurred frequently in the Central Rhineland assemblages, beaver became occasionally attested. A direct date of beaver which indicates a contrasting landscape to the saïga was made on a scapula fragment found in the upper horizon of Andernach 2. The calibrated age range of this sample suggested the first appearance of this species in the Central Rhineland during the mid-Lateglacial Interstadial (GrA-16987: 12,050 ± 70 years ^{14}C-BP, 14,100-13,700 years cal. b2k; Kegler 2002).

In addition, roe deer supplemented the species in all sub-areas. Two ^{14}C dates made on roe deer material from the Central Rhineland have potentially been contaminated (see **tab. 75**). However, roe deer was identified in almost all the FMG assemblages; only in the limited excavation area of Urbar and in the Boppard assemblage it has thus far not been determined. Hence, the presence of roe deer in the Central Rhineland can indirectly be dated to the onset of the mid-Lateglacial Interstadial. Equally, roe deer was found in many Belgian cave assemblages such as Trou des Nutons, Trou de Chaleux (Charles 1998), or Goyet (Germonpré 1997). However, these remains usually originated from old excavations and their association with the cold adapted Magdalenian fauna was questioned. Thus far, roe deer remains from these collections were not directly dated but other questionable elements in these assemblages such as wild boar or red deer were demonstrated to be of Holocene age (Hedges et al. 1994). In northern France, roe deer was determined in the assemblages of Grotte de Gouy (Bordes et al. 1974) and the lower horizon of Conty (Coudret/Fagnart 2006). Even though the remains were not directly dated, the evidence from Conty is reliable and the assemblage was well dated to the transition from the mid- to the late Lateglacial Interstadial (see p. 237-239, p. 479-481, and **figs 69-71**, **tabs 44. 76**). The material from the Grotte de Gouy was dated to the transition from the early to the mid-Lateglacial Interstadial but again the association of roe deer with the other material inside the cave remained uncertain (Fosse 1997). A direct date from Reichwalde produced an early Lateglacial Interstadial age (GrA-15437: 12,350 ± 50 years ^{14}C-BP, 14,750-14,070 years cal. b2k; Vollbrecht 2005). Even though this date is in accordance with the stratigraphic position in an early Lateglacial Interstadial soil, it remains questionable because the sampled material consisted of calcined bones which produced occasionally unreliable dates in the Lateglacial (Lanting/Niekus/Stapert 2002). Another bone of roe deer was found in the early Lateglacial horizon B of the southern Polish Komarowa Cave (Wojtal 2007). However, within this horizon giant deer (*Megaloceros giganteus*) remains were found which dated to the early Upper Palaeolithic. Using these dates, otherwise undetected movements within the cave sediment were proven. Consequently, the attribution of the roe deer remain to the early Lateglacial Interstadial remains uncertain. Nevertheless, an expansion of roe deer from eastern Europe, possibly from a Carpathian refuge,

after the LGM was previously suggested based on the palaeogeographic and genetic evidence (Sommer et al. 2009).
Comparable to roe deer, large bovids were found in most assemblages from the mid- and late Lateglacial Interstadial in the sub-areas. If these remains could be determined to species they usually originated from aurochs (Coudret/Fagnart 2006; Baales 2002). On the British Isles some specimens were dated already to the transition between the Late Pleniglacial and the early Lateglacial Interstadial (Jacobi 2004). Perhaps, these early occurrence in the north-western corner of Europe can confirm the evidence of aurochs alongside steppe wisent and musk ox in the Belgian assemblages (Germonpré/Sablin 2002), although an admixture cannot be fully excluded in these assemblages.
In northern France, wild boar probably remained present in this period. Among the faunal remains recovered from the Grotte de Gouy, wild boar was determined (Bordes et al. 1974; cf. Bignon/Bodu 2006). Even though the recovery of the material was again doubtful, the assemblage reflected a temperate forest community in which wild boar did not appear intrusive. An undetermined bone from this assemblage was dated to the transition from the early Lateglacial Interstadial to the mid-Lateglacial Interstadial (Fosse 1997, 242). The possibly contaminated wild boar sample from the *locus* 4 of Le Closeau produced a mid-Lateglacial Interstadial age but neither in the intermediate nor the upper horizon from this site were wild boar remains identified. However, this absence could be due to the significant decrease in bone preservation in these sediments.
After the establishment of this forest faunal community around the onset of GI-1c, this composition remained stable until the end of the Lateglacial Interstadial in the three sub-areas. Furthermore, in the northern Europe an expansion of this community can be registered around GI-1c_3 (**fig. 63**). In particular, elk moved to these northern areas but also wild boar (Hanik 2009) and roe deer (Richards et al. 2005) were occasionally found further in the north.
However, elks were still found in the Central Rhineland during the late Lateglacial Interstadial. Elks from Miesenheim 4 and Niederbieber 19 (previously 2; Street/Terberger 2004; cf. Fiedel et al. 2013) yielded the LAD of this in the Central Rhineland.
In contrast to northern France, wild boar was only determined in late Lateglacial Interstadial assemblages of the Central Rhineland (Niederbieber, Boppard). Perhaps, this late appearance in the Central Rhineland was related with the expansion of denser forests at the end of the Lateglacial Interstadial. During this period, wild boar also appeared in several Dutch assemblages such as Doetinchem (Johansen et al. 2000), or Wierden Enterse Akkers (Deeben et al. 2006). In sites further to the north such as Stellmoor (Bratlund 1999) or Bromme (Mathiassen 1948), this species seemed again to represent a Holocene intrusion. Nevertheless, an expansion north-eastwards of this species can be identified at the end of the Lateglacial Interstadial. In northern France, at Saleux 114 which also dated to the late Lateglacial Interstadial wild boar was found again (Fagnart 1997; Coudret/Fagnart 2006) proving its constant presence in this sub-area during the Lateglacial Interstadial.
The second, directly dated piece of red deer from the Paris Basin came from a test trench in Saleux and resulted in a late Lateglacial age (Beta-170494: 11,180 ± 50 years ^{14}C-BP, 13,180-12,940 years cal. b2k; Coudret/Fagnart 2004). However, red deer was determined in all assemblages from Saleux (Coudret/Fagnart 2006). For the western uplands the identification of this species was problematic due to the lack of reliable assemblages. However, an unmodified mandible of red deer from one of the Presle caves produced a calibrated age of late Lateglacial Interstadial to early Lateglacial Stadial indicating the presence of this species in the western uplands.
From the North European Plain and southern Scandinavia, this species is almost absent. A single date on a barbed point from Lemförde am Dümmer must be considered critically regarding the presence of this species

in this region (Veil et al. 1991; Riede et al. 2010). However, near the late Lateglacial Bromme site at Trollesgrave red deer remains were recovered from lake sediments that were considered of the same age as the site (Fischer/Mortensen 1977). Nevertheless, this relation cannot be proven unambiguously and the remains were not dated (cf. Fischer et al. 2013). Therefore, a Holocene age of this material cannot be excluded.
With the return of cold climate conditions during the Lateglacial Stadial the faunal composition again changed in northern Europe. For instance, reindeer returned into the western uplands (Baales 1996). Thus, the LAD of reindeer in the western uplands is of a Holocene age.
Nevertheless, some forested elements could have survived in sheltered areas. The evidence is relatively sparse because in the Central Rhineland as well as in the Seine valley, no sites from this period are preserved. Thus, the absence of wild boar from northern French sites during the Lateglacial Stadial related probably to the absence of reliable assemblages because the species is again known from Holocene assemblages in Le Closeau. The survival of wild boar in the western upland zone throughout the Lateglacial Stadial is poorly understood because the presence of this species in Ahrensburgian assemblages such as Hohle Stein (Kallenhardt) or Fond-de-Forêt was also assumed to represent Holocene intrusions (Baales 1996). Furthermore, elk was found in the Ahrensburgian assemblage of the Hohle Stein (Kallenhardt) but could also represent a Holocene admixture in this case (Baales 1996) or a visitor from the North European Plain where it remained a common species throughout the Lateglacial (Schmölcke/Zachos 2005; Riede et al. 2010).
In the assemblage from the Hohler Stein (Kallenhardt), red deer remains were also found from the Lateglacial Stadial horizon but again a Holocene intrusion cannot be excluded. However, red deer as well as aurochs were still attested in the fauna in a top horizon of Belloy-sur-Somme (Fagnart 1997). This indirect evidence indicates that these species survived in the western sub-area during this cold event. The Holocene record of red deer is again very numerous in the Paris Basin, the Central Rhineland, and the western upland (cf. Sommer et al. 2008). Frequently, aurochs were found in Mesolithic assemblages such as Bedburg-Königshoven (Street 1991).
Furthermore, roe deer and wild boar became also common representatives of the temperate forests in all the sub-areas again and elk was also frequent in most parts of Europe including northern France (Schmölcke/Zachos 2005).

In conclusion, reindeer seemed to appear quasi-contemporaneously as a frequent inhabitant in the sub-areas around the onset of GS-2a. The disappearance at the onset of the Lateglacial Interstadial began in the east and ended in the west. The retreat of the reindeer seemed a gradual process with some specimen occurring until GI-1d in the Paris Basin. However, the numbers of animals changed significantly between some assemblages in Pincevent horizon IV to the singular examples at Marsangy. Possibly, the migration behaviour of this species changed already with the onset of the Lateglacial Interstadial leaving only few individuals to range in the northern French sub-area and the larger herds to establish elsewhere (**fig. 64**). With the onset of GI-1c, reindeer had probably left the study area. Only in the northern part of the western uplands was a return of reindeer documented during the Lateglacial Stadial.
During the Lateglacial Interstadial, the number of determined horses also became significantly smaller but this species was still regularly found in the assemblages of the different sub-areas. These finds showed the continued presence of this species but in how far the group sizes changed from the larger steppe herds to small and solitary forest inhabitants (cf. MacFadden 1992, 263-298) remains a matter of discussion.
Elk occurred in western Central Europe during the transition of the Late Pleniglacial to the Lateglacial Interstadial. The absence of this species from northern France and most assemblages in the western uplands suggested that this large cervid migrated onto the North European Plain and into western Europe through the water rich, northern environments, probably from refugia in eastern Europe. In regard to the relation of

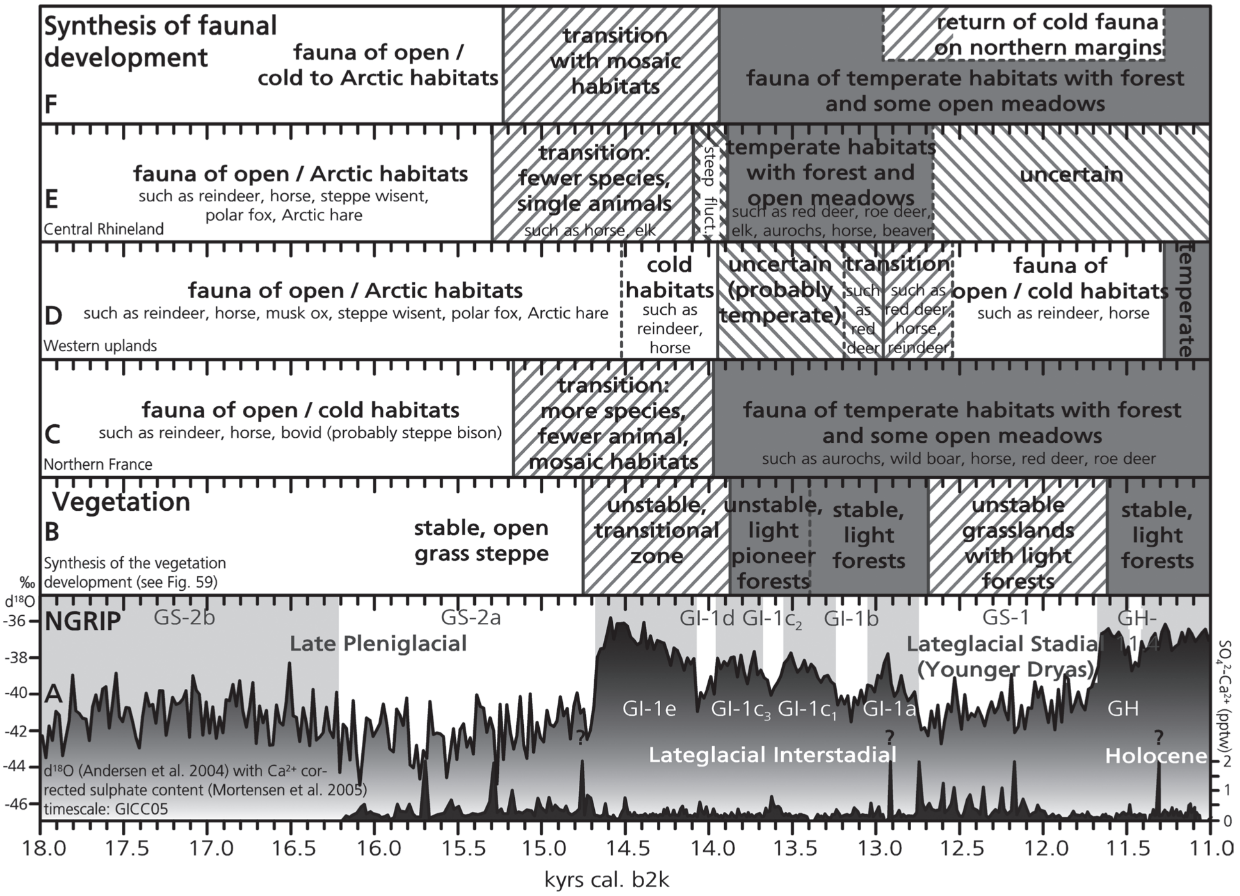


Fig. 64 Synthesis of faunal development in the sub-areas of this study (**C-F**; see **figs 59-60. 62**) in comparison to the synthesis of the vegetation development (**B**; see **fig. 58**) and the oxygen isotope record as well as the gypsum corrected sulphate content of NGRIP (**A**; see **fig. 53**). White backgrounds: cold and open environments; hatched background: transitional environments; grey shaded background: temperate forest environments.

this species to early stages of forest succession (Peterson 1955), the quick development of denser vegetation in the river valleys of the Paris Basin (see p. 388-394) possibly hindered the expansion of elks further to the west. Another possibility is a lack of moist areas providing sufficient nutrition for elks. The later argument could also help to explain the absence of beaver in this western sub-area during the Lateglacial. This species was first documented in the Central Rhineland at the transition from GI-1d to GI-1c.

Also since this period, large bovids, mainly aurochs, and red deer became regular prey of human hunters in the Central Rhineland and the northern French sub-area.

For the distribution of wild boar the different vegetation developments in the study area seemed to have played an important role. In the early forested environments of the French sub-area, wild boar were quickly established as regular inhabitants, whereas this species seemed to have colonised the western uplands including the Central Rhineland only after the local vegetation developed into a denser forest community.

According to these few indicator species, the arctic (arctic fox, arctic hare, musk ox) and arid (saïga antelope) climatic conditions and the grass dominated steppe zone was superseded as the predominant landscape in north-western Europe by forested wetlands (beaver, roe deer) at the onset of the mid-Lateglacial Interstadial (GI-1c_3). Thus, these indicator species further confirm the impression based on the selected species that the major transition in the faunal composition occurred considerably later than the onset of the Lateglacial Interstadial (**fig. 64**) and seemed to rather correlate with the onset of the mid-Lateglacial Interstadial.

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
reindeer (*Rangifer tarandus*), n = 181								
Kastelhöhle-Nord, Solothurn (CH) – SEF	OxA-9738**	19,620	140	bone	*Rangifer tarandus*	modified	23,950-23,190	1-2
Aschenstein, Niedersachsen (D) – EU	KIA-33773	19,570	100	antler	*Rangifer tarandus*	unworked	23,860-22,900	3
Kastelhöhle-Nord, Solothurn (CH) – SEF	OxA-9739**	19,200	150	bone	*Rangifer tarandus*	modified	23,540-22,540	1-2
Aschenstein, Niedersachsen (D) – EU	KN-2712	18,820	180	bone/antler	*Rangifer tarandus*	palaeontological specimens; PROBLEMATIC: bulked sample	23,050-22,370	3
Wiesbaden-Igstadt, Hessen (D) – EU	OxA-6809*	18,670	160	bone	*Rangifer tarandus*		23,040-21,840	2; 4-5
Kastelhöhle-Nord, Solothurn (CH) – SEF	OxA-9737**	18,530	150	bone	*Rangifer tarandus*	modified	22,730-21,770	1-2
Wiesbaden-Igstadt, Hessen (D) – EU	OxA-7501	18,220	180	bone	*Rangifer tarandus*		22,650-21,410	2; 4-5
Wiesbaden-Igstadt, Hessen (D) – EU	OxA-7500	17,820	240	bone	*Rangifer tarandus*		22,110-20,710	2; 4-5
Deszczowa Cave, Śląskie (PL) – SP	Gd-10212	17,480	150	antler	*Rangifer tarandus*		21,490-20,410	6
Deszczowa Cave, Śląskie (PL) – SP	Gd-9464	16,150	280	long bone	*Rangifer tarandus*		20,120-18,720	6
Munzingen, Baden-Württemberg (D) – SU	OxA-4785*	16,060	140	bone	*Rangifer tarandus*	PROBLEMATIC: possibly contaminated by chemical preservatives	19,610-18,890	7-8
Munzingen, Baden-Württemberg (D) – SU	*ETH-7499*	*15,700*	*135*	metatarsus	*Rangifer tarandus*	REJECT: possibly contaminated by chemical preservatives and unusually low δ^{13}C value	×	7-8
Munzingen, Baden-Württemberg (D) – SU	OxA-4786*	15,670	140	bone	*Rangifer tarandus*	PROBLEMATIC: possibly contaminated by chemical preservatives	19,190-18,630	7-8
Maszycka Cave, Małopolskie (PL) – SP	Ly-2454	15,490	310	antler	*Rangifer tarandus*	modified; PROBLEMATIC: large standard deviation	19,470-17,950	9-10
Munzingen, Baden-Württemberg (D) – SU	OxA-4783*	15,400	130	bone	*Rangifer tarandus*	PROBLEMATIC: possibly contaminated by chemical preservatives	18,940-18540	7-8
Maszycka Cave, Małopolskie (PL) – SP	KIA-39226	15,025	50	antler	*Rangifer tarandus*	artefact: point	18,660-17,940	10

Tab. 80 ^{14}C dates from selected faunal samples in north-western Europe outside the study area. If the sub-assemblage is known from which the sample originated, the sub-assemblage is given behind the site name. Otherwise the province and the country is given, as well as the sub-area. Abbreviations: **SEF** Switzerland and eastern France; **SU** southern uplands; **EU** eastern uplands; **SP** southern Polish uplands; **NEP** North European Plain; **SCA** southern Scandinavia; **GB** British Isles; **?** uncertain species determination (behind probable species); ***** dates which were pretreated by the use of ion-exchanged gelatin (Lab.code: AI) in the Oxford series (cf. Jacobi/Higham 2009, 1896); ****** dates which might be contaminated due to the use of a method leaving traces of a humectant in the collagen (Lab.code: AF*) in the Oxford series (cf. Higham et al. 2007, S55 & S2). Doubtful dates are shaded grey. Rejected dates are shaded grey and set in italics and, in addition, the main reason for rejection is given in comment. For further details see p. 259-263, p. 265-269, and p. 412-429. The dates were calibrated with the calibration curve of the present study (see p. 358-364) and the calibration program CalPal (Weninger/Jöris/Danzeglocke 2007). The result range of 95 % confidence is given for the calibrated ages (years cal. b2k). – References (ref.): **1** Bronk Ramsey et al. 2002; **2** erberger/Street 2002; **3** Terberger et al. 2009; **4** Hedges et al. 1998a; **5** Street/Terberger 1999; **6** Cyrek et al. 2000; **7** Pasda 1994; **8** Pasda 1998; **9** Kozłowski et al. 1995; **10** Kozłowski et al. 2012; **11** Jacobi/Higham 2009; **12** Housley et al. 1997; **13** Napierala 2008a; **14** Hedges et al. 1997; **15** Pion 1997; **16** Hedges et al. 1998b; **17** Hedges et al. 1989; **18** Schuler 1994; **19** Bowman/Ambers/Lesse 1990; **20** Albrecht 1979; **21** Fischer/Tauber 1986; **22** Grimm/Weber 2008; **23** Holm/Rieck 1992; **24** Aaris-Sørensen/Mühldorff/Petersen 2007; **25** Aaris-Sørensen 2009; **26** Hedges et al. 1987; **27** Jacobi 2004; **28** Rubin/Suess 1956; **29** Bridault et al. 2000; **30** Drucker et al. 2003; **31** Münnich 1957; **32** Fischer 1996; **33** Petersen/Johansen 1996; **34** Hedges et al. 1994; **35** Riede et al. 2010; **36** Hedges et al. 1991; **37** Hedges et al. 1992; **38** Jacobi/Higham/Lord 2009; **39** Aaris-Sørensen 1995; **40** Clausen 2004; **41** Larsson et al. 2002; **42** Lanting/van der Plicht 1996; **43** Hedges et al. 1996b; **44** Hedges et al. 1995; **45** Stensager 2004; **46** Gowlett et al. 1986a; **47** Barendsen/Deevey/Gralenski 1957; **48** Weber/Grimm/Baales 2011; **49** Hedges et al. 1990b; **50** Gowlett et al. 1986b; **51** Burleigh 1986; **52** Ambers/Matthews/Burleigh 1985; **53** Currant 1991; **54** Mellars 1969; **55** Barker/Burleigh/Meeks 1971; **56** Pestle/Colvard/Pettitt 2006; **57** Stevens/Hedges 2004; **58** Grünberg 2006; **59** Higham et al. 2007; **60** Bodu et al. 2009b; **61** Verpoorte/Šída 2009; **62** Benecke et al. 2006; **63** Richards et al. 2000; **64** Gillespie et al. 1985; **65** Vencl 1995; **66** Hedges et al. 1996a; **67** Kaiser/de Klerk/Terberger 1999; **68** Bronk Ramsey et al. 2000; **69** Burleigh/Hewson/Meeks 1976; **70** Hedges et al. 1990a; **71** Hanik 2009; **72** Fiedorczuk/Schild 2002; **73** Heinemeier/Rud 2000; **74** Kabaciński/Schild 2005; **75** Benecke/Heinrich 2003; **76** Meiri et al. 2013; **77** Drucker et al. 2009; **78** Barton/Roberts 1996; **79** Veil et al. 1991; **80** Richards et al. 2005; **81** Bailey et al. 1996; **82** Hedges et al. 1993a; **83** Hedges et al. 1988a; **84** Tietz 2005; **85** Street 1998a; **86** Irish et al. 2008; **87** Vollbrecht 2005.

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Maszycka Cave, Małopolskie (PL) – SP	KIA-32225	14,885	60	antler	*Rangifer tarandus*	artefact: navettes	18,720-17,840	10
Reindeer Rift, Devon/England (GB) – GB	OxA-17160**	14,550	55	calcaneum	*Rangifer tarandus*	no association with archaeology	17,980-17,620	11
Munzingen, Baden-Württemberg (D) – SU	OxA-4784*	14,510	110	bone	*Rangifer tarandus*	PROBLEMATIC: possibly contaminated by chemical preservatives	18,010-17,530	7
Kent's Cavern, Devon/England (GB) – GB	OxA-14826	14,395	60	astralagus	*Rangifer tarandus*		17,870-17,510	11
Munzingen, Baden-Württemberg (D) – SU	OxA-4788*	14,270	120	bone	*Rangifer tarandus*	PROBLEMATIC: possibly contaminated by chemical preservatives	17,800-17,080	7-8
Kesslerloch, Schaffhausen (CH) – SEF	OxA-5749*	14,150	100	antler	*Rangifer tarandus*	modified, shed antler, possible collection of fossil material	17,660-17,060	12-13
Abri de la Fru, Savoie/Rhône-Alpes, (F) – SEF	OxA-5260* (Ly-130)	14,060	130	metapodium	*Rangifer tarandus*		17,660-16,980	14-15
Abri de la Fru, Savoie/Rhône-Alpes, (F) – SEF	OxA-4937* (Ly-89)	13,810	110	mandible	*Rangifer tarandus*		17,170-16,930	14-15
Kesslerloch, Schaffhausen (CH) – SEF	OxA-5750*	13,670	100	antler	*Rangifer tarandus*	modified, shed antler, possible collection of fossil material	17,100-16,820	12-13
Munzingen, Baden-Württemberg (D) – SU	ETH-7500	13,560	120	metatarsus	*Rangifer tarandus*	PROBLEMATIC: possibly contaminated by chemical preservatives	17,110-16,550	7-8
Kniegrotte, Thüringen (D) – EU	OxA-4832*	13,310	110	scapula	*Rangifer tarandus*	cutmarks	16,980-15,940	16
Munzingen, Baden-Württemberg (D) – SU	OxA-4820*	13,230	110	bone	*Rangifer tarandus*	PROBLEMATIC: possibly contaminated by chemical preservatives	16,920-15,640	7-8
Kniegrotte, Thüringen (D) – EU	OxA-4845*	13,120	130	tibia	*Rangifer tarandus*	probable marrow extraction	16,720-15,440	16
Teufelsküche, Baden-Württemberg (D) – SU	ETH-7501	13,080	120	metatarsus	*Rangifer tarandus*	PROBLEMATIC: also treated with chemicals? unusually low δ^{13}C value	16,620-15,420	7
Pin Hole, Derbyshire/England (GB) – GB	OxA-1936	13,050	250	antler	*Rangifer tarandus*	palaeontological specimen; PROBLEMATIC: large standard deviation	16,970-14,970	17
Schussenquelle I, Baden-Württemberg (D) – SU	KN-4251	13,050	120	antler	*Rangifer tarandus*		16,540-15,380	18
Kesslerloch, Schaffhausen (CH) – SEF	B-3329	12,970	180	bone	*Rangifer tarandus*	PROBLEMATIC: bulked sample of mainly reindeer	16.620-15,060	13
Abri Stendel XVIII, Niedersachsen (D) – EU	OxA-10471**	12,860	75	antler	*Rangifer tarandus*	PROBLEMATIC: possibly contaminated series	15,730-15,290	1
Schussenquelle I, Baden-Württemberg (D) – SU	KN-4250	12,860	120	scapula	*Rangifer tarandus*		15,980-15,140	18
Picken's Hole, Somerset/England (GB) – GB	*BM-2118R*	*12,710*	*1,500*	metacarpus	*Rangifer tarandus*	uncertain association to archaeology; revised version not measured date; REJECT: very large standard deviation	×	19
Petersfels 1, AH 4, Baden-Württemberg (D) – SU	H-7145-7303	12,700	100	metatarsus	*Rangifer tarandus*		15,620-14,820	20

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Petersfels 1, AH 3, Baden-Württemberg (D) – SU	H-7138-7057	12,685	75	metatarsus	*Rangifer tarandus*		15,500-14,940	20
Oelknitz, Thüringen (D) – EU	OxA-5717*	12,670	110	calcaneum	*Rangifer tarandus*		15,640-14,560	16
Petersfels 1, AH 3, Baden-Württemberg (D) – SU	H-7135-6879	12,670	100	long bone	*Rangifer tarandus?*		15,600-14,640	20
Teufelsbrücke, Thüringen (D) – EU	OxA-5726*	12,640	130	humerus	*Rangifer tarandus*	black bone	15,650-14,410	7
Petersfels 1, AH 4, Baden-Württemberg (D) – SU	H-7144-7302	12,630	95	ribs	*Rangifer tarandus*		15,560-14,520	20
Oelknitz, Thüringen (D) – EU	OxA-5714*	12,620	120	maxilla	*Rangifer tarandus*	cutmarks	15,580-14,420	16
Petersfels 1, AH 3, Baden-Württemberg (D) – SE	H-7133-6877	12,580	130	ribs and vertebras	*Rangifer tarandus*		15,570-14,250	20
Poggenwisch, Schleswig-Holstein (D) – NEP	K-4332	12,570	115	bone	*Rangifer tarandus*		15,510-14,310	21-22
Gough's New Cave, Somerset/England (GB) – GB	OxA-18064	12,535	55	antler	*Rangifer tarandus*	artefact: perforated rod; redating of OxA-2797	15,310-14,510	11
Petersfels 1, AH 3, Baden-Württemberg (D) – SU	H-7140-7058	12,530	90	tibia	*Rangifer tarandus*		15,410-14,290	20
Slotseng, kettle hole, Syddanmark (DK) – SCA	AAR-906	12,520	190	antler/bone	*Rangifer tarandus*	modified	15,640-13,920	22; 23-25
Schussenquelle I, Baden-Württemberg (D) – SU	ETH-6155	12,510	130	vertebra	*Rangifer tarandus*		15,470-14,070	18
Aveline's Hole, Somerset/England (GB) – GB	OxA-1122	12,480	130	antler	*Rangifer tarandus*		15,420-14,020	26-27
Castlepook Cave, Cork (IRL) – GB	OxA-3602*	12,480	130	antler	*Rangifer tarandus*	base	15,420-14,020	14
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	W-261	12,450	200	antler	*Rangifer tarandus*	uncertain association with archaeology; PROBLEMATIC: pretreatment procedure?	15,550-13,830	22; 28
Poggenwisch, Schleswig-Holstein (D) – NEP	K-4331	12,440	115	bone	*Rangifer tarandus*		15,320-14,000	21-22
Poggenwisch, Schleswig-Holstein (D) – NEP	K-4577	12,440	115	bone	*Rangifer tarandus*	butchering marks; carnivore gnawing; PROBLEMATIC: unusually high δ^{13}C value	15,320-14,000	21-22
Abri de Rochedane, Doubs/Franche-Comté (F) – SEF	OxA-8030 (Ly-709)	12,420	75	bone	*Rangifer tarandus*		15,170-14,050	29-30
Slotseng, kettle hole, Syddanmark (DK) – SCA	AAR-8159	12,410	70	antler	*Rangifer tarandus*		15,150-14,030	22; 24
Munzingen, Baden-Württemberg (D) – SU	OxA-4787*	12,370	100	bone	*Rangifer tarandus*	PROBLEMATIC: possibly contaminated by chemical preservatives	15,140-13,940	7-8
Aschenstein, Niedersachsen (D) – EU	KIA-33772	12,366	61	antler	*Rangifer tarandus*	debris of spall production	14,830-14,070	1
Poggenwisch, Schleswig-Holstein (D) – NEP	KIA-32926	12,365	60	antler	*Rangifer tarandus*	modified	14,820-14,060	22

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Meiendorf pond, Schleswig-Holstein (D) – NEP	K-4329	12,360	110	antler	*Rangifer tarandus*		15,150-13,910	21-22
Poggenwisch, Schleswig-Holstein (D) – NEP	KIA-32927	12,330	55	antler	*Rangifer tarandus*	with attached cranial bone	14,750-14,030	22
Petersfels 1, AH 3, Baden-Württemberg (D) – SU	H-7136-6890	12,320	90	bone	*Rangifer tarandus*		14,860-13,940	20
Meiendorf pond, Schleswig-Holstein (D) – NEP	*H-38-121B*	*12,300*	*300*	antler	*Rangifer tarandus*	organic fraction; REJECT: without further pre-treatment	×	22; 31
Slotseng, kettle hole, Syddanmark (DK) – SCA	AAR-8157	12,299	41	antler	*Rangifer tarandus*	modified	14,670-13,990	22; 24
Slotseng, kettle hole, Syddanmark (DK) – SCA	AAR-8165	12,290	75	vertebra	*Rangifer tarandus*		14,760-13,920	22; 24
Oelknitz , Thüringen (D) – EU	OxA-5712*	12,270	110	radius	*Rangifer tarandus*		14,850-13,810	16
Poggenwisch, Schleswig-Holstein (D) – NEP	KIA-32925	12,265	55	antler	*Rangifer tarandus*	modified; PROBLEMATIC: unusually low $\delta^{13}C$ value	14,570-13,930	22
Slotseng, kettle hole, Syddanmark (DK) – SCA	AAR-8160	12,240	50	vertebra	*Rangifer tarandus*	with embedded flint projectile	14,360-13,960	22; 24
Slotseng, kettle hole, Syddanmark (DK) – SCA	AAR-8162	12,220	100	antler	*Rangifer tarandus*		14,680-13,760	22; 24
Slotseng, kettle hole, Syddanmark (DK) – SCA	AAR-8163	12,205	65	tibia	*Rangifer tarandus*		14,320-13,880	22; 24
Slotseng, kettle hole, Syddanmark (DK) – SCA	AAR-8164	12,190	50	rib	*Rangifer tarandus*		14,220-13,900	22; 24
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	K-4261	12,190	125	antler	*Rangifer tarandus*		14,740-13,660	21-22
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	K-4328	12,180	130	bone	*Rangifer tarandus*		14,720-13,640	21-22
Slotseng, kettle hole, Syddanmark (DK) – SCA	AAR-8158	12,165	55	antler/bone	*Rangifer tarandus*	modified	14,190-13,870	22; 24
Køge Bugt 1, Sjælland (DK) – SCA	AAR-1036	12,140	110	antler	*Rangifer tarandus*	modified; also known as »offshore Solrød Strand«	14,370-13,690	22; 32-33
Munzingen, Baden-Württemberg (D) – SU	*H4738-4660*	*12,130*	*130*	bone	*Rangifer tarandus*	GH 4; REJECT: poor bone preservation; disturbed site	×	7-8
Villestofte, Syddanmark (DK) – SCA	AAR-4187	12,080	90	bone	*Rangifer tarandus*		14,170-13,690	24
Slotseng, kettle hole, Syddanmark (DK) – SCA	AAR-8161	12,065	80	antler	*Rangifer tarandus*	modified	14,130-13,690	22; 24
Teufelsküche, Baden-Württemberg (D) – SU	*ETH-7503*	*12,040*	*120*	metatarsus	*Rangifer tarandus*	REJECT: unusually low $\delta^{13}C$ value	×	7
Church Hole Cave, Nottinghamshire/England (GB) – GB	OxA-3717*	12,020	100	antler	*Rangifer tarandus?*	artefact: point/rod with scooped end	14,120-13,640	34

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Meiendorf pond, Schleswig-Holstein (D) – NEP	H-38-121A	12,000	200	antler	*Rangifer tarandus*	PROBLEMATIC: large standard deviation	14,500-13,380	22; 31
Fox Hole Cave, Derbyshire/England (GB) – GB	OxA-1493	11,970	120	antler	*Rangifer tarandus*	artefact: point/rod with scooped end	14,110-13,550	17
Teufelsküche, Baden-Württemberg (D) – SU	*ETH-7502*	*11,960*	*120*	metatarsus	*Rangifer tarandus*	REJECT: unusually low δ^{13}C value	×	7
Borneck Kammer III, Schleswig-Holstein (D) – NEP	KIA-33949	11,940	50	humerus	*Rangifer tarandus*	PROBLEMATIC: unusually high δ^{13}C value	13,930-13,650	35
Petersfels 3, AH 4, Baden-Württemberg (D) – SU	H-4743-4137	11,890	130	bone/antler	*Rangifer tarandus*	PROBLEMATIC: unusual dating of reindeer in SU	14,060-13,420	20
Gough's New Cave, Somerset/England (GB) – GB	*OxA-2797**	*11,870*	*110*	antler	*Rangifer tarandus*	artefact: perforated rod; REJECT: redating available (OxA-18064)	×	11; 27; 36
Meiendorf pond, Schleswig-Holstein (D) – NEP	*W-281*	*11,870*	*200*	antler	*Rangifer tarandus*	REJECT: carbonate fraction?	×	22; 28
Meiendorf pond, Schleswig-Holstein (D) – NEP	*W-264*	*11,790*	*200*	antler	*Rangifer tarandus*	REJECT: without pretreatment?	×	22; 28
Victoria Cave, North Yorkshire/England (GB) – GB	OxA-2455*	11,750	120	antler	*Rangifer tarandus?*	artefact: double bevelled point	13,820-13,340	37-38
Poggenwisch, Schleswig-Holstein (D) – NEP	*W-271*	*11,750*	*200*	antler	*Rangifer tarandus*	REJECT: without pretreatment	×	22; 28
Pellegård, Hovedstaden (DK) – SCA	K-4875	11,650	120	antler	*Rangifer tarandus*	PROBLEMATIC: unusually high δ^{13}C value	13,770-13,210	24
Victoria Cave, North Yorkshire/England (GB) – GB	OxA-2457*	11,590	130	radius	*Rangifer tarandus*		13,710-13,150	37
Nørre Lyngby, Nordjylland (DK) – SCA	AAR-1511	11,570	110	rib	*Rangifer tarandus*	cutmarks	13,630-13,190	25; 39
Klappholz LA 63, Schleswig-Holstein (D) – NEP	AAR-2785	11,560	110	antler	*Rangifer tarandus*	artefact: Lyngby axe	13,620-13,180	25; 40
Hässleberga 1, Skåne (S) – SCA	LuA-4489	11,410	130	humerus	*Rangifer tarandus*		13,550-12,990	41
Hässleberga 1, Skåne (S) – SCA	Ua-3296	11,390	90	antler	*Rangifer tarandus*	shed	13,410-13,050	41
Nørre Lyngby, Nordjylland (DK) – SCA	K-6188	11,370	165	bone	*Rangifer tarandus*		13,550-12,910	25; 39
Hässleberga 1, Skåne (S) – SCA	LuA-4492	11,300	140	metatarsus	*Rangifer tarandus*		13,410-12,890	41
Køge Bugt 2, Sjælland (DK) – SCA	K-4321	11,290	160	bone	*Rangifer tarandus*		13,440-12,840	24
Kinsey Cave, North Yorkshire/England (GB) – GB	OxA-2456*	11,270	110	antler	*Rangifer tarandus*	artefact fragment	13,320-12,920	37
Poggenwisch, Schleswig-Holstein (D) – NEP	*GrN-11262*	*11,250*	*50*	antler	*Rangifer tarandus*	association with archaeology uncertain; REJECT: from Preboreal peat, thus, stratigraphic uncertainties	×	22; 42
Nørre Lyngby, Nordjylland (DK) – SCA	AAR-1910	11,190	100	bone	*Rangifer tarandus*		13,270-12,830	25; 39
Nørre Lyngby, Nordjylland (DK) – SCA	K-6189	11,190	135	bone	*Rangifer tarandus*		13,330-12,730	25; 39
Nørre Lyngby, Nordjylland (DK) – SCA	AAR-1909	11,180	130	bone	*Rangifer tarandus*		13,300-12,740	25; 39

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Torbryan Six Cave, Devon/England (GB) – GB	*OxA-3894**	*11,130*	*100*	tooth	*Rangifer tarandus*	cutmarks; uncertain association; REJECT: unusually low δ^{13}C value	×	43
Nørre Lyngby, Nordjylland (DK) – SCA	AAR-1908	11,120	160	bone	*Rangifer tarandus*	PROBLEMATIC: unusually high δ^{13}C value	13,300-12,660	25; 39
Kalø Vig, Sjælland (DK) – SCA	K-7067	10,990	110	antler	*Rangifer tarandus*		13,070-12,670	24
Kilgreany Cave, Waterford (IRL) – GB	OxA-4240*	10,990	120	bone	*Rangifer tarandus*		13,100-12,660	14
Mickelsmosse, Skåne (S) – SCA	OxA-2791*	10,980	110	antler	*Rangifer tarandus*	club	13,070-12,670	44
Victoria Cave, North Yorkshire/England (GB) – GB	OxA-2454*	10,970	120	mandible	*Rangifer tarandus*		13,090-12,650	37
Hässleberga 1, Skåne (S) – SCA	LuA-4491	10,920	140	calcaneum	*Rangifer tarandus*		13,080-12,600	41
Dyndeby, Hovedstaden (DK) – SCA	K-4874	10,880	150	antler	*Rangifer tarandus*		13,080-12,560	24
Edenvale Cave, Clare (IRL) – GB	OxA-3701*	10,850	80	bone	*Rangifer tarandus*		12,970-12,610	14
Odense Kanal, Syddanmark (DK) – SCA	AAR-9298	10,815	65	antler	*Rangifer tarandus*	artefact: Lyngby axe	12,800-12,640	45
Victoria Cave, North Yorkshire/England (GB) – GB	OxA-2607*	10,810	100	antler	*Rangifer tarandus*	artefact: point with two rows of barbs	12,930-12,570	37
Klemensker, Hovedstaden (DK) – SCA	K-4877	10,780	145	antler	*Rangifer tarandus*	PROBLEMATIC: unusually high δ^{13}C value	13,010-12,410	24
Ossom's Cave, Staffordshire/England (GB) – GB	OxA-631	10,780	160	mandible	*Rangifer tarandus*	PROBLEMATIC: from disturbed context	13,040-12,360	46
Hässleberga 2, Skåne (S) – SCA	LuA-4493	10,770	150	metacarpus	*Rangifer tarandus*		13,010-12,370	41
Meiendorf pond, Schleswig-Holstein (D) – NEP	*Y-158.2*	*10,760*	*250*	antler	*Rangifer tarandus*	REJECT: collagen date with uncertain pretreatment	×	22; 47
Chelm's Combe Shelter, Somerset/England (GB) – GB	OxA-17828	10,655	45	metacarpus	*Rangifer tarandus*	re-dating of OxA-1781	12,710-12,550	11
Hässleberga 1, Skåne (S) – SCA	LuA-4494	10,640	120	humerus	*Rangifer tarandus*		12,790-12,310	42
Nahe LA 11, Schleswig-Holstein (D) – NEP	*KIA-23369*	*10,610*	*80*	humerus	*Rangifer tarandus*	REJECT: humic acid; too little amount of carbon	×	48
Arreskov, Syddanmark (DK) – SCA	OxA-3173*	10,600	100	antler	*Rangifer tarandus*	club	12,750-12,310	32
Ossom's Cave, Staffordshire/England (GB) – GB	OxA-632	10,600	140	antler	*Rangifer tarandus*	spike	12,830-12,110	46
Chelm's Combe Shelter, Somerset/England (GB) – GB	*OxA-1781*	*10,600*	*200*	metacarpus	*Rangifer tarandus*	REJECT: redating available (OxA-17828)	×	11; 49
Hässleberga 1, Skåne (S) – SCA	LuA-4490	10,580	140	radius	*Rangifer tarandus*		12,810-12,090	41
Nahe LA 11, Schleswig-Holstein (D) – NEP	KIA-23372	10,544	49	antler/bone	*Rangifer tarandus*	with attached cranial bone	12,670-12,390	48
Bølling Sø, Midtjylland (DK) – SCA	K-7079	10,540	80	antler	*Rangifer tarandus*		12,740-12,220	24
Chelm's Combe Shelter, Somerset/England (GB) – GB	OxA-17831	10,480	45	mandible with teeth	*Rangifer tarandus*	re-dating of OxA-1784	12,650-12,210	11
Bjerremarks Gård, Sjælland (DK) – SCA	AAR-4210	10,450	70	antler	*Rangifer tarandus*		12,640-12,080	24
Gough's New Cave, Somerset/England (GB) – GB	OxA-1461	10,450	110	maxilla	*Rangifer tarandus*		12,710-11,990	27; 49
Hässleberga 2, Skåne (S) – SCA	LuA-4496	10,450	140	metatarsus	*Rangifer tarandus*		12,750-11,910	41

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Køge Bugt 3, Sjælland (DK) – SCA	K-4322	10,380	140	bone	*Rangifer tarandus*		12,690-11,770	24
Earl's Barton, Northamptonshire/England (GB) – GB	OxA-803	10,320	160	antler	*Rangifer tarandus*	artefact: Lyngby axe	12,690-11,530	50
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	Y-159.2	10,320	250	antler	*Rangifer tarandus*	PROBLEMATIC: large standard deviation	12,860-11,220	47-48
Nørregård, Hovedstaden (DK) – SCA	*K-4876*	*10,280*	*140*	antler	*Rangifer tarandus*	REJECT: unusually high $\delta^{13}C$ value	×	24
Hässleberga 1, Skåne (S) – SCA	Ua-3294	10,265	140	skull	*Rangifer tarandus*		12,610-11,450	41
Chelm's Combe Shelter, Somerset/England (GB) – GB	*OxA-1784*	*10,230*	*110*	mandible with teeth	*Rangifer tarandus*	REJECT: redating available (OxA-17831)	×	11; 49
Victoria Cave, North Yorkshire/England (GB) – GB	OxA-2453*	10,220	110	antler	*Rangifer tarandus*	artefact: double bevelled point	12,410-11,490	37
Chelm's Combe Shelter, Somerset/England (GB) – GB	BM-2431	10,220	130	tibia	*Rangifer tarandus*		12,500-11,380	27; 51
Hässleberga 1, Skåne (S) – SCA	LuA-4495	10,200	130	pelvis	*Rangifer tarandus*		12,450-11,330	41
Gough's Old Cave, Somerset/England (GB) – SCA	OxA-1120	10,190	120	antler	*Rangifer tarandus*		12,370-11,370	25
Chelm's Combe Shelter, Somerset/England (GB) – GB	BM-2318	10,190	130	radius	*Rangifer tarandus*		12,410-11,330	27; 51
Nahe LA 11, Schleswig-Holstein (D) – NEP	KIA-23370	10,172	45	antler/bone	*Rangifer tarandus*		12,120-11,680	48
Horsens, Nordjylland (DK) – SCA	K-7080	10,170	80	antler	*Rangifer tarandus*		12,210-11,490	24
Chelm's Combe Shelter, Somerset/England (GB) – GB	OxA-17829	10,150	40	mandible with teeth	*Rangifer tarandus*	re-dating of OxA-1782	12,110-11,630	11
Sun Hole, Somerset/England (GB) – GB	OxA-14827**	10,145	55	phalange	*Rangifer tarandus*	cutmarks	12,140-11,540	11; 38
Nahe LA 11, Schleswig-Holstein (D) – NEP	*KIA-23371*	*10,142*	*49*	antler/bone	*Rangifer tarandus*	REJECT: unusually high $\delta^{13}C$ value	12,120-11,560	48
Chelm's Combe Shelter, Somerset/England (GB) – GB	*OxA-1782*	*10,140*	*100*	mandible with teeth	*Rangifer tarandus*	REJECT: redating available (OxA-17829)	×	11; 49
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	K-4326	10,140	105	bone	*Rangifer tarandus*		12,260-11,300	22; 32
Kjelleklintegård, Sjælland (DK) – SCA	*K-7069*	*10,140*	*120*	antler	*Rangifer tarandus*	REJECT: unusually high $\delta^{13}C$ value	12,280-11,280	24
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	K-4327	10,130	105	antler	*Rangifer tarandus*	PROBLEMATIC: uncertain attribution	12,240-11,280	22; 32
Søhjem, Hovedstaden (DK) – SCA	K-4870	10,120	140	antler	*Rangifer tarandus*		12,300-11,220	24
Meiendorf? or Stellmoor, Schleswig-Holstein (D) – NEP	K-4330	10,110	85	bone	*Rangifer tarandus*	PROBLEMATIC: falsely labled?	12,180-11,300	22; 32
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	K-4262	10,110	105	antler	*Rangifer tarandus*		12,220-11,260	22; 32
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	K-4578	10,100	100	bone	*Rangifer tarandus*		12,180-11,260	22; 32

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Hässleberga 1, Skåne (S) – SCA	Ua-3295	10,055	80	skull	*Rangifer tarandus*		12,020-11,260	41
Strangegård, Hovedstaden (DK) – SCA	K-4871	10,050	130	antler	*Rangifer tarandus*		12,170-11,170	24
Dead Man's Cave, South Yorkshire/England (GB) – GB	OxA-5804*	10,020	80	phalange	*Rangifer tarandus*	PROBLEMATIC: either not associated with archaeology or too young date	11,940-11,220	43
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	K-4325	10,010	100	bone	*Rangifer tarandus*		11,990-11,190	22; 32
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	K-4581	9,990	105	antler	*Rangifer tarandus*		11,970-11,170	22: 32
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	K-4579	9,980	105	antler	*Rangifer tarandus*		11,960-11,160	22; 32
Grejsdalen, Midtjylland (DK) – SCA	K-7078	9,950	70	antler	*Rangifer tarandus*		11,780-11,180	24
Vedde, Sjælland (DK) – SCA	K-7077	9,940	100	antler	*Rangifer tarandus*		11,870-11,150	24
King Arthur's Cave, Herefordshire/England (GB) – GB	OxA-6839*	9,930	90	bone	*Rangifer tarandus*		11,800-11,160	1
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	K-4323	9,930	100	antler	*Rangifer tarandus*		11,860-11,140	22; 32
Soldier's Hole, Somerset/England (GB) – GB	BM-2249	9,930	210	metacarpus	*Rangifer tarandus*	PROBLEMATIC: large standard deviation	12,230-10,870	52
Gough's New Cave, Somerset/England (GB) – GB	Q-1581	9,920	130	antler	*Rangifer tarandus*		11,930-11,090	53
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	K-4324	9,900	105	antler	*Rangifer tarandus*		11,830-11,110	22; 32
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	K-4580	9,810	100	antler	*Rangifer tarandus*		11,550-11,030	22; 32
Dead Man's Cave, South Yorkshire/England (GB) – GB	BM-440 (b)	9,750	110	antler	*Rangifer tarandus*	PROBLEMATIC: unassociated with archaeology	11,480-10,760	54-55
Aveline's Hole, Somerset/England (GB) – GB	OxA-802	9,670	110	antler	*Rangifer tarandus*		11,380-10,700	50
Meiendorf pond, Schleswig-Holstein (D) – NEP	Y-158	9,540	130	antler	*Rangifer tarandus*	PROBLEMATIC: pretreatment procedure?	11,320-10,520	22; 47
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	W-262	9,500	200	bone	*Rangifer tarandus*	PROBLEMATIC: pretreatment procedure?, large standard deviation	11,410-10,290	22; 28
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	*Y-159*	*9,310*	*260*	antler	*Rangifer tarandus*	REJECT: insufficient pretreatment	11,380-9,900	47
Nørre Lyngby, Nordjylland (DK) – SCA	AAR-8919	9,110	65	antler	*Rangifer tarandus*	artefact: Lyngby axe	10,510-10,190	25; 45
Munzingen, Baden-Württemberg (D) – SU	*OxA-4789**	*9,080*	*80*	bone	*Rangifer tarandus*	REJECT: preservative glue	×	8
Meiendorf pond, Schleswig-Holstein (D) – NEP	*Y-158.1*	*7,060*	*400*	antler	*Rangifer tarandus*	REJECT: carbonate fraction	×	22; 47

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Meiendorf pond, Schleswig-Holstein (D) – NEP	*H-38-121C*	*6,150*	*500*	antler	*Rangifer tarandus*	REJECT: carbonate fraction	×	22; 31
Stellmoor, kettle hole, Schleswig-Holstein (D) – NEP	*Y-159.1*	*5,340*	*200*	antler	*Rangifer tarandus*	REJECT: residue	×	47
horse (*Equus* sp.), n = 140								
Wiesbaden-Igstadt, Hessen (D) – EU	OxA-7502	19,320	240	phalange 2	*Equus* sp.		23,660-22,580	2; 4
Wiesbaden-Igstadt, Hessen (D) – EU	OxA-7406	19,200	160	phalange 3	*Equus* sp.		23,550-22,510	2; 4
Wiesbaden-Igstadt, Hessen (D) – EU	OxA-6808*	19,080	160	shaft	*Equus* sp.?		23,540-22,380	2; 4
Wiesbaden-Igstadt, Hessen (D) – EU	UZ-3768 / ETH-13380	17,210	135	tibia	*Equus* sp.	PROBLEMATIC: singular date	21,090-20,290	2
Solutré, Saône-et-Loire/Bourgogne (F) – SEF	OxA-6730*	15,080	130	P3/ P4	*Equus* sp.	cutmarks; PROBLEMATIC: singular date	18,780-17,900	14
Solutré, Saône-et-Loire/Bourgogne (F) – SEF	OxA-6731*	14,570	130	calcaneum	*Equus* sp.	cutmarks	18,090-17,530	14
Solutré, Saône-et-Loire/Bourgogne (F) – SEF	OxA-13299**	14,565	60	maxilla	*Equus* sp.		18,010-17,610	56
Maszycka Cave, Małopolskie (PL) – SP	Ly-2453	14,520	240	bone	*Equus* sp.	PROBLEMATIC: large standard deviation	18,360-17,120	9-10
Kesslerloch, Schaffhausen (CH) – SEF	KIA-11828	13,858	55	radius	*Equus* sp.		17,130-17,010	13
Kniegrotte, Thüringen (D) – EU	OxA-4852*	13,520	130	lumbar vertebra	*Equus* sp.	cutmarks and fracture	17,120-16,400	16; 57
King Arthur's Cave, Herefordshire/England (GB) – GB	*OxA-6734**	*13,320*	*130*	M1/ M2	*Equus* sp.	REJECT: unusually low δ^{13}C value	×	11; 57
Kniegrotte, Thüringen (D) – EU	OxA-4846*	13,190	130	femur	*Equus* sp.	cutmarks and marrow fracture	16,880-15,520	16; 57
Nebra, Sachsen-Anhalt (D) – EU	OxA-11893**	13,160	60	humerus	*Equus* sp.		16,610-15,650	58-59
Kniegrotte, Thüringen (D) – EU	OxA-4848*	13,150	130	metatarsus	*Equus* sp.	cutmarks	16,790-15,470	16; 57
Geißenklösterle, Baden-Württemberg (D) – SU	OxA-6254*	13,130	100	bone	*Equus* sp.		16,650-15,530	57
Abri Stendel XVIII, Niedersachsen (D) – EU	OxA-10470	13,105	70	bone	*Equus* sp.		16,480-15,560	1; 57
Nebra, Sachsen-Anhalt (D) – EU	OxA-11892**	13,070	60	humerus	*Equus* sp.		16,320-15,560	58-59
Monruz, Sect. 1, lower layer, Neuchâtel (CH) – SEF	OxA-20699	13,055	60	bone	*Equus* sp.		16,300-15,540	60
Kesslerloch, Schaffhausen (CH) – SEF	KIA-11827	13,052	53	metacarpus 3	*Equus* sp.		16,270-15,550	13
Petersfels 1, AH 4, Baden-Württemberg (D) – SU	H-7142-7348	12,980	90	bone	*Equus* sp.		16,280-15,320	20
Abri Stendel XVIII, Niedersachsen (D) – EU	OxA-10494**	12,970	70	bone	*Equus* sp.		16,160-15,360	57
Saaleck, Sachsen-Anhalt (D) – EU	OxA-11891**	12,945	60	humerus	*Equus* sp.		15,930-15,370	58-59

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Gough's New Cave, Somerset/England (GB) – GB	*OxA-3413**	*12,940*	*140*	cervical vertebra	*Equus* sp.	cutmarks; REJECT: redating available (OxA-16292); unusually high δ^{13}C value	×	11; 27; 34
Kesslerloch, Schaffhausen (CH) – SEF	*KIA-11829*	*12,897*	*53*	metacarpus 3	*Equus* sp.	REJECT: unusually high δ^{13}C value	×	13
Teufelsbrücke, Thüringen (D) – EU	OxA-5722*	12,860	130	phalange 3	*Equus* sp.	white	16,080-15,080	16
Champréveyres, sect. 1, lower layer, Neuchâtel (CH) – SEF	OxA-20700	12,815	65	bone	*Equus* sp.		15,660-15,260	60
Champréveyres, sect. 1, lower layer, Neuchâtel (CH) – SEF	OxA-20701	12,805	75	bone	*Equus* sp.		15,660-15,220	60
Oelknitz, Thüringen (D) – EU	OxA-5716*	12,790	110	metacarpus 3	*Equus* sp.		15,780-15,020	16
Saaleck, Sachsen-Anhalt (D) – EU	OxA-11890**	12,780	60	metatarsus	*Equus* sp.		15,610-15,210	58-59
Kesslerloch, Schaffhausen (CH) – SEF	*KIA-11825*	*12,774*	*54*	phalange 1	*Equus* sp.	REJECT: unusually high δ^{13}C value	×	13
Oelknitz, Thüringen (D) – EU	OxA-5713*	12,740	120	phalange 2	*Equus* sp.	cutmarks	15,740-14,820	16
Keblice, Ústecký (CZ) – SU	GrA-37169	12,730	60	tooth	*Equus* sp.		15,530-15,090	61
Abri Fuchskirche, Thüringen (D) – EU	KIA-12928	12,721	65	metacarpus	*Equus* sp.		15,530-15,050	62
Gough's New Cave, Somerset/England (GB) – GB	OxA-11241	12,710	90	tooth	*Equus* sp.		15,590-14,910	57
Wallendorf-Weinberg, Sachsen-Anhalt (D) – EU	OxA-13849	12,685	55	femur	*Equus* sp.	formerly known as Friedensdorf and Kriegsdorf	15,450-15,010	58-59
Keblice, Ústecký (CZ) – SU	GrA-37168	12,680	50	tooth	*Equus* sp.		15,450-15,010	62
Petersfels 1, AH 3, Baden-Württemberg (D) – SU	H-7141-6985	12,680	110	teeth or mandible	*Equus* sp.		15,650-14,610	20
Gough's New Cave, Somerset/England (GB) – GB	*OxA-4106**	*12,670*	*120*	cervical vertebra	*Equus* sp.	cutmarks; REJECT: redating available (OxA-18068)	15,670-14,510	11; 27; 34
Oelknitz, Thüringen (D) – EU	OxA-8075	12,660	80	bone	*Equus* sp.		15,490-14,810	57
Oelknitz, Thüringen (D) – EU	OxA-8076	12,630	75	bone	*Equus* sp.		15,510-14,630	57
Ranis-Ilsenhöhle 5, Thüringen (D) EU	OxA-12052**	12,615	50	metatarsus	*Equus* sp.		15,390-14,830	58-59
King Arthur's Cave, Herefordshire/England (GB) – GB	OxA-17725	12,610	55	M1/ M2	*Equus* sp.		15,440-14,680	11
Sun Hole, Somerset/England (GB) – GB	*OxA-14476*	*12,610*	*90*	P4	*Equus* sp.	fractured; same dentary as OxA-14477; REJECT: too low % wt. coll.	×	11
Abri de la Fru, Savoie/Rhône-Alpes (F) – SEF	OxA-4408*	12,600	120	bone	*Equus* sp.		15,570-14,370	14
Gough's New Cave, Somerset/England (GB) – GB	OxA-16292	12,585	55	cervical vertebra	*Equus* sp.	cutmarks; redating of OxA-3413	15,440-14,560	11
Pixie's Hole, Devon/England (GB) – GB	OxA-14068	12,585	60	P3/ P4	*Equus* sp.	fractured	15,430-14,550	11
Gough's New Cave, Somerset/England (GB) – GB	OxA-17833	12,570	45	phalange 2	*Equus* sp.	cutmarks; redating of OxA-465	15,390-14,550	11
Mother Grundy's Parlour, Derbyshire/England (GB) – GB	OxA-19505	12,545	50	bone/tooth	*Equus* sp.		15,330-14,530	11

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Sun Hole, Somerset/England (GB) – GB	OxA-14438	12,545	55	tibia	*Equus* sp.	fractured	15,330-14,530	11
Mother Grundy's Parlour, Derbyshire/England (GB) – GB	OxA-4102*	12,540	140	premolar	*Equus* sp.		15,560-14,080	27; 34
Sun Hole, Somerset/England (GB) – GB	*OxA-14477*	*12,540*	*75*	M1	*Equus* sp.	same dentary as OxA-14476; high C/N ratio; REJECT: too low % wt. coll.	×	11
Gough's Old Cave, Somerset/England (GB) – GB	OxA-587	12,530	150	phalange 1	*Equus* sp.	cutmarks	15,560-14,040	27; 46; 63
Gough's New Cave, Somerset/England (GB) – GB	OxA-18068	12,520	55	cervical vertebra	*Equus* sp.	cutmarks; redating of OxA-4106	15,250-14,490	11
Kesslerloch, Schaffhausen (CH) – SEF	KIA-11826	12,502	52	metacarpus 3	*Equus* sp.		15,210-14,450	13
Gough's New Cave, Somerset/England (GB) – GB	*OxA-592*	*12,500*	*160*	metapodium	*Equus* sp.	same sample as BM-2187R; REJECT: amino acids of OxA-591	×	27; 46
Gough's Cave, Somerset/England (GB) – GB	OxA-12104	12,495	50	M1/ M2	*Equus* sp.		15,170-14,450	11; 27
Gough's Cave, Somerset/England (GB) – GB	OxA-18065	12,490	55	phalange 1	*Equus* sp.	cutmarks; redating of OxA-3452	15,200-14,360	11
Sun Hole, Somerset/England (GB) – GB	OxA-18705	12,490	45	M1	*Equus* sp.	cutmarks	15,170-14,450	11
Petersfels 1, AH 3, Baden-Württemberg (D) – SU	H-7137-7067	12,470	100	teeth	*Equus* sp.		15,320-14,080	20
Gough's New Cave, Somerset/England (GB) – GB	*OxA-464*	*12,470*	*160*	metacarpus	*Equus* sp.	cutmarks; REJECT: redating available (OxA-17832); unusually low $\delta^{13}C$ value	×	27; 64
Gough's New Cave, Somerset/England (GB) – GB	BM-2186R	12,470	240	metapodium	*Equus* sp.	PROBLEMATIC: large standard deviation	15,690-13,770	27; 53
Mother Grundy's Parlour, Derbyshire/England (GB) – GB	OxA-19504	12,455	55	bone/tooth	*Equus* sp.		15,180-14,180	11
Geißenklösterle, Baden-Württemberg (D) – SU	OxA-5158*	12,450	120	bone	*Equus* sp.		15,330-14,010	57
Hostim, Středočeský (CZ) – SU	Ly-1108	12,420	470	scapula and longbone	*Equus* sp.	PROBLEMATIC: large standard deviation	16,440-13,200	65
Gough's New Cave, Somerset/England (GB) – GB	OxA-17832	12,415	50	metacarpus	*Equus* sp.	cutmarks; redating of OxA-464	15,090-14,090	11
Gough's Cave, Somerset/England (GB) – GB	*OxA-3452**	*12,400*	*110*	phalange 1	*Equus* sp.	cutmarks; REJECT: redating available (OxA-18065)	×	11; 27; 34
Gough's New Cave, Somerset/England (GB) – GB	BM-2188R	12,380	230	metapodium	*Equus* sp.	PROBLEMATIC: large standard deviation	15,520-13,680	27; 53
Gough's New Cave, Somerset/England (GB) – GB	*OxA-590*	*12,370*	*150*	atlas	*Equus* sp.	cutmarks; same sample as BM-2183R; REJECT: amino acids of OxA-589	×	27; 46
Gough's New Cave, Somerset/England (GB) – GB	OxA-465	12,360	170	phalange 2	*Equus* sp.	cutmarks	15,340-13,780	11; 27; 63-64
Gough's New Cave, Somerset/England (GB) – GB	*BM-2183R*	*12,350*	*160*	atlas	*Equus* sp.	cutmarks; REJECT: same sample as OxA-589 and OxA-590	×	27; 53

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Gough's New Cave, Somerset/England (GB) – GB	OxA-589	12,340	150	atlas	*Equus* sp.	cutmarks; same sample as BM-2183R and OxA-590	15,260-13,780	27; 46
Mother Grundy's Parlour, Derby-shire/England (GB) – GB	OxA-3400*	12,340	110	premolar	*Equus* sp.		15,110-13,870	27; 34
Victoria Cave, North Yorkshire/England (GB) – GB	OxA-15078	12,325	50	atlas	Equus ferus	cutmarks	14,740-14,020	38
Mother Grundy's Parlour, Derby-shire/England (GB) – GB	OxA-19503	12,315	55	bone/tooth	*Equus* sp.		14,740-13,980	11
Gough's New Cave, Somerset/England (GB) – GB	*BM-2187R*	*12,300*	*200*	metapodium	*Equus* sp.	cutmarks; REJECT: same sample as OxA-591 and OxA-592	×	27; 53
Mother Grundy's Parlour, Derby-shire/England (GB) – GB	OxA-19507	12,280	50	bone/tooth	*Equus* sp.		14,630-13,950	11
Mother Grundy's Parlour, Derby-shire/England (GB) – GB	OxA-5698*	12,280	110	premolar	*Equus* sp.	incised/cutmarks	14,870-13,830	27; 43
Mother Grundy's Parlour, Derby-shire/England (GB) – GB	OxA-3398*	12,280	110	premolar	*Equus* sp.		14,870-13,830	27; 34
Oelknitz, Thüringen (D) – EU	OxA-5709*	12,270	120	metacarpus 3	*Equus* sp.	cutmarks	14,900-13,780	16
Gough's New Cave, Somerset/England (GB) – GB	OxA-591	12,260	160	metapodium	*Equus* sp.	same sample as BM-2187R and OxA-592	15,100-13,660	27; 46
Gough's New Cave, Somerset/England (GB) – GB	BM-2184R	12,250	160	calcaneum	*Equus* sp.		15,080-13,640	27; 53
Kent's Cavern, Devon/England (GB) – GB	OxA-5692*	12,250	110	metacarpus	*Equus* sp.	cutmarks; PROBLEMATIC: unusually low C/N ratio	14,820-13,780	27; 43
Kent's Cavern, Devon/England (GB) – GB	OxA-8002	12,240	100	tooth	*Equus* sp.	cutmarks	14,770-13,770	1; 27; 57
King Arthur's Cave, Herefordshire/Eng-land (GB) – GB	OxA-6733*	12,230	100	molar	*Equus* sp.	intentionally fractured	14,730-13,770	27; 57
Three Holes Cave, lower hearth, Devon/England (GB) – GB	OxA-4494*	12,220	110	P2	*Equus* sp.		14,760-13,720	66
Robin Hood's Cave, Derbyshire/England (GB) – GB	OxA-6324*	12,210	100	bone	*Equus* sp.		14,630-13,750	57
Gough's New Cave, Somerset/England (GB) – GB	BM-2185R	12,200	250	metapodium	*Equus* sp.	PROBLEMATIC: large standard deviation	15,350-13,390	27; 53
Petersfels 1, AH 3, Baden-Württemberg (D) – SU	H-7139-7300	12,180	100	front limb	*Equus* sp.		14,470-13,750	20
Mother Grundy's Parlour, Derby-shire/England (GB) – GB	OxA-8739	12,170	80	premolar	*Equus* sp.	transversely fractured	14,290-13,810	1; 27; 57
Mother Grundy's Parlour, Derby-shire/England (GB) – GB	OxA-19506	12,155	50	bone/tooth	*Equus* sp.		14,180-13,860	11
King Arthur's Cave, Herefordshire/Eng-land (GB) – GB	OxA-6732*	12,150	100	tooth	*Equus* sp.		14,330-13,730	57

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Three Holes Cave, lower hearth, Devon/England (GB) – GB	*OxA-3890**	*12,150*	*110*	tooth	*Equus* sp.	fractured (snapped); REJECT: unusually low δ^{13}C value	14,410-13,690	27; 66
Oelknitz, Thüringen (D) – EU	OxA-5710*	12,080	110	metatarsus 3	*Equus* sp.	cutmarks	14,230-13,670	16
Oelknitz, Thüringen (D) – EU	OxA-5711*	12,050	110	metacarpus 4	*Equus* sp.	cutmarks	14,180-13,660	16
Mother Grundy's Parlour, Derbyshire/England (GB) – GB	OxA-6666*	12,040	80	tooth	*Equus* sp.		14,090-13,690	57
Buttentalhöhle, Baden-Württemberg (D) – SU	OxA-4981*	12,040	120	bone	*Equus* sp.		14,190-13,630	57
Fox Hole Cave, Derbyshire/England (GB) – GB	OxA-6311*	12,030	90	bone	*Equus* sp.		14,110-13,670	57
King Arthur's Cave, Herefordshire/England (GB) – GB	OxA-6631*	12,000	80	tooth	*Equus* sp.		14,060 1 13,660	57
Mother Grundy's Parlour, Derbyshire/England (GB) – GB	OxA-8738	11,970	75	premolar	*Equus* sp.	transversely fractured	14,010-13,630	1; 57
Three Holes Cave, Devon/England (GB) – GB	OxA-1499	11,970	150	tooth	*Equus* sp.	lower hearth?	14,200-13,480	17
Fox Hole Cave, Derbyshire/England (GB) – GB	OxA-6310*	11,920	130	bone	*Equus* sp.		14,090-13,450	57
Endingen, Horst VI, Mecklenburg-Vorpommern (D) – NEP	UtC-5681	11,830	50	rib	*Equus* sp.	artefact: blade-like shaped rib	13,790-13,510	67
Oelknitz, Thüringen (D) – EU	OxA-5715*	11,810	110	metacarpus 3	*Equus* sp.		13,860-13,420	16; 57
Dead Man's Cave, South Yorkshire/England (GB) – GB	OxA-6326*	11,800	100	bone	*Equus* sp.		13,830-13430	57
Kent's Cavern, Devon/England (GB) – GB	OxA-8003	11,800	180	tooth	*Equus* sp.		14,050-13,250	57; 68
Dead Man's Cave, South Yorkshire/England (GB) – GB	OxA-6327*	11,630	100	bone	*Equus* sp.		13,710-13,230	57
Sun Hole, Somerset/England (GB) – GB	OxA-4986*	11,530	120	M1	*Equus* sp.		13,610-13,130	66
Petersfels 3, AH 2/3, Baden-Württemberg (D) – SU	H-4741-4145	11,300	85	vertebra	*Equus* sp.		13,310-12,990	20
Hässleberga 1, Skåne (S) – SCA	Ua-3969	11,190	100	skull	*Equus* sp.		13,270-12,830	41
Hässleberga 1, Skåne (S) – SCA	Ua-3293	11,180	95	mandible	*Equus* sp.		13,240-12,840	41
Moughton Fell Cave, North Yorkshire/England (GB) – GB	OxA-6321*	11,070	100	bone	*Equus* sp.		13,140 12,700	57
Fox Hole Cave, Derbyshire/England (GB) – GB	OxA-6312*	10,980	90	bone	*Equus* sp.		13,040-12,680	57
Ossom's Cave, Staffordshire/England (GB) – GB	OxA-6316*	10,920	90	tooth	*Equus* sp.		13,010-12,650	57
Bridget Pot Shelter, Somerset/England (GB) – GB	OxA-6632*	10,810	75	bone	*Equus* sp.		12,830-12,630	57
Hässleberga 1, Skåne (S) – SCA	Ua-4763	10,725	110	skull	*Equus* sp.		12,810-12,450	41

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Sewell's Cave, North Yorkshire/England (GB) – GB	OxA-6636*	10,715	75	bone	*Equus* sp.		12,760-12,560	57
Hässleberga 2, Skåne (S) – SCA	LuA-4497	10,610	130	radius	*Equus* sp.		12,810-12,170	41
Robin Hood's Cave, Derbyshire/England (GB) – GB	BM-604	10,590	90	humerus	*Equus* sp.		12,740-12,340	69
Hässleberga 2, Skåne (S) – SCA	Ua-4765	10,510	95	tibia	*Equus* sp.		12,740-12,100	41
Hässleberga 2, Skåne (S) – SCA	Ua-4764	10,495	95	pelvis	*Equus* sp.		12,730-12,090	41
Robin Hood's Cave, Derbyshire/England (GB) – GB	OxA-6323*	10,460	90	bone	*Equus* sp.		12,690-12,050	57
Kaster, Nordrhein-Westfalen (D) – NEP	OxA-1392 (OxA-78?)	10,380	140	bone	*Equus* sp.	PROBLEMATIC: disturbed context	12,690-11,770	17; 57
Chelm's Combe Shelter, Somerset/England (GB) – GB	OxA-1785	10,370	110	metacarpal	*Equus* sp.		12,610-11,890	49
Sproughton, Devil's Wood Pit, Suffollk/England (GB) – GB	OxA-6315*	10,290	100	bone	*Equus* sp.		12,530-11,690	57
Three Ways Wharf, Scatter A, Greater London/England (GB) – GB	OxA-1788	10,270	100	molar	*Equus* sp.		12,490-11,650	70
Aveline's Hole, Somerset/England (GB) – GB	*OxA-6671**	*10,220*	*90*	tooth	*Equus* sp.	REJECT: unusually low δ^{13}C value and high C/N	×	57
Flixton 2, North Yorkshire/England (GB) – GB	OxA-6319*	10,150	80	bone	*Equus* sp.		12,190-11,430	57
Flixton 2, North Yorkshire/England (GB) – GB	OxA-6328*	10,150	90	bone	*Equus* sp.		12,220-11,380	57
Wolf's Den, Somerset/England (GB) – GB	OxA-6633*	10,125	70	bone	*Equus* sp.		12,150-11,390	57
Flixton 2, North Yorkshire/England (GB) – GB	OxA-6318*	10,090	90	bone	*Equus* sp.		12,150-11,270	57
Teufelsbrücke, Thüringen (D) – EU	OxA-5727*	10,040	120	mandible	*Equus* sp.	white; PROBLEMATIC: very young for the context	12,130-11,170	16; 57
Three Ways Wharf, Scatter A, Greater London/England (GB) – GB	OxA-1902	10,010	120	mandible	*Equus* sp.		12,050-11,170	70
Kendrick's Cave, Conwy/Wales (GB) – GB	OxA-111	10,000	200	mandible	*Equus* sp.	artefact: engraved mandible; PROBLEMATIC: very young for context and large standard deviation	12,290-11,010	64
Flixton 2, North Yorkshire/England (GB) – GB	*OxA-6329**	*9,160*	*80*	bone	*Equus* sp.	REJECT: unusually high C/N ratio	×	57
Wustermark 22, Brandenburg (D) – NEP	?	9,135	75	metatarsus	*Equus* sp.	PROBLEMATIC: disturbed context in alluvial deposits	10,560-10,200	71
Wilczyce, Świętokrzyskie (PL) – SP	*Ua-15721*	*8,415*	*100*	*bone*	Equus *sp.*	Artefact; REJECT: stratigraphic position not in accordance	×	72

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Victoria Cave, North Yorkshire/England (GB) – GB	*OxA-6634**	*1,740*	*40*	*bone*	Equus *sp.*	REJECT: unusually low δ^{13}C value and high C/N	×	57
Gough's Cave, Somerset/England (GB) – GB	*OxA-6668**	*1,190*	*40*	*astralagus*	Equus *sp.*	cutmarks; REJECT: unusually low δ^{13}C value	×	27
Bromme, Sjælland (DK) – SCA	*AAR-4540*	*1,040*	*65*	*tooth*	Equus *sp.*	REJECT: unusually low δ^{13}C value; apparently too young and no association with archaeology	×	73
Mirkowice 33, Wielkopolskie (PL) – NEP	*UtC-8492*	*165*	*32*	*premolar*	Equus *sp.*	REJECT: apparently too young and association uncertain	×	22; 74
elk (*Alces alces*), n=21								
High Furlong, Lancashire/England (GB) – GB	*OxA-X-2100-6*	*24,410*	*100*	*metacarpus*	*Alces alces*	REJECT: extracted humics/preservatives; non-routine chemistry	×	38
High Furlong, Lancashire/England (GB) – GB	*OxA-151*	*21,500*	*250*	*metatarsus*	*Alces alces*	artefact: barbed point; REJECT: extracted humics/preservatives	×	64
High Furlong, Lancashire/England (GB) – GB	*OxA-X-2066-43*	*16,100*	*70*	*metacarpus*	*Alces alces*	REJECT: extracted humics/preservatives; non-routine chemistry	×	38
High Furlong, Lancashire/England (GB) – GB	*OxA-150*	*12,400*	*300*	*metatarsus*	*Alces alces*	REJECT: amino-acids, presumably contaminated	×	64
Arrie, Skåne (S) – SCA	*St-13310*	*12,390*	*150*	*metatarsus*	*Alces alces*	REJECT: redating available (LuS-7685)	×	25
Abri Fuchskirche, Thüringen (D) – EU	KIA-12926	12,232	50	P4	*Alces alces*		14,320-13,960	62
Abri Fuchskirche, Thüringen (D) – EU	KIA-12925	12,158	50	M3	*Alces alces*		14,180-13,860	62
Vonsmose, Midtjylland (DK) – SCA	K-6124	11,770	190	bone	*Alces alces*		14,030-13,190	25
Borneck Kammer III, Schleswig-Holstein (D) – NEP	KIA-33950	11,770	55	tibia	*Alces alces*		13,750-13,470	35
High Furlong, Lancashire/England (GB) – GB	OxA-13075**	11,715	50	metacarpus	*Alces alces*		13,710-13,430	38
High Furlong, Lancashire/England (GB) – GB	OxA-11151	11,660	60	metacarpus	*Alces alces*	PROBLEMATIC: non-routine chemistry	13,680-13,320	38
Bart's Shelter, Cumbria/England (GB) – GB	OxA-11646	11,600	70	P3 / P4	*Alces alces*		13,580-13,260	38
Braunsbedra, Sachsen-Anhalt (D) – EU	OxA-13283**	11,400	45	antler	*Alces alces* ?	artefact: fish hook	13,340-13,140	58-59
Arrie, Skåne (S) – SCA	LuS-7685	11,345	70	metatarsus	*Alces alces*	re-dating of St-13310	13,320-13,040	25
Coniston(e) Dib, North Yorkshire (GB) – GB	OxA-2847*	11,210	90	bone	*Alces alces* ?	artefact: point	13,260-12,900	37-38
Hässleberga 2, Skåne (S) – SCA	LuA-3969	11,040	130	skull	*Alces alces*		13,150-12,670	41
Klein Nordende D, Schleswig-Holstein (D) – NEP	KIA-33951	11,035	50	femur	*Alces alces*		13,050-12,730	35
Berlin-Tiergarten, Berlin (D) – NEP	KIA-4937	10,730	40	bone	*Alces alces*		12,740-12,620	75

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Bromme, Sjælland (DK) – SCA	*AAR-4539*	*10,720*	*90*	lumbar verterbra	*Alces alces*	REJECT: too small amount of carbon; minimum age	×	73
Wustermark 22, Brandenburg (D) – NEP	?	10,005	70	antler	*Alces alces*	artefact; PROBLEMATIC: disturbed context in alluvial deposits	11,870-11,230	71
Meiendorf pond, Schleswig-Holstein (D) – NEP	*KIA-33952*	*6,900 (c.)*	*200 (c.)*	bone	*Alces alces*	REJECT: too small amount of carbon; unusually low δ^{13}C value	×	35
wild boar (*Sus scrofa*) / domestic pig (*Sus scrofa domesticus*), n=3								
Wustermark 22, Brandenburg (D) – NEP	unknown	11,720	45	femur	*Sus scrofa*	PROBLEMATIC: disturbed context in alluvial deposits	13,720-13,440	71
Pin Hole, Derbyshire/England (GB) – GB	*OxA-1469*	*3,750*	*80*	bone	*Sus scrofa domesticus*	REJECT: Holocene admixture	×	17
Gough's New Cave, Somerset/England (GB) – GB	*OxA-815*	*1,740*	*60*	bone	*Sus scrofa domesticus*	REJECT: Holocene admixture	×	50
red deer (*Cervus elaphus*), n=36								
Solutré, Saône-et-Loire/Bourgogne (F) – SEF	OxA-13298**	19,740	90	calcaneum	*Cervus elaphus*	PROBLEMATIC: only red deer remain in the assemblage	23,950-23,350	56
Gough's New Cave, Somerset/England (GB) – GB	*OxA-466*	*12,800*	*170*	metatarsal	*Cervus elaphus*	cutmarks; REJECT: unusually low δ^{13}C value	×	11; 27; 63-64
Aveline's Hole, Somerset/England (GB) – GB	OxA-17722	12,565	50	phalange 2	*Cervus elaphus*	cutmarks; possibly redating of OxA-1121	15,380-14,540	11
Gough's New Cave, Somerset/England (GB) – GB	OxA-16378	12,515	50	metatarsal	*Cervus elaphus*	cutmarks; redating of OxA-466	15,220-14,500	11
Gough's New Cave, Somerset/England (GB) – GB	OxA-17845	12,500	50	phalange 2	*Cervus elaphus* (formerly bovid)	cutmarks; redating of OxA-1071	15,190-14,470	11
Gough's New Cave, Somerset/England (GB) – GB	*OxA-3412**	*12,490*	*120*	tibia	*Cervus elaphus*	cutmarks; REJECT: redating available (OxA-18067)	15,420-14,060	11; 27; 34
Aveline's Hole, Somerset/England (GB) – GB	OxA-1121	12,380	130	phalange	*Cervus elaphus* (previously: bovid)	cutmarks; possibly redating available (OxA-17722)	15,250-13,890	26-27
Kesslerloch, Schaffhausen (CH) – SEF	KIA-33351	12,335	45	calcaneus	*Cervus elaphus*		14,730-14,050	13
Ossom's Cave, Staffordshire/England (GB) – GB	OxA-15215	12,310	50	bone/antler	*Cervus elaphus*		14,710-13,990	76
Gough's New Cave, Somerset/England (GB) – GB	*OxA-1071*	*12,300*	*180*	phalange 2	*Cervus elaphus* (previously bovid)	cutmarks; REJECT: redating available (OxA-17845)	15,290-13,650	11; 26-27
Kent's Cavern, Devon/England (GB) – GB	OxA-13683**	12,270	45	metacarpus	*Cervus elaphus*	cutmarks	14,500-13,980	38
King Arthur's Cave, Herefordshire/England (GB) – GB	OxA-6844*	12,250	100	bone	*Cervus elaphus*		14,790-13,790	1
Abri de Rochedane, Doubs, Franche-Comté (F) – SEF	GrA-21512	12,250	70	radius	*Cervus elaphus*		14,600-13,880	77

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Gough's New Cave, Somerset/England (GB) – GB	OxA-18067	12,245	55	tibia	*Cervus elaphus*	cutmarks; redating of OxA-3412	14,420-13,940	11
King Arthur's Cave, Herefordshire/England (GB) – GB	OxA-1563	12,210	120	tooth	*Cervus elaphus*		14,770-13,690	17
King Arthur's Cave, Herefordshire/England (GB) – GB	OxA-1562	12,120	120	tooth	*Cervus elaphus*		14,370-13,650	17
Aveline's Hole, Somerset/England (GB) – GB	OxA-801	12,100	180	antler	*Cervus elaphus*		14,760-13,480	27; 50
Pixie's Hole, Devon/England (GB) – GB	OxA-5796*	12,070	90	pelvis	*Cervus elaphus*	associated with hearth	14,160-13,680	16; 78
Three Holes Cave, lower hearth, Devon/England (GB) – GB	OxA-3891*	11,980	100	metatarsus	*Cervus elaphus*	fractured	14,060-13,620	27; 43
Plunkett Cave, Keshcorran Caves, Sligo (IRL) – GB	OxA-3693*	11,790	120	bone	*Cervus elaphus*		13,840-13,400	14
Abri de Rochedane, Doubs, Franche-Comté (F) – SEF	GrA-21516	11,600	80	metatarsus	*Cervus elaphus*		13,600-13,240	77
Abri de Rochedane, Doubs, Franche-Comté (F) – SEF	GrA-21514	11,570	70	metatarsus	*Cervus elaphus*		13,560-13,240	77
Porth-y-Waen, Shropshire/England (GB) – GB	OxA-1946	11,390	120	bone/antler?	*Cervus elaphus*?	artefact: barbed point, one row	13,500-12,980	49
Hyaena Den, Wookey Hole, Somerset/England (GB) – GB	OxA-5700*	11,320	120	phalange 2	*Cervus elaphus*		13,390-12,950	43
Lemförde am Dümmer, Niedersachsen (D) – NEP	Hv-14972	10,955	315	antler	*Cervus elaphus*	artefact: point; PROBLEMATIC: only red deer remain in N-Germany before the Holocene	13,440-12,200	79
Chelm's Combe Shelter, Somerset/England (GB) – GB	OxA-1783	10,910	110	mandible	*Cervus elaphus*		13,030-12,630	49
Abri de Rochedane, Doubs, Franche-Comté (F) – SEF	GrA-23147	10,880	50	metatarsus	*Cervus elaphus*		12,900-12,660	77
Abri de Rochedane, Doubs, Franche-Comté (F) – SEF	GrA-23150	10,880	50	metatarsus	*Cervus elaphus*		12,900-12,660	77
Abri de Rochedane, Doubs, Franche-Comté (F) – SEF	GrA-21518	10,830	70	metatarsus	*Cervus elaphus*		12,840-12,640	77
Elderbush Cave, Staffordshire (GB) – GB	OxA-811	10,600	110	vertebra and ribs	*Cervus elaphus*	cutmarks; PROBLEMATIC: uncertain conservation history	12,770-12,250	50
Hyaena Den, Wookey Hole, Somerset/England (GB) – GB	OxA-6728*	10,460	90	tooth	*Cervus elaphus*		12,690-12,050	4
Three Holes Cave, upper hearth, Devon/England (GB) – GB	OxA-4478*	10,020	80	humerus	*Cervus elaphus*	PROBLEMATIC: unusually high δ^{13}C value	11,940-11,220	43
Elderbush Cave, Staffordshire/England (GB) – GB	*OxA-812*	*9,000*	*130*	bone/charcoal?	*Cervus elaphus*?	REJECT: sample material is questionable	10,510-9,750	50
Abri de Rochedane, Doubs, Franche-Comté (F) – SEF	GrA-21519	8,640	60	metatarsus	*Cervus elaphus*	PROBLEMATIC: unusually low δ^{13}C value	9,810 -9,530	77

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Three Holes Cave, Devon/England (GB) – GB	OxA-4491*	6,330	75	bone	*Cervus elaphus*	PROBLEMATIC: Neolithic intrusion?	7,490-7,130	43
Three Holes Cave, Devon/England (GB) – GB	OxA-4492*	6,120	75	bone	*Cervus elaphus*	PROBLEMATIC: Neolithic intrusion?	7,300-6,820	43
large bovids (*Bison priscus* / *Bos* sp. / *Bos primigenius*), n=31								
Soldier's Hole, Somerset/England (GB) – GB	OxA-649	19,300	400	tibia	*Bos* sp.	PROBLEMATIC: singular date	24,100-22,260	50
Ranis-Ilsenhöhle 4, Thüringen (D) – EU	OxA-12049**	14,780	60	humerus	*Bos* sp. / *Bison* sp.	PROBLEMATIC: singular date and disturbed context	18,720 -17,720	58-59
Pin Hole, Derbyshire/England (GB) – GB	OxA-1615	12,480	160	astralagus	*Bos primigenius*		15,510-13,950	17; 27
Kent's Cavern, Devon/England (GB) – GB	OxA-7994	12,430	80	bone/teeth	*Bos primigenius*	cutmarks	15,210-14,050	27; 68
Kendrick's Cave, Conwy/Wales (GB) – GB	OxA-6146*	12,410	100	bone	*Bos* sp. / *Bison* sp.	PROBLEMATIC: uncertain association	15,230-13,990	80
Pin Hole, Derbyshire/England (GB) – GB	OxA-1471	12,400	140	astragalus	*Bos primigenius*		15,300-13,900	17; 27
Bob's Cave, Devon/England (GB) – GB	OxA-5860*	12,380	90	astralagus	*Bos primigenius*	cutmarks	15,130-13,970	27
Bob's Cave, Devon/England (GB) – GB	OxA-5861*	12,290	90	phalange	*Bos primigenius*	cutmarks	14,810-13,890	27; 81
Holywell Coombe, Kent/England (GB) – GB	OxA-1752	12,280	140	scapula	*Bos primigenius*		15,050-13,730	82
Mother Grundy's Parlour, Derbyshire/England (GB) – GB	OxA-734	12,190	140	bone	*Bos* sp. / *Bison* sp.	found in hearth context	14,820-13,620	50
Mother Grundy's Parlour, Derbyshire/England (GB) – GB	OxA-733	12,060	160	bone	*Bos* sp. / *Bison* sp.	found in hearth context	14,420-13,540	50
Abri Fuchskirche, Thüringen (D) – EU	KIA-12927	12,030	52	radius	*Bos primigenius*		14,030-13,710	62
Gough's New Cave, Somerset/England (GB) – GB	OxA-588	12,030	150	phalange	*Bos primigenius*		14,280-13,560	27; 46; 63
Pixie's Hole, Devon/England (GB) – GB	OxA-5795*	11,910	90	metacarpus	*Bos* sp.		13,990-13,510	16
Gough's New Cave, Somerset/England (GB) – GB	OxA-813	11,900	140	astragalus	*Bos primigenius*		14,090-13,410	27; 50
Kent's Cavern, Devon/England (GB) – GB	OxA-1203	11,880	120	mandible	*Bos primigenius*		14,000-13,440	83
Kent's Cavern, Devon/England (GB) – GB	BM-2168R	11,800	420	atlas	*Bos* sp. / *Bison* sp.	PROBLEMATIC: large standard deviation	15,160-12,680	19
Pixie's Hole, Devon/England (GB) – GB	OxA-5794*	11,630	120	scapula	*Bos* sp.	scratch marks, spiral breakage; PROBLEMATIC: uncertain association	13,750-13,190	16; 78
Kent's Cavern, Devon/England (GB) – GB	BM-2168	11,570	410	atlas	*Bos* sp. / *Bison* sp.	PROBLEMATIC: large standard deviation	14,450-12,610	52
Pin Hole, Derbyshire/England (GB) – GB	OxA-1937	10,970	110	tibia	*Bos primigenius*	PROBLEMATIC: younger admixture or contaminated?	13,060-12,660	17

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Berzdorf, Sachsen (D) – EU	KIA 15252-2	10,810	50	skull	*Bos primigenius*		12,770-12,650	84
Berzdorf, Sachsen (D) – EU	KIA 15252-1	10,750	35	skull	*Bos primigenius*		12,730-12,650	84
Bedburg-Königshoven, Nordrhein-Westfalen (D) – NEP	*KN-4138*	*10,670*	*100*	skull	*Bos primigenius*	REJECT: from Preboreal peat	12,770-12,410	1; 85
Bedburg-Königshoven, Nordrhein-Westfalen (D) – NEP	KN-4137	10,290	100	skull	*Bos primigenius*		12,530-11,690	85
Bedburg-Königshoven, Nordrhein-Westfalen (D) – NEP	KN-4139	10,140	100	skull	*Bos primigenius*		12,240-11,320	85
Bedburg-Königshoven, Nordrhein-Westfalen (D) – NEP	KN-4136	10,020	100	rib	*Bos primigenius*		12,000-11,200	85
Mother Grundy's Parlour, Derbyshire/England (GB) – GB	*OxA-3399**	*9,910*	*90*	premolar	*Bos* sp. / *Bison* sp.	REJECT: unusually high δ^{13}C value	11,780-11,140	34
Bedburg-Königshoven, Nordrhein-Westfalen (D) – NEP	KN-4135	9,740	100	rib	*Bos primigenius*		11,450-10,770	1; 85
Mother Grundy's Parlour, Derbyshire/England (GB) – GB	*OxA-3395*	*8,480*	*95*	bone	*Bos* sp.	PROBLEMATIC: unusually low δ^{13}C value; REJECT: charred	9,680-9,320	34
Three Holes Cave, Devon/England (GB) – GB	OxA-4493*	5,060	70	tooth	*Bos primigenius*		6,010-5,690	66
Broken Cavern, Devon/England (GB) – GB	OxA-3207*	5,015	80	tooth	*Bos taurus*	juvenile	6,010-5,610	66
Three Holes Cave, Devon/England (GB) – GB	OxA-4495*	5,010	70	tooth	*Bos primigenius*		5,990-5,630	66
Ossom's Cave, Staffordshire/England (GB) – GB	OxA-629	2,030	80	tibia	*Bos* sp. / *Bison* sp.	cutmarks	2,250-1,850	46
others, n=16								
Boltinggaards Skov, Sjælland (DK) – SCA	AAR-1977	14,040	200	bone	*Saiga tatarica*	PROBLEMATIC: large standard deviation	17,720-16,920	25
Boltinggaards Skov, Sjælland (DK) – SCA	AAR-1456	13,880	140	bone	*Saiga tatarica*		17,410-16,890	25
Ranis-Ilsenhöhle 2, Thüringen (D) – EU	OxA-12047**	13,450	60	femur	*Capreolus capreolus*	PROBLEMATIC: species determination roe deer or saiga?	16,980-16,540	58-59
Wilczyce, Świętokrzyskie (PL) – SP	Oxa-16728	13,180	60	tooth	*Alopex lagopus*	artefact: drilled; PROBLEMATIC: uncertain association; sunken into ice wedge	16,650-15,690	86
Kniegrotte, Thüringen (D) – EU	OxA-4850*	13,160	140	tibia	*Alopex lagopus*	cutmarks	16,830-15,470	16
Kniegrotte, Thüringen (D) – EU	OxA-4849*	13,130	120	cranium/horn core	*Saiga tatarica*		16,720-15,480	16
Kniegrotte, Thüringen (D) – EU	OxA-4853*	13,090	130	skull/cranium	*Saiga tatarica*		16,680-15,400	16

Tab. 80 (continued)

site	lab. no.	years ^{14}C-BP	± years	material	species	comment	years cal. b2k	ref.
Gough's New Cave, Somerset/England (GB) – GB	OxA-1200	12,400	110	mandible, partial	*Alopex lagopus*		15,230-13,950	27; 63; 83
Gough'sNew Cave, Somerset/England (GB) – GB	OxA-463	12,380	160	calcaneum	*Saiga tatarica*	unmodified	15,340-13,820	27; 64
Reichwalde 5049, Sachsen (D) – NEP	*GrA-15437*	*12,350*	*50*	bone	*Capreolus* sp.	REJECT: calcined	×	87
Soldier'sHole, Somerset/England (GB) – GB	OxA-1464	12,100	140	metacarpal	*Saiga tatarica*		14,440-13,600	17
Wilczyce, Świętokrzyskie (PL) – SP	Ua-15723	11,890	105	bone	*Alopex lagopus*	PROBLEMATIC: uncertain association; sunken into ice wedge	13,990-13,470	72
Kendrick's Cave, Conwy/Wales (GB) – GB	OxA-6116*	11,795	65	bone	*Capreolus capreolus*	artefact: ochre-stained & engraved tally	13,760-13,480	80
Wilczyce, Świętokrzyskie (PL) – SP	Ua-15722	11,665	135	tooth	*Castor fiber*	PROBLEMATIC: uncertain association; sunken into ice wedge	13,800-13,200	72
Kesslerloch, Schaffhausen (CH) – SEF	KIA-33352	9,920	40	metacarpus	*Capreolus capreolus*	PROBLEMATIC: Holocene admixture?	11,520-11,240	13
Gough's Old Cave, Somerset/England (GB) – GB	OxA-1119	9,320	120	bone	*Castor fiber*	PROBLEMATIC: Holocene admixture	10,920 -10,240	26

Tab. 80 (continued)

HUMAN BEHAVIOUR AND CHRONOLOGY

In the following, results of the analysed archaeological material are described. The chronological relation of the assemblages represents an important issue since only a reliable chronological succession of the assemblages allows for considerations about interrelations of the sites and causal connections with the climatic and environmental changes.

Chronologies of the analysed sites

For most of the studied sites, the chronology was clear and outlined in the previous presentation of the material (see Material-Archaeology, p. 75-244). However, for some assemblages the internal chronology required further discussion after the evaluation and calibration of the ^{14}C dates. The chronological order of the sites is of major interest since it is the base for the establishment of sub-steps in the transition from the Late Magdalenian to the FMG.

Central Rhineland

This project started in the Central Rhineland where 12 Lateglacial complexes were recovered from ten sites. These complexes consisted of several concentrations at Andernach, Gönnersdorf, Kettig, and Niederbieber. Problems regarding the internal chronology at these multi-concentration sites were previously discussed. For a comparison within a process of behavioural change, the possibility of different accumulation periods for these complexes ranging between days and centuries must be kept in mind.
The oldest complexes were assigned to the Late Magdalenian at Gönnersdorf and the lower horizon of Andernach. The general chronological position of Gönnersdorf was relatively undisputed, even though the internal chronology remained unclear. A separate phase within concentration I was considered possible due to material refitting, seasonal indicators, and the ^{14}C ages from this area that tend to be younger than in the other concentrations (see **tab. 20**). However, the more recently published faunal analysis qualified the previous seasonal indicators as incomplete and revealed that activities within concentration I were indeed related to the other concentrations at the site (Street/Turner 2013). The calibrated ^{14}C dates from Gönnersdorf form a consistent set (**fig. 65**) with significant overlap of the probability distributions if separated by concentration. Consequently, the four main concentrations of Gönnersdorf are indistinguishable on a general chronostratigraphic level and must be considered as quasi-contemporaneous.
The results from the lower horizon in Andernach are as comparably indistinguishable as the Late Magdalenian at Gönnersdorf. Although the spatial analysis suggested two possible phases, the environmental indicators and the stratigraphic evidence made a chronological distinction impossible. Moreover, the 15 reliable Late Magdalenian dates scatter evenly across the concentrations I-III. In a χ^2-test, fourteen of these dates are consistent with a single event with a weighted mean of 13,080 ± 25 ^{14}C-BP ($p = 18.0\,\%$). The fifteenth date is a recently dated sample of horse recovered from a pit in concentration III (OxA-V-2223-37) and statistically compatible with the next youngest Late Magdalenian date (OxA-1127, **tab. 20**; Stevens et al. 2009b, 140). However, this young date is younger than the majority of the other reliable dates and also significantly older than the next youngest reliable date (OxA-V-2218-39). After calibration this young Late Magdalenian result overlaps with the calibrated age ranges of several other Late Magdalenian dates but is still inconsistent with the five oldest results. These older results were mainly found in concentration II, whereas the younger results

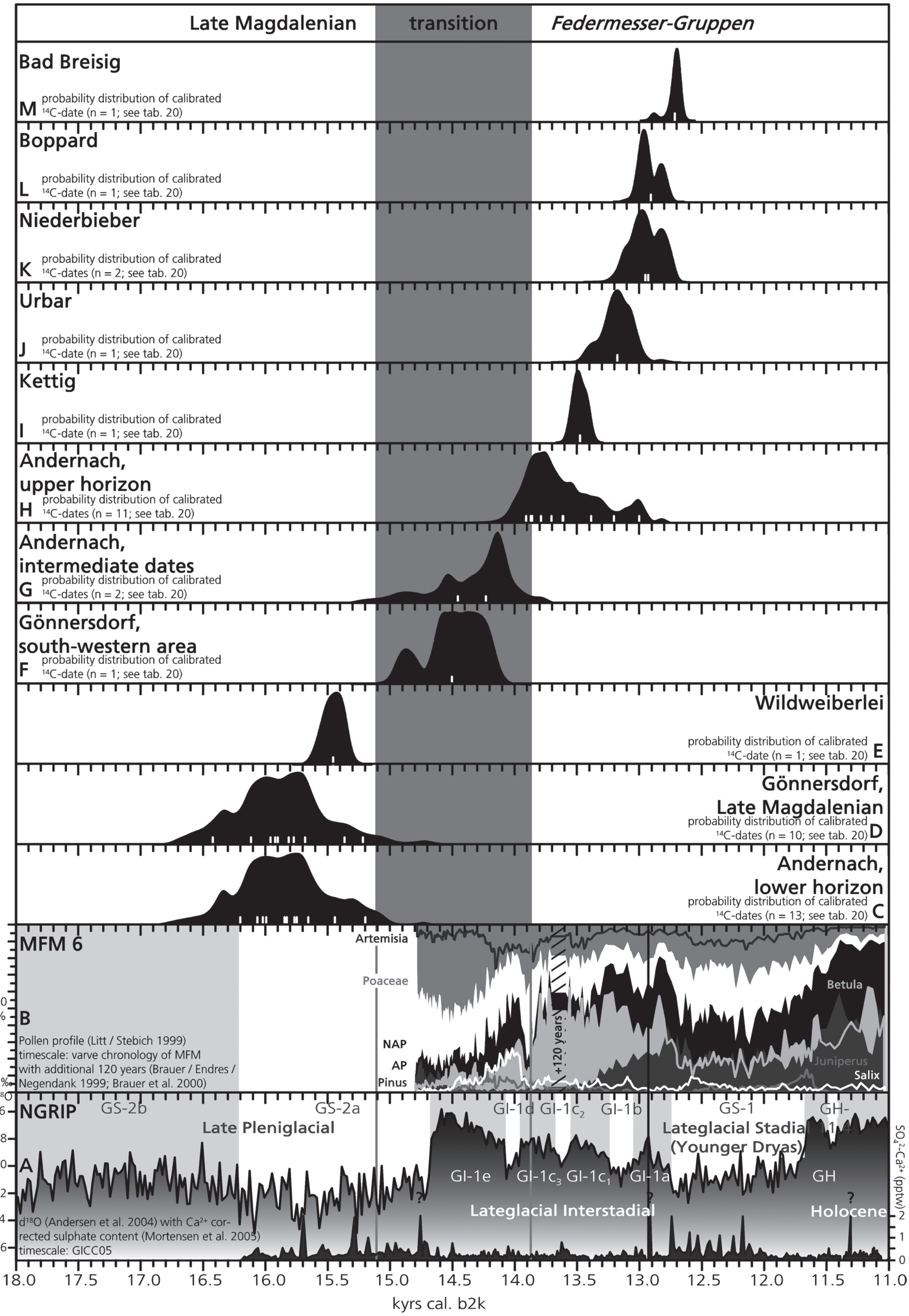


Fig. 65 Probability distributions of the calibrated ^{14}C dates from assemblages from the Central Rhineland (**C-M**) contrasted by the Meerfelder Maar pollen diagram (**B**) and the oxygen isotope record of NGRIP (**A**; see **fig. 53**).

originated mainly from concentration I and III. Thus, two possibly distinct phases within the Late Magdalenian at Andernach are visible in the calibrated age ranges. Nevertheless, this evidence is considered too faint thus far and, therefore, the material from the lower horizon is treated as a single complex until further evidence is presented.

According to the environmental indicators and the radiometric dating, the Late Magdalenian complexes from Gönnersdorf and the lower horizon at Andernach must be considered as quasi-contemporaneous. The amount of archaeological material, its complex spatial distribution, and the radiometric results suggest a use of these sites over a considerable period during the Late Pleniglacial.

In contrast, the small assemblage of the Wildweiberlei yielded only one reliable ^{14}C date and few environmental indicators. The environment appeared comparable to Gönnersdorf and Andernach and the calibrated date fell into the second half of the age range for the Late Magdalenian at these two sites. Consequently, this small assemblage must also be considered quasi-contemporaneous with the last Late Magdalenian occupations at the two Neuwied basin sites. Perhaps, the Wildweiberlei site was used once for a relatively short period and, thus, represents a contrast to the more permanently inhabited open-air sites at Gönnersdorf and Andernach.

A plateau in the calibration curve begins around 12,600 years ^{14}C-BP (*c.* 15,200 years cal. b2k) and continues until 11,700 years ^{14}C-BP (*c.* 13,550 years cal. b2k), with an increasing declination of the curve beginning from 12,000 years ^{14}C-BP (*c.* 13,750 years cal. b2k) onwards. Thus, at the end of the Late Magdalenian age range and at the onset of the FMG dates, the calibration results are less distinct and result occasionally in longer fringes of the probability distributions. Based on the environmental data at the different sites, many of these fringes can be ignored in the Central Rhineland record. Only the elk date from Gönnersdorf and the intermediate dates from Andernach fell completely into the plateau period. Moreover, the results from Bonn-Oberkassel, Irlich, and the main group of dates from the upper horizon in Andernach 2 fell into the final phase of this plateau. Therefore, these dates require some more consideration for a precise attribution.

The Gönnersdorf sample was made on elk, which was otherwise unknown from the Late Pleniglacial and found in a stratigraphically higher position. The calibrated age range attributed the date to the last centuries of the Late Pleniglacial and the first temperate event (GI-1e) in the Lateglacial Interstadial. Thus, the radiometric age and the stratigraphic position as well as faunal succession are in accordance with an age at the transition from the Late Pleniglacial to the early Lateglacial Interstadial. However, the sample cannot be related unambiguously with the lithic projectile points. Besides these points, the lithic material recovered in the south-western area appeared to represent a Late Magdalenian assemblage.

Besides the early Late Magdalenian set of dates from Andernach, three further sets of ^{14}C ages can be distinguished in this assemblage (**fig. 66**). An intermediate horizon was identified by two ^{14}C dates made on horse and chamois. Thus far, the archaeological material could not be distinguished unambiguously from the main cluster of archaeological material from the upper horizon. In contrast to the intermediate data set, which falls onto the plateau, the main and late data sets from Andernach fall along a portion of the calibration curve with some steep fluctuations. A first steep decrease (**fig. 66C**, steep fluctuation 1) followed by a comparably steep increase (**fig. 66C**, steep fluctuation 2) occurred approximately between 14,100 and 14,000 years cal. b2k. This period correlated to the first increase of forested vegetation in the Meerfelder Maar record (MFM; **fig. 66B**) and the coldest part of the early Lateglacial Interstadial (GI-1d; **fig. 66A**). This attribution seemed unreliable in comparison with the temperate fauna of this horizon. Furthermore, even though this fluctuation falls beyond the ^{14}C age ranges for the intermediate and a portion of the main data set (**fig. 66**), the majority of dates from the main cluster remain inconsistent with the older dates. The main cluster relates to a small plateau followed by a long-stretched fluctuation in the calibration curve. At the end of this period another steep decline in the curve occurred (**fig. 66C**, steep fluctuation 3). Due to this

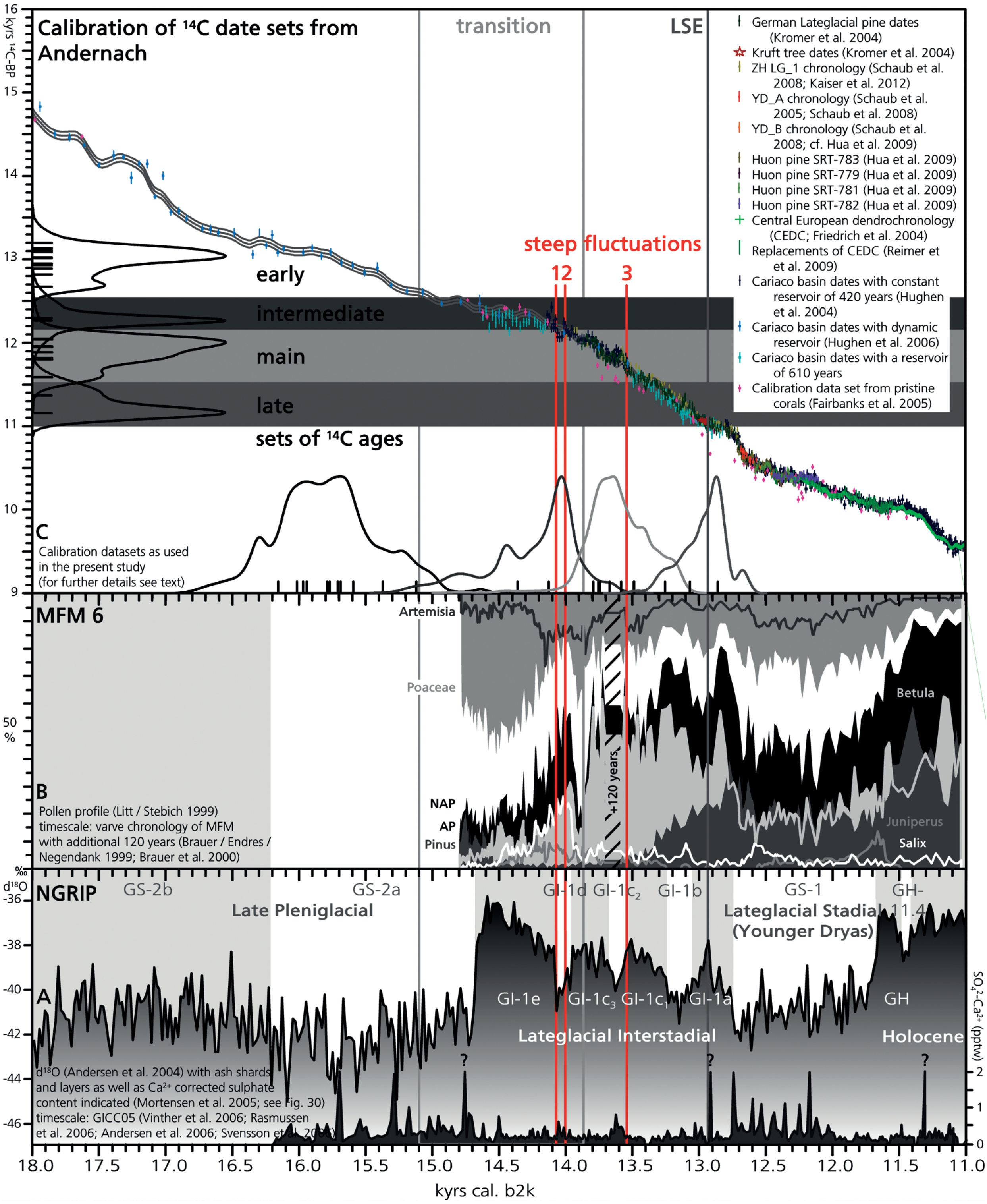


Fig. 66 Calibration of the different data sets of Andernach (**C**; see text and **tab. 20**) contrasted by the Meerfelder Maar pollen diagram (**B**) and the oxygen isotope record of NGRIP (**A**; see **fig. 53**). The limits of the transition between the Late Magdalenian and the FMG are indicated by light grey lines (see **fig. 65**), the Laacher See eruption (LSE) and steep moves in the calibration data which are mentioned in the text are indicated by dark grey lines. – For further details see text.

steep decline, the calibrated age of the older Andernach 3 date overlaps with the calibration results of the main group of dates. However, the remaining two dates of the late phase are not explicable by fluctuations and either reveal a younger period, possibly associated with a phase of chalcedonies in the southern part of the site, or the two dates were contaminated. Consequently, the fluctuations in the calibration curve cannot explain the complete date range from the intermediate to the late data sets and at least two distinct episodes are reflected by the radiometric results. The archaeological remains of the two episodes can be divided into the main accumulation from Andernach 2 and the accumulations from Andernach 3 and the south of Andernach 2. The latter material could not be separated from the main material in Andernach 2 based on the literature (cf. Veil 1982; Bolus 1984; Street 1993; Stapert/Street 1997). Thus, the values given for Andernach 2-FMG in the following material sub-chapters reflect the remains of at least two chronologically distinct episodes. Moreover, if the intermediate dates were considered as indistinguishable from to this main phase, this assemblage accumulated over a considerable period of time. According to the faunal composition, the main FMG phase at Andernach 2 reflected a temperate forest community. This additional information combined with the record from the MFM further narrows the position of the site to the early mid-Lateglacial Interstadial (GI-1c_3; **fig. 66**). The complex spatial patterns and the presence of at least three hearths in this main FMG accumulation could further support the hypothesis of repetitive visits to this site during the mid-Lateglacial Interstadial. The detailed spatial analysis is on-going and could make possible the distinction between different phases within the main concentration and the material associated to these phases. Analysis of the faunal assemblage from Andernach 3 is also still incomplete, but the identified species include red deer and large bovid, presumably aurochs. These species also indicate a temperate forest environment, conditions that prevailed in the late Lateglacial Interstadial to which this phase was dated. Since the horizons were sealed by the LST, this marker sets an upper limit to the age range of the Lateglacial occupation at Andernach.

The seven ^{14}C dates from Bonn-Oberkassel are statistically inconsistent with the hypothesis of a single event. They form two sub-sets, the first comprising the samples from the man (OxA-4790), the dog (KIA-4163), and the penis bone of bear (OxA-4791). This chronologically younger sub-set is similar to the results from Irlich (see p. 472). The second sub-set consists of a sample from the female (OxA-4792) and three remains of dog (KIA-4161, KIA-4163, OxA-4793). However, the oldest and the youngest date from the site were made on left and right ulnae, which were considered as mirror pieces from a sub-adult dog (Street 2002). The presence of two dogs which were almost the same age and physique at the time of death as suggested by the ^{14}C dates appears improbable. Indications for contamination were not apparent although the Oxford dates were made with the ion-exchange pretreatment method, which could result in contamination of the sample, particularly, if the sample yielded only small amounts of carbon (Jacobi/Higham 2009, 1896). Furthermore, preliminary results of a stable isotope analysis on the human remains revealed that their diet was presumably supplemented by freshwater fish (Giemsch/Schmitz in Holzkämper et al. 2014), which has been suggested elsewhere as a potential source of contamination for ^{14}C dates on human remains (Olsen et al. 2010; cf. Nalawade-Chavan et al. 2013); this effect usually resulted in older dates. In addition, if the difference in ages were mainly attributed to nutrituion, the proportion of freshwater fish would have been more significant for the dog and the woman than for the man. Thus, the differences in the radiometric results can probably be attributed to some type of contamination and/or reservoir effect. Therefore, new ^{14}C dates accompanying the stable isotope analysis are desirable. However, assuming that Verworn's conclusion of a double burial is correct (Verworn/Bonnet/Steinmann 1919, 191 f.) and the contamination of the ^{14}C ages is of only minor degree, the comparison of the probability distributions with the calibration curve again indicates that the significant wiggles in the calibration curve could have also contributed to the ambiguous results (**fig. 67**).

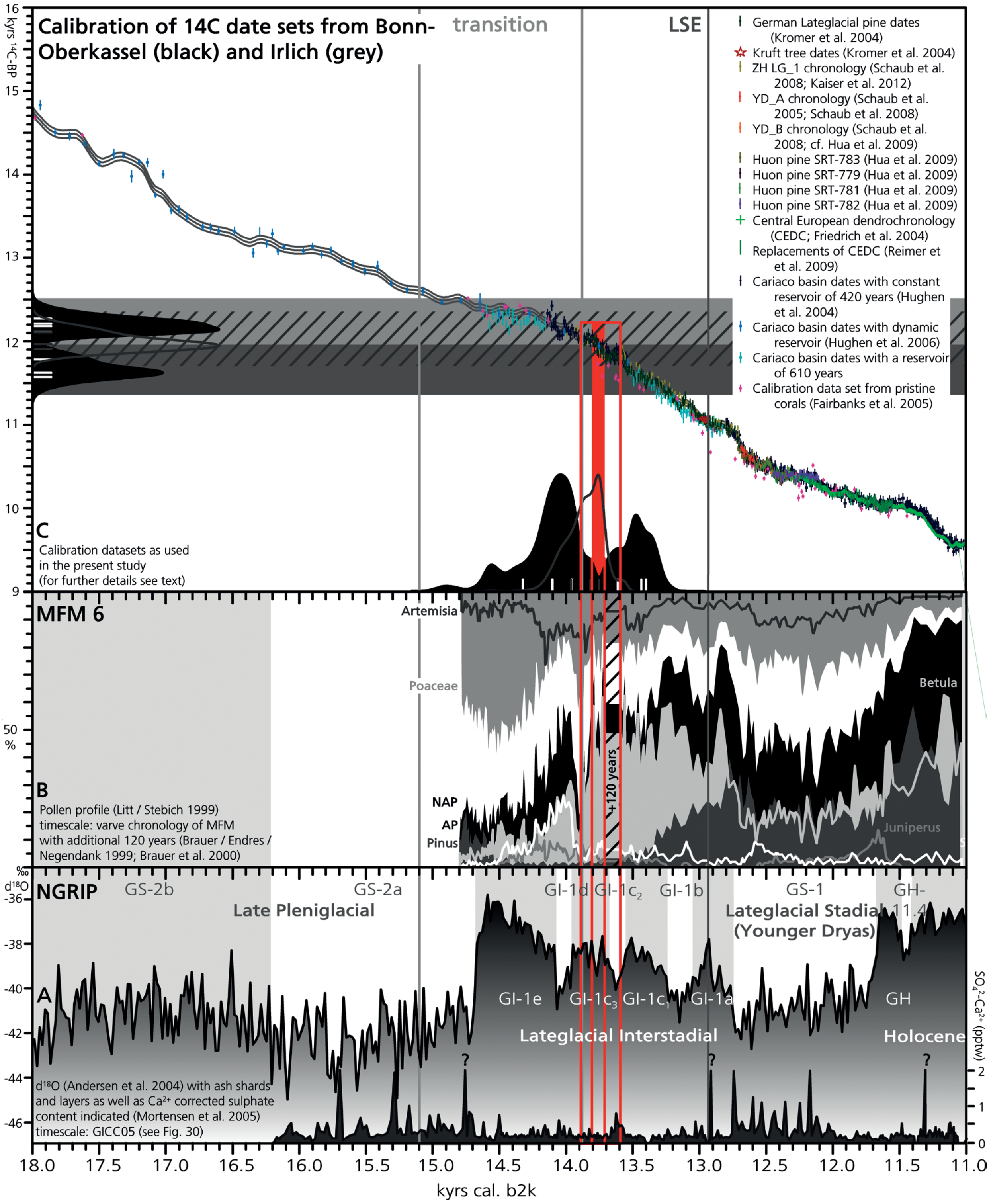


Fig. 67 Calibration of the different date sets of Bonn-Oberkassel (black fields) and Irlich (grey lines; **C**; see text and **tab. 20**) contrasted by the Meerfelder Maar pollen diagram (**B**) and the oxygen isotope record of NGRIP (**A**; see **fig. 53**). The limits of the transition between the Late Magdalenian and the FMG are indicated by light grey lines (see **fig. 65**) and the Laacher See eruption (LSE) are indicated by dark grey lines. – For further details see text.

Five AMS dates were taken on the human material from Irlich and produced only slightly heterogeneous results (**tab. 20**; cf. Bronk Ramsey et al. 2002), which can be evaluated more precisely by the attribution of those remains to the various individuals. Besides the uncoloured, adult skull fragment (OxA-9876) from the Hallstatt period, an uncoloured or brownish coloured bone (OxA-9736) yielded an early Lateglacial Interstadial age that is incompatible with an Oxford date taken on the adult femur (OxA-9847) and the other Oxford dates in a χ^2-test. However, the sample is compatible with another date made in the Utrecht laboratory (UtC-9221). Hence, either the adult bones were from two different individuals that died several centuries apart, or one of the samples was contaminated. Since the reclassification produced no indication of a second adult and attributed further cranial fragments to the young female, the contamination hypothesis appears more probable. In fact, the four Oxford dates were made in the series of Oxford AMS dates (numbers between OxA-9361 and OxA-11851) that might be affected significantly by traces of humectant left in the collagen (Higham et al. 2007, S2 and S55). redating of some of the affected samples resulted in ages that on average were 120 ^{14}C years younger than the previous dates. If a redating of the OxA-9736 date altered the age consistent with these other redatings, OxA-9736 would yield a similar age to the Utrecht date and, thus, be compatible with the other Oxford dates. Nevertheless, although the different colour might indicate different conditions of preservation and, thus, single out the OxA-9736 sample, the other Oxford dates could equally be affected by the contamination. Moreover, the only compatible date from Utrecht was taken on a sample which was considered a juvenile or neonate, possibly from the same individual that supplied a sample for one of the younger Oxford dates (OxA-9848). Perhaps, the samples for OxA-9848 and UtC-9221 originated from the youngest child as the OxA-9848 sample was a rib, and ribs were only attributed to the youngest individual during the reclassification. In addition, the two younger Oxford results (OxA-9847; OxA-9848) and the Utrecht date are congruent with each other in a weighted mean of 11,977 ± 42 ^{14}C-BP ($p = 36.67\,\%$). Calibrated, this weighted mean falls along the transition between early to mid-Lateglacial Interstadial; thus, the dates could again be affected by the inconsistency of the carbon isotopes in the atmosphere during the first part of the Lateglacial Interstadial (**fig. 67**). Possibly, the dates can be explained by the same steep decline as the Bonn-Oberkassel dates (see p. 470). In this case, the burial episodes were comparable. In comparison with the MFM, these episodes occurred during a period when light forests became established in the western upland area. According to the calibrated age ranges, this period corresponded to the end of the transition between the Late Magdalenian and the FMG in the Central Rhineland.

The other ^{14}C dates for FMG sites in the Central Rhineland were in accordance with the assumed chronology. However, several dates from these sites for example Niederbieber, had be rejected due to the stratigraphic positions below the LST. In addition, many dates, such as those from Kettig, were rejected due to the uncertainty resulting from dating calcined bone from the Lateglacial (Lanting / Aerts-Bijma / van der Plicht 2001; Lanting / Niekus / Stapert 2002).

According to the calibrated age ranges (**fig. 65**), the transition between the Late Magdalenian and the FMG in the Central Rhineland can be set between 15,100 and 14,000 years cal. b2k. This period corresponds to the end of the Late Pleniglacial and the early Lateglacial Interstadial. However, with the more precisely attributed main group of dates from Andernach 2-FMG, this transitional period could be expanded to approximately 13,900 years cal. b2k. After this transition, a relatively clear succession of sites until shortly after the LSE can be established. Nevertheless, some of the more complex sites such as Kettig and Niederbieber yielded very few dates, therefore, the duration of the occupation of these sites could be underestimated. The single acceptable date from Kettig was made on bulked material and could represent a mean of heterogeneous ages. Two concentrations were observed in Kettig, and with a single possible radiometric date, it remained unclear whether these concentrations were distinct or quasi-contemporaneous episodes. Therefore, new dates from this site are particularly desirable. Comparably, Niederbieber yielded several distinct

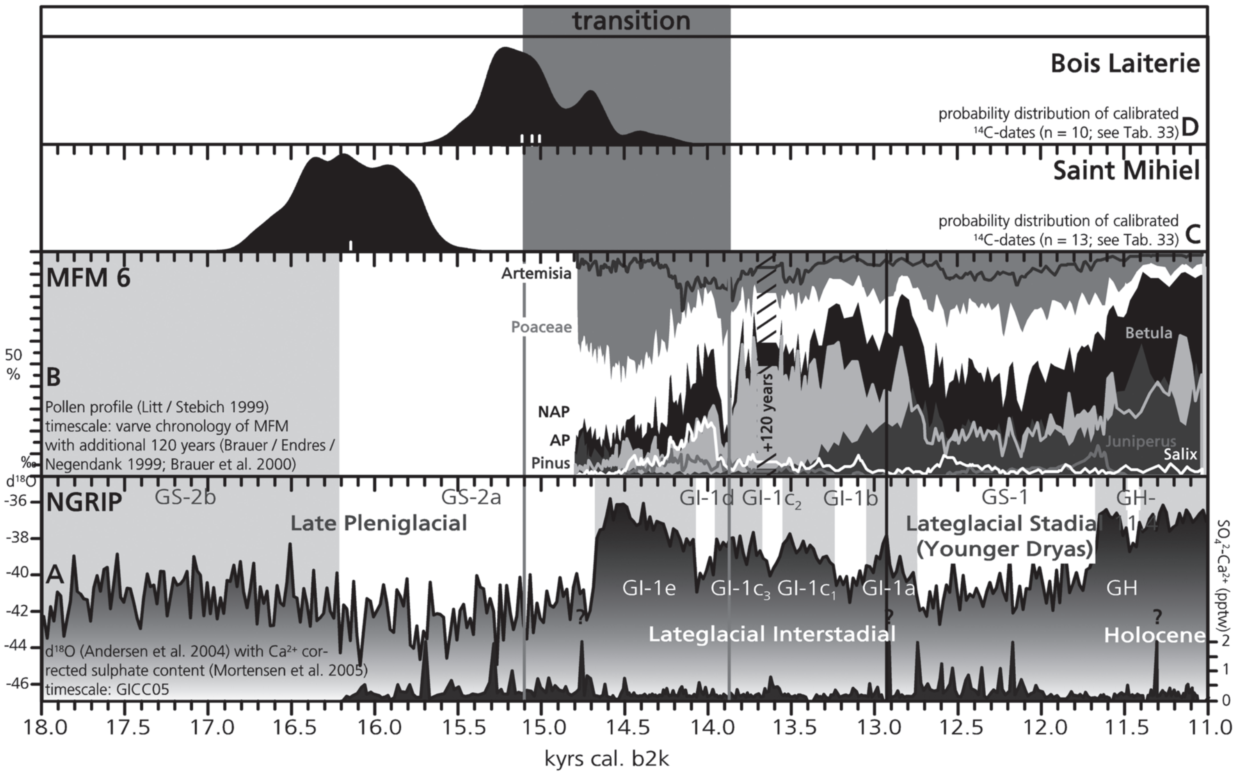


Fig. 68 Probability distributions of the calibrated ^{14}C dates from assemblages from the western uplands (**C-D**) contrasted by the Meerfelder Maar pollen diagram (**B**) and the oxygen isotope record of NGRIP (**A**; see **fig. 53**). The transition period between the Late Magdalenian and the FMG as identified in the Central Rhineland (see **fig. 65**) is indicated in grey. – For further details see text.

concentrations but only two technically acceptable dates. For one of these dates (OxA-1135), the association with the archaeological scatter remained uncertain. Moreover, the samples for both dates originated from concentrations along the periphery, whereas the main area yielded no reliable date. The number of concentrations and their interpretation as repeatedly visited hunting preparation camps (Gelhausen 2011b; Gelhausen 2011a) suggested a longer use of this site that is not reflected in the few radiometric results. Thus, although the dating for many FMG sites suggested very short-lived occupation, this impression resulted from the scarcity of reliable dates. At least for Kettig and Niederbieber, longer periods of use are possible.

Western uplands

The two assemblages from this sub-area are described in relation to the sites from the Central Rhineland to identify their chronological position in the transition process.

The Saint Mihiel assemblage can be attributed to the Late Magdalenian based on the faunal composition and the ^{14}C date (see **tab. 33**). However, the sample for the radiometric measurement was a bulked sample of reindeer remains. The considerable number of unmodified antler remains at the site could indicate that shed and/or fossil material was gathered at the site. A date containing fossil material would result in an older age than the moment of gathering the piece. Thus, even though the ^{14}C date yielded a slightly older result than the data set from Gönnersdorf (**fig. 68**), the assemblage from Saint Mihiel could have formed quasi-contemporaneously with Gönnersdorf and the lower horizon of Andernach.

In contrast, the calibrated age range of Bois Laiterie fell at the onset of the transition period between the Late Magdalenian and the FMG in the Central Rhineland (**fig. 68**) and the onset of the plateau in the calibration curve. The fauna reflected a very heterogeneous habitat and was possibly the result of stratigraphic disturbances, for example caused by a Mesolithic burial. Even though the radiometric dates for this site are very consistent, the direct dating of some unusual species, such as the cave bear, cave hyena, elk, musk ox, steppe bison, and the possible roe deer/saiga antelope material, is desirable to further evaluate their meaning for the Lateglacial occupation. However, the major species which were unambiguously related to human use were still very comparable to the Late Magdalenian assemblages from the Central Rhineland. Thus, according to the faunal evidence and the radiometric results, the Bois Laiterie material can be attributed to the Late Pleniglacial. Nevertheless, the site can be considered as the first assemblage within the transition process. In fact, a reanalysis of the lithic material highlighted differences from the Late Magdalenian (Sano/Maier/Heidenreich 2011), although many similarities in the archaeological assemblages remained consistent with an attribution to the Late Magdalenian such as the stone pavement with occasional engravings and the drilled shells (Miller/López Bayón 1997; Lejeune 1997).

Northern France

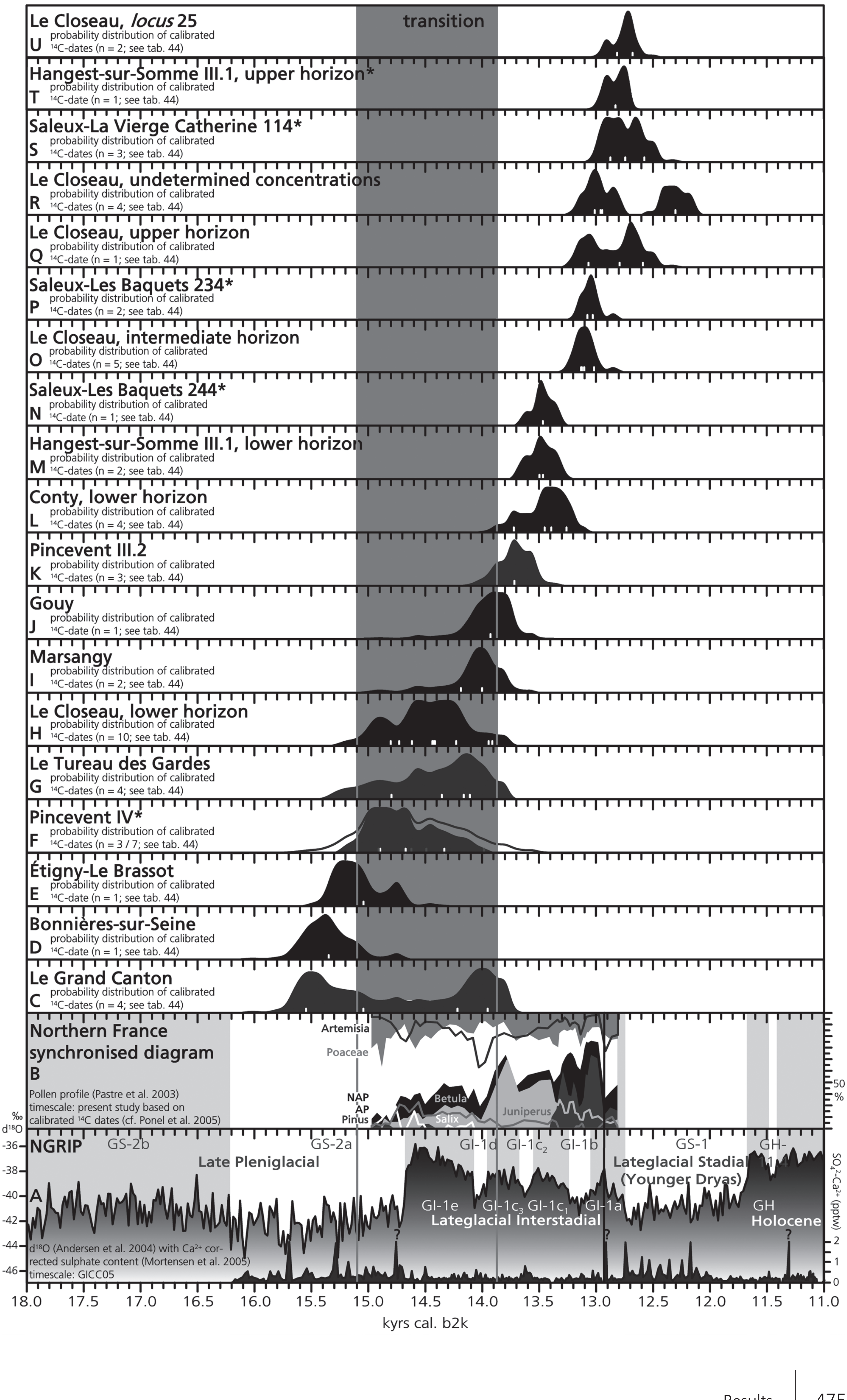
Even though the collection of ^{14}C dates from Lateglacial sites has grown to a considerable size in the northern France sub-area (n = 140), many problems and uncertainties remain. For example, several sites produced regularly younger ^{14}C dates than were considered possible based on the stratigraphic and environmental evidence (cf. Bodu 2004; Bodu et al. 2009b; Débout et al. 2012). Several reasons probably caused these arbitrary results.

In the present study, charcoal samples from several of these sites were excluded as possible intrusions from stratigraphically higher positions. From the intermediate and upper horizon of Le Closeau many dates were made on charcoal samples that appeared to yield reliable Lateglacial ages but many of these charcoal patches could have originated from natural wild fires, thus the reliable dates do not necessarily provide information on the occupation period. Besides the probable movement of this material in the light sediment of the river floodplains of various northern French sites, a reanalysis of hearth material from Marsangy indicated that previously assumed wood charcoal samples were heavily contaminated by other materials (Bodu et al. 2009b). Moreover, spatial distributions suggested repeated visits for many of the northern French sites (e. g. Julien et al. 1999; Bodu 2010). Consequently, bulked samples, often necessary for the conventional dating, from these sites were particularly questionable. Nevertheless, several single faunal remains dated in the early days of the AMS method also resulted in unexpected ages, and many of the Oxford dates were made within technically problematic dating series (Jacobi/Higham 2009).

If these ambiguous AMS dates and those from bulked samples were excluded from the record, the number of ^{14}C dates from the Paris Basin decreased significantly (**tab. 44**). However, the problem of considerably younger results would still not be solved. For example, some well-selected samples of charcoal and bone from the Late Magdalenian deposit of Pincevent yielded surprisingly young calibrated ages (**fig. 69**). Furthermore, two of three dates made on horse remains from *locus* 10 at Le Tureau des Gardes (AA-

→

Fig. 69 Probability distributions of the calibrated ^{14}C dates from assemblages from northern France (**C-U**) contrasted by the synchronised northern French pollen diagram (**B**) and the oxygen isotope record of NGRIP (**A**; see **fig. 53**). * assemblages not analysed in detail in this project. Probability distributions from the Seine-Yonne-confluence basin are set in grey. The transition period between the Late Magdalenian and the FMG as identified in the Central Rhineland (see **fig. 65**) is indicated by a grey background. – For further details see text.


transition
Le Closeau, locus 25
U probability distribution of calibrated 14C-dates (n = 2; see tab. 44)
Hangest-sur-Somme III.1, upper horizon*
T probability distribution of calibrated 14C-date (n = 1; see tab. 44)
Saleux-La Vierge Catherine 114*
S probability distribution of calibrated 14C-dates (n = 3; see tab. 44)
Le Closeau, undetermined concentrations
R probability distribution of calibrated 14C-dates (n = 4; see tab. 44)
Le Closeau, upper horizon
Q probability distribution of calibrated 14C-date (n = 1; see tab. 44)
Saleux-Les Baquets 234*
P probability distribution of calibrated 14C-dates (n = 2; see tab. 44)
Le Closeau, intermediate horizon
O probability distribution of calibrated 14C-dates (n = 5; see tab. 44)
Saleux-Les Baquets 244*
N probability distribution of calibrated 14C-date (n = 1; see tab. 44)
Hangest-sur-Somme III.1, lower horizon
M probability distribution of calibrated 14C-dates (n = 2; see tab. 44)
Conty, lower horizon
L probability distribution of calibrated 14C-dates (n = 4; see tab. 44)
Pincevent III.2
K probability distribution of calibrated 14C-dates (n = 3; see tab. 44)
Gouy
J probability distribution of calibrated 14C-date (n = 1; see tab. 44)
Marsangy
I probability distribution of calibrated 14C-dates (n = 2; see tab. 44)
Le Closeau, lower horizon
H probability distribution of calibrated 14C-dates (n = 10; see tab. 44)
Le Tureau des Gardes
G probability distribution of calibrated 14C-dates (n = 4; see tab. 44)
Pincevent IV*
F probability distribution of calibrated 14C-dates (n = 3 / 7; see tab. 44)
Étigny-Le Brassot
E probability distribution of calibrated 14C-date (n = 1; see tab. 44)
Bonnières-sur-Seine
D probability distribution of calibrated 14C-date (n = 1; see tab. 44)
Le Grand Canton
C probability distribution of calibrated 14C-dates (n = 4; see tab. 44)
Northern France synchronised diagram
B
Pollen profile (Pastre et al. 2003) timescale: present study based on calibrated 14C dates (cf. Ponel et al. 2005)
Artemisia
Poaceae
NAP
AP
Pinus
Betula
Salix
Juniperus
50 %
‰ d18O
NGRIP
A
GS-2b
GS-2a
GI-1d
GI-1c3
GI-1c2
GI-1c1
GI-1b
GI-1e
GI-1a
GS-1
GH-11.4
GH
Late Pleniglacial
Lateglacial Interstadial
Lateglacial Stadial (Younger Dryas)
Holocene
d18O (Andersen et al. 2004) with Ca2+ corrected sulphate content (Mortensen et al. 2005) timescale: GICC05
SO42–-Ca2+ (pptw)
-36
-38
-40
-42
-44
-46
0
1
2
18.0
17.5
17.0
16.5
16.0
15.5
15.0
14.5
14.0
13.5
13.0
12.5
12.0
11.5
11.0
kyrs cal. b2k

44214 and AA-44215) returned relatively young results, whereas the date of AA-44216 was consistent with stratigraphic and archaeological expectations. Despite the stratigraphic and environmental inconsistency a chronological divergence was considered possible for these young Late Magdalenian dates (Débout et al. 2012). In contrast, the date from Étigny-Le-Brassot and numerous dates from the lower horizon in Le Closeau were also made more recently and yielded results older than expected (Bignon/Bodu 2006). Comparably, archaeological material from the lower horizon in Le Closeau and Gouy dated at least 200 ^{14}C years younger (**tab. 44**) than material from horizon III.2 at Pincevent. Only few independent indications for a chronological attribution of this younger horizon at Pincevent were found such as the stratigraphy and the generally temperate fauna but these indicators were in accordance with the calibrated ^{14}C date from this horizon. For the offset between Le Closeau, Gouy, and Pincevent III.2, the wiggling calibration curve could provide a possible explanation, but the Late Magdalenian discrepancies are usually too large to be explicable by fluctuations in the calibration curve. Consequently, these results further affirmed that many previous dates from the Paris Basin were possibly unreliable. According to the climatic and environmental comparisons in the present project, a lag development of the Paris Basin in contrast to the relatively consistent record of the Late Magdalenian in the Central Rhineland, the western uplands, or Switzerland (cf. Débout et al. 2012) appears improbable. However, in comparison with the synchronised and NGRIP-tuned pollen profile, many of the younger dates correlated with a period in the early Lateglacial Interstadial in which open vegetation returned. Nevertheless, the evidence from Marsangy suggested that in this period loamy deposits had already formed, which was not the case in the Late Magdalenian horizons of Pincevent, Le Tureau des Gardes, or Le Grand Canton. The question remains: Why do the samples from these sites produce such young dates?

The dates from the Late Magdalenian concentrations at Étiolles or Verberie are generally consistent with the Late Magdalenian records from the neighbouring areas. Younger dates from these sites could be linked to one of the previously named sources of contamination. However, some young dates, slightly older or comparable to the result from the south-western area of Gönnersdorf, remained unexplained. Perhaps, these samples also related to a last Late Magdalenian visit to these sites. To answer whether these last visits contained material that showed initial changes in the behavioural repertoires, such as found in Bois Laiterie or Gönnersdorf, a comprehensive presentation of these sites, their *loci*, and their material is required due to the complex stratigraphic and spatial distribution of the material (Audouze/Enloe 1997; Olive 2004; Enloe 2006; Olive/Pigeot 2006). Analyses of these sites are still on-going, but clarifications on the assemblages from which the dated material originated may help to evaluate the chronological questions in this area. The TL dates and the reliable dates of Étiolles (Olive 2004, tab. 1) indicate that U5-P15 can unambiguously be attributed to the Late Pleniglacial. Only a small horse concentration (A17) produced a significantly younger date which suggested the comparability to the horse date at Andernach. At Verberie, the oldest date (GifA-95454: 12,950 ± 130 years ^{14}C-BP; 16,380-15,180 years cal. b2k; Bodu 2004) originated from an intermediate horizon (II.2), whereas the youngest date (GifA-99421: 12,300 ± 120 years ^{14}C-BP; 14,990-13,830 years cal. b2k; Bodu 2004) originated from a lower horizon (II.3; Audouze/Enloe 1997). From this lower horizon another older date originated (GifA-99106: 12,520 ± 120 years ^{14}C-BP; 15,470-14,110 years cal. b2k; Bodu 2004) and a further old date came from the upper horizon (II.1; GifA-95453: 12,430 ± 120 years ^{14}C-BP; 15,300-13,980 years cal. b2k; Bodu 2004). Thus, three of the dates fall at the transition between the Late Pleniglacial and the Lateglacial Interstadial. The fauna at Verberie was dominated by reindeer, indicating sufficiently cold and open areas. This assessment was partially supported by the small malacological assemblage from the archaeological horizons (David 1994; Rodriguez 1994). The malacological sample taken on top of the archaeological horizon indicated an amelioration based on increased numbers of forest species and dry indicators. These environmental parameters could also relate to a later period in the

Lateglacial Interstadial. Since this sample overlaid the archaeological horizons, the youngest archaeological horizon should not be younger than the early Lateglacial Interstadial, but more likely dates to the youngest period of the Late Pleniglacial.

In the two sites near Marolles-sur-Seine (Le Tureau des Gardes and Le Grand Canton), the horizontal and vertical stratigraphy was complex and occasionally featured imprecise distinctions between earlier and later episodes of occupation. At both sites, material suggesting an archaeologically younger development was found. Thus, admixture of different events could have resulted in younger dates. Some areas at these sites were reliably attributed to the Late Magdalenian yet still yielded younger ages (e.g. Le Tureau des Gardes 6). However, this argument is not applicable to Pincevent. Although the dated micro-charcoal produced older results, those dates were still too young in comparison with the stratigraphy, the environmental setting, and the results from the neighbouring regions. The recently dated bone was again clearly too young. However, the three problematic sites were located within a basin formed by the confluence of the Seine and the Yonne rivers. Perhaps, some undetected geochemical process contaminated the organic material deposited in the floodplain of this basin. The absorption of some type of reservoir by drinking the waters in this basin during prehistoric times seems an improbable explanation because the few dates from the nearby site Le Tilloy appeared less affected. A reservoir due to dissolved carbon from carboniferous mountains, for example, would result in older ages, not younger ones. Therefore, contamination with younger residues such as humic acids are considered more probable. More detailed geochemical analyses within this basin are suggested to identify potential contaminations. As such, the dates from this area are considered with caution.

Additionally, the relatively old ^{14}C date from Hallines (**tab. 44**) was not unambiguously associated with the actions of humans. Even though the faunal composition appeared as comparably heterogeneous as Bois Laiterie, suggesting a very late Late Pleniglacial age, the questionable relationship with archaeological material limits the usefulness in a chronological argumentation. Thus, this assemblage has to be attributed mainly stratigraphically. According to the stratigraphic position, two episodes must be assumed, both probably during the Late Pleniglacial. A more precise attribution would be desirable; until then, the site is placed at the onset of the succession of sites.

Comparably, the date of Bonnières-sur-Seine probably predates the archaeological material. Based on this *terminus post quem*, the stratigraphy, the composition of the faunal and the lithic assemblage, the archaeological material is considered quasi-contemporaneous with the inventory of Bois Laiterie.

In addition, the material from Cepoy and the lower horizon from Belloy-sur-Somme yielded no ^{14}C date thus far. No organic material was preserved at either site, so these assemblages are only attributed stratigraphically. Cepoy was dated to the early Lateglacial Interstadial due to a change in the sediment regime. The lower horizon of Belloy-sur-Somme was found within a soil from the first part of the Lateglacial Interstadial, probably younger than the Cepoy material. However, the Marsangy material was found in a loamy deposit, perhaps linking the formation of a soil in northern France to this early Lateglacial Interstadial.

In Le Closeau, the probability distributions of calibrated ^{14}C dates from *loci* attributed to the intermediate horizon and those from the *locus* 25 indicated a clear succession. However, the calibrated age range for the upper horizon encompassed both periods. Furthermore, the calibrated ages from undetermined *loci* produced an age range comparable to those from the intermediate and upper horizon, and one younger than the age range of *locus* 25. Thus, the dates from *locus* 45 and possibly the one from structure IV in the greyish deposits originated from the early Younger Dryas.

These assemblages were attributed to different archaeological units in northern France, mainly according to typo-technological observations (Schmider 1971; Fagnart 1997; Valentin 2008a). With this archaeological distinction, the calibration results, and the stratigraphic considerations about the sites, a succession of the

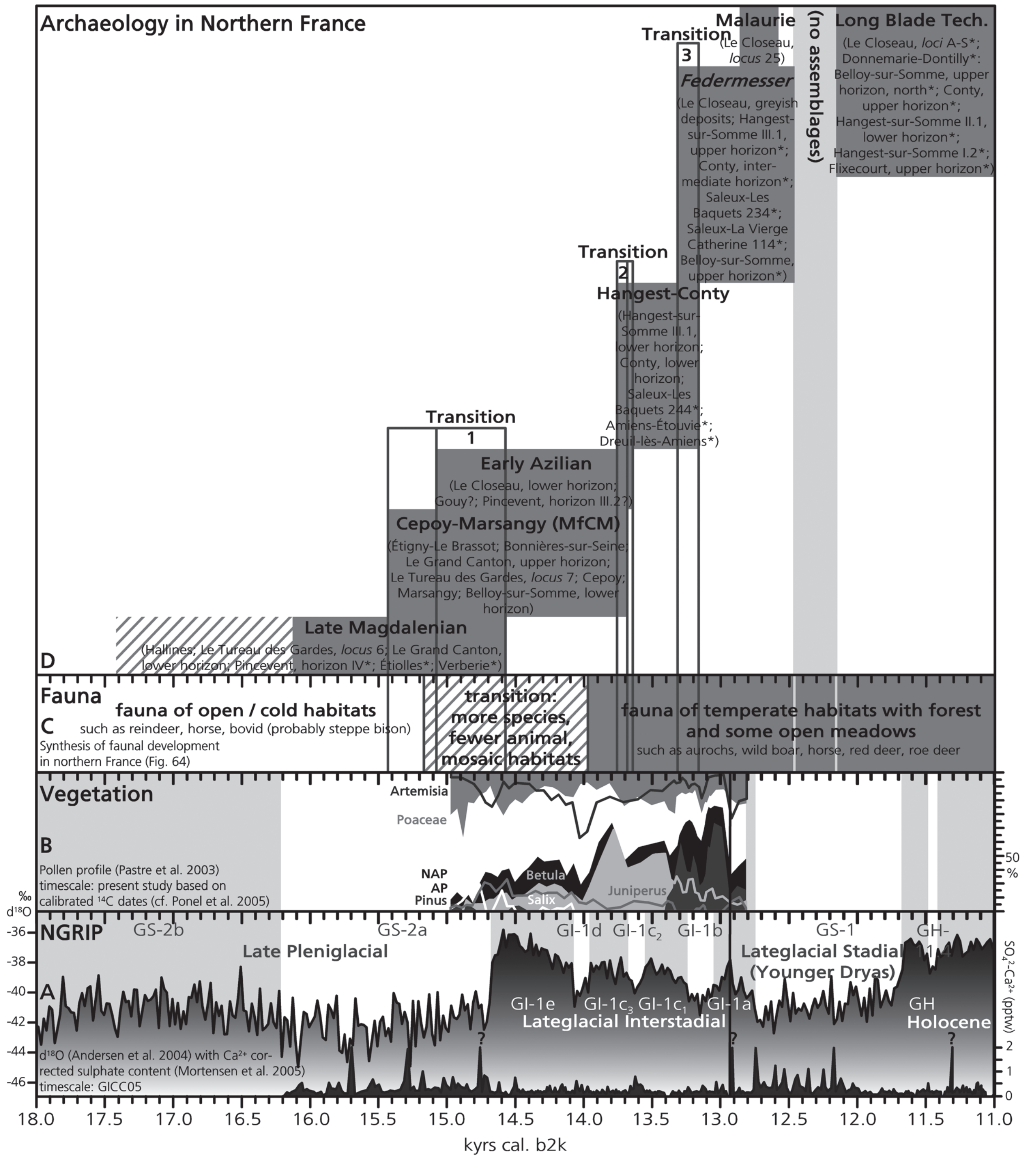


Fig. 70 Succession of archaeological units (bold) and attributed assemblages in northern France (**D**) contrasted by the synthesised faunal (**C**; see **fig. 64**) and vegetation development in northern France (**B**; see **fig. 59**) as well as the oxygen isotope record of NGRIP (**A**; see **fig. 53**). Some similarities can arise from the fact that the vegetation development was synchronised with the oxygen istotpe record and the faunal database relied mainly on the material from the archaeological assemblages. * assemblages not analysed in detail in this project. – For further details see text.

archaeological units can be established for northern France (**fig. 70**). This succession shows that the behavioural development in northern France was only interrupted during the mid-Lateglacial Stadial to which no assemblage was reliably attributed.

Assuming that the different typo-technological units reflected different behavioural recipes (cf. Mesoudi/O'Brien 2008b), a gradual replacement of some behaviours is revealed by the often considerable temporal overlap of these units. Three periods of transition in which three, or at least two, different units occur concomitantly can be identified.

In the first transition, the Late Magdalenian occurs contemporaneously with assemblages attributed to the Final Magdalenian MfCM (MfCM), and both were accompanied by Early Azilian assemblages. The end of this transition is set to the youngest reliable attribution of the Late Magdalenian. This period relates to the end of the Late Pleniglacial and the onset of the Lateglacial Interstadial.

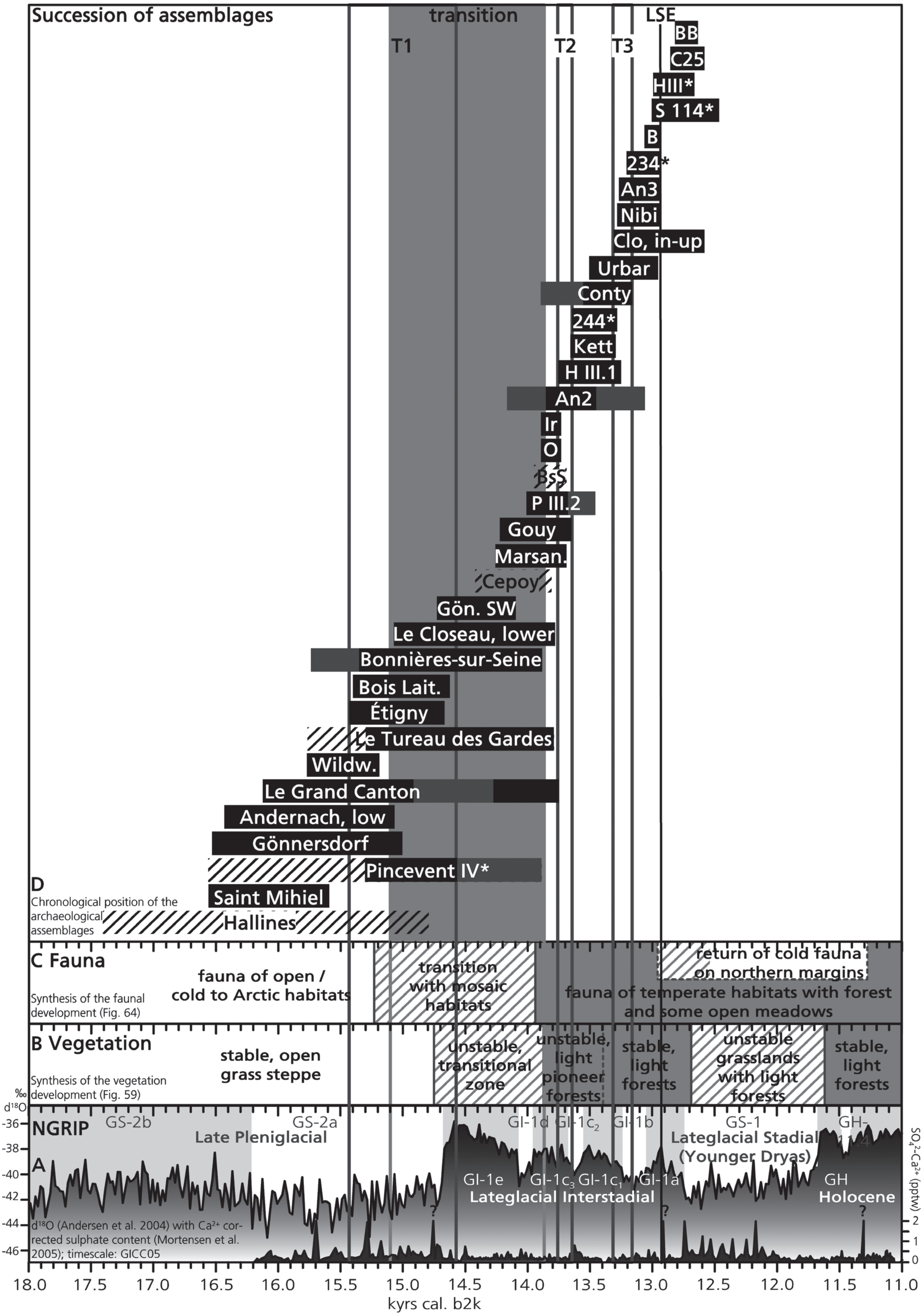
However, after this transition the MfCM and the Early Azilian continue to co-occur. This co-existence can be explained by an insufficient chronological resolution or two different modes of adaptation, where two different groups behave differently or one group behaves differently depending on the seasonal cycle or the function of the site. In the latter case, a supposed ethno-historical differentiation of typo-technological units (Audouze/Valentin 2010) would not be applicable to these groups. In fact, the chronological resolution of these assemblages is problematic due to the plateau in the calibration curve at the transition from the Late Pleniglacial to the Lateglacial Interstadial. However, a co-occurrence cannot be disproven by the chronology. The comparability of the behavioural expressions seen in MfCM and Early Azilian assemblages is discussed in the following chapters.

The co-occurrence of these entities ends with the second transition period when these behavioural repertoires appear for a very short period contemporaneously with inventories from the lower horizons of Hangest-sur-Somme III.1 and Conty. The assemblages from the Somme region were considered as a very early faciès of FMG (Coudret/Fagnart 1997) and comparable to the Hengistbury Head type industries of southern England (Barton et al. 2009). The very short intervals between the appearance of these Hangest-Conty assemblages and the disappearance of the MfCM and the Early Azilian imply a very rapid process. According to the correlation of the present study, this transition relates to the end of a first expansion of trees to northern France and the end of a more unstable period in the NGRIP climate record (**fig. 70**). After the transitional period, these inventories are the only types of assemblages identified in northern France until the third transition.

The third transition in northern France marks the overlap of these Hangest-Conty assemblages with those attributed to the typical FMG, as they were also found in the Central Rhineland. It correlates with the onset of pine-dominated forests in northern France. Although not as long as the overlaps during Transition 1, the third transition gives the impression of a more gradual change from one type of behaviour to another. The identification of a fourth or fifth transition was impossible due to the gap in the record. For instance, according to the calibration results, the typical Malaurie assemblage from Le Closeau, *locus* 25 forms a sub-set of these FMG assemblages. The behavioural recipe associated with Malaurie points (Laborian) possibly superseded the FMG in the mid-Lateglacial Stadial, as was indicated in south-western France (Le Tensorer 1981; Célérier/Chollet/Hantaï 1997). How the Long Blade Technology assemblages were related to these Laborian behaviours remains a matter of debate, but new data can be revealed by on-going research on the assemblages of the Long Blade Technology and their affiliations (personal communication, Mara-Julia Weber).

In conclusion, the varying lengths of overlap imply that the process of change in northern France was a continuous but uneven development.

A comparative and successional representation of all Lateglacial complexes considered in this study (**fig. 71**) reveals that relatively few assemblages fall into the transition period identified in the Central Rhineland (Bois Laiterie; Étigny-Le-Brassot; Le Closeau, lower horizon; Gönnersdorf, south-western area; Cepoy; Marsangy; Gouy; Belloy-sur-Somme, lower horizon). The calibrated age ranges of Le Tureau des Gardes, Le Grand Canton, and Pincevent IV are also attributed to the transition period. However, some sub-assemblages of Le



Succession of assemblages
transition
T1
T2
T3
LSE
BB
C25
HIII*
S 114*
B
234*
An3
Nibi
Clo, in-up
Urbar
Conty
244*
Kett
H III.1
An2
Ir
O
BsS
P III.2
Gouy
Marsan.
Cepoy
Gön. SW
Le Closeau, lower
Bonnières-sur-Seine
Bois Lait.
Étigny
Le Tureau des Gardes
Wildw.
Le Grand Canton
Andernach, low
Gönnersdorf
Pincevent IV*
D
Chronological position of the archaeological assemblages
Saint Mihiel
Hallines
C Fauna
Synthesis of the faunal development (Fig. 64)
fauna of open / cold to Arctic habitats
transition with mosaic habitats
fauna of temperate habitats with forest and some open meadows
return of cold fauna on northern margins
B Vegetation
Synthesis of the vegetation development (Fig. 59)
stable, open grass steppe
unstable, transitional zone
unstable, light pioneer forests
stable, light forests
unstable grasslands with light forests
stable, light forests
‰ d18O
NGRIP
A
GS-2b
GS-2a
Late Pleniglacial
GI-1d
GI-1c2
GI-1b
GS-1
Lateglacial Stadial (Younger Dryas)
GH-11.4
GI-1e
GI-1c3
GI-1c1
GI-1a
Lateglacial Interstadial
GH
Holocene
d18O (Andersen et al. 2004) with Ca2+ corrected sulphate content (Mortensen et al. 2005); timescale: GICC05
SO4 2--Ca2+ (pptw)
kyrs cal. b2k

Tureau des Gardes and Le Grand Canton could possibly originate from this period but the Late Magdalenian assemblages from these sites and from Pincevent IV were certainly older.
In a direct comparison between the transitions in northern France and the transition period in the Central Rhineland (**fig. 71**), Transitions 1 and 2 with the co-occurrence of the MfCM and the Early Azilian, covered the Rhenish transition period. However, according to the archaeological units, Transitions 1 and 3 related to the behavioural change that occurred in the Central Rhineland. In addition, the comparison of the Central Rhineland assemblages with the northern French ones reveals that the faciès represented by the assemblages from the lower horizons at Conty and Hangest-sur-Somme III.1, and possibly by the inventory from Saleux-Les Baquets 244, was quasi-contemporaneous with the main cluster in the upper horizon of Andernach, as well as Kettig and Urbar. Thus, in this mid-Lateglacial Interstadial phase, at least two regional sub-groups can be established for the Somme basin and the Central Rhineland. In contrast, the material from the greyish deposits in Le Closeau as well as the inventories from Saleux-Les Baquets 234 and Saleux-La Vierge Catherine 114 (Fagnart 1997; Coudret/Fagnart 2004; Coudret/Fagnart 2006), dated to the late Lateglacial Interstadial, are similar to the quasi-contemporaneous assemblages in the Central Rhineland.
Fewer changes in the typo-technological units in the Central Rhineland indicate more conservative behaviours in this region than in northern France. Perhaps the richer availability of raw materials in northern France allowed for increased experimentation, which led tp more technical innovations than in the conservative Central Rhineland.

Changes in the Lateglacial exploitation strategies

Acquisition of resources

A first step in the exploitation strategies is the acquisition of the resources. The fossil and mineral resources were presented in the archaeological material chapters according to distance classes (**tabs 12. 25. 36**).
In these tables, a gap can frequently be observed between the very local (5-10 km surrounding of the site) and the next regional raw materials. This gap appears in the Late Magdalenian as well as in the FMG sites and in almost all sites that yielded besides local also a considerable amount of regional raw materials which seemed not to result from exchange but rather from procurement. In the Central Rhineland and the western uplands this gap lies usually around 15-25 km, whereas in the Paris Basin the gap in the few assemblages yielding non local raw materials encompassed 30-40 km. Since the exact acquisition sites of the raw materials are often unknown and, in particular, in the Paris Basin fluvial transport played an important role in diffusing the material, this picture of raw material distances is further indistinct and this diffusion possibly compensates the gap. Therefore, further analyses with more precise localisations of material origins (e. g.

Fig. 71 Succession of assemblages named in this study (**D**) contrasted by the synthesised faunal (**C**; see **fig. 64**) and vegetation development (**B**; see **fig. 59**) as well as the oxygen isotope record of NGRIP (A; see **fig. 53**). Black horizontal bars: probable chronological attribution according to calibrated ^{14}C ages; dark grey horizontal bars: range of unreliable calibrated ^{4}C ages; hatched area: possible age attribution. The transition period between the Late Magdalenian and the FMG as identified in the Central Rhineland (see **fig. 65**) is indicated by a grey background. The limits of the three transition periods in northern France (T1–T3) are indicated by dark grey lines (see **fig. 70**). * assemblages not analysed in detail in this project. Abbreviations: **low** lower horizon; **Wildw.** Wildweiberlei; **Bois Lait.** Bois Laitèrie; **Gön.SW** Gönnersdorf, south-western area; **Marsan.** Marsangy; **P III.2** Pincevent, horizon III.2; **BsS** Belloy-sur-Somme, lower horizon; **O** Bonn-Oberkassel; **Ir** Irlich; **An2** Andernach, upper horizon, main cluster; **H III.1** Hangest-sur-Somme III.1, lower horizon; **Kett** Kettig; **244** Saleux-Les Baquets, *locus* 244; **Clo in-up** Le Closeau, intermediate to upper horizon and undetermined *loci*; **Nibi** Niederbieber; **234** Saleux-Les Baquets, *locus* 234; **B** Boppard; **S 114** Saleux-La Vierge Catherine, *locus* 114; **HIII** Hangest-sur-Somme III.1, upper horizon; **C25** Le Closeau, *locus* 25; **BB** Bad Breisig. – For further details see text.

Pettitt/Rockman/Chenery 2012)[47] are desirable in the future to further locate the source/acquisition areas of raw materials in relation to the site at which the materials were used to allow for further considerations about the Lateglacial settlement systems.

In a more detailed comparison of the tables, a decreasing importance of very long distance sources (250 km >) is apparent between the Late Magdalenian sites and the FMG sites in the Central Rhineland (**tab. 12**). These distances referred particularly to the few numbers of (fossil) shell materials which could be interpreted as special goods. These special good materials were mostly absent from the comparative sites in the western uplands and northern France; only in Bois Laiterie, the upper horizon of Le Grand Canton, and in Marsangy were molluscs found. Probably, these specimens originated from fossil deposits in the Paris Basin and, thus, from a distance of 65-235 km to these sites. Moreover, good quality flint material was available locally in these areas. Therefore, very long distance imports were generally absent from the northern French Late Magdalenian sites[48] and the majority of lithic artefacts was usually made of local raw material. Consequently, these areas are not very useful to exactly identify the end of very far connections. However, since these very long distance imports are already absent in the Wildweiberlei and, presumably, in the younger episode in the south-western area of Gönnersdorf (assuming the jasper artefacts belong to concentration II), the end of these connections can be set to the younger part of the Late Magdalenian occupation (**fig. 72**).

Besides the absence of far distance resources on FMG sites in the Central Rhineland, a tendency towards a major use of local or regional raw materials can be observed on these sites (**tabs 12. 83**; cf. Street et al. 2006, 765-770). In the Late Magdalenian concentrations, local materials such as Tertiary quartzite or indurated slate were usually supplemented by significant amounts of materials such as Western European flint, Baltic flint, or foreign chalcedonies from more distant sources (60 km >). The local to regional Tertiary quartzite clearly dominated in the assemblages attributed to Andernach I and III but from both concentrations the lithic inventory was only partially recovered. This lack of approximately two thirds of the material (Eickhoff-Cziesla 1992, 308) could alter the proportions significantly. Furthermore, according to the spatial analysis and the filling of the pits, Tertiary quartzite was used throughout the occupation of concentration I but it was also used during the last stage of the occupation of this concentration and, thus, other, foreign raw materials could have been cleared out of this concentration (Eickhoff-Cziesla 1992, 309). Therefore, a more numerous supplement to these concentrations by a more distant raw material cannot be excluded. Furthermore, in the concentration III of Gönnersdorf, indurated slate was the most dominant raw material and was not supplemented by an equally numerous distant raw material. Yet, in this concentration the raw material composition was very heterogeneous with several distant raw materials supplementing the inventory (see **tab. 12**, p. 105 f., p. 117, and p. 121). Thus, the Wildweiberlei assemblage, where only the local indurated slate dominated, forms an exception in the Late Magdalenian assemblages. In contrast, the foreign Western European and Baltic flint were only dominant in Kettig and Niederbieber 7 and 20 in FMG assemblages. The other FMG sites and concentrations were dominated by the local indurated slate, Tertiary quartzite, or the regional Muffendorf chalcedony and, thus, during this period people covered the majority of their lithic raw material supply by local to regional sources.

47 The problem of an element analysis in many parts of north-western Europe is that the results can identify the site where the material had been formed but that the raw material has been diffused by glaciers or rivers from this formation site and, thus, the source site where humans gathered the raw material is not identical with the formation site. These source sites remain difficult to identify since the post-formation deposition conditions hardly influenced the material. Often, only the cortex patterns and the shape of complete nodules make some considerations about the depositional processes possible but this information does still not allow the identification of a precise deposition site.

48 Exceptions are jet pearls from habitation 1 of Pincevent which originated from outside the Paris Basin (Leroi-Gourhan/Brézillon 1966, 279) and a mollusc from Étiolles which was of possible Atlantic origin (Alvarez Fernández 2001, 554). In this period, the next Atlantic coast was approximately 435 km west-south-westwards of Étiolles. Known jet sources in southern France are located 430 km south of Pincevent and locations in southern Germany are over 475 km eastwards of Pincevent.

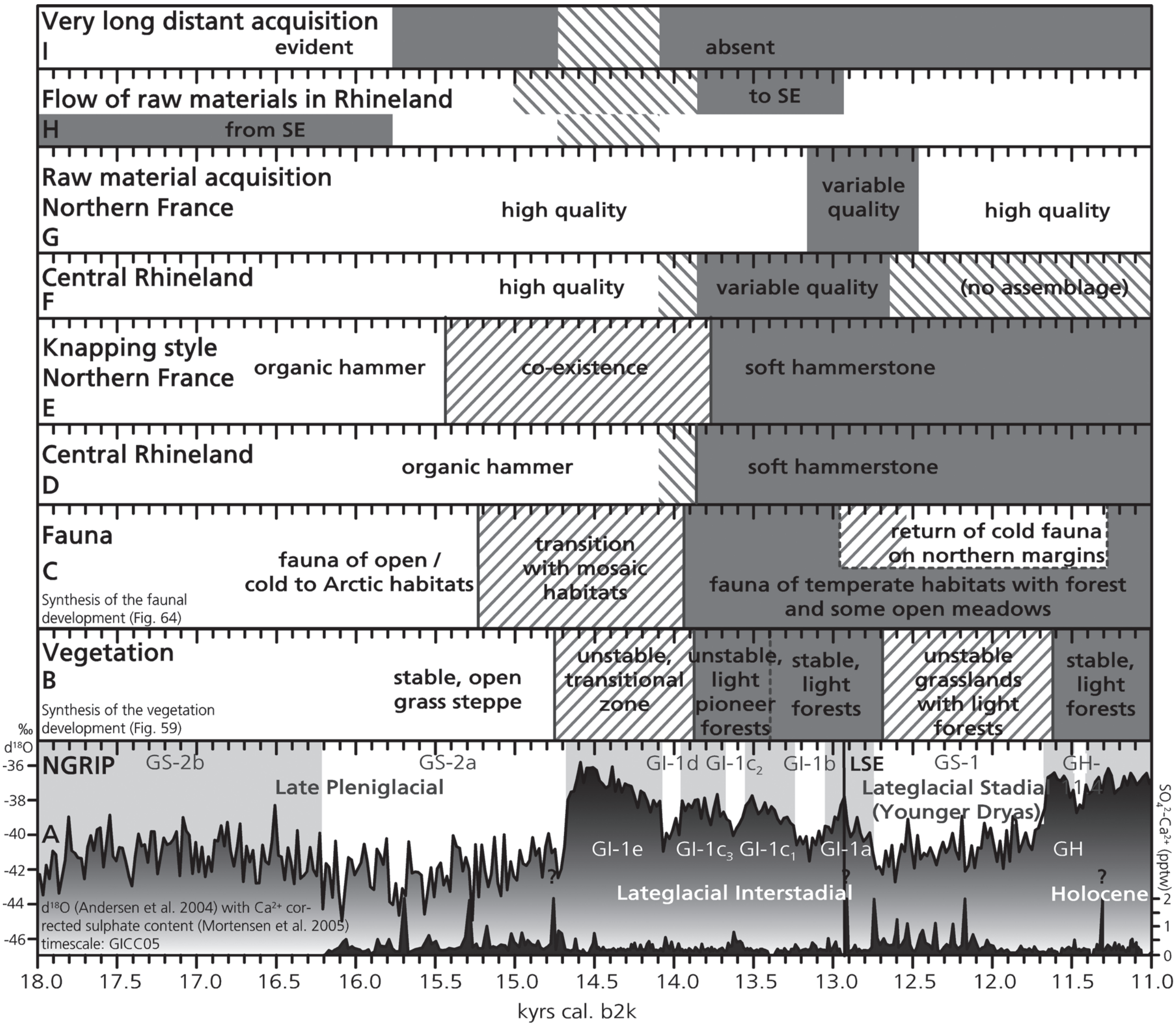


Fig. 72 Behavioural developments related to raw material acquisition (**D-I**) contrasted by the synthesised faunal (**C**; see **fig. 64**) and vegetation development (**B**; see **fig. 59**) as well as the oxygen isotope record of NGRIP (**A**; see **fig. 53**). Hatched areas (low left to up right): transition periods; hatched areas (up left to low right): uncertainties due to the lack of reliable assemblages. – For further details see text.

Nevertheless, except for the chalcedonies and the siliceous oolite from the region around the Rhine-Main basin, foreign raw materials known from the Late Magdalenian assemblages werestill present among the raw materials of FMG sites. Consequently, contacts to these source areas were still evident in the period of the FMG but the relevance of these resources for the everyday supply had decreased.

The chalcedonies used in the Late Magdalenian inventories originated probably from the Main region but no material from this region was identified among the FMG assemblages in the Central Rhineland. However, in the Main region the FMG site Rüsselsheim 122 was located approximately 30 km west of the potential Late Magdalenian source for chalcedonies and the inventory yielded small numbers of Tertiary quartzite which possibly originated from the Taunus and flint varieties which were presumably from the Baltic moraines and/or from the Meuse gravels (Loew 2006). Thus, the acquisition of the latter resource set the Main region in at least a transitional relation to the Central Rhineland during the period before the LSE. In contrast, the raw material from the Late Magdalenian site Dreieich-Götzenhain in the Main region suggested close relations to southern Germany and comprised no northern material (Terberger et al. 2013). Thus, the flow of raw materials along the Rhine seemed to have changed its direction between the Late Magdalenian when raw materials were taken northwards and the FMG when materials were taken southwards (**fig. 72H**). When exactly this change in direction occurred is difficult to estimate due to the limited evidence. The dating of the sites in the Main region was based on the stratigraphic positions and the techno-typological attribution which made only an approximate chronological position possible. These positions are in accordance with the Late Magdalenian (Dreieich-Götzenhain) and typical FMG sites (Rüsselsheim 122) in the Central Rhineland. In the Central Rhineland, the single artefact from Irlich could possibly be a Muffendorf chalcedony and in the upper horizon of Andernach 2, chalcedonies from Muffendorf were already used. Thus, the change of the raw material flow seemed accomplished then. However, chalcedonies were unrelated to the south-western area of Gönnersdorf and they were also not found among the Wildweiberlei assemblage. Consequently, the transport of materials from the south-east to the Central Rhineland could have stopped as early as the younger period of the Late Magdalenian and, thus, around the same time when long distance relations ceased. Comparable to other distant raw materials such as the Western European flint, the connections between the Rhine-Main region and the Central Rhineland were not permanently capped after the Late Magdalenian but due to the lack of sites with a reliable and detailed chronology from the Main area, it remains a matter of debate when exactly during the transition period the reversed flow began. Moreover, a few artefacts made of a jasper from the Upper Rhine valley were found in the south-western area at Gönnersdorf. These jasper artefacts were spatially related to red deer remains (Buschkämper 1993, Plan 11; Street/Turner 2013, Plan 40) but a connection to activities of a Late Magdalenian occupation of the site, in particular of concentration II cannot be excluded (Buschkämper 1993, 50-52; Street/Turner 2013, 134f.). Nevertheless, if the jasper was related to the later episode of the south-western area very long distance transport from south-eastern origins would still have occurred within the transition period in the Central Rhineland. Thus, the discontinuation of these far connections had to be placed towards the end of the transition in the Central Rhineland.

An increasing use of the local resources was considered elsewhere as a sign for increasing knowledge about the local resources (Conneller 2007; cf. Rockman 2003a). However, in the Late Magdalenian assemblages from the Central Rhineland a very high quality Tertiary quartzite was already used suggesting that the landscape and its mineral sources were already well explored by the Late Magdalenian hunter-gatherers. Moreover, local sources of fossil material appeared to be also well known by these people because a source for the possibly burnable fossil wood material, which is scarce today, was regularly found in the Late Magdalenian hearths (see **tab. 12** and cf. p. 167). In fact, a difference which is observable between the Late Magdalenian and the FMG assemblages is a decreasing purity and nodule size of the local as well as the distant raw materials and the form in which the distant raw materials were transported (Street et al. 2006; cf. Floss 1994, 332-336). This difference suggests that the size of the raw pieces as well as the purity and, thus, the knapping abilities of a raw material were of a minor importance for the FMG. Thus, the quality was considered sufficient and/or the ability to handle imperfect raw materials which were available at numerous spots in the local and regional surrounding had increased.

This tendency can also be observed in the Paris Basin where FMG sites were no longer set near good quality sources (Valentin 2008b) or nodules of mediocre quality were occasionally selected from these resources for the FMG assemblages (Bodu/Valentin 1997). An attentive choice of the raw materials comparable to the Late Magdalenian acquisition was still observed in assemblages attributed to the Early Azilian such as the lower horizon at Le Closeau or the assemblage from Gouy (Bodu/Valentin 1997). In contrast, the raw material in the upper horizons of Le Closeau appeared more variable in its quality. Moreover, in the Somme valley where raw material of good quality is easily available, the typical FMG inventories such as Saleux 114 or the upper horizon of Hangest-sur-Somme III.1 used a good quality, fine grained Coniacian flint. Nevertheless, in the assemblages such as the lower horizons of Belloy-sur-Somme, Conty, and Hangest-sur-Somme III.1 an even better, very fine grained, excellent raw material from the Upper Turonian to Lower Coniacian was used (Fagnart 1997). Thus, the decreasing relevance of the raw material properties affect the raw material acquisition in northern France later than in the Central Rhineland (see **fig. 71**).

In both sub-areas, this changed raw material choice (**fig. 72**) occurred in combination with a prevalence in the technical behaviour which was associated with specific characteristics on the raw material blanks attributed to the use of a soft hammerstone (Bodu/Valentin 1997; Valentin 2008a; Ludovic Mevel, written communication)[49]. However, these specific characteristics which distinguish a different knapping style from the typical Late Magdalenian one related to organic hammers occurred already in assemblages of the MfCM (Valentin 2008a) and also in Bois Laiterie (Sano/Maier/Heidenreich 2011). In addition, this knapping style was dominant in the lower horizons of Le Closeau, Hangest-sur-Somme III.1, and Conty (Valentin 2008a). In the assemblages of the MfCM, the relation of the soft hammerstone knapping style with the production of blanks with a straighter longitudinal profile and the use of these blanks in the production of lithic projectile tips was demonstrated (Valentin 1995). The introduction of the technical behaviour associated with the soft hammerstone appeared more flexible and allowed for a wider range of raw materials to be transformed to a designated form. Perhaps, this flexibility turned the balance towards an increasing use of this behavioural recipe. However, the raw material acquisition in the assemblages of the MfCM and the Early Azilian was still comparable to the Late Magdalenian one. In fact, the acquisition of high-quality raw materials did not change until the appearance of typical FMG assemblages in northern France. Thus, the change of acquisition patterns was not instantly connected to the introduction of an alternative technical behaviour but more closely to the discontinued use of the classic knapping style which apparently required a more rigid choice of high-quality raw materials. Nevertheless, after the abandonment of the classic Late Magdalenian blank production process, high-quality raw materials still remained the first choice in the flint-rich area of northern France and raw materials of more variable qualities were only collected during the late Lateglacial Interstadial. Perhaps, the decreasing qualitative choice in northern France was related to an increasing use of harder hammerstones. This tendency was shown for southern Scandinavian assemblages where hard hammerstones became the most important knapping instrument in Brommean inventories during the late Lateglacial Interstadial (Madsen 1992; Madsen 1996). However, on-going technological analyses of northern French inventories and possible comparisons with northern European assemblages can help to evaluate this possibility in the near future.

Exploitation of lithic resources

The size and composition of a lithic assemblage is influenced by raw material types, including the knapping properties, along with the knapping style employed, as well as the function and formation of the site (cf. Löhr 1979; Richter 1990). Understanding these influences, permits a further consideration about the role of a site in the settlement system of a hunter-gatherer group.

49 Even though these characteristics are well described based on material of experienced modern flintknappers (Pelegrin 2000; cf. Madsen 1996), it must remain a matter of debate whether these characteristics were solely related to a different knapping instrument until further experiments with a variety of knapping instruments, raw materials, styles, and larger samples produce a statistically reliable corpus for this correlation. In addition, Ludovic Mevel's on-going technological analysis of the Kettig FMG assemblage might contribute further important observations to this debate because an organic hammer with a zone of scars, presumably from flintknapping, was found within a lithic inventory described as being made by knapping directly with a hard hammerstone (Baales 2002).

assemblage size class	artefacts ≥ 1 cm	artefacts total
5 (large)	**Gönnersdorf**; Le Tureau des Gardes; Étigny-Le Brassot, south; Cepoy; Le Grand Canton, upper horizon; Marsangy; *Le Closeau, greyish layers; Niederbieber*; Le Tureau des Gardes, *locus* 10; Cepoy, sector 1 and sector 2; Le Grand Canton, sector 2, upper horizon; Marsangy N19	**Gönnersdorf**; **Andernach, lower horizon**; *Kettig; Niederbieber; Bad Breisig*
4	**Andernach, lower horizon**; Le Closeau, lower horizon; Belloy-sur-Somme, lower horizon; *Bad Breisig;* **Le Tureau des Gardes, *locus* 6** and *locus* 7	Andernach, upper horizon; **Gönnersdorf II**; **Andernach I and IV**; Le Tureau des Gardes, *locus* 7; *Niederbieber 4+17a, 6+10a, and 18*; *Andernach 3-FMG*
3	Andernach, upper horizon; Kettig; Le Closeau, *locus* 46 and *loci* 4+50; Gönnersdorf, south-western area; *Niederbieber 1, 4+17a, and 9*; *Andernach 3-FMG*	Niederbieber 1, 5, 8, 12, 13, and 14
2	Bois Laiterie; Bonnières-sur-Seine; **Andernach IV**; Le Grand Canton, sector 1, upper horizon; *Andernach 2-FMG*; *Niederbieber 5, 6+10a, 7, and 12*	Bois Laiterie; **Andernach II**; *Niederbieber 9, 11, 16, and 20*
1	**Hallines**; **Saint Mihiel**; **Wildweiberlei**; Hangest-sur-Somme III.1, lower horizon; *Urbar*; **Gönnersdorf IV**; **Le Grand Canton, sector 2, lower horizon**; *Niederbieber 8, 10, 13, 14, 18, and 20*	**Saint Mihiel**; Hangest-sur-Somme III.1, lower horizon; Conty, lower horizon; *Urbar*; **Gönnersdorf IV** and south-western area; *Andernach 2-FMG*; *Niederbieber 7, 10, and 17*
0 (small)	Gouy; Pincevent III.2; *Niederbieber 3, 11, 15, 16, 17, and 19*; *Le Closeau, locus 25*	**Wildweiberlei**; Pincevent III.2; **Andernach III**; *Niederbieber 3, 15, and 19*

Tab. 81 Attribution of the studied assemblages to assemblage size classes (see p. 273 f. and **tab. 52**). Late Magdalenian assemblages are set in bold and *Federmesser-Gruppen* assemblages are set in italics.

Firstly, assemblages were differentiated by the number of lithic artefacts to distinguish them by size. Subsequently, the general composition of the lithic inventory was differentiated in relation to the number of cores and retouched artefacts as well as the composition and diversity of the retouched artefacts. A comparison of the assemblages by weight rather than number of the lithic material brought to the site is desirable. For example, the 76 kg of lithic raw material from Gönnersdorf (Floss 1994, 219 f.) provided almost 25 % more artefacts (n ≈ 33,000) than the 334 kg from Le Grand Canton (n = 25,175; Valentin et al. 1999b, tabs 14-15). Certainly in relation to resource exploitation and transport conditions, the weight of lithic raw material imported seemed of a greater importance than the numbers of lithics. However, these values are not regularly presented in the literature and, thus far, further comparisons can therefore not be accomplished.

Generally, comparing assemblages composed of artefacts ≥ 1 cm in size indicates that most of these assemblages are of a small to medium assemblage size (assemblage size classes 1 and 2), whereas larger assemblages (assemblage size classes 4 and 5) were usually found on sites with several concentrations (**tab. 81**). Very small assemblages (assemblage size class 0) were only found in the context of the Early Azilian and the FMG, including the Malaurie *locus* 25 of Le Closeau. However, some of these very small inventories were considered as special task assemblages such as Niederbieber 3, or incomplete excavations such as Gouy. In these inventories, the knapping process and consequential debris was of minor importance or neglected during collection, which can explain the very small numbers (≤ 500 artefacts ≥ 1 cm). The lack of such small, possibly specialised assemblages from the Late Magdalenian could be due to the choice of sites included in this project. However, assemblages considered as special task camps such as Beeck in the northern Rhineland (Jöris / Schmitz / Thissen 1993) or Götzenhain-Dreieich (Terberger et al. 2013) yielded more than 1,000 artefacts ≥ 1 cm. Moreover, lithic workshops and / or lithic procurement sites such as Kanne, Orp, or Mesch (Vermeersch / Lauwers / van Peer 1985; Vermeersch et al. 1987; Rensink 2000) provided large numbers of lithic artefacts, mainly debris. Thus, the absence of very small lithic assemblages from Late Magdalenian

site	no.
Hallines	1
Saint Mihiel	2
Gönnersdorf	3
Andernach, lower horizon	4
Le Grand Canton, sector 2, lower horizon	5
Wildweiberlei	6
Le Tureau des Gardes, *locus* 6	7
Le Tureau des Gardes, *locus* 7	8
Le Tureau des Gardes, *locus* 10	9
Étigny-Le Brassot, south	10
Bois Laiterie	11
Le Grand Canton, sector 1	12
Le Grand Canton, sector 2, upper horizon	13
Bonnières-sur-Seine	14
Le Closeau, *locus* 46	15
Le Closeau, *loci* 4+50	16
Gönnersdorf SW	17

site	no.
Cepoy, sector 1	18
Cepoy, sector 2	19
Marsangy	20
Gouy	21
Pincevent III.2	22
Belloy-sur-Somme	23
Andernach 2-FMG	24
Hangest-sur-Somme III.1, lower horizon	25
Kettig	26
Conty, lower horizon	27
Urbar	28
Le Closeau, intermediate, upper, and undetermined horizons (greyish deposits)	29
Niederbieber	30
Andernach 3-FMG	31
Le Closeau, *locus* 25	32
Bad Breisig	33

Tab. 82 Numeration of assemblages in the graphs.

contexts[50], perhaps reflects a behavioural habit where lithic material was not discarded unless there was sufficient replacement available. Similarly, a knapping process was not started unless absolutely necessary, or the knapping process created usually more than 500 pieces. Another possible explanation of the lack of these assemblages is that these inventories were not diagnostic enough to be identified as Late Magdalenian remains. However, this overview indicates that the largest variety of assemblage sizes was found in the FMG assemblages.

Even though assemblages of the assemblage size class 0 are absent, Late Magdalenian concentrations are not generally larger than the ones attributed to the FMG. In contrast, some FMG concentrations produced more artefacts than Late Magdalenian ones, in particular in the comparison of total numbers of artefacts (**tab. 81**). In fact, some of the Late Magdalenian inventories fall into the small and very small assemblage size class if the total number of artefacts is considered. This observation suggests that more and tendentially smaller material remained at FMG sites. This increase in discarded material could relate to a change in knapping style, probably using mineral hammers resulting in more splintering of the lithic raw materials during the knapping process. Nevertheless, very small assemblages were all attributed to the use of soft hammerstone but the scarcity of knapping in these assemblages can also explain the lack of numerous splintered material. Furthermore, even though Late Magdalenian concentrations such as Gönnersdorf II were considered to be repeatedly visited or occupied for a longer period, these inventories did not provide more artefacts than Niederbieber 4+17a or Bad Breisig which were usually considered to be short-term camps (Grimm 2004; Gelhausen 2011b). The alternative suggestion that FMG concentrations were also formed by longer occupations or single accumulations formed by repetitive visits is contradicted by the small overall quantities of preserved fauna. The well defined and organised spatial distributions of the lithic artefacts and splinters, the clearly separated concentrations on repetitively visited FMG sites such as Niederbieber (Gelhausen 2011a) or

50 The assemblages of the south-western area from Gönnersdorf and Bois Laiterie were not further attributed to an archaeological unit but summarised in a not further specified Final Magdalenian group as a provisional solution. According to the recent results (Sano/Maier/Heidenreich 2011), an attribution of the Bois Laiterie inventory to the MfCM seems possible but requires further confirmation because it is located outside the main concentration of this archaeological unit (cf. Valentin 2008a,132-136) and also contained elements of the Late Magdalenian (Lejeune 1997; Straus/Orphal 1997).

site	assemblage size class	density index	% cores	main raw material	exploitation index	% retouched artefacts	function index
Hallines	1 (×)	**158** (×)	**5.82** (×)	Senonian flint	17 (×)	15.4 (×)	2.7
Saint Mihiel	1 (1)	50 (150)	1.00 (0.33)	Western European flint	100 (300)	2.7 (0.9)	2.7
Gönnersdorf	5 (5)	48 (119)	0.94 (0.38)	Tertiary quartzite; Western European flint; Baltic flint	**107** (×)	14.7 (5.9) / 13.1 (5.3)	15.7 / 13.9
Gönnersdorf II	× **(5)**	× (138)	× (0.09)	Western European flint	× **(1,062)**	× (5.2)	55.4
Gönnersdorf IV	1 (1)	7 (22)	**3.28** (1.02)	chalcedony	31 (99)	21.3 (6.6)	6.5
Andernach, lower horizon	4 (5)	27 (179)	0.84 (0.13)	Tertiary quartzite; Western European flint	119 (797)	28.1 (4.2)	33.3
Andernach I	× **(4)**	× **(209)**	× (0.18)	Tertiary quartzite; Baltic flint	× **(543)**	× (3.3)	17.7
Andernach II	× (2)	× **(341)**	× (0.05)	Western European flint	× **(1,930)**	× (8.7)	167.7
Andernach III	× (0)	× (59)	× (0.45)	Tertiary quartzite; Baltic flint; chalcedony	× (223)	× (16.2)	36.2
Andernach IV	2 **(4)**	11 (175)	0.75 (0.05)	Western European flint	133 (2,202)	23.0 **(1.4)**	30.6
Le Grand Canton, sector 2, lower horizon	1 (×)	41 (×)	0.49 (×)	Senonian gravel flint	**206** (×)	**2.6** (×)	5.3
Wildweiberlei	1 (0)	24 (28)	4.83 (4.23)	indurated slate (lydite)	21 (24)	17.1 (15.0)	3.5
Le Tureau des Gardes	5 (×)	**132** (×)	1.55 (×)	local Cretaceous flint	65 (×)	**5.7** (×)	3.7
Le Tureau des Gardes, *locus* 6	**4** (×)	**853** (×)	1.41 (×)	local Cretaceous flint	71 (×)	**5.8** (×)	4.2
Le Tureau des Gardes, *locus* 7	4 (4)	54 (114)	1.11 (0.53)	local Cretaceous flint	90 (190)	10.4 (4.9)	9.3
Le Tureau des Gardes, *locus* 10	5 (×)	**166** (×)	**1.96** (×)	local Cretaceous flint	51 (×)	8.4 (×)	4.3
Étigny-Le Brassot, south	5 (×)	41 (×)	× (×)	Senonian gravel flint	× (×)	**1.2** (×)	×
Bois Laiterie	2 (2)	58 (107)	0.22 (0.12)	Western European flint	454 (842)	14.0 (7.5)	63.5
Le Grand Canton, upper horizon	5 (×)	24 (×)	**4.13** (×)	Senonian gravel flint	24 (×)	**4.2** (×)	1.0
Le Grand Canton, sector 1	2 (×)	17 (×)	**18.41** (×)	Senonian gravel flint	5 (×)	11.1 (×)	0.6
Le Grand Canton, sector 2, upper horizon	5 (×)	47 (×)	**3.51** (×)	Senonian gravel flint	29 (×)	**3.9** (×)	1.1
Bonnières-sur-Seine	2 (×)	44 (×)	0.53 (×)	local flint	188 (×)	**1.0** (×)	1.9
Le Closeau, lower horizon	4 (×)	6 (×)	0.83 (×)	Campanian flint	**120** (×)	8.8 (×)	~10.5
Le Closeau, *locus* 46	3 (×)	12 (×)	1.00 (×)	Campanian flint	**100** (×)	10.6 (×)	8.7
Le Closeau, *loci* 4+50	3 (×)	14 (×)	0.81 (×)	Campanian flint	**124** (×)	8.7 (×)	13.1
Gönnersdorf SW	3 (1)	20 (25)	0.27 (0.21)	Baltic flint; Western European flint	**375** (467)	6.6 (5.3)	24.7
Cepoy	5 (×)	85 (×)	1.18 (×)	local Cretaceous gravel flint	85 (×)	**0.9** (×)	0.8
Cepoy, sector 1	5 (×)	71 (×)	1.74 (×)	local Cretaceous gravel flint	58 (×)	**1.0** (×)	0.6
Cepoy, sector 2	5 (×)	**100** (×)	0.69 (×)	local Cretaceous gravel flint	**146** (×)	**0.8** (×)	~1.2
Marsangy	5 (×)	**102** (×)	1.75 (×)	local Cretaceous flint	57 (×)	**3.0** (×)	1.7
Marsangy N19	5 (×)	**179** (×)	**1.90** (×)	local Cretaceous flint	53 (×)	**3.0** (×)	1.6

Tab. 83 Indices of lithic material referring to the size and use of the studied assemblages. Assemblage size classes refer to numbers of lithic artefacts ≥1 cm (total) found at a site/concentration. The classes are **0** 1-500 (1-1,500); **1** 501-1,000 (1,501-3,000); **2** 1,001-2,000 (3,001-6,000); **3** 2,001-4,000 (6,001-12,000); **4** 4,001-8,000 (12,001-24,000); **5** 8,000> (24,000>). Density index is calculated by dividing the no. of artefacts ≥1 cm by excavated m². Exploitation index is formed by dividing no. of artefacts ≥1 cm by no. of cores. The % cores is given for all cores and core fragments (see **tabs 11. 24. 35**) in relation to lithic artefacts ≥1 cm. In parentheses the indices are given calculated with no. of total artefacts. The same applies to % retouched artefacts. Function index is the no. of formally retouched artefacts divided by the no. of cores and core fragments. In bold, values that are indicative for a wasteful exploitation strategy.

site	assemblage size class	density index	% cores	main raw material	exploitation index	% retouched artefacts	function index
Gouy	0 (×)	× (×)	0.86 (×)	Cretaceous flint	**116** (×)	13.8 (×)	16.0
Pincevent III.2	0 (0)	2 (2)	**2.05** (1.78)	local gravel flint	49 (56)	6.3 (5.5)	3.1
Belloy-sur-Somme	4 (×)	14 (×)	1.68 (×)	local Turonian and Coniacian flint	59 (×)	**2.5** (×)	1.5
Andernach, upper horizon	3 **(4)**	16 (81)	1.74 (0.33)	Tertiary quartzite; chalcedony	58 (×)	7.4 (1.4)	4.2
Andernach 2-FMG	2 (1)	13 (28)	**1.82** (0.86)	Tertiary quartzite	55 (116)	11.3 (5.4)	6.2
Hangest-sur-Somme III.1, lower horizon	1 (1)	6 (13)	**2.50** (1.08)	local Turonian and Coniacian flint	40 (93)	11.9 (5.1)	4.8
Kettig	3 **(5)**	16 (100)	1.59 (0.25)	Tertiary quartzite; Western European flint	63 (395)	9.2 **(1.5)**	5.7
Conty, lower horizon	× (1)	× (20)	× (0.15)	local Turonian flint	× (×)	× (2.1)	14.0
Urbar	1 (1)	30 (97)	1.55 (0.49)	Tertiary quartzite	65 (205)	23.3 (7.3)	15.0
Le Closeau, greyish layers	5 (×)	2 (×)	**2.00** (×)	Campanian flint	50 (×)	**2.0** (×)	1.0
Niederbieber	5 (5)	19 (116)	1.38 (0.22)	Tertiary quartzite; chalcedony	72 (449)	9.0 **(1.4)**	6.3
Niederbieber 1	3 (3)	54 (166)	1.28 (0.41)	chalcedony	78 (242)	10.5 (3.4)	8.2
Niederbieber 3	0 (0)	9 (50)	0.39 (0.07)	chalcedony	258 (1,402)	3.5 (0.6)	9
Niederbieber 4 (+17a)	3 **(4)**	29 **(233)**	1.37 (0.17)	chalcedony	73 **(593)**	12.3 **(1.5)**	9
Niederbieber 5	2 (3)	39 (184)	1.46 (0.31)	Tertiary quartzite	68 (×)	6.7 **(1.4)**	4.6
Niederbieber 6 (+10a)	2 **(4)**	41 **(288)**	0.76 (0.11)	chalcedony; Tertiary quartzite	131 (924)	5.7 (0.8)	7.4
Niederbieber 7	2 (1)	29 (63)	1.54 (0.71)	Baltic flint	65 (141)	12.0 (5.5)	7.8
Niederbieber 8	1 (3)	7 (151)	0.93 (0.04)	Tertiary quartzite	107 (2,267)	6.9 **(0.3)**	7.4
Niederbieber 9	3 (2)	17 (40)	1.49 (0.63)	Tertiary quartzite	67 (158)	8.3 (3.6)	5.6
Niederbieber 10	1 (1)	35 (101)	1.36 (0.48)	Tertiary quartzite	74 (210)	7.2 (2.5)	5.3
Niederbieber 11	0 (2)	9 (85)	**2.20** (0.23)	chalcedony; Tertiary quartzite	45 (430)	13.2 **(1.4)**	6
Niederbieber 12	2 (3)	24 (148)	**1.90** (0.31)	Tertiary quartzite	53 (324)	5.9 (1.0)	3.1
Niederbieber 13	1 (3)	18 (178)	1.29 (0.13)	Tertiary quartzite	77 **(770)**	7.2 **(0.7)**	5.6
Niederbieber 14	1 (3)	18 (157)	**2.93** (0.33)	indurated slate; chalcedony	34 (300)	11.9 **(1.4)**	4.1
Niederbieber 15	0 (0)	10 (18)	**2.47** (1.27)	chalcedony	41 (79)	14.8 (7.6)	1.3
Niederbieber 16	0 (2)	11 (146)	1.68 (0.13)	indurated slate; chalcedony	60 **(769)**	7.4 **(0.6)**	6
Niederbieber 17	0 (1)	3 (40)	1.24 (0.10)	chalcedony	81 **(1,030)**	38.9 (3.1)	15.5
Niederbieber 18	1 **(4)**	19 **(368)**	0.14 (0.01)	indurated slate (greenish; Western European flint; chalcedony	715 (13,991)	1.4 (0.1)	9
Niederbieber 19	0 (0)	6 (10)	**4.40** (2.44)	chalcedony	23 (41)	**5.7** (3.1)	10
Niederbieber 20	1 (2)	16 (57)	1.02 (0.29)	Baltic flint	98 (340)	4.6 (1.3)	4.5
Andernach 3-FMG	3 **(4)**	21 (151)	1.70 (0.24)	chalcedony	59 (×)	5.1 (0.7)	3.0
Le Closeau, *locus* 25	0 (×)	5 (×)	0.79 (×)	Campanian flint	**126** (×)	**3.0** (×)	10
Bad Breisig	4 (5)	119 (910)	**3.09** (0.41)	Tertiary quartzite	32 (247)	5.0 (0.7)	1.6

Tab. 83 (continued)

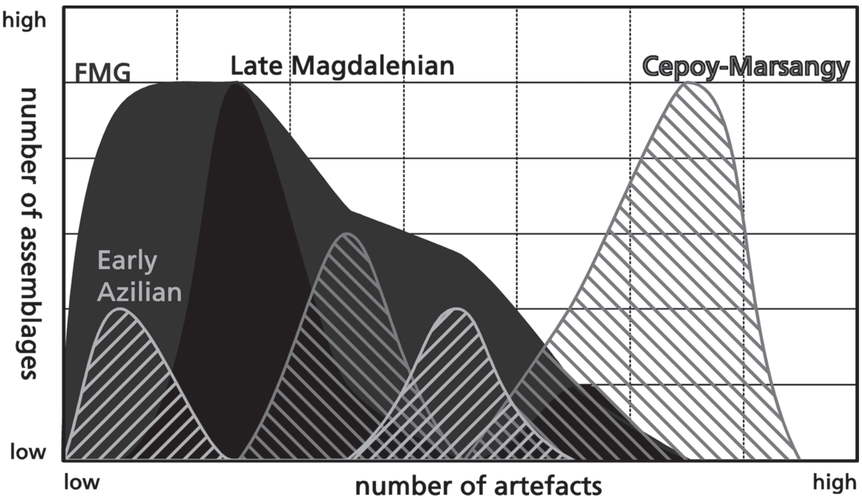
Rekem (De Bie/Caspar 2000), and the massive structural elements found in the Late Magdalenian concentrations indicate the longer use, whether repetitive or continuous, at these sites. Accordingly, it seems that the careful preparation of the Late Magdalenian cores produced some waste material with a series of good quality blanks that were, in general, further used. In contrast, the FMG knapping process produced a lot of discarded blanks and debris. Consequently, the larger assemblages are probably an expression of a more wasteful handling of lithic raw materials in the FMG than the Late Magdalenian. Furthermore, although the Andernach 2-FMG site was possibly repeatedly visited, the concentrations are not as clearly defined as the Niederbieber concentrations but the site also produced a relatively small assemblage with tendentially bigger pieces. Thus, this increasingly wasteful handling seemed to further increase within the FMG resulting in a high quantity of discard at Bad Breisig (**tab. 81**).

In fact, the only assemblage of a single Late Magdalenian concentration yielding more artefacts ≥ 1 cm than most FMG concentrations (only Bad Breisig was larger) was Le Tureau des Gardes, *locus* 6. *Locus* 6 was only excavated over a very small area, which explains the very high density index (**tab. 83**). However, the assemblages from Le Tureau des Gardes were recovered from depressions in the palaeosurface (Lang 1998, 84). Consequently, the possibility that these concentrations represent sediment traps and, thus, accumulation by natural processes rather than a single anthropogenic concentration can only be excluded though a more comprehensive excavation and detailed spatial and micromorphological analyses that are not yet published (Lang 1998, 104; cf. Julien/Rieu 1999). In addition, several of the *loci* from this site produced material attributed to the MfCM where the knapping style attributed to the use of soft hammerstones was first identified. Inventories of this archaeological unit yielded the most numerous lithic assemblages. Thus, did the use of this knapping style create more discard material and did the change of the knapping style result in a more wasteful handling of the resources? Could this wasteful style only appear in a region such as the Paris Basin with rich lithic resources? To answer these questions further attributes of the inventories must be considered (see below).

However, besides the MfCM, the Early Azilian occurred in the same sub-area and, in these assemblages, the change of knapping style towards the use of soft hammerstone was well established. Since the number of analysed sites varied between the archaeological units, the distribution of sites to the different assemblage size classes only makes it possible to establish general comparative observations about the occurrence of different assemblage sizes in the archaeological units (**fig. 73**). Nevertheless, the assemblage sizes of both, the Early Azilian and the MfCM, were bivariate but the distributions are alternating. The few Early Azilian assemblages were generally small to medium-sized, whereas the MfCM inventories were medium-to very large-sized. In fact, all archaeological units yielded a bivariate distribution of assemblage size classes, except for the many FMG concentrations that produced a monovariate distribution. This difference is possibly due to the number of analysed sites and if equal numbers were studied for the Late Magdalenian, the MfCM, or the Early Azilian a comparable monovariate distribution would appear. However, the peaks of these distributions are comparable for the Early Azilian and the FMG. Perhaps, the Late Magdalenian assemblages were similar to the former but might also be tendentially bigger. It is already apparent that assemblages of the MfCM yielded many large assemblages (**fig. 73**).

The assemblages of the lower horizons of Hangest-sur-Somme III.1 and Conty are rather small and the early FMG assemblages of the Central Rhineland are also small to medium-sized, whereas on younger sites such as Niederbieber, Bad Breisig, and also the greyish deposits of Le Closeau are large and very large assemblages again present. In these FMG horizons, the concentrations were well defined and usually appeared to respect one another (cf. Bodu 1998; Gelhausen 2011a). In contrast, the large assemblages of the MfCM sites were often found in dense but diffuse distributions of material, occasionally around hearths, which seem to be unrelated to one another. Assuming that this pattern was not primarily caused by post-depositional

Fig. 73 Generalised frequency of assemblages according to their assemblage size. Black area: Late Magdalenian; grey hatched area: Final Magdalenian faciès Cepoy-Marsangy (Cepoy-Marsangy); light grey hatched area: Early Azilian; grey area: *Federmesser-Gruppen*.



processes (cf. Julien et al. 1999), these latter horizons appear to have accumulated over a longer period of time resulting in a greater diffusion by more intense settlement dynamics and/or partial cover of previous concentrations. However, the undifferentiated presentation of some of these sites such as the sectors 1 of Cepoy or Le Grand Canton and the unclear accumulation history (and still questionable post-depositional influences) of these assemblages can only partially be responsible for this impression. Single concentrations such as the southern concentration of Étigny-Le Brassot or Marsangy N19 yielded more than 8,000 artefacts ≥1 cm and, thus, fall into the group of the largest assemblages (assemblage size class 5). The sector 2 of Le Grand Canton was analysed in greater detail (Julien/Rieu 1999) and also yielded some very dense clusters with occasionally 7-10 cores per squaremetre (Julien et al. 1999, fig. 84D). Thus, the impression of very wasteful handling of the raw materials on these sites persists. Nevertheless, to identify a wasteful handling of raw materials further criteria have to be considered.

For this project, some of the criteria identified as indicative of wasteful handling of lithic resources can be further tested. For instance, besides the amounts of material (assemblage size class) brought to a site, the density of this material on the excavated site, the percentage of cores (% cores), and the relation of these cores to the debris material was calculated for the analysed sites (**tab. 83**). In addition, the relation of the blanks produced at a site to those used, with or without formal retouch, and those that were abandoned without signs of use could be an indicator for an efficient exploitation of the lithic resources[51]. However, this efficiency in lithic products remains difficult to evaluate. For example, for some cores the state of exploitation in which they arrived at the site cannot be exactly reconstructed; some blanks could have arrived at the site prepared and were discarded there. Therefore, the efficiency of secondary exploitation cannot be considered further in this project.

Based on the available values, a wasteful handling of material could be characterised by a high assemblage size class for a single concentration with a high artefact density at the site (density index). For example, a high proportion of cores that produced little other material (low exploitation index for artefacts ≥1 cm) but many small pieces (high exploitation index for total artefacts). Furthermore, a low number of blanks transformed into formally retouched tools can be considered as a sign of unfocused blank production if the unretouched specimens were not intensely used. However, this later characteristic also depends on the function of a site because large numbers of formally retouched artefacts cannot be expected on a raw material acquisition/exploitation site. In contrast, a more economic use of raw materials would result in a medium to small

51 At this point, the author likes to thank Ludovic Mevel, Nanterre, for the fruitful discussion.

assemblage size class for a single concentration with an intermediate density assuming that the knapping was a more organised activity and, thus, distributed in a more restricted space. These economic assemblages had very few abandoned cores at the site (low % cores) assuming that useful blanks were imported and still usable cores exported. Furthermore, the exploitation index for artefacts ≥1 cm would also be low assuming that in addition to the cores, blanks were exported from the site. In contrast to the wasteful handling, an economic use would not probably tolerate a raw material that splinters a lot and, thus, the exploitation index for the total artefacts would also be low. Moreover, the remaining lithic artefacts should bear traces of intensive use in an efficient exploitation strategy. Since use-wear analyses are infrequently conducted and usually focused on only a small sample of the unretouched material, this indicator cannot be used in the present comparison. However, the percentage of formally retouched artefacts could provide a proxy for the transformation of the blanks into tools and, thus, the secondary use of the raw material.

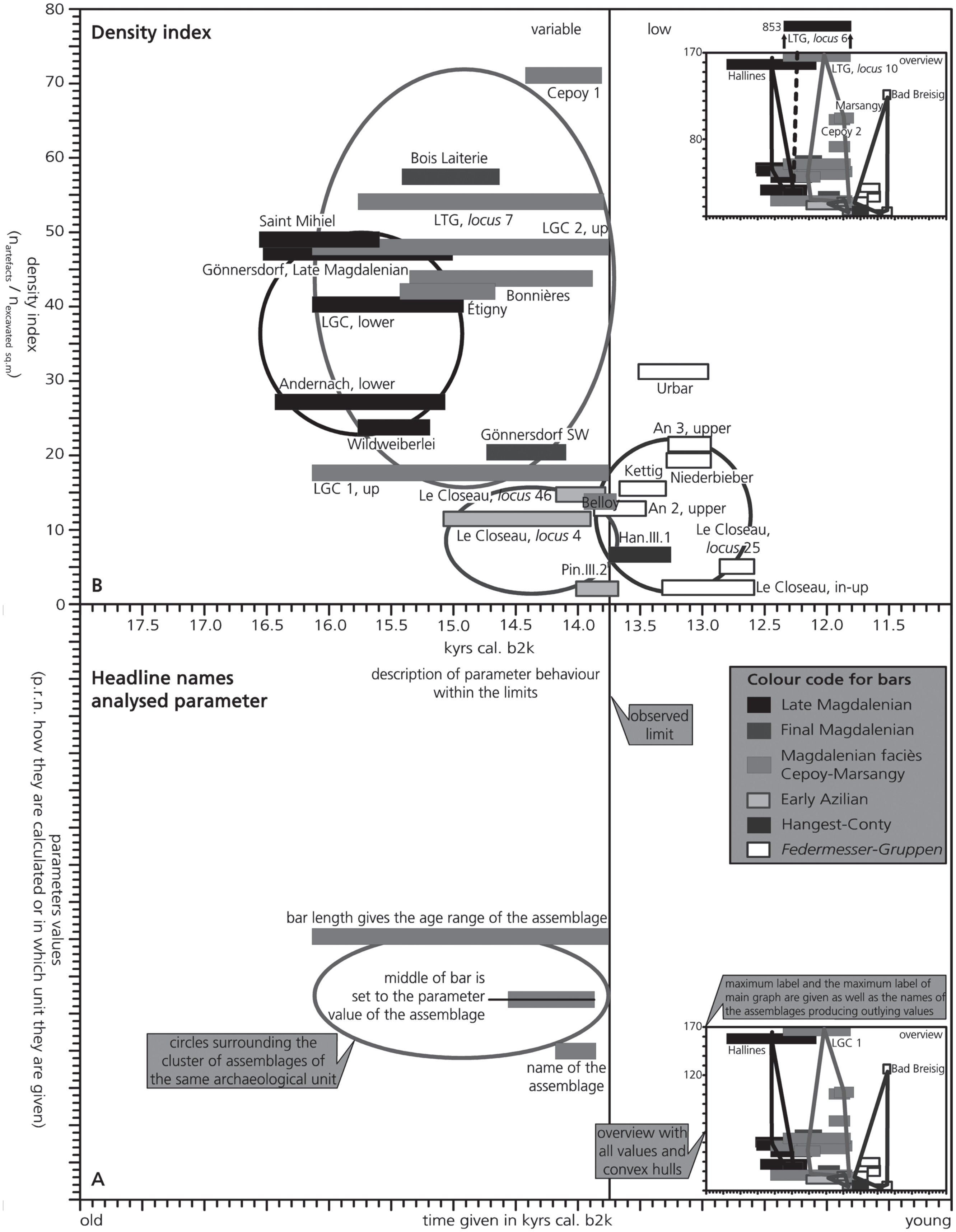
To visualise the temporal development of these parameters, graphs were created that give the age range, the archaeological attribution, and the value of the analysed parameter for each analysed assemblage (fig. 74A). To prevent an overemphasis of outlying values, a complete distribution of values is given in a small overview, whereas in the main graph mostly contains the main cluster of values.

In general, the density index (di; tab. 83) appears to develop from very variable values to relatively low values (fig. 74B). Thus, the impression that the Early Azilian and FMG sites were rather ephemeral is further confirmed by the di. The Early Azilian as well as the FMG assemblages range below or at the lower limit of Late Magdalenian or MfCM densities. Bad Breisig forms a single, clear outlier with a di of 119 and also the di of the Urbar assemblage is with a value of 30 higher than in the other FMG sites that range between values of 2 and 21. The excavation of Bad Breisig was oriented along the main concentration and so stopped where the main density decreased. Comparably, only some parts of a concentration were excavated at Urbar resulting in a higher di. In contrast, the vast excavation area of Le Closeau comprised several, almost sterile, square-metres resulting in a lower value as a consequence of these sterile areas. Therefore, the values from this site form the lower range of the FMG assemblages. However, if the single concentrations of Niederbieber are considered (tab. 83), they reveal a larger range of dis from 3 to 55. Thus, the low values displayed by the Le Closeau assemblages appear not only as a result of the large excavation area and the values fall well within the occasionally, very ephemeral concentrations of the FMG.

The majority of the Late Magdalenian assemblages yielded density values of 24 to 50 and, thus, higher than the range of the main FMG units but within the range of the single concentrations of Niederbieber. Assuming that sites such as Gönnersdorf and possibly also Saint Mihiel were occupied over a longer period or visited repetitively, this longer use resulted in Late Magdalenian sites having a higher density. Nevertheless, the occupation of Niederbieber was also considered to have been repetitively used over a longer period (Gelhausen 2011b; Gelhausen 2011a). At this location, behaviour resulted in contrary values due to the spread of the concentrations over a larger area. Single FMG concentrations that yielded dense clusters were possibly also used over a longer period such as Niederbieber 1 (di = 54). This site is interpreted as being used for several weeks during the late winter/early spring (Bolus 1992, 183). Concentration 4

→

Fig. 74 **A** Template graph for values given per time and archaeological unit. **B** Values of the density index given per time and archaeological unit. – Circles were set around the main cluster of assemblages attributed to the same archaeological unit. The distribution of all assemblages is given in the overview where also the convex hulls were set per archaeological unit (see p. 281 f.). In the overview, names are only given for sites which are not shown in the main graph. Abbreviations: **LTG** Le Tureau des Gardes; **Cepoy 1/2** Cepoy, sector 1/2; **LGC lower** Le Grand Canton, lower horizon; **LGC 1/2, up** Le Grand Canton, sector 1/2, upper horizon; **An 2/3 up(per)** Andernach 2/3, upper horizon; **Pin. III.2** Pincevent, horizon III.2; **Han III.1** Hangest-sur-Somme III.1, lower horizon; **Conty** Conty, lower horizon; **Le Closeau, in-up** Le Closeau, intermediate to upper horizons (greyish deposits). – For further details see text.


Density index
variable
low
853
LTG, locus 6
170
overview
Hallines
LTG, locus 10
Bad Breisig
Marsangy
Cepoy 2
80
Cepoy 1
Bois Laiterie
LTG, locus 7
LGC 2, up
Saint Mihiel
Gönnersdorf, Late Magdalenian
Bonnières
Étigny
LGC, lower
Urbar
Andernach, lower
Wildweiberlei
Gönnersdorf SW
An 3, upper
Kettig
Niederbieber
LGC 1, up
Le Closeau, locus 46
Belloy
An 2, upper
Le Closeau, locus 4
Le Closeau, locus 25
Han.III.1
Pin.III.2
Le Closeau, in-up
B
density index
($n_{artefacts}$ / $n_{excavated\ sq.m}$)
80
70
60
50
40
30
20
10
0
17.5
17.0
16.5
16.0
15.5
15.0
14.5
14.0
13.5
13.0
12.5
12.0
11.5
kyrs cal. b2k
Headline names analysed parameter
description of parameter behaviour within the limits
observed limit
Colour code for bars
Late Magdalenian
Final Magdalenian
Magdalenian faciès Cepoy-Marsangy
Early Azilian
Hangest-Conty
Federmesser-Gruppen
parameters values
(p.r.n. how they are calculated or in which unit they are given)
bar length gives the age range of the assemblage
middle of bar is set to the parameter value of the assemblage
circles surrounding the cluster of assemblages of the same archaeological unit
name of the assemblage
maximum label and the maximum label of main graph are given as well as the names of the assemblages producing outlying values
170
overview
Hallines
LGC 1
120
Bad Breisig
overview with all values and convex hulls
A
old
time given in kyrs cal. b2k
young

at Niederbieber (di = 29) was assumed to have been used even longer due to the more »spoiled« appearance (Bolus 1992, 183). These more intense settlement dynamics with occasional clearings of the main activity area(s) certainly occurred during the Late Magdalenian (Sensburg 2007; Sensburg / Moseler 2008). These clearings resulted in a widening of the main concentration, whereas in FMG assemblages a new concentration was installed after a certain limit of lithic density was reached. Presumably, this more readily made reinstallation of the FMG concentrations was partially due to the lighter constructions on these sites that were easier to move. Moreover, lighter lithic material was covered more easily underneath the heavy plates or within the pits of Late Magdalenian concentrations allowing for a higher density of this material to accumulate within a concentration. Nevertheless, Late Magdalenian concentrations were generally dense and yielded the most compact cluster, uncovered in the *locus* 6 of Le Tureau des Gardes with 853 artefacts on average per squaremetre. However, the uncertainties of a human accumulation of these concentrations were pointed out previously. Furthermore, the accumulation in Hallines (di = 158) was also very high. This assemblage was recovered from only a very small test pit area and included the material of at least two episodes (see p. 183-189), which could explain the relatively high di. In contrast, the assemblage from the lower horizon of Andernach was not very dense (di = 27) but in this excavation area only three major concentrations were cut and not completely excavated. Furthermore, the wasteful blank production process seems clearly under-represented either because it was of a minor importance or because the knapping workshops or the refuse area were not excavated (pers. comm. Martin Street, Neuwied, and Ludovic Mevel, Nanterre). For the small Wildweiberlei assemblage (di = 24), the question remains, which material was lost due to the position in a cliff (Lateglacial disposal of waste into the valley), the early excavations (neglect of small pieces), and / or the destruction of the cave. Thus, the accumulation of 40 to 50 artefacts per squaremetre seems the more common density on Late Magdalenian sites and on several sites of the MfCM (**fig. 74B**).

The assemblages of the south-western area from Gönnersdorf and Bois Laiterie fall slightly out of the typical range of the Late Magdalenian di but into the very variable range of the MfCM di. In comparison with the Late Magdalenian assemblages, the material on the south-western area in Gönnersdorf was more scattered (di = 20) and the material in the cave of Bois Laiterie was too dense (di = 58). The di of the south-western area of Gönnersdorf is comparable to the one from sector 1 of Le Grand Canton and also to values from the lower horizons of Belloy-sur-Somme as well as Le Closeau and several FMG sites in the Central Rhineland (**fig. 74B**). However, on some of these sites large surfaces containing almost empty spaces were uncovered resulting in a lower di. The factor of used versus excavated spaces could also explain the low value in the south-western area of Gönnersdorf. Moreover, refittings showed that some of the material from the Late Magdalenian areas were recovered from this part of the site suggesting that it was partially a Late Magdalenian refuse area. Thus, without the Late Magdalenian input the assemblage appears even smaller and, thus, the di would be even lower. This assumption makes the south-western assemblage from Gönnersdorf appear as a very ephemeral episode in contrast to the dense Late Magdalenian clusters at the same site.

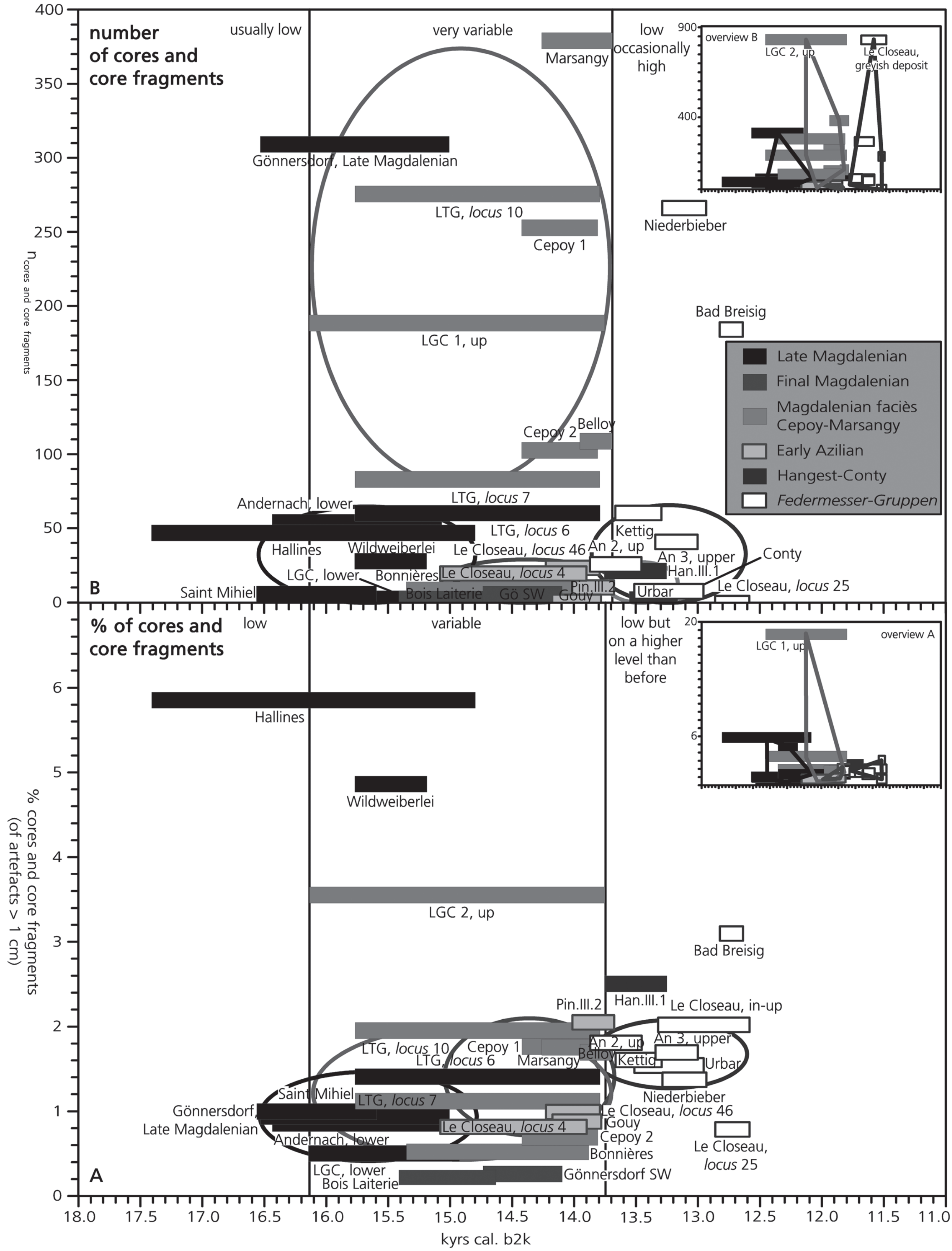
In Le Closeau, Conty, and Pincevent, horizon III.2, large surfaces were uncovered alongside the main concentrations lowering the di of these assemblages. However, the densities do not increase significantly in Pincevent or Le Closeau if the calculation was only focused on the sections with the Lateglacial concentrations (see **tab. 83**). Thus, these sites seem to represent this first trend towards a different, more ephemeral use of space. Since a typo-technologically comparable assemblage to Conty was found in the lower horizon of Hangest-sur-Somme III.1 and yielded also a cluster that was not very dense, this ephemeral character continued in these as well as the FMG sites.

In contrast, sites from the MfCM frequently yielded high and occasionally very high di values. The uncertainties of the concentrations from Le Tureau des Gardes discussed previously and *locus* 10 from this sites, which also yielded a very high di (di = 166) has to be considered comparably problematic. *Locus* 7 was presented in more detail (Weber 2006) and this concentration was only slightly denser (di = 54) than Saint Mihiel and a marginally less dense than Bois Laiterie. However, the densities in Marsangy (di = 102) and the sector 2 of Cepoy (di = 100) were very high even for MfCM sites. In Marsangy, the high values were caused by the very dense cluster around the hearth N19 (di = 179; **tab. 83**), which probably represented a knapping workshop (see p. 225 f.). The high densities of the material in sector 2 of Cepoy were probably also formed by several knapping episodes that were evident in this area (Wenzel 2009, 47-61). Nevertheless, other activity areas were identified in this sector which should balance out for the debris-rich knapping areas. Consequently, the very high density value at Cepoy, sector 2 reflects either an intense use of lithic material or a very wasteful knapping process. The latter can be tested by examining the percentage of cores and the exploitation index. In fact, the cores form only a very small portion of the material from sector 2 of Cepoy (**tab. 83**). Moreover, the value for sector 1 of Cepoy is also among the highest (di = 71). The upper horizon of sector 1 of Le Grand Canton yielded a very low value, unlike the comparably low value from Belloy (di = 14), could not be explained by the large unexcavated surface but partially by the destruction of the surface by various processes and the preservation of only a semi-circular concentration (Alix et al. 1993). The composition of this half concentration dominated by large pieces such as cores and core tablets suggests that it was a blank production workshop or a refuse area for the knapping process. The latter appeared more probable because small flakes and splinters were rare.

Thus, during the early period of this study, a very variable range of densities from small to high and occasionally very high values occur. In contrast, whereas in the second half only a limited range could be observed. The variable values point to the methodological problem of differentiating between concentrations, used areas, and excavated areas. This problem also reflects the differentiated use of space which was more focused in the Magdalenian than during the FMG. The impression of a more limited range of results from the disappearence of dense and very dense concentrations that correlates with the disappearance of assemblages attributed to the MfCM in this study. In general, the higher densities on sites of the MfCM seems related to intense knapping processes that resulted in areas densely covered with artefacts. However, to determine whether this knapping process was particularly wasteful, it is important to consider the composition of the assemblages with special focus on cores.

Although the majority of Lateglacial assemblages (artefacts ≥ 1 cm) yielded a very comparable ratio of cores (**tab. 83**), the general temporal trend of this ratio seems to suggests a gradual increase in number of cores during the studied time period (**fig. 75A**). Thus, more cores were used to produce the lithic material. However, a comparison with the assemblage size classes reveals that the general size of the assemblage and the presence of cores was not a one-to-one ratio. This finding emphasises that further factors such as technical abilities, raw material, spatial organisation, site function, and the duration of the occupation played a role in the size and composition of the assemblages.

The proportion of cores lies usually between 0.2 and 2.5 % in the analysed assemblages. The Late Magdalenian assemblages yielded values between 0.5 and 1.5 %. Contrastingly, the values of the Early Azilian inventories ranged between 0.8 and 2.1 % and the ratio of cores in FMG assemblages ranged between 1.4 and 2 %. The assemblages of the MfCM of the Magdalenian seemed to bridge between the Early Azilian and the Late Magdalenian values byranging between 0.5 to 2 %. However, if the horizon III.2 from Pincevent is excluded, the Early Azilian had a more limited range between 0.8 and 1 % cores. The percentage of cores in this upper horizon at Pincevent lies closer to the upper limits of MfCM or FMG assemblages than to the Early Azilian. The high ratio of the cores can be explained possibly, by the general character of this part of the excavation appearing as an area of waste disposal material and no actual knapping spots. The ratio of cores in the assemblages from Bois Laiterie and the south-western area of Gönnersdorf lies with 0.2 and


number of cores and core fragments
usually low
very variable
low occasionally high
Marsangy
Gönnersdorf, Late Magdalenian
LTG, locus 10
Cepoy 1
Niederbieber
LGC 1, up
Bad Breisig
Late Magdalenian
Final Magdalenian
Magdalenian faciès Cepoy-Marsangy
Early Azilian
Hangest-Conty
Federmesser-Gruppen
Cepoy 2
Belloy
LTG, locus 7
Andernach, lower
LTG, locus 6
Kettig
Hallines
Wildweiberlei
Le Closeau, locus 46
An 2, up
An 3, upper
Conty
LGC, lower
Bonnières
Le Closeau, locus 4
Han.III.1
Saint Mihiel
Bois Laiterie
Gö SW
Pin.III.2
Gouy
Urbar
Le Closeau, locus 25
B
overview B
LGC 2, up
Le Closeau, greyish deposit
% of cores and core fragments
low
variable
low but on a higher level than before
overview A
LGC 1, up
Hallines
Wildweiberlei
LGC 2, up
Bad Breisig
Han.III.1
Pin.III.2
Le Closeau, in-up
LTG, locus 10
Cepoy 1
An 2, up
An 3, upper
LTG, locus 6
Marsangy
Belloy
Kettig
Urbar
Niederbieber
Saint Mihiel
LTG, locus 7
Gönnersdorf, Late Magdalenian
Le Closeau, locus 46
Gouy
Le Closeau, locus 4
Andernach, lower
Cepoy 2
Bonnières
Le Closeau, locus 25
LGC, lower
Bois Laiterie
Gönnersdorf SW
A
kyrs cal. b2k
% cores and core fragments (of artefacts > 1 cm)

0.3 % below the Late Magdalenian range. Perhaps, these particularly low amount of cores was due to the function of the concentrations.

In contrast, these general ranges were exceeded in the assemblages from the upper horizon of Le Grand Canton, in the Late Magdalenian assemblages of Hallines and the Wildweiberlei as well as in Bad Breisig.

In Bad Breisig, as well as in sector 1 of Le Grand Canton, only half a concentration was found. High values at these sites are surprising but could be explained by the discard of cores for Le Grand Canton and the possibility of a nearby source of fragmented raw material at Bad Breisig (see p. 164 f.). In the Wildweiberlei assemblage, excavations during the early 20th century could have influenced the composition of the recovered assemblage with larger pieces such as cores being more readily collected and archived. In Hallines, recovery by an amateur collector could have introduced similar biases into the collection. Moreover, the small area of excavation at Hallines only represents the limits of a much larger concentration. If this excavated area represented a knapping or refuse area that could explain the over-representation of cores. Comparably, if the depressions of Le Grand Canton are sediment traps, lighter lithic material could have been washed out and heavier pieces such as cores would have remained trapped in the depressions. This scenario could explain the high values of these assemblages. In fact, the highest densities in sector 2 of Le Grand Canton, particularly smaller material, accumulated where the terrain gradually slopes into the deepest part of the area (Julien et al. 1999, 144 fig. 66). However, according to the spatial analysis of this sector, the distribution of artefacts was considered to be almost undisturbed by post-depositional processes but clearings of the main activity zones during the occupation were assumed possible (Julien et al. 1999, 152 f.). Accordingly, the large excavation area which also contained the refuse areas would explain the high amount of cores. In this case the di would be higher than on not so extensively excavated sites.

However, the di values are very similar for sector 2 of Le Grand Canton, Gönnersdorf, and Saint Mihiel. Therefore, the question could be posed: Would Late Magdalenian sites such as Gönnersdorf and Saint Mihiel, which were not excavated much beyond the limits of the main concentrations, have revealed a higher amount of cores if more of the surrounding area was excavated? In fact, the numbers of cores are very low on Late Magdalenian sites (**fig. 75B**) ranging between 6 and 60 cores. In contrast, the number of cores found at Gönnersdorf (n = 309) where in the south-western area a scattered, potential, refuse area was excavated, is clearly higher. Nevertheless, the outstanding number of cores from Gönnersdorf was not due to this refuse area but was mainly due to the numerous cores found within concentration III (n ≈ 145; cf. Franken / Veil 1983, Abb. 57. 82. 96). The other Late Magdalenian concentrations of Gönnersdorf yielded values that ranged between 28 and approximately 35 cores (see **tab. 11**) and, thus, well within the range of the other Late Magdalenian assemblages. In analogy to Gönnersdorf, clearings and the extension of the excavation area cannot solely explain the exceptionally high values of Le Grand Canton.

In contrast, for the other Late Magdalenian assemblages yielding exceptionally high ratios of cores (Hallines and Wildweiberlei), the suggested reason was that smaller material was not archived suggesting some bias towards larger specimens. This observation was also made for the assemblage from Le Grand Canton, sector 1 (Alix et al. 1993) where 188 cores were found but only a small assemblage (n = 1,021). This variation within the assemblage was due to either the collection represented a specific refuse area or to the washing out of material and redeposition. However, both explanations do not apply to sector 2 where also a high ratio of cores was found. Hence, was smaller material such as blades possibly also taken away from Le Grand

Fig. 75 Percentage (**A**) and numbers of cores and core fragments (**B**) in relation to the lithic assemblages (≥ 1 cm) given per time and archaeological unit. Circles were set around the main cluster of assemblages attributed to the same archaeological unit. The distribution of all assemblages is given in the overview where also the convex hulls were set per archaeological unit (see p. 281 f.). In the overview, names are only given for sites which are not shown in the main graph. Abbreviations see **fig. 74**. – For further details see text.

Canton by the Lateglacial hunter-gatherers? In this case, the site could have served besides the hunting as a lithic workshop.

From Le Grand Canton 89 kg from a total of 334 kg were attributed to cores, some 155 kg identified as preparation material, and over 48 kg were determined as blanks (Valentin et al. 1999b, Tabl. 14). These vast amounts, along with the incidental preparation of cores due to their natural shape (Valentin et al. 1999b, 81), and limited exploitation of cores, strengthens the idea of a lithic extraction site or blank production workshop near such a site. In contrast, the amount of aimed material remaining at the site suggests that this workshop was not necessarily intended to produce material for export but the intense lithic blank production seemed rather intended for the local use. Since butchering activity played an important role at this site (Bridault / Bemilli 1999), the unretouched blanks could have been used in this process. Therefore, a traceological analysis of the remaining blanks without further modification would be of particular interest (cf. Bodu / Mevel 2008; Sano 2012a 170-217). An additional factor was probably the selected length of the cores that usually clustered around 9 cm in size (Valentin et al. 1999b, 76-79). Moreover, blank production was mainly focused on bladelets (Valentin et al. 1999b, 83) that is also reflected in the dimensions of the projectiles which were particularly small for the northern French assemblages (see p. 529-532). Perhaps, the convenience of a good raw material source in combination with a reliable hunting spot where freshly knapped, sharp edged material was used for butchering as well as reequipping and resulted in an apparently wasteful handling of the lithic resource and the exceptional values for Le Grand Canton.

The number of cores (n = 827) further sustains the exceptional position of the assemblage from sector 2 of Le Grand Canton, even though the general range of cores between 84 and 379 specimens from sites attributed to the MfCM was already very high (**fig. 75B**). However, the intermediate, undetermined, and upper horizons including *locus* 25 from Le Closeau yielded a similar number of cores (n = 827) as sector 2 of Le Grand Canton but the ratio of cores in Le Closeau (% cores = 2.0) was similar to the other FMG assemblages. Thus, these concentrations were clearly different to the exploitation strategy from sector 2 of Le Grand Canton.

The FMG sites yielded usually comparable numbers to the Late Magdalenian assemblages ranging between 1 and 61 cores (**tab. 83**). Besides the numerous concentrations of the greyish deposits at Le Closeau, Niederbieber also has numerous concentrations, whilst Bad Breisig is the exception. Although the total number of cores found at Niederbieber is very high (n = 267), the number of cores found per concentration at this site is within the lower half of the FMG distribution with number between 1 and 33 cores and an average of approximately 14 cores per concentration (see **tab. 11**).

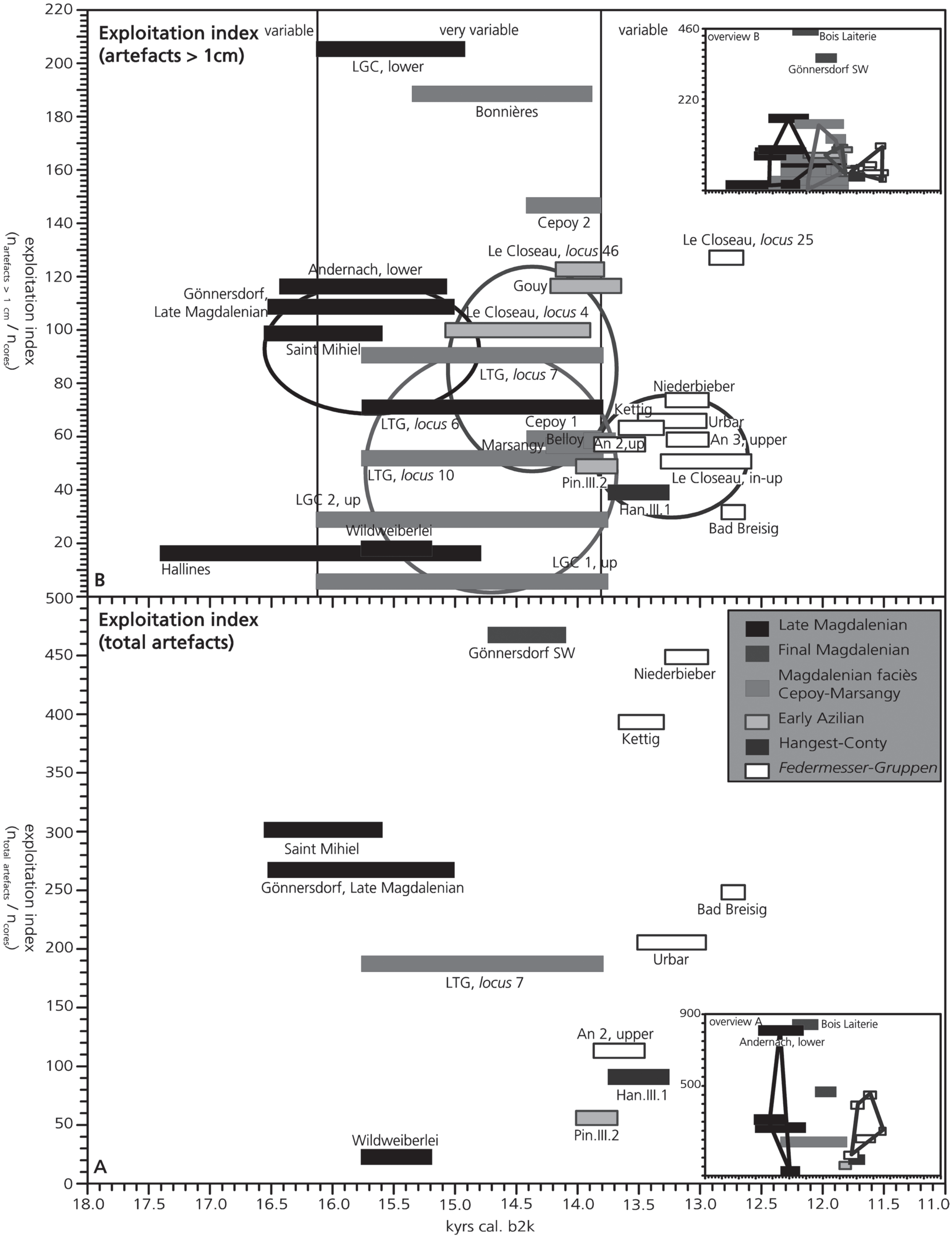
The material from Le Closeau was found in some 52 concentrations and the number of cores ranged further than the usual FMG sites with 0 to 91 cores found in the concentrations. Thus, on average almost 16 cores were found in a concentration in the greyish deposits at Le Closeau. If these numbers and ratios are further separated by the different horizons, the intermediate horizon yielded a range from 1 to 91 cores and an average number of 21 cores per concentration. Yet, these numerous cores formed only 0.8 to 7.3 % of the material found in the concentrations with an average of 1.6 % forming a smaller part of the material than in the other concentrations from the greyish deposits. In contrast, cores usually made up to 2.3 % of the assemblage (range between 0.9 and 12.5 %) in the concentrations attributed to the upper horizon but only 16 cores were found on average per concentration and the actual number of cores found in the concentrations ranged between 2 and 68. Thus, the assemblages attributed to the upper horizon were very similar to the main FMG cluster, composed mainly of assemblages from the Central Rhineland. In comparison with material from the intermediate horizon, the assemblages of the upper horizon yielded in general a smaller number of artefacts. Moreover, the undetermined concentrations were the smallest assemblages and the lowest values: with 0 to 40 cores found in the concentrations and an average of 11 cores per concentration.

Apparently, it is easier to assign material to specific typo-technological attributes with a greater quantity of material. In *locus* 25, only a single core was found. However, in the other excavated areas of Le Closeau (sud RN13) more material was recovered from this top horizon suggesting an increase of cores per concentration (range: 0-142; average: 33 cores/concentration) and also an increase of the ratio of cores with values between 1.3 and 11.6 % and an average share of 3.7 % in the assemblage as a whole. However, since these assemblages are claimed to be partially the result of post-depositional processes, this trend cannot be sustained further without a spatial analysis of this part of the site.

Nevertheless, the relatively similar numbers and ratios in Le Closeau suggest that the number of cores necessary to produce a certain number of blanks and, thus, the exploitation strategy was similar for all these concentrations. However, if the assemblages from the intermediate horizon are tendentially older than the ones from the upper horizon, which were certainly older than the material from the top horizon, a chronological trend was observable within the FMG assemblages. Use of a higher number of cores that produced larger quantities of material leading to the overexploitation of these cores that hence formed a smaller ratio of the assemblages. Subsequently, cores became less numerous but also less productive and, thus, the ratio increased. Finally, the number of cores again increased but their share of the assemblages further increased suggesting that numerous unproductive cores were abandoned at the site (or numerous blanks were exported from the site). This latter argument is most comparable to the assemblages from Le Grand Canton with relatively high ratios of cores and very high numbers of cores.

In contrast to Le Closeau and Niederbieber, Bad Breisig as well as sector 1 from Le Grand Canton were only half of a lithic concentration. However, the number of cores found in Le Grand Canton, sector 1 were within the range of cores found in concentrations of the MfCM, even though the ratio was relatively high. This difference can be explained by a differentiated spatial distribution (cf. Julien et al. 1999) and partial preservation. In contrast, Bad Breisig appears to be a unique FMG assemblage in terms of the ratios of cores (3.1 %) as well as the number of cores (n = 184). Hence, the exploitation of the lithic resources, mainly the Tertiary quartzite, at Bad Breisig was more comparable to the handling of the flint at Le Grand Canton or the material in the top horizon of Le Closeau sud RN 13. This behaviour is in contrast to the exploitation scheme before the LSE in the Central Rhineland or the upper horizon of Le Closeau. Presumably, this change was due to the presence of a reliable sources in the immediate vicinity of the site. The cores in Bad Breisig were usually used in short production sequences with little preparations (pers comm. Ludovic Mevel, Nanterre) or the cores were abandoned as soon as preparations became necessary.

A similar case of raw material exploitation can also be seen in the Late Magdalenian assemblage of Gönnersdorf where the majority of cores (n = 309) came from concentration III (n ≈ 145). These cores were predominantly made of the small, local indurated slate gravels (n ≈ 122; cf. Franken/Veil 1983, Abb. 57). These small gravels as a major source are comparable to the relatively small dimensions of the gravel flints at Le Grand Canton. In contrast to the flint, it is difficult to obtain a steady sequence of regular bladelets from the fissured indurated slate but this raw material is also available in regular quantities in the nearby gravels of the Rhine. Consequently, instead of receiving a number of blanks from one core, the same number of blanks was obtained from many cores. Thus, for different reasons (poor knapping abilities of the indurated slate and, perhaps, the weathered Tertiary quartzite, need for numerous blanks), the easy accessibility to larger quantities of smaller-size material resulted in a behaviour that appears similarly wasteful in concentration III of Gönnersdorf, the upper horizon of sector 2 in Le Grand Canton, and Bad Breisig. Perhaps, in the sector 2 some admixture of Late Magdalenian material resulted in the similarities observed with the material from Gönnersdorf. However, Bad Breisig was chronologically distinct from the two other assemblages. Thus, the different attribution and chronological position of these concentrations mark this wastefulness as a diachronic phenomenon.


Exploitation index (artefacts > 1cm)
variable
very variable
variable
LGC, lower
Bonnières
Cepoy 2
Le Closeau, locus 25
Le Closeau, locus 46
Andernach, lower
Gouy
Gönnersdorf,
Late Magdalenian
Le Closeau, locus 4
Saint Mihiel
LTG, locus 7
Niederbieber
Kettig
LTG, locus 6
Cepoy 1
Urbar
Belloy
Marsangy
An 2, up
An 3, upper
LTG, locus 10
Pin.III.2
Le Closeau, in-up
LGC 2, up
Han.III.1
Bad Breisig
Wildweiberlei
Hallines
LGC 1, up
B
overview B
Bois Laiterie
Gönnersdorf SW
exploitation index
($n_{artefacts > 1 cm}$ / n_{cores})
Exploitation index (total artefacts)
Gönnersdorf SW
Niederbieber
Kettig
Late Magdalenian
Final Magdalenian
Magdalenian faciès Cepoy-Marsangy
Early Azilian
Hangest-Conty
Federmesser-Gruppen
Saint Mihiel
Gönnersdorf, Late Magdalenian
Bad Breisig
Urbar
LTG, locus 7
An 2, upper
Han.III.1
Pin.III.2
Wildweiberlei
A
overview A
Bois Laiterie
Andernach, lower
exploitation index
($n_{total\ artefacts}$ / n_{cores})
kyrs cal. b2k

Likewise the ratio of cores (0.8 %), the number of cores in the lower horizon of Le Closeau (n ≥47) was significantly smaller than the values of the concentrations from the greyish deposits (% cores = 2.0; n = 827). The other assemblages attributed to the Early Azilian yielded comparably low numbers of cores. These numbers clearly distinguish the Early Azilian assemblages from the assemblages of the MfCM except for the site of Bonnières-sur-Seine that yielded only seven cores. This very low number for assemblages of this faciès can be explained by several factors: Firstly, the assemblage comes from a very small area of a partially excavated rockshelter that was first examined in the early 20th century. Moreover, the site was located near an accessible flint source (Valentin 1995, 404) and, thus, some blocks may have only been tested in Bonnières and were then removed to other localities. In addition, the site was considered as a short-term observation point, possibly used several times during the Lateglacial or a once used residential camp (see p. 196-204). Thus, the function of this site appeared more comparable to the function of the sites of the lower horizon from Le Closeau than the usual sites of the MfCM that were frequently associated with hunting and butchering. The assemblages from the south-western area of Gönnersdorf and from Bois Laiterie are also similar to the Early Azilian assemblages but with even lower numbers and ratios of cores. This group of assemblages with low number of cores forms a contrast to the quasi-contemporary assemblages with high numbers of cores, mainly of the MfCM, whereas the ratio of cores was similar in both groups. Consequently, the handling of cores and the raw material was comparable in these assemblages, only the amounts of material used on the sites differed which was already seen in the assemblage size classes.
The exploitation index provides the ratio of artefacts to cores and, thus, should produce a comparable result to the percentage of cores. In addition, the exploitation indices allow for an estimate of how fragmented the material became on site. This degree of fragmentation contributes to an impression of the amount and quality of the raw material brought to a site in order to allow for a successful knapping episode that eventually resulted in an abandoned core. This information relates to transport possibilities and the procurement strategies of hunter-gatherers and, therefore, makes considerations possible about the position of resource economy within the settlement system.
In the present project, a further refined index of the ratio of blanks to cores is not calculated, even though this index could be used to approximate the exploitation potential of a single core allowing for insights in the quality of the raw material, the technical abilities of the knappers, and / or the exploitation strategy (see p. 270-272). However, some of the possible information of such an index were already given for several studied assemblages. For example, technical abilities used in Late Magdalenian assemblages were demonstrated by single expressions from FMG inventories to be comparably elaborated (Gelhausen 2011a, 24). In contrast to the Late Magdalenian, these skills were not an integral part of the lithic production for everyday use. Furthermore, the raw material sources were often shown to be comparable between the Late Magdalenian or the Early Azilian and the FMG (Bodu / Valentin 1997; Floss 2002) but the quality of the raw material was often described as decreasing. Nevertheless, since high-quality material is often still identifiable at the source areas, this mediocre quality seemed to represent a choice, which considered these materials as sufficient for the tasks required. In general, FMG groups selected a lower quality of lithic raw materials than Late Magdalenian groups (Stapert / Street 1997; Barton / Roberts 1996; Floss 2002). However, low quality indurated slate was already used in the Late Magdalenian assemblages In the Central Rhineland

Fig. 76 Values of the exploitation index calculated with the complete lithic assemblage (**A**) and with artefacts ≥ 1 cm (**B**) given per time and archaeological unit. Circles were set around the main cluster of assemblages attributed to the same archaeological unit. The distribution of all assemblages is given in the overview where also the convex hulls were set per archaeological unit (see p. 281 f.). In the overview, names are only given for sites which are not shown in the main graph. Abbreviations see **fig. 74**. – For further details see text.

such as at Gönnersdorf III or Wildweiberlei. In addition, in the Paris Basin and the Somme region, the fine-grained flint material used in Lateglacial Interstadial contexts possessed more consistent knapping properties in comparison to the Rhenish Tertiary quartzite. Thus, if predominant raw materials and their splintering properties had an observable effect on the assemblage compositions and exploitation indices, the northern French sites would regularly form a separate group from the sites in Central Rhineland. The use of flint at these sites would have resulted in greater comparability to the sites from the western uplands and to the Late Magdalenian assemblages of the Central Rhineland than to the FMG sites from the Central Rhineland. As this pattern was not observed consistently within the analysed archaeological record, then the quality of the raw materials appears to be of minor importance in creating similarities and differences between these regions and between the Late Magdalenian and the FMG.

In contrast, the exploitation index (ei; **fig. 76**) reveals a clear differentiation, particularly between the assemblages attributed to the MfCM and those attributed to the inventories of the Early Azilian. The former generally yielded values between 5 and 90, with only Cepoy, sector 2 (ei = 146) and Bonnières-sur-Seine (ei = 188) having exceptional values. For the latter, the explanations have been previously discussed, but a careless excavation and/or documentation and spatial limitations do not apply to the sector 2 of Cepoy. Possibly, the high density of the lithic material in combination with this high ei and the locally accessible gravel flints suggest that this site is comparable to the suggested exploitation character of Bonnières-sur-Seine where blocks and cores were mainly prepared and tested and exported to other localities. The amount of material received from a single core in Le Grand Canton are in general small. Perhaps, this is due to outwashing of smaller material or dumping of cores in sector 1 which in fact yielded the lowest value (ei = 5) for this archaeological unit. However, this explanation was rejected for sector 2 (Julien et al. 1999), which produced the second lowest value with an ei of 29. Thus, again the export of blanks should be considered a possible explanation for the composition of this assemblage and, consequently, the blank production as a major activity at this site. The intentional production of a few, large blanks for butchering can be excluded based on the dimensions of the projectiles (see p. 529-532) and the cores (see p. 495-502). However, to what degree smaller, unretouched blanks were used in the processing of the prey cannot be determined without further use-wear analyses. The number of retouched artefacts in the assemblage of sector 2 were intermediate but the function index was relatively low indicating the larger importance of cores in the lithic material. Nevertheless, the presence of at least some 74 horses and the composition of the lithic assemblage with mainly burins and end-scrapers indicates that the processing of the prey was an important factor at this site.

The ei of the Early Azilian assemblages ranges between values of 49 and 124. If the horizon III.2 of Pincevent is excluded the range is further limited to values of 100 to 124 and, thus, clearly above the majority of the assemblages attributed to the Magdalenian MfCM. The Pincevent, horizon III.2 yielded comparable values for the ei based on artefacts ≥ 1 cm and based on the total number of artefacts which suggests that small splinters were hardly recovered. This observation further sustains the impression of this material representing waste scatters rather than knapping spots.

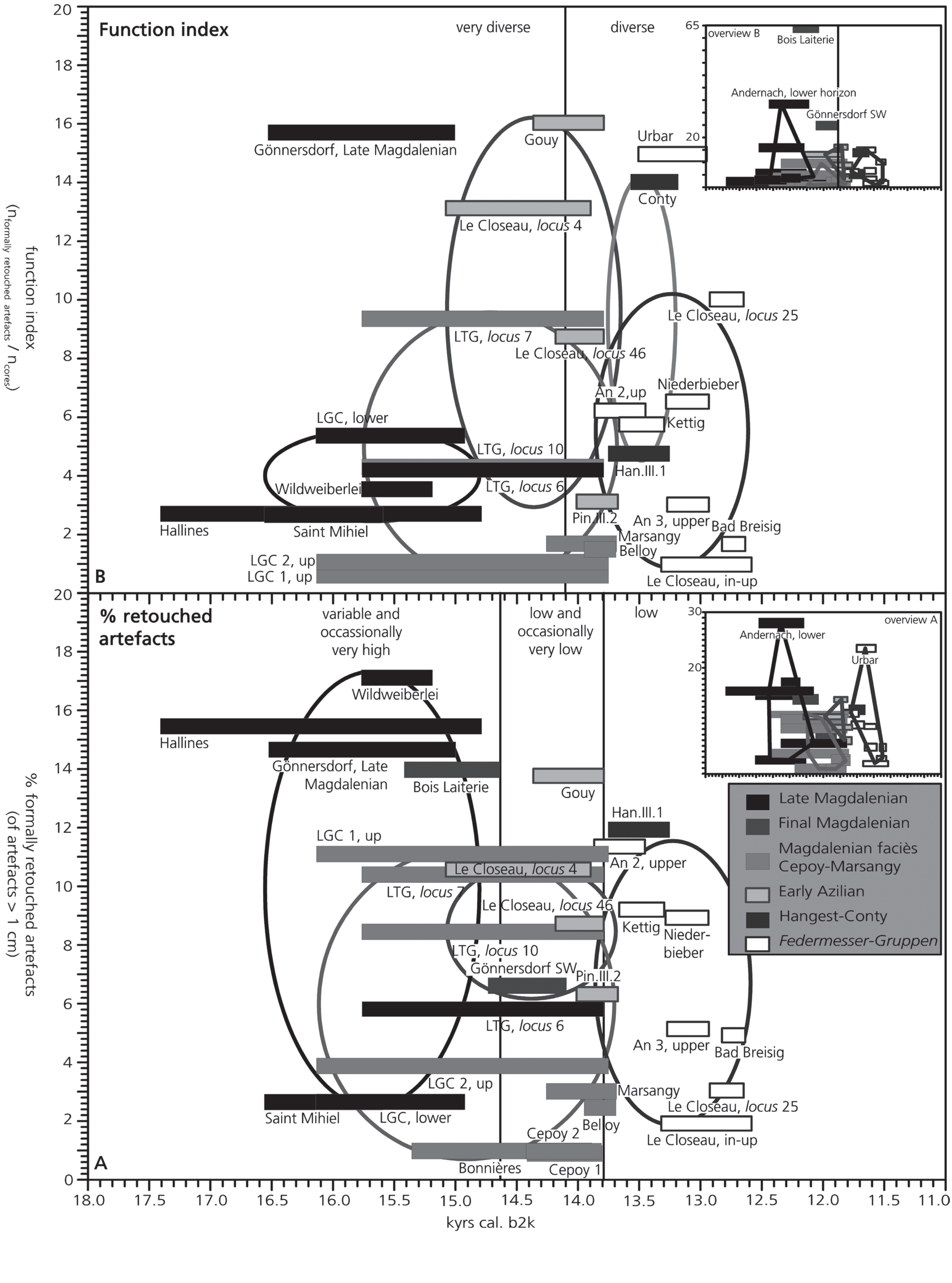
In contrast, the Late Magdalenian assemblages have a very varied ei of 17 (Hallines) to 206 (Le Grand Canton, sector 2, lower horizon). This very broad range contributes to the picture of very differentiated site function resulting in very different exploitation strategies. However, the second highest value for a Late Magdalenian assemblage comes from the lower horizon of Andernach (ei = 119) that suggest to narrow the range by excluding the lower horizon of Le Grand Canton, sector 2 (a special case due to selective excavation of a special activity zone). Furthermore, the assemblages from Bois Laiterie (ei = 453.5) and the south-western area of Gönnersdorf (ei = 375.2) yielded very small ratios as well as total numbers of cores and stand out with high exploitation values (**fig. 76B**, overview B; **tab. 83**). A use as workshop or exploitation site can be excluded for these concentrations due to the low numbers of cores and the lack of a nearby lithic source.

Instead, the low numbers and ratios indicate that these sites were supplied by mainly imported material and the flintknapping was no particular activity at these sites.

Thus, this index suggests that there was greater variability of assemblages in the Late Magdalenian and the MfCM, whilst the FMG assemblages appear very similar. The latter yielded values ranging from 50 to 72 with the youngest assemblages from Bad Breisig (ei = 32) and *locus* 25 of Le Closeau (ei = 126) forming clear outliers. The assemblage from Hangest-sur-Somme (ei = 40) falls into this larger range of the FMG assemblages. However, if the single assemblages at Niederbieber or Le Closeau are considered, the range of FMG concentrations is considerably enlarged: The values from the concentrations in the greyish deposits of Le Closeau range between 5 and 148 and in Niederbieber the ei of the single concentrations ranges from 23 to 715. The upper limit on the latter site was reached in concentration 18 with the next highest value from the special task camp in concentration 3 (ei = 258) followed by the double concentration 6 and 10a (ei = 131). Thus, these values exceed even the outliers of Bois Laiterie and Gönnersdorf but seem to indicate a special task area (concentration 3; Bolus 1992) or possible knapping spots or refuse areas (concentration 18; Gelhausen 2011c). The adjacent area 19 yielded the lowest value (ei = 23) and, thus, it seems probable that these areas complement one another which can be further sustained by the distribution of Tertiary quartzite and Baltic flint (Gelhausen 2011c, Abb. 11b; 12b) as well as the faunal materials (Gelhausen 2011c, Abb. 14). The second lowest ei comes from Niederbieber 14 (ei = 34) and, thus, excluding the complement areas and the special task camp, the range for the concentrations of Niederbieber are well in accordance with the limits set by the assemblages of Bad Breisig and *locus* 25 of Le Closeau. Values below 25 at Le Closeau were mainly associated with partially excavated concentrations, supplementary concentrations, concentrations from the disturbed channel area, or areas with a thin scatter of material. Values above 125 occurred only twice (*loci* 19 and 34) and were related to dense and larger clusters. This detailed comparison shows that different assemblages were also present within the FMG range. However, the very low values such as found in Hallines, Wildweiberlei (ei = 21), or Le Grand Canton are hardly found in FMG concentrations. Thus, the range of ei in FMG assemblages was compared with the Late Magdalenian range located in the upper part of this range.

The ei of total assemblages (ei_T) can only be calculated for a few sites. The value of the lower horizon of Andernach ($ei_T = 797$) forms, together with Bois Laiterie ($ei_T = 842$), clear outliers to the other assemblages (**fig. 76A**). The other assemblages range between the value of the south-western area of Gönnersdorf ($ei_T = 467$) and the value from the Wildweiberlei ($ei_T = 24$). The latter further sustains the previous consideration that material of smaller dimensions was not archived for this assemblage. The other two Late Magdalenian assemblages, Gönnersdorf ($ei_T = 265$) and Saint Mihiel ($ei_T = 300$), produced very comparable results.

The lower horizon of Hangest-sur-Somme III.1 yielded a comparably low value ($ei_T = 93$) to horizon III.2 of Pincevent ($ei_T = 56$). This observation is perhaps due to the splintering qualities of the raw material used in northern France combined with the aim for particularly large blanks during this time period. However, a higher value was reached in *locus* 7 of Le Tureau des Gardes ($ei_T = 190$), perhaps, indicating the still present Magdalenian trend of producing smaller material such as bladelets. The FMG assemblages vary considerably from the upper horizon of Andernach 2 ($ei_T = 116$) to the example of Niederbieber ($ei_T = 449$). Again the range is significantly enlarged if the single concentrations of Niederbieber are considered (**tab. 83**). Besides the previously described assemblages, which show the same pattern in the ei_T as in the ei, dense clusters (concentrations 8 and 17) yielded very high values marking them as almost undisturbed knapping areas where the small splinters remained *in situ* (cf. Gelhausen 2011a). However, most of the concentrations from Niederbieber that yielded high values were dominated by chalcedony indicating that this raw material had a tendency to produce more small splinters than other raw materials.


Function index
very diverse
diverse
function index
(n formally retouched artefacts / n cores)
overview B
Bois Laiterie
Andernach, lower horizon
Gönnersdorf SW
Gönnersdorf, Late Magdalenian
Gouy
Urbar
Conty
Le Closeau, locus 4
Le Closeau, locus 25
LTG, locus 7
Le Closeau, locus 46
An 2,up
Niederbieber
Kettig
LGC, lower
LTG, locus 10
Han.III.1
Wildweiberlei
LTG, locus 6
Hallines
Saint Mihiel
Pin.III.2
An 3, upper
Bad Breisig
Marsangy
Belloy
LGC 2, up
LGC 1, up
Le Closeau, in-up
B
% retouched artefacts
variable and occassionally very high
low and occasionally very low
low
% formally retouched artefacts (of artefacts > 1 cm)
overview A
Andernach, lower
Urbar
Wildweiberlei
Hallines
Gönnersdorf, Late Magdalenian
Bois Laiterie
Gouy
Han.III.1
LGC 1, up
An 2, upper
Le Closeau, locus 4
LTG, locus 7
Le Closeau, locus 46
Kettig
Nieder-bieber
LTG, locus 10
Gönnersdorf SW
Pin.III.2
LTG, locus 6
An 3, upper
Bad Breisig
LGC 2, up
Marsangy
Le Closeau, locus 25
Saint Mihiel
LGC, lower
Belloy
Le Closeau, in-up
Cepoy 2
Bonnières
Cepoy 1
A
Late Magdalenian
Final Magdalenian
Magdalenian faciès Cepoy-Marsangy
Early Azilian
Hangest-Conty
Federmesser-Gruppen
kyrs cal. b2k

In general, besides the knapping style and the economy of handling raw materials, the excavated area had some impact on the composition of the assemblage. This impact was particularly the case if the settlement organisation was more complex including sites with special functions as well as specialised areas and clearing episodes on residential sites such as in the Late Magdalenian (cf. Sensburg 2007). Therefore, the function index and the diversity of the material is compared further to take possible site function into consideration.

The function of an assemblage also had some influence on the intensity of the exploitation performed at this site. Besides the blank production process, the production and use of formally retouched artefacts reflected an important field of functions and influenced the composition of the lithic assemblage. In comparison, the ratio of formally retouched artefacts decreased from the Late Magdalenian of 2.6 and 28.1 % to the FMG values of between 2.0 and 11.3 % (**fig. 77A; tab. 83**). The outstanding value from Urbar (% retouched = 23.3) among the FMG variety can be explained by the selective excavation of the site where a single specific activity area was recovered. The relatively high value of the Early Azilian assemblage from Gouy (% retouched = 13.8) could be similarly explained because only a superficial excavation was conducted at this site. Moreover, the value from the lower horizon of Andernach (% retouched = 28.1) appears outstanding in comparison to the following value from Wildweiberlei being only 17.1 %. However, single Late Magdalenian concentrations such as Andernach IV or Gönnersdorf IV also yielded values above 20 %, whereas the single FMG concentrations from Niederbieber provided values just above 15 % (**tab. 83**). Thus, the Late Magdalenian assemblages contained, in general, a higher ratio of formally retouched artefacts than FMG assemblages. Niederbieber 17 is an exception with 38.9 %. According to the spatial analysis, this very small assemblage perhaps originated from a sheltered area, possibly a dwelling structure where a variety of activities were performed (Gelhausen 2011a, 232-237). However, the relatively high ratio in this concentration is related to the total number of artefacts that are particularly small. The percentage of the formally retouched artefacts from Niederbieber 17 is well within the range of the other concentrations from Niederbieber (**tab. 83**). The ratios of the MfCM inventories already fit approximately into the FMG range with values up to 11.1 % (Le Grand Canton, sector 1, upper horizon) but some assemblages contained percentages of formally retouched artefacts as low as 0.8 % (Cepoy, sector 1). In contrast, the Early Azilian assemblages were composed of 6.3 to 13.8 % formally retouched artefacts. The highest value came from Gouy where the inventory was possibly biased against larger and formally retouched artefacts. The remaining three values had up to 10.6 % into the upper range of the MfCM. In the lower horizon from Hangest-sur-Somme III.1 (% retouched = 11.9), some more formally retouched artefacts were found compared to the main FMG assemblages but the ratio was within the usual range of single Niederbieber concentrations. The value of the south-western area of Gönnersdorf (% retouched = 6.6) falls within the range of all archaeological units, whereas the higher ratio from Bois Laiterie (% retouched = 14.0) placed this assemblage into the range of the Late Magdalenian.

To consider the importance of formally retouched artefacts, in contrast to the blank production process, the function index (fi; see p. 272-275) was calculated for all assemblages (**fig. 77B; tab. 83**). This index revealed some clear differentiation within the Late Magdalenian assemblages which ranged between values of 2.7 (Saint Mihiel and Hallines) and 5.3 (lower horizon of Le Grand Canton, sector 2) but also yielded some very

Fig. 77 Percentages of formally retouched artefacts (**A**) and values of the function index (**B**) given per time and archaeological unit. Circles were set around the main cluster of assemblages attributed to the same archaeological unit. The distribution of all assemblages is given in the overview where also the convex hulls were set per archaeological unit (see p. 281 f.). In the overview, names are only given for sites which are not shown in the main graph. Abbreviations see **fig. 74**. – For further details see text.

high values such as the values of Gönnersdorf (fi = 15.7) and the lower horizon of Andernach (fi = 33.3) in general and of Gönnersdorf II (fi = 55.4) and Andernach II (fi = 167.7) in particular. These very high values suggest that in some assemblages the blank production was of very low importance and/or numerous retouched artefacts were used at the site, perhaps due to a higher degree of specialisation. Very low values were probably not present due to the selection of sites in this study.

The wide range remained throughout the transition period. The indices of the south-western area of Gönnersdorf (fi = 24.7) and of Bois Laiterie (fi = 63.5) are exceptionally high but in this period fi values as low as 0.6 (Le Grand Canton, sector 1, upper horizon) were recorded. These very low values reflect the importance of blank production on these sites. The highest values of the MfCM were reached in Le Tureau des Gardes (fi of *locus* 7 = 9.3; fi of *locus* 10 = 4.3) but otherwise the fi was considerably lower and ranged between values of 1.7 and 0.6. This major range points to the importance of blank production of sites attributed to the MfCM. In contrast, the Early Azilian sites yielded values between 3.1 (horizon III.2 of Pincevent) and 16.0 (Gouy). The values were also relatively high for the lower horizons of Conty (fi = 14.0) and Hangest-sur-Somme III.1 (fi = 4.8). Although the range of the FMG assemblages was lower with values between 1.0 and 10, the Hangest-Conty range was still comparable to the FMG range due to Urbar yielding an exceptionally high fi of 15.0. However, this value was possibly due to the selective character of the inventory. In contrast to the separated clusters of the Magdalenian units, the FMG assemblages formed no apparent groups suggesting that the functional variability of these assemblages was of a more gradual nature. Nevertheless, the assemblages of Bad Breisig (fi = 1.6) and the greyish deposits of Le Closeau (fi = 1.0) yielded values that were within the range of the low cluster of the MfCM sites. These unusually consistent values of cores and formally retouched artefacts distinguish the blank production process at these sites as of major importance and, thus, characterise these sites as a type of lithic exploitation sites. Thus, values suggesting an ostensibly wasteful handling of raw materials on these sites could be the result of the function of these sites.

In fact, the only assemblage that fit most of the criteria suggested to identify a wasteful handling of raw material (high % cores, low ei, high ei_T, high di, high assemblage size class) is Bad Breisig. Further assemblages (Hallines, the upper horizon of sector 2 in Le Grand Canton, *locus* 10 of Le Tureau des Gardes, Marsangy, and the greyish deposits of Le Closeau as well as Niederbieber 11 and 14) matched only three of the criteria. However, the differentiation between an ei and ei_T was only possible for a few assemblages. For instance, the ei_T could not be calculated for the upper horizon of Le Grand Canton and most northern French assemblages. The few available double values (**tab. 83**) show that, in general, the two indices developed comparably indicating that more artefacts ≥ 1 cm were found on a Lateglacial site, the more total artefacts were found. Some changes between the two values were observable suggesting that the lithic raw material influenced the number of splinters.

According to the archaeological attribution, the assemblages that matched three or more criteria of wasteful raw material handling were mostly sites of the Magdalenian faciès Cepoy Marsangy and the FMG. Thus, the suggestion of these sites as representing a particular wasteful raw material handling seemed partially supported. However, according to the sub-area, the majority of these sites were located in northern France where a wide range of excellent lithic raw materials was locally available and the large amount of waste could rather relate to a function of the sites than a particularly careless use of the resources.

How far the majority of criteria can be also applied to Gönnersdorf III, remains a matter of reanalysis of this assemblage and a more detailed presentation of the material. However, the handling of particularly numerous cores was already observed in this inventory as well as the upper horizon of Le Grand Canton and Bad Breisig. They indicate that a wasteful handling in the sense of abandoning numerous cores is a diachronic phenomenon and the handling of resources was not in general more wasteful at FMG sites than during the Late Magdalenian. The three mentioned inventories suggest that an abandonment of numerous cores in the Lateglacial occurred usually at sites where plentiful, small-sized material was available in a very nearby source. Thus, it appears that in these assemblages, quantity was a substitute for larger dimensions.

Since wastefulness of lithic resources was considered as an explanation for the large and very large assemblages, the three small or very small assemblages (Hallines, Niederbieber 11 and 14) reveal that the acquiescence of producing much lithic waste with only few tools does not necessarily create large assemblages. In all three assemblages the ratio of cores was high but the ei was relatively low suggesting that not many larger blanks were abandoned in the assemblage. The two Niederbieber concentrations yielded a relatively high ei_T as a third matching criteria. However, in both concentrations chalcedony was among the dominant raw materials suggesting that the number of splinters was very high due to the choice of raw material. The other Niederbieber concentrations partially matched one or two of the criteria, and, consequently, the Niederbieber assemblage indicates no particularly wasteful handling of raw material. In Hallines, the third matching criteria was the density of the artefacts which can be explained by the restricted excavation area. This explanation can also explain the low ei and high percentage of cores: Assuming that spatial organisation was more complex at Late Magdalenian sites, this pattern could reflect a knapping spot from which the ready made blanks were removed or refuse area where only cores and knapping debris was abandoned. Thus, the values of these three concentration could be explained by other behaviours than wastefulness.

The other assemblages matching three or more criteria (the upper horizon of sector 2 in Le Grand Canton, *locus* 10 of Le Tureau des Gardes, Marsangy, the greyish deposits of Le Closeau, and Bad Breisig) were all large or very large and had a low ei. In all these assemblages, except Le Tureau des Gardes, *locus* 10, very low values of retouched artefacts were found resulting in a low fi. Except Marsangy, these assemblage also yielded high percentages of cores which further sustained the blank production as the major task in these assemblages. This major task attributed these assemblages (the upper horizon of sector 2 in Le Grand Canton, Marsangy, the greyish deposits of Le Closeau, and Bad Breisig) to a type of sites focused on lithic exploitation which explained the very high values. Thus, function rather than a particular careless handling caused these very large assemblages. In Bad Breisig, Marsangy, and Le Tureau des Gardes, *locus* 10, the density of artefacts was very high suggesting that large quantities of raw material were transformed at least at the two latter, widely excavated sites. In Le Tureau des Gardes, *locus* 10, the formally retouched artefacts were numerous and, for a Lateglacial assemblage, formed a relatively typical proportion. In summary, the material abandoned at this site was not very numerous in relation to the cores with a limited number of blanks transformed into formally retouched tools. Thus, no intense lithic exploitation was performed at this site but since the assemblage is nevertheless very large, a relatively wasteful handling and/or a longer use of the site can be assumed. The examples from Hallines and, particularly, Niederbieber 11 and 14 suggest that to create a numerous assemblage as found in *locus* 10 of Le Tureau des Gardes, both factors need to co-occur in the Lateglacial. Nevertheless, large assemblages were more frequently the result of an intense lithic exploitation at a site.

In general, the ei_T was not directly related to the density or the assemblage size class but a regular relation to high function indices could be observed. Thus, the production of formally retouched artefacts seemed to have produced more splinters and where this production was intended it also guided the blank production towards a more numerous blank exploitation of the cores. However, density and assemblage size were closely related, except for Hallines and Bois Laiterie. The former was already explained by the restricted excavation area and the cave of Bois Laiterie can be explained comparably with the restriction of space resulted in a higher density. The restriction or rather the openness of space also explains some very large sites with neither a high amount of blank production nor high densities such as Gönnersdorf, the lower horizon of Le Closeau, Belloy, Niederbieber, and Étigny-Le Brassot. The large open space made a large settlement at favourable spots possible whether these were occupied concurrently or repetitively.

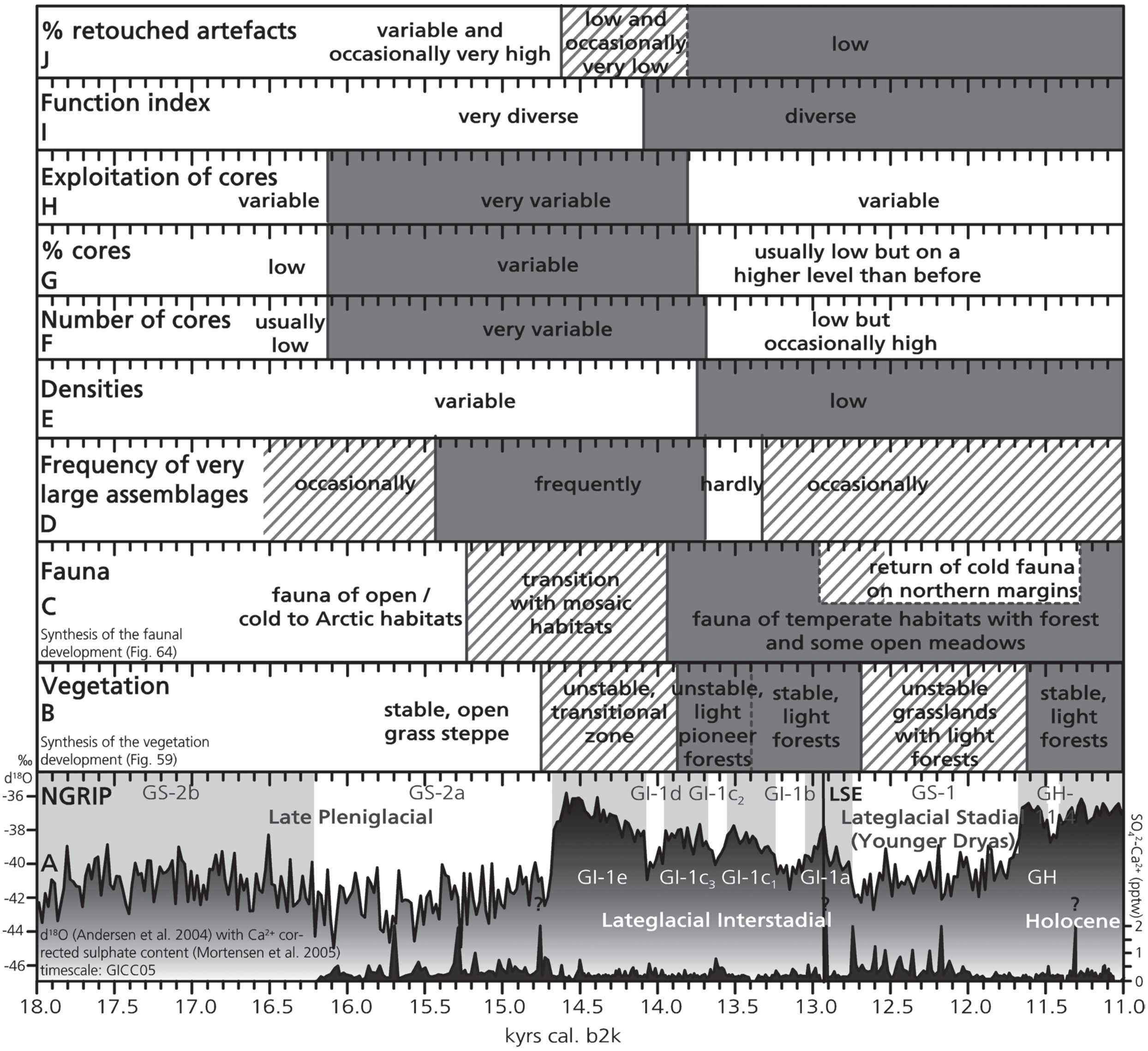


Fig. 78 Developments in lithic assemblages related to lithic raw material exploitation (**D-J**) contrasted by the synthesised faunal (**C**; see **fig. 64**) and vegetation development (**B**; see **fig. 59**) as well as the oxygen isotope record of NGRIP (**A**; see **fig. 53**). Hatched areas: transition periods. – For further details see text.

These examples further sustained that based on the suggested characteristics, a wasteful handling of the lithic resource can be rejected for most sites as an explanation for their large size. Consequently, besides the intense lithic exploitation, accumulation is the most common reason for large and very large assemblages in Lateglacial north-western Europe. This accumulation was either due to a long continued and/or a repetitive use of the site and/or by the presence of numerous inhabitants. These factors possibly explain the differences between the assemblages and can be further refined by consideration of the function of the sites and their place in the settlement system.

In summary, the comparison of the sites according to indicators related to the exploitation of lithic resources reveals some clear changes in the behaviour of Lateglacial hunter-gatherers. The Late Magdalenian assemblages were characterised by a relative wide variability and diversity in the reflected behaviour (**fig. 78**). This behaviour sustains the impression of sites being used for very specific purposes. This specific function resulted in the assemblages forming clusters within the used ranges. In the transition period, this specification seemed to disappear and the assemblages spread throughout the full range that was occasionally further enlarged. As a result, the assemblages seemed to be more variable, even though the activities conducted at the sites were less differentiated than before. In the process of this transition, the sites of the Early Azilian and those of the MfCM often overlap with a tendency towards the opposing ends of the continuum but only in numerical comparisons such as the number of artefacts or cores, they form distinct clusters. These overlaps and similarities raise the question how different these two archaeological units truly are. Could they represent sites with two, possibly complementary purposes? Was the difference in the function expressed in this period also by a variation in the techno-typological characteristics of the assemblages? Usually, the values of the Late Magdalenian assemblages, in particular the ones from the Central Rhineland and the western uplands, were more similar to the range of the Early Azilian sites than to the results from the MfCM sites. Following the idea of two different functions, this similarity could indicate a more residential character for the older Azilan and a more specialised character of the MfCM sites. However, further details of the functionality of the assemblages are necessary to confirm this conclusion.

At the end of the transition period, the differentiation of sites according to specific purposes seems widely abandoned and, therefore, the variability of the assemblages decreased. Apparent numerical differences seem to only result from differing durations of use and/or the number of concentrations forming the site. Perhaps, the more distinct values of Le Closeau, *locus* 25 and Bad Breisig signal that towards the end of the studied period more specialised assemblages begin reappearing. A more wasteful handling of lithic resources was not apparent. In a direct comparison of the Late Magdalenian and the FMG assemblages, the approximate number of blanks produced per core becomes reduced and instead the proportion of the cores increases. This change could be explained by the decreasing dimensions of the collected raw material nodules. In fact, the numbers of cores found per site remain, in general, in the same relatively narrow range. Only sites that were considered to be used over a longer period, repetitively or continuously, such as Gönnersdorf or Le Closeau were higher numbers of cores recorded. However, in the transition period, higher values occurred more frequently raising the question as to whether these sites were used over a longer time and/or more often?

Besides the faunal material (see p. 534-548), the diversity of the lithic assemblages forms another important line of evidence for the study of the occupation duration and the function of sites as well as the process of change.

Diversity of the lithic assemblages

Diversity of single lithic assemblages was previously introduced as a marker for a diverse set of activities and/or a longer occupation of a site (Löhr 1979; Richter 1990). However, in a model of changing behavioural codices, diversity can also mark a transformation between two phases of stable compositions. In this transformation, the older stable composition (consistent phase) disintegrated (post-consistent and threshold phase) and by testing of innovations and inventions (threshold and formative phase) causing a higher diversity, new characteristics were selected resulting in a new fixed composition (new consistent phase; Clarke 1968, 276-283; cf. Shennan 2008). Besides the diversity of the assemblage composition, this concept of change can also be applied to single sub-sections of this assemblage (Eerkens/Lipo 2005; White 2008) such as projectile implements (Mesoudi/O'Brien 2008a; Hamilton/Buchanan 2009). In all these models, the social transmission of the complex behavioural recipes underlying the production of the assemblages was emphasised as a stabilising factor (cf. Mesoudi/O'Brien 2008b). Assuming that the stabilising function of the transmission systems was formed by a general social consensus to secure survival within unstable environments (Stein Mandryk 1993), changes in the stability of the transmission may also reflect a destabilisation of the social consensus. In this context, diversity of lithic assemblages becomes an important factor in the study of a transition process in social networks. Consequently, diversity of retouched artefact assemblages in a quasi-contemporaneous comparison shows a functional quality and in a diachronic perspective allows for considerations about the stage of social network stability.

Thus, the composition of complete lithic assemblage, formally retouched artefacts, and, particularly, of the LMP was analysed for this project to reveal changes in different types of diversity that can occur in lithic assemblages.

In regard to the general composition of the lithic assemblages, some observations were already made in the previous section. In a short summary: The Late Magdalenian assemblages differ significantly from one another in the proportion of formally retouched artefacts (**fig. 77A**) as well as of cores and core fragments (**fig. 75A**), in particular on a single site such as the lower horizon of Andernach (**tab. 83**). The proportion of formally retouched artefacts as well as cores and core fragments decreased during the transition period between the Late Magdalenian and the FMG. Nevertheless, the proportion of unretouched blanks and debris did not increase significantly because both equated up to values comparable to the share that was contributed by a single of these categories in a Late Magdalenian assemblage. As a result of the alignment of the values, the assemblage composition of the FMG sites remains relatively stable, in particular in Niederbieber where the assemblages from numerous concentrations are almost identical. This similarity of assemblages in the FMG implies that the share of the main activities was similar for all concentrations (cf. Gelhausen 2011a), whereas in the Late Magdalenian activities were more clearly differentiated in space. During the transition period, sites of the MfCM and the Early Azilian seem to form two extremes within a continuum. The former sites appeared to be more focused on the lithic exploitation and/or the blank production process and yielded significant shares of cores and core fragments. In contrast, the Early Azilian sites seem more dominated by indicators for the use of formally retouched artefacts.

As previously suggested, the relation of cores and core fragments to formally retouched artefacts within an assemblage could reveal the function of a site. This relations permits considerations of occupation duration. Usually, these considerations presume some extreme values. However, on several Lateglacial sites blank production as well as retouching and use of artefacts was performed suggesting a non-specialised activity. Moreover, the limit towards significantly higher values is not fixed but depends on the studied record.

In the present record, several assemblages from the different archaeological units yielded rather inconsistent values. Usually, these sites ranged between 0 and 13 % for formally retouched artefacts and 0 and 4 % for cores and core fragments (**fig. 79A** and detail view A). Very few sites and concentrations yielded extreme values (**tab. 83**) suggesting some specialisation such as the lower horizon of Andernach, Hallines, Wildweiberlei, Urbar, and the upper horizon of sector 1 in Le Grand Canton. However, the former two Late Magdalenian sites and Urbar were not comprehensively excavated and, thus, the specialisation could reflect the function of the excavated activity area/s. In the Wildweiberlei, selective processes before and within the recovery of the material cannot be excluded leading to a disproportional preservation of the lithic material other than cores and formally retouched pieces. Besides the outstanding value for cores and core fragments in Le Grand Canton, sector 1, the values of sector 2 were also clearly dominated by cores and core fragments marking this site as one focussed on specialised blank production. Compared to other sites in this region, the choice of smaller raw material units could explain the extreme values. Moreover, sector 1 perhaps either represented a knapping refuse area and/or was possibly affected by post-depositional processes.

Besides the outstanding values, the values for the upper horizon of sector 2 in Le Grand Canton, Bad Breisig, Gouy, Bois Laiterie, and the Late Magdalenian assemblage of Gönnersdorf were contrasted with the other values. The former two sites were more dominated by cores indicating that the blank production was of greater

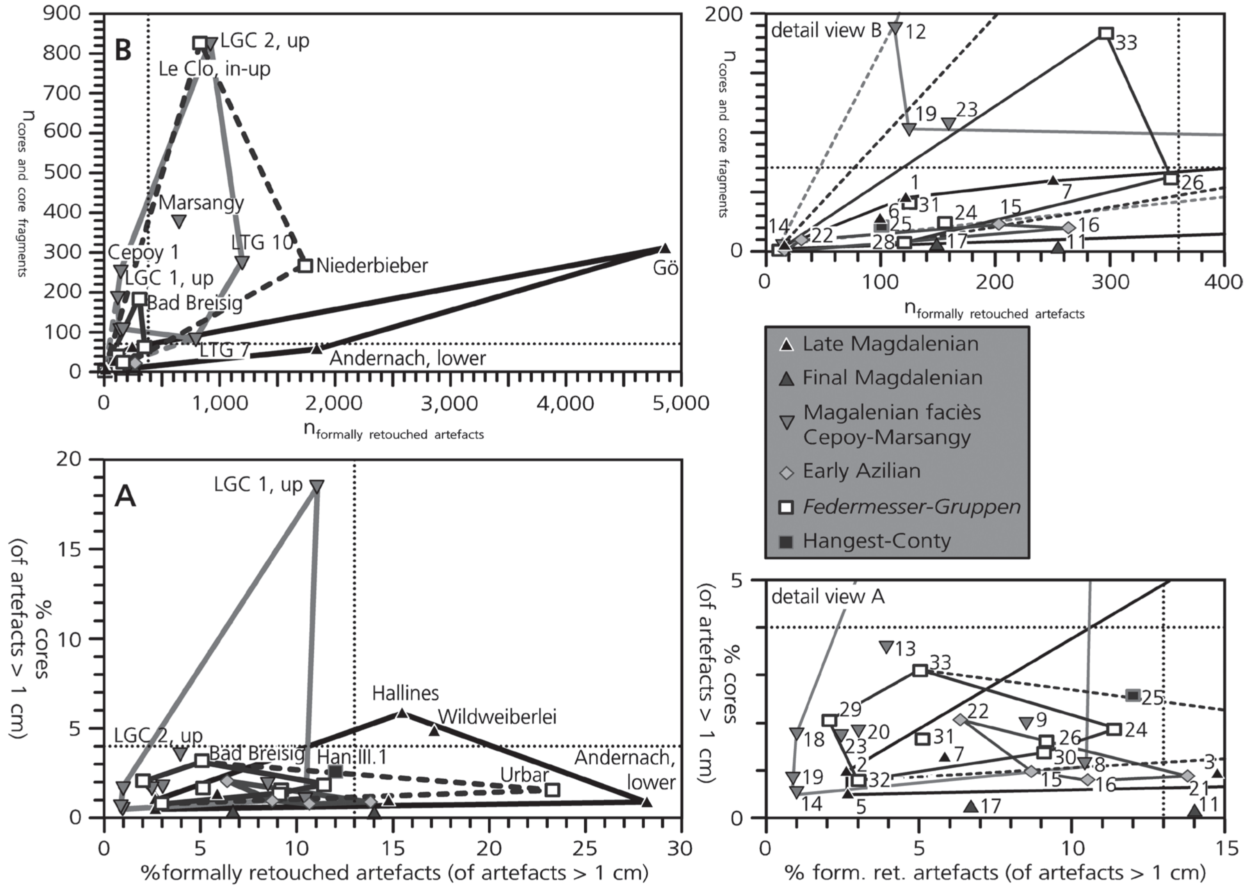


Fig. 79 Percentages (**A**) and numbers of formally retouched artefacts in contrast to cores and core fragments (**B**) given per site and archaeological unit. The distribution of all assemblages is given in the main view where also the convex hulls were set per archaeological unit (see p. 281 f.). Numbers for the sites are used in the detail views according to **tab. 82**. In the detail view B, the unlabled symbols around the 0 points are: Saint Mihiel, the lower horizon of Le Grand Canton, Gouy, and *locus* 25 of Le Closeau. The lines of the convex hulls are also given in the detail views. If an assemblage produced unusually outstanding values for the archaeological unit, the line is dashed. Black dotted lines: the limits of observable breaks in the data beyond which the values can be considered as extreme. For abbreviations see **fig. 74**. – For further details see text.

importance, whereas the latter three assemblages yielded a larger share of formally retouched artefacts suggesting that these sites had a specialised character related to the use of the retouched artefacts.

However, if the inventories were numerically compared instead of using proportional values (**fig. 79B** and detail view B), the results differ, perhaps because the actual numbers are influenced by both the function and by duration of the occupation or the number of inhabitants. In this comparison, the assemblages attributed to the MfCM stand out by their large numbers of cores and core fragments with the exception of Bonnières. Bonnières was previously described as differing by its location from the other sites of this units and, perhaps, this spatial restriction was also the reason for the lower numbers recovered from this site. The Late Magdalenian assemblage of Gönnersdorf, Bad Breisig, Niederbieber, and the intermediate, upper, and undetermined concentrations of Le Closeau also contained significant numbers of cores and core fragments. For the latter two sites, the number of visible concentrations suggests that these sites were used repetitively over a considerable period. Both sites also contained higher numbers of formally retouched artefacts and, therefore, had normal proportional values.

If the single concentrations of these sites, along with the lower horizon of Andernach, Late Magdalenian concentrations of Gönnersdorf, and Marsangy N19 are considered, the tendency does not change only the amplitude of the outstanding values becomes smaller. For example, Marsangy N19 was more similar to Bad Breisig with a clear dominance of cores. Gönnersdorf III contained the greatest number of cores for the Late Magdalenian assemblages but this number was still lower than those from Marsangy N19 or Bad Breisig. The numbers of formally retouched artefacts from Gönnersdorf I and II were still exceptional. This result further emphasises the functional and spatial differentiation of Magdalenian sites resulting in almost exclusive distributions for the Magdalenian faciès Cepoy Marsangy and the Late Magdalenian assemblages. In contrast, the numerous concentrations from Niederbieber and the greyish deposits of Le Closeau were scattered in a dense cluster near the zero points with some concentrations containing more cores and others clearly more formally retouched artefacts. In general, the Le Closeau concentrations yielded tendentially more cores, whereas the Central Rhineland concentrations were dominated by more formally retouched tools. This tendency hints at a continuity of different raw material behaviours in the Paris Basin and the Central Rhineland. Nevertheless, the numbers were usually below 100 pieces for cores as well as for formally retouched artefacts. Thus, the number of concentrations and, consequently, the duration of the use influenced the high numbers on those sites if compared at a site level. The assemblages from *loci* 7 and 10 of Le Tureau des Gardes, the upper horizon of sector 2 in Le Grand Canton, and Marsangy contained comparably high numbers of cores and formally retouched artefacts. The assumption that these sites were formed by a longer duration of use at the locations appears very probable. Moreover, the Late Magdalenian concentrations of Gönnersdorf and from the lower horizon of Andernach contained outstanding values of formally retouched artefacts and following the assumption based on Niederbieber and the greyish deposits of Le Closeau, a longer duration of the occupation for these concentrations (repetitive or continuous) also seems a possible conclusion. However, the large quantity of formally retouched artefacts singles out these assemblages suggesting an intense and regular use of the formally retouched artefacts on the sites. In the lower horizon of Andernach, the larger values are not accompanied by higher values of cores. Probably, this difference was due to the restriction of the Andernach excavation area which did not encompass a blank production area or a knapping refuse zone. Nevertheless, this comparison further sustains a major difference of the Late Magdalenian and the FMG settlement organisations: In the Late Magdalenian, various activities were performed in a restricted area creating a tell-like accumulation, occasionally cleaned up, whereas this process seemed almost absent on FMG sites. Most activities were still performed in a small, restricted area on those sites with a very similar layout (Gelhausen 2011a) but once the material accumulation became to dense or the activities were finished, this spot was not reused and the occupation was moved to another, often nearby spot. These changes in occupied areas resulted sometimes in a large areals with several, clearly distinct and very similar concentrations reminiscent of planned suburban areas. The Early Azilian concentrations of Le Closeau were previously considered as comparable to the Late Magdalenian layouts of more intensely used and architecturally limited activity areas (Jöris/Terberger 2001). More detailed analyses on this site have shown that special working zones were occasionally performed in spatially distinct satellite spots (Bodu/Debout/Bignon 2006). These distinct areas were also observed in Pincevent, horizon III.2 (Bodu/Orliac/Baffier 1996; Orliac 1996b) but these more ephemeral concentrations already resembled the layout of Niederbieber (Gelhausen 2011a). In contrast, the sites of the MfCM as well as the Magdalenian scatters of Monruz (Bullinger/Leesch/Plumettaz 2006) and Champréveyres (Leesch 1997) appear as a mixture of these two types of spatial behaviour with an accumulation of concentrations in the periphery of one another and partially merging into one another. These sites near an open water source were considered as favourable hunting grounds on which the carcasses could be instantly processed (Müller et al. 2006) in the proximity of one or more hearths (Leesch et al. 2010). The composition of the lithic inventories was comparably heterogeneous in the Swiss examples (Bullinger/Leesch/Plumettaz 2006, 99) as in the FMG sites and clearings, except that maintaining a fire also appeared absent. The dense cluster of stone slab refitting was suggested as a result of reuse of previous constructions as source for the creation of new hearth constructions (Leesch et al. 2010). Thus, the activity areas remained at approximately the same spot but gradually shifted in the periphery of previous accumulations along the lake shore. Possibly, this shifting was due to dry grounds and the exact position where large prey animals perished. These gradual movements of successive parties resulted in large areals covered by the site without clear limits of single episodes. In contrast, on the northern French sites attributed to the MfCM, clearings, for instance of knapping debris, and more specialised activity areas were still identified (Julien et al. 1999). A comparable gradual movement between the repetitive visits of the sites as seen on the Swiss lake shores had also resulted in a dense scatter of material over a large area but often with still detectable limits.

On sites mainly used as hunting camps, the numbers and proportions of formally retouched artefacts could be influenced by the numerous, mainly broken LMP. However, subtracting the LMP from the formally retouched artefacts in this record only resulted in a compressed version of the previously described distributions and, thus, did not substantially alter the interpretation.

The convex hull (see p. 281 f.) shows that the Late Magdalenian assemblages in this record tend to be dominated by formally retouched artefacts rather than cores and core fragments. This trend could be a result of the choice of the sites. However, the numbers from potential extraction sites such as Eyserheide (Rensink 2012), Orp (Vermeersch et al. 1987; Wenzel 2009), and Kanne (Vermeersch / Lauwers / van Peer 1985) fall within the range of this convex hull. Subtracting the LMP, the hull becomes compressed but remains an elongated shape with fewer cores and more formally retouched artefacts. Furthermore, this trend is also observable for the Early Azilian sites, whereas the convex hulls of the MfCM and the FMG sites clearly differ from this trend and tend to be more dominated by cores. Besides an increasing number of cores, this trend also reflects a decrease in importance of formally retouched artefacts. To find out whether this decrease was due to a wider decline of standardised artefacts or due to a specific part of the inventory, the diversity of the formally retouched inventories is of interest. Moreover, this diversity was also proposed to be useful to further specify the function of site as well as the duration of their use (Löhr 1979).

For a first general impression of the diversity of the formally retouched artefacts, the seven general classes are compared (**tab. 84**). Through this comparison, a clear distinction can be made between the Late Magdalenian assemblages and the preceding period: In Late Magdalenian assemblages, the seven classes are all usually present and this observation also applies to more specialised hunting sites such as Pincevent (Leroi-Gourhan / Brézillon 1966; Bodu et al. 2006b) or the concentrations along the shores of the Lake Neuchâtel (Bullinger / Leesch / Plumettaz 2006; Leesch et al. 2010). In the studied record, some classes were only missing from the assumed hunting camps at Saint Mihiel and in the lower horizon of Le Grand Canton, sector 2. The missing classes in both cases were truncations, composite tools, and other retouched artefacts. The absence of the latter class is surprising but could be due to the lack of activity areas where unstandardised forms were used or discarded, a very high standardisation in the production of retouched implements, the wish of the presenters to attribute any retouched piece to a standardised type, or pieces of uncertain attribution being unmentioned in the presentation of the site. The lack of composite tools is not so surprising if the formation of these tools is considered as a type of reuse for a tool and thereby becomes comparable to the reuse as splintered pieces which was suggested to occur late in the occupation process (see **fig. 27**; Löhr 1979). However, truncations were thought to occur very early within the appearance of formally retouched artefacts on a site. Therefore, the absence of truncations seemed surprising again and could be explained by a transformation of all these artefacts into burins or the absence of the activity in which truncations were used from the excavated areas. The latter is a very probable explanation, in particular, because both assemblages are very small and, in fact, could reflect the very first stage of an inventory where only the material introduced from elsewhere was abandoned at the sites. The next suggested stage in the devel-

site	function index	% ret. artefacts	retouched artefact groups	missing group/s of retouched artefacts	dominant group/s	Simpson index for ret. artefacts	end-scraper-burin index	% borers	% LMP	point-burin index
Hallines	2.7	15.4 (×)	7	0	**burins**, end-scrapers	0.2931	0.5	18.9	2.5	0
Saint Mihiel	2.7	2.7 (0.9)	4	truncations, composite tools, others	LMP, end-scrapers	0.2656	1.7	18.8	31.3	0.3333
Gönnersdorf	15.7 / 13.9	14.7 (5.9) / 13.1 (5.3)	7	0	LMP, burins	0.2467	0.2	9.9 / 11.1	39.7	0
Gönnersdorf I	×	× (×)	7	0	LMP, burins	0.2398	0.1	10.9	33.1	×
Gönnersdorf II	55.4	× (5.2)	7	0	**LMP**, (others), burins	0.2618	0.7	10.8	44.6	×
Gönnersdorf III	×	×	7	0	**LMP**, burins	0.2544	0.3	16.4	41.0	×
Gönnersdorf IV	6.5	21.3 (6.6)	7	0	**LMP**, burins	0.2422	0.2	2.8	47.3	×
Andernach, lower horizon	33.3	28.1 (4.2)	7	0	(others), burins, LMP	0.2224	0.6	5.4	20.0	0.0025
Andernach I	17.7	× (3.3)	7	0	end-scrapers, LMP	0.2248	1.8	7.9	23.0	×
Andernach II	167.7	× (8.7)	7	0	burins, LMP	0.2474	0.1	9.9	30.0	×
Andernach III	36.2	× (16.2)	7	0	LMP, burins	0.2326	0.8	5.0	30.9	×
Andernach IV	30.6	23.0 (1.4)	7	0	**burins**, (others), LMP	0.2874	0.2	3.6	13.5	×
Le Grand Canton, sector 2, lower horizon	5.3	2.6 (×)	4	truncations, composite tools, others	**LMP**, burins	0.3672	0.4	6.3	50.0	0
Wildweiberlei	3.5	17.1 (15.0)	7	0	**(others)**, LMP, burins	0.681	0.5	9.1	20.2	0
Le Tureau des Gardes	3.7	5.7 (×)	7	0	LMP, burins	0.1900	0.9	12.8	30.7	0.0352
Le Tureau des Gardes, *locus* 6	4.2	5.8 (×)	7	0	**LMP**, (others), borers	0.2916	1.0	11.7	49.0	×
Le Tureau des Gardes, *locus* 7	9.3	10.4 (4.9)	7	0	LMP, (others), end-scrapers	0.2335	1.4	10.2	39.9	0.1861
Le Tureau des Gardes, *locus* 10	4.3	8.4 (×)	7	0	LMP, burins	0.1861	0.7	12.1	28.3	×
Étigny-Le Brassot, south	×	1.2 (×)	×	borers, truncations, composite tools, others	end-scrapers, LMP	0.1379	1.7	×	23.0	0.5333
Bois Laiterie	63.5	14.0 (7.5)	7	0	**LMP**, burins	0.2459	0.7	8.3	44.9	0.3871
Le Grand Canton, upper horizon	1.0	4.2 (×)	7	0	burins, end-scrapers	0.2097	0.6	12.0	16.9	0.0172
Le Grand Canton, sector 1	0.6	11.1 (×)	7	0	burins, LMP	0.2070	0.7	6.2	25.7	×
Le Grand Canton, sector 2, upper horizon	1.1	3.9 (×)	7	0	burins, end-scrapers	0.2119	0.6	12.7	15.8	×
Bonnières-sur-Seine	1.9	1.0 (×)	5	truncations, others	LMP, borers	0.2426	1.0	30.8	30.8	1
Le Closeau, lower horizon	~10.5	8.8 (×)	6	borers	**(others)**, *end-scrapers, LMP*	0.3633	3.4	0.0	16.4	0.3793
Le Closeau, *locus* 4+50	13.1	10.6 (×)	6	borers	**(others)**, end-scrapers, LMP	0.3239	2.0 (2.1)	0.0	17.2	0.4783
Le Closeau, *locus* 46	8.7	8.7 (×)	5	borers, truncations	**(others)**, end-scrapers, LMP	0.4183	12.3	0.0	13.9	×
Gönnersdorf SW	24.7	6.6 (5.3)	7	0	LMP, burins	0.2569	0.2	8.1	39.2	0.0882
Cepoy	0.8	0.9 (×)	6-7	composite tools	end-scrapers, borers, LMP	0.1802	2.4	18.7	18.4	0.6207
Cepoy, sector 1	0.6	1.0 (×)	7	0	end-scrapers, borers	0.1962	2.2	23.9	17.6	0.7778

Tab. 84 IIndices referring to the function of the studied assemblages. Function index is the no. of formally retouched artefacts (ret. artefacts) divided by the no. of cores and core fragments. % ret. artefacts is calculated in relation to artefacts ≥ 1 cm and in parentheses to total artefacts. The two (or three, if the »others« group is included) most numerous groups are given and if a single group formed more than 40 % of the formally retouched artefacts, this group is set in bold. Simpson index is the sum of the square-results of dividing the number of implements within a retouched artefact group by the total number of retouched artefacts. End-scraper-burin index is the no. of end-scrapers divided by the number of burins. % values (if not specified) calculated in relation to all retouched artefacts. % borers/LMP is calculated in relation to all formally retouched artefacts. Point-burin index is the no. of points (see **tab. 85**) divided by the number of burins.

site	function index	% ret. artefacts	retouched artefact groups	missing group/s of retouched artefacts	dominant group/s	Simpson index for ret. artefacts	end-scraper-burin index	% borers	% LMP	point-burin index
Cepoy, sector 2	~1.2	0.8 (×)	6	composite tools	(others), end-scrapers, LMP	0.1996	2.6	12.8	13.9	0.2727
Marsangy	1.7	3.0 (×)	7	0	burins, LMP	0.2006	0.4	17.3	26.2	0.1341
Marsangy N19	1.6	3.0 (×)	7	0	LMP, burins	0.2020	0.4	21.4	27.5	0.1216
Gouy	16.0	13.8 (×)	6	others	LMP, borers, burins	0.2344	0.3	18.8	37.5	1.3333
Pincevent III.2	3.1	6.3 (5.5)	5	borers, composite tools	(others), end-scrapers, truncations	0.2570	4.0	0.0	9.7	2
Belloy-sur-Somme	1.5	2.5 (×)	6	composite tools	**(others)**, end-scrapers, burins	0.2984	1.1	6.3	12.7	0.5238
Andernach, upper horizon	4.2	7.4 (1.4)	6	borers	**LMP**, (others), end-scrapers, burins	0.2877	1	0.0	45.7	0.6585
Andernach 2-FMG	6.2	11.3 (5.4)	6	borers	**LMP**, (others), end-scrapers	0.2691	1.1	0.0	42.3	0.8182
Hangest-sur-Somme III.1, lower horizon	4.8	11.9 (5.1)	5	borers, composite tools	**LMP**, burins	0.3599	0.2	0.0	52.0	0.1482
Kettig	5.7	9.2 (1.5)	7	0	end-scrapers, LMP	0.216	3.1	1.4	28.4	0.6111
Conty, lower horizon	14.0	× (2.1)	6	composite tools	**LMP**, burins	0.3708	0.3	4.8	57.1	1.6667
Urbar	15.0	23.3 (7.3)	5	borers, composite tools	**end-scrapers,** LMP	0.245	49	0.0	10.8	3
Le Closeau, greyish deposits	1.0	2.0 (×)	7	0	**LMP**, end-scrapers	0.3723	3.8	2.9	58.3	0.2258
Niederbieber	6.3	9.0 (1.4)	7	0	LMP, (others), end-scrapers	0.2123	1.2	2.1	31.9	0.4025
Niederbieber 1	8.2	10.5 (3.4)	6	composite tools	LMP, (others), end-scrapers	0.681	1.2	1.8	25.4	0.2245
Niederbieber 3	9	3.5 (0.6)	3	all (except LMP, burins, others)	**LMP**, burins	0.4321	×	0.0	55.6	0
Niederbieber 4 (+17a)	9	12.3 (1.5)	6	composite tools	LMP, end-scrapers	0.2329	2.2	0.8	30.8	0.2059
Niederbieber 5	4.6	6.7 (1.4)	6	composite tools	(others), LMP, truncations	0.2582	0.9	1.9	32.4	1.4286
Niederbieber 6 (+10a)	7.4	5.7 (0.8)	6	composite tools	**LMP**, (others), truncations	0.3522	1	1.0	51.0	3
Niederbieber 7	7.8	12.0 (5.5)	7	0	burins, (others), truncations	0.2209	0.4	4.0	18.4	0.2286
Niederbieber 8	7.4	6.9 (0.3)	5	borers, composite tools	burins, LMP	0.2739	0.2	0.0	32.4	0.2308
Niederbieber 9	5.6	8.3 (3.6)	6	composite tools	LMP, (others), end-scrapers	0.2518	2.3	2.3	37.4	0.9286
Niederbieber 10	5.3	7.2 (2.5)	6	composite tools	**LMP**, (others), end-scrapers	0.2699	2	1.7	43.1	1
Niederbieber 11	6	13.2 (1.4)	7	0	**LMP**, end-scrapers	0.2665	2.3	1.5	40.9	0.2857
Niederbieber 12	3.1	5.9 (1.0)	5	borers, composite tools	**LMP**, (others), burins	0.2923	0.4	0.0	40.0	0.3076
Niederbieber 13	5.6	7.2 (0.7)	6	composite tools	**LMP**, end-scrapers, (others)	0.2824	3	2.0	40.0	0.5
Niederbieber 14	4.1	11.9 (1.4)	6	composite tools	LMP, end-scrapers	0.2026	1.4	5.6	28.1	0.1333
Niederbieber 15	1.3	14.8 (7.6)	5	borers, composite tools	LMP, end-scrapers, (others)	0.229	2.8	0.0	26.2	0.5
Niederbieber 16	6	7.4 (0.6)	6	composite tools	**LMP**, burins	0.4131	0.3	2.4	61.3	0.25
Niederbieber 17	15.5	38.9 (3.1)	5	borers, composite tools	LMP, truncations	0.2336	0.6	0.0	34.9	0.4167
Niederbieber 18	9	1.4 (0.1)	2	all (except LMP, burins)	**LMP**, end-scrapers	0.46	×	0.0	60.0	×
Niederbieber 19	10	5.7 (3.1)	4	borers, composite tools, others	**LMP**, end-scrapers, truncations, burins	0.4815	1	0.0	66.7	×
Niederbieber 20	4.5	4.6 (1.3)	6	composite tools	**LMP**, burins	0.3353	0.2	6.7	51.1	×
Andernach 3-FMG	3.0	5.1 (0.7)	6	borers	**LMP**, burins	0.3123	0.8	0.0	50.0	0.4737
Le Closeau, *locus* 25	10	3.0 (×)	1	all (except LMP)	LMP	1.0000	×	0.0	100	×
Bad Breisig	1.6	5.0 (0.7)	6	borers	**LMP**, end-scrapers	0.2844	3.9	0.0	38.5	0.76

Tab. 84 (continued)

opment of a Magdalenian lithic inventory is an initial blank production with the production of burins and first bladelets that were transformed into backed bladelets before truncations were made. The relatively low numbers and percentages of the cores in the assemblages of Saint Mihiel and the lower horizon of Le Grand Canton, sector 2 (**fig. 79**) further support the impression of these assemblages reflecting only a brief occupation. The Late Magdalenian inventories were generally dominated by the LMP (**tab. 84**) confirming Jürgen Richter's suggestion that the LMP reflect a basic group of retouched artefacts on Magdalenian sites (Richter 1990). However, on some sites such as the lower horizon of Andernach, burins occurred in an even greater number than LMP. In Andernach, the different focus of activities becomes apparent particularly in regard to the most numerous group. Although LMP are always numerous, the most numerous group varies in almost each concentration, further suggesting that some concentrations were perhaps supplementary installations.

In general, the appearance of all retouched artefact groups also applies to the sites of the MfCM. Only in sector 2 of Cepoy and in the lower horizon of Belloy-sur-Somme, composite tools were not identified and in Bonnières-sur-Seine, no truncations or other retouched artefacts were found. Besides reasons for the absence of these groups, the limited excavation area at Bonnières could be an additional bias for these groups. Moreover, the rich lithic sources at Belloy-sur-Somme as well as at Cepoy created a surplus of blanks making reuse unnecessary and, perhaps, the use of one instrument for various tasks unwanted. Until the lithic inventory from Étigny-Le Brassotis presented comprehensively, it remains uncertain which groups are missing. According to a short, preliminary presentation (Lhomme et al. 2004), borers seemed to be absent along with the three groups not present at Saint Mihiel and in the lower horizon of Le Grand Canton, sector 2. Based on the evidence from Le Tureau des Gardes, Laurent Lang suggested that besides burins, (heavily retouched) borers could indicate work with antler material and that a decrease in their number could reflect a diminishing importance of antler as a resource (Lang 1998, 99). However, use-wear analysis on *becs* from the Late Magdalenian site Verberie and the perforators of Gönnersdorf revealed that mostly these pieces were in fact used for piercing and boring (Beyries / Janny / Audouze 2005; Sano 2012b). The heavily retouched specimens from Verberie were generally used on hard organic material such as bone or antler but the finer pieces from Gönnersdorf were used on a variety of material such as stone, bone, antler, ivory, tooth, or shell. Thus, the disappearance of this group of artefacts might also indicate a decreasing importance of working hard organic material but the abandonment of drilling activities of hard substances and / or the use of standardised pieces for this activity seems to more generally reflect the decrease in importance of borers. The changes in the blank production process which were widely observed in the assemblages of the MfCM produced more solid and pointed flakes and blades which could perhaps have been substituted for the borers without the need for further retouch. Comparably, no borers were found in the Early Azilian assemblages of Le Closeau and Pincevent III.2 where the knapping technique using soft hammerstone had become exclusive. Besides LMP and burins, end-scrapers become a dominant group in these inventories. The most numerous groups become more heterogeneous in these assemblages and no group reached values of over 40 % as did the LMP and occasionally burins in the Late Magdalenian. Besides a greater spatial specialisation among the Late Magdalenian, the generally lower proportion of formally retouched artefacts in assemblages of the MfCM is probably of less importance regarding assemblage composition.

In contrast to the Magdalenian inventories, Early Azilian and the FMG assemblages infrequently contained the complete set of formally retouched artefacts and usually this set was only found in horizons formed by several concentrations. Moreover, truncations were usually present in these inventories. Besides the lack of borers, no composite tools were found in Pincevent III.2 and the group of other retouched artefacts was absent from Gouy. The absence of these groups is comparable to Saint Mihiel and the lower horizon of Le Grand Canton, sector 2. The most numerous groups of retouched artefacts varied significantly between these assemblages. End-scrapers became more frequent than burins and besides these groups, other retouched artefacts became of greater importance in the Early Azilian assemblages.

Composite tools were most frequently missing in FMG assemblages followed by borers. In contrast to the MfCM and the Early Azilian assemblages, LMP were the clearly dominant group again which frequently covered more than 40 % of the retouched artefacts. Besides this group, end-scrapers were the second most numerous group. Infrequently, burins formed a more numerous group. Besides these typical groups, truncations and other retouched artefacts were also occasionally dominant groups. In some FMG inventories, only very few formally retouched artefacts were found and comprised usually of pieces identified as LMP and burin. Thus, even though the numbers and shapes of the burins became unstable in the FMG assemblages, they remained one of the more essential lithic artefact types.

According to the missing as well as the dominant groups of retouched artefacts in this project (**tab. 84**), the LMP can be confirmed as a basic group (cf. Richter 1990) throughout the Late Pleniglacial and the Lateglacial Interstadial. In fact, most Lateglacial assemblages contained 30-50 % LMP among the retouched artefacts (**fig. 80A**). Nevertheless, these values differed, sometimes considerably, between the sites and within the assemblages (**tab. 84**). Tendentially, the FMG assemblages contained a larger proportion of LMP than the Late Magdalenian. The FMG assemblages ranged generally between 28.4 and 58.3 % LMP but the value of Urbar (% LMP = 10.8 %) formed a clear outlier. Since the site was only partially excavated, the low proportion could be a result of this bias. In contrast, the Late Magdalenian assemblages contained 20 to 50 % LMP with Hallines (% LMP = 2.5 %) again representing an outlier. Likewise at Urbar, the restriction of the excavation area, which caused high values of intense blank production on this site, probably also caused the low share of LMP. However, the trend from the Late Magdalenian to the FMG assemblages was not a continuous increase because the inventories of the MfCM contained relatively small proportions of LMP (range of % LMP: 12.7-39.9 %) and the ratio further decreased in the Early Azilian assemblages (range of % LMP: 9.7-17.2 %). The assemblage from Gouy formed an exception to the latter with a value of 37.5 %. The superficial excavation at this site could have also biased this value. Since some of the MfCM sites were considered as hunting and/or butchering locales, the low values are surprising. These generally lower values become explicable if the types of LMP are taken into account (**tab. 85**). In the Late Magdalenian assemblages such as Gönnersdorf, small backed bladelets were the aimed shape which often was produced by the intentional breakage of larger backed blades into smaller sections (see **pl. 1, 29-30**). This procedure resulted in numerous pieces including the debris which often bore partial retouch. According to the limited evidence (Leroi-Gourhan 1983), several of these fragments were used as composite tools. In contrast, only a few of these small implements were found on sites of the MfCM or the Early Azilian. On these sites, lithic points were the major LMP. The points were generally considered to be used as single implements glued in or on top of a shaft (cf. Valentin 2008a; figs 31-32). Thus, counted per projectile significantly fewer lithic inserts were necessary and less debris material was produced resulting probably in an overall decrease of LMP numbers and proportions, although the same number of ready made projectiles might be present at the site.

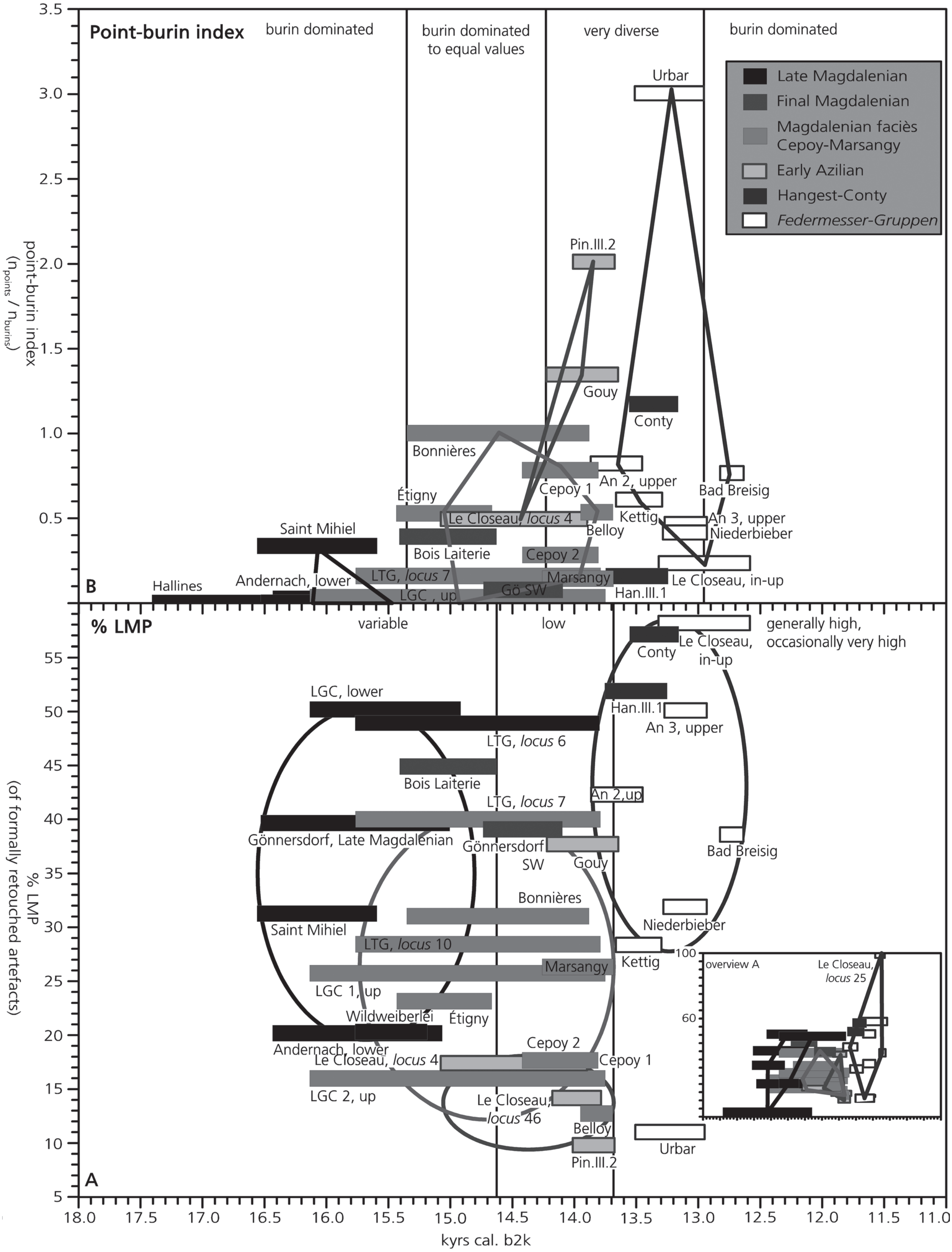
Thus, the number of points per site could help balance for this possible disproportion. However, besides previously mentioned difficulties for estimating the number of points, this number is also dependent on the size of the occupation and/or number of occupants or occupying episodes. To take this assemblage size into account, the points can be set in relation to a group of the formally retouched artefacts attributed to the *fond commun*. Since burins are the second most frequently present type, the point-burin index can be used for this count (**fig. 80B**). Burins were usually considered as antler or bone working tools, in particular for the fabrication of spalls which were often the preform of organic points. These numbers also changed significantly. Therefore, the index was proposed as a possible indicator for the significance of organic points in contrast to lithic projectiles (see p. 275-282). Thus, the suggestion that the increase of lithic points was

site	total	displayed / % of total	ref.	indet./ % of displayed	couteau à dos	backed blade(let)	simple point	straight-backed point	curve-backed point	angle-backed point	tanged point	no. of types	no. of points
Hallines	3	1 / 33.3	1	0 / 0	**1* / 100**	0	0	0	0	0	0	1	0
Saint Mihiel	5	6 / 120.0	2	5 / 83.3	0	0	0	0	0	**1 / 16.7**	0	1	1
Gönnersdorf	1,927	67 / 3.5	5	35 / 52.2	0	**32 / 47.8**	0	0	0	0	0	1	0
Andernach, lower horizon	367	46 / 12.5	3-4	32 / 69.6	0	**13 / 28.3**	0	1	0	0	0	2	1
Le Grand Canton, lower horizon	8	8 / 100	7	8 / 100	0	0	0	0	0	0	0	0	0
Wildweiberlei	20	15 / 75.0	6	9 / 60.0	0	**6 / 40.0**	0	0	0	0	0	1	0
Le Tureau des Gardes	1,057	28 / 2.7	12-13	6 / 21.4	0	1	0	0	3	**18 / 64.3**	0	3	21°
Le Tureau des Gardes, locus 7**	313	16 / 5.1	13	0 / 0 (189 / 60.4)	0 (0)	0 (14)	0	0 (0)	2 (4)	**14 / 87.5 (106 / 33.9)**	0 (0)	2 (3)	16° (124)
Étigny-Le Brassot, south	23	8 / 34.8	11	0 / 0	0	0	0	0	**6 / 75.0**	2	0	2	8
Bois Laiterie	254	47 / 18.5	9-10	27 / 57.5	2	**6 / 12.8**	2	1	5	1	3	**7**	12
Le Grand Canton, upper horizon	174	59 / 33.9	7	45 / 76.3	0	**8 / 13.6**	1	1	1	3	0	**5**	6
Bonnières-sur-Seine	4	4 / 100	8	1 / 25.0	0	1	0	0	0	**2 / 50.0**	0	2	2
Le Closeau, locus 4+50	45	18 / 40.0	14-15	7 / 38.9	0	0	2	0	**7 / 38.9**	2	0	3	11
Gönnersdorf SW	58	34 / 58.6	16	29 / 85.3	0	**2 / 5.9**	0	0	1	**2 / 5.9**	0	3	3
Cepoy	47	17 / 36.2	17-18	0 / 0	0	0	1	0	2	**14 / 82.4**	0	3	17
Cepoy, sector 1	25	14 / 56.0	18	0 / 0	0	0	1	0	2	**11 / 78.6**	0	3	14
Marsangy	168	69 / 41.1	19	39 / 56.5	1	5	2	1	5	**13 / 18.8**	3	**7**	24
Marsangy N19	86	35 / 40.7	19	22 / 62.9	1	2	0	1	0	**7 / 20.0**	1	**5**	9
Gouy	6	6 / 100	20	1 / 16.7	1	0	0	0	**3 / 50.0**	1	0	3	4
Pincevent III.2	5	5 / 100	25-26	1 / 20.0	0	0	0	0	**4 / 80.0**	0	0	1	4
Belloy-sur-Somme	20	18 / 90	1	4 / 22.2	1	3	3	0	2	**6 / 40.0**	0	**5**	11
Irlich	1	1 / 100	21	1 / 100	0	0	0	0	0	0	0	0	0
Andernach, upper horizon	128	128 / 100	22-24	94 / 73.4	3	4	5	1	**20 / 16.4**	1	0	**6**	27
Andernach 2-FMG	66	71 / 107.6	22	52 / 73.2	1*	0	5	0	**13 / 19.7**	0	0	3	18

Tab. 85 Numbers of LMP types in the studied assemblages. The most numerous defined type is given in bold and, in addition, the % of all displayed figures. The number of types refers to the number of determined types and excluding indetermined pieces. ***** Magdalenian (pointed) blades; ****** the numbers set in parantheses refer to numbers given in Lang 1998, 28-36 (the plates from this report were not available to the present author); ******* in the original publication the fragments were counted, whereas in the present study the complete pieces are counted; **°** these numbers are according to what was found displayed in publications, the given numbers in the publications are considerably higher; **×** unknown. References (ref.): **1** Fagnart 1997, figs 20, 40, 41, 89, and 166; **2** Stocker et al. 2006, figs 6-7; **3** Floss/Terberger 2002, Abb. 120. 124; **4** Holzkämper 2006, Taf. 16; **5** Franken/Veil 1983, Taf. 22 and 33; **6** Terberger 1993, Taf. 72; **7** Valentin et al. 1999b, figs 22 and 26-27; **8** Barois-Basquin/Charier/Lécolle 1996, fig. 10; **9** Straus/Orphal 1997, figs 10-17; **10** Sano/Maier/Heidenreich 2011, figs 5-6; **11** Lhomme et al. 2004, fig. 32; **12** Alix et al. 1993, fig. 20; **13** Weber 2006, fig. 4; **14** Bodu/Mevel 2008, fig. 6; **15** Bodu 1998, fig. 418; **16** Buschkämper 1993, Abb. 6 Taf. 2 and 3; **17** Valentin 1995, Planche 38; **18** Wenzel 2009, fig. 52; **19** Schmider 1992a, figs 106, 108-109, and 111; **20** Bordes et al. 1974, fig. 1; **21** Baales 2002, Abb. 8, 80-81, and 83-84; **22** Bolus 1984, Abb. 21, 35, 39, 78, 91, and 129; **23** Kegler 1999; **24** Kegler 2002; **25** Bodu/Orliac/Baffier 1996, fig. 72; **26** Orliac 1996b, fig. 78; **27** Baales/Mewis/Street 1998; **28** Bolus 1992; **29** Loftus 1984; **30** Loftus 1985; **31** Gelhausen 2011a; **32** Gelhausen 2011b; **33** Husmann 1988; **34** Husmann 1989; **35** Thomas 1990; **36** Freericks 1989; **37** Wenzel 2004; **38** Baales/Grimm/Jöris 2001; **39** Grimm 2004; **40** Grimm 2003.

site	total	displayed / % of total	ref.	indet./ % of displayed	couteau à dos	backed blade(let)	simple point	straight-backed point	curve-backed point	angle-backed point	tanged point	no. of types	no. of points
Hangest-sur-Somme III.1 lower horizon	51	15 / 29.4	1	1 / 6.7	4	**6 / 40.0**	0	0	2	2	0	4	4
Kettig	100	96 / 96.0	21	63 / 65.6	0	11	7	2	**12 / 12.5**	1	0	**5**	22
Conty, lower horizon	24	19 / 79.2	1	4 / 21.1	**7 / 36.8**	1	0	0	4	3	0	4	7
Urbar	13	13 / 100	27	6 / 46.2	0	1	1	1	**2 / 15.4**	**2 / 15.4**	0	**5**	6
Niederbieber	551	393 / 71.3	28-16	245 / 62.3	8	45	5	12	**60 / 15.3**	18	0	**6**	95
Niederbieber 1	69	75 / 108.7	28-29	54 / 72.0	0	**10 / 13.3**	0	0	**10 / 13.3**	1	0	3	11
Niederbieber 2 (18+19+20)	35	29 / 82.9	30-31	23 / 79.3	0	**2 / 6.9**	0	1	**2 / 6.9**	0	0	3	3
Niederbieber 3	5	5 / 100	28	5 / 100	0	0	0	0	0	0	0	0	0
Niederbieber 4+17a	80	78 / 97.5	28; 32	59 / 75.6	1*	**11 / 14.1**	0	1	5	1	0	**5**	7
Niederbieber 5	34	41 / 120.6	33-34	26 / 63.4	0	5	3	0	**6 / 14.6**	1	0	4	10
Niederbieber 6+10a	53	43 / 81.1	32; 35	26 / 60.5	0	**8 / 18.6**	0	1	6	2	0	4	9
Niederbieber 7	23	12 / 52.2	36	4 / 33.3	0	0	0	1	3	**4 / 33.3**	0	3	8
Niederbieber 8	12	5 / 41.7	32	2 / 40.0	0	0	0	0	**2 / 40.0**	1	0	2	3
Niederbieber 9	65	27 / 41.5	32	5 / 18.5	**7 / 25.9**	2	0	3	**7 / 25.9**	3	0	**5**	13
Niederbieber 10	25	11 / 44.0	32	5 / 45.5	0	1	0	0	**5 / 45.5**	0	0	2	5
Niederbieber 11	27	7 / 25.9	32	3 / 42.9	0	**2 / 28.6**	0	1	1	0	0	3	2
Niederbieber 12	26	9 / 34.6	32	3 / 33.3	0	2	0	1	**3 / 33.3**	0	0	3	4
Niederbieber 13	20	6 / 30.0	32	4 / 66.7	0	0	0	0	**2 / 33.3**	0	0	1	2
Niederbieber 14	25	7 / 28.0	32	5 / 71.4	0	0	0	0	**2 / 28.6**	0	0	1	2
Niederbieber 15	11	5 / 45.5	32	3 / 60.0	0	0	0	0	**1 / 20.0**	**1 / 20.0**	0	2	2
Niederbieber 16	19	7 / 36.8	32	6 / 85.7	0	0	0	0	0	**1 / 14.3**	0	1	1
Niederbieber 17	22	12 / 54.5	32	4 / 33.3	0	**3 / 25.0**	2	0	**3 / 25.0**	0	0	4	5
Andernach 3-FMG	62	57 / 91.9	23-24	42 / 73.7	2	4	0	1	**7 / 12.5**	1	0	**5**	9
Boppard	×	4 / ×	37	0	0	0	0	**1 / 25.0**	**1 / 25.0**	**1 / 25.0**	**1 / 25.0**	4	4
Le Closeau, locus 25	10***	10 / 100	15	4 / 40	0	**1 / 10.0**	0	0	**4 / 40**	**1 / 10**	0	3	5
Bad Breisig	114	83 / 72.8	38-40	57 / 68.7	0	7	0	**10 / 12.1**	6	3	0	4	19

Tab. 85 (continued)


Point-burin index
burin dominated
burin dominated to equal values
very diverse
burin dominated
Late Magdalenian
Final Magdalenian
Magdalenian faciès Cepoy-Marsangy
Early Azilian
Hangest-Conty
Federmesser-Gruppen
point-burin index (n_{points} / n_{burins})
Urbar
Pin.III.2
Gouy
Conty
Bonnières
An 2, upper
Cepoy 1
Bad Breisig
Étigny
Kettig
Le Closeau, locus 4
An 3, upper
Belloy
Niederbieber
Saint Mihiel
Bois Laiterie
Cepoy 2
LTG, locus 7
Marsangy
Le Closeau, in-up
Hallines
Andernach, lower
Gö SW
Han.III.1
LGC , up
B
% LMP
variable
low
generally high, occasionally very high
Le Closeau, in-up
LGC, lower
LTG, locus 6
An 3, upper
Bois Laiterie
An 2,up
Gönnersdorf, Late Magdalenian
Gönnersdorf SW
Bad Breisig
Saint Mihiel
LTG, locus 10
Kettig
LGC 1, up
Wildweiberlei
Étigny
Andernach, lower
Le Closeau, locus 4
Cepoy 2
Cepoy 1
LGC 2, up
Le Closeau, locus 46
Belloy
Urbar
Pin.III.2
overview A
Le Closeau, locus 25
A
% LMP (of formally retouched artefacts)
kyrs cal. b2k

possibly due to the gradual disappearance of antler as resource for projectiles (Lang 1998, 96-99), perhaps, also explains the decrease of backed bladelets.

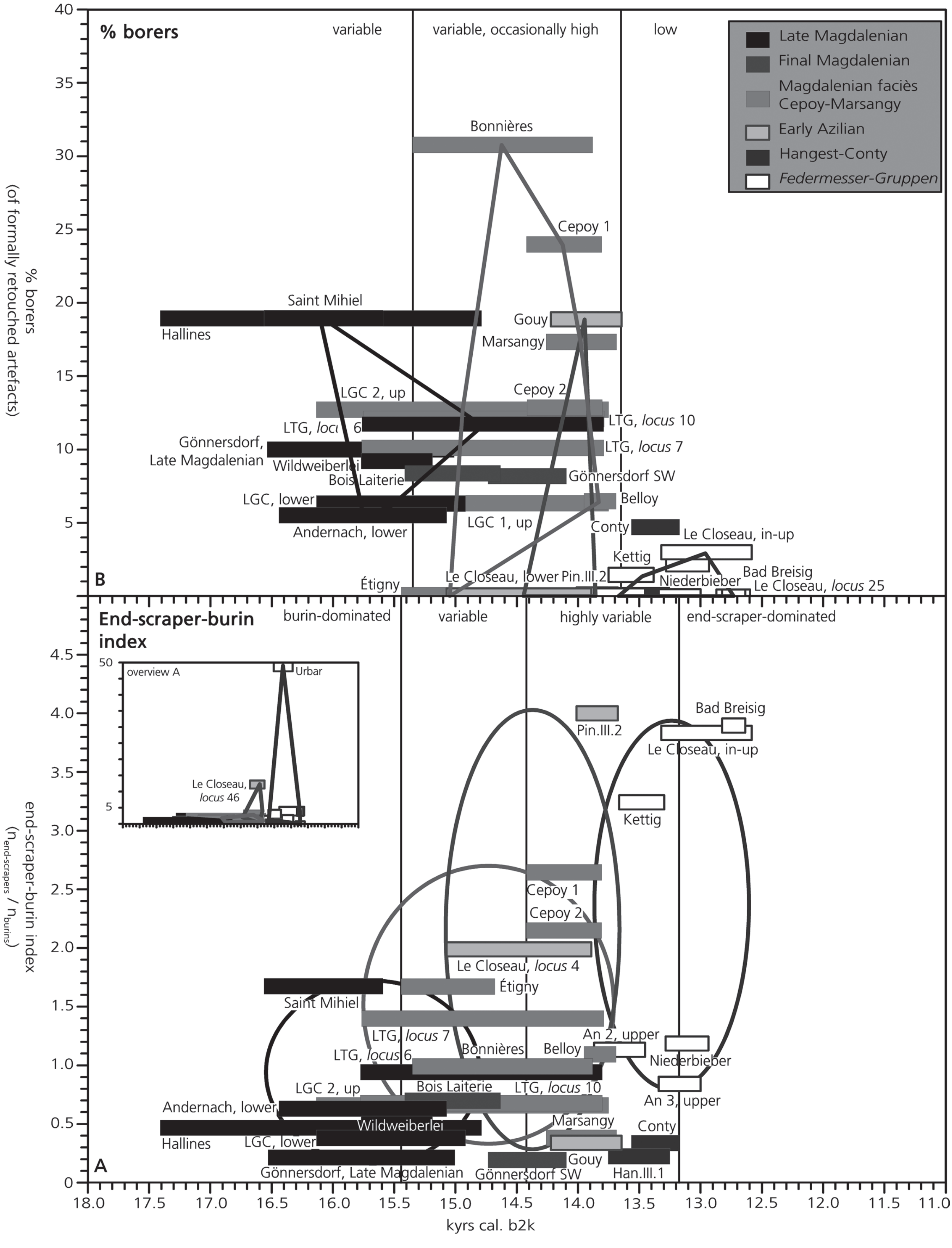
However, in the present record, the phases observable in the proportions of the LMP and the point-burin index differ suggesting no direct relation between the values. Nevertheless, the lowest LMP percentages co-occur temporally with the appearance of point-dominated assemblages. In particular, the inventories of Pincevent, horizon III.2 and Cepoy 1 are characterised by a low proportion of LMP and a high (point-dominated) result in the point-burin index. The LMP as well as the burins did not belong to the most numerous groups in both inventories and small changes in the number of points could result in obvious changes in the index value. Nevertheless, Pincevent III.2 is a very small inventory of formally retouched artefacts and drawings of the LMP were completely displayed in publications. Thus, a change in these values is not very probable but this possibility remains possible for other inventories and could shift the limits of the phases in the point-burin index. The most outstanding correlation of low LMP proportion and a high point-burin index occurs in the Urbar assemblage. From this assemblage all LMP were displayed and changing values seem improbable. However, this assemblage came from a restricted excavation and the complete assemblage could again alter the value. In the concentrations from Niederbieber, very high LMP percentages occurred with very low as well as very high point-burin indices but low LMP percentages were only accompanied by burin-dominated index values. Even though lithic points were the usual LMP in the FMG inventories, the ratio of LMP sometimes became very high. Moreover, in these assemblages backed bladelets occurred again and many fragments which could not be further determined were also found on these sites. Thus, the decrease of LMP values due to the introduction of points applied possibly for the initial period of use but certainly not for the continuous use.

In regard to the relationship of organic and lithic projectile points, the point-burin index suggests that the importance of lithic armatures increases, in particular in the Early Azilian, but that working of hard organic tissues remains of some importance. In order to consider the importance of antler and bone working on Lateglacial sites, the burins were also set in relation to end-scrapers and the proportions of borers as alternative tools was used (**fig. 81**). These values further refine the picture of the development of the Lateglacial inventories, specifically in regard to possible indicators for working of hard organic tissues. Thus, for the validity of the results, sites with preserved organic artefacts are also of interest.

The point-burin index is, generally, burin-dominated in Late Magdalenian assemblages because only single pointed implements were found at these sites. The end-scraper-burin index is also dominated by burins and the ratio of borers range between 5.35 and 18.85 %. Only in single assemblages such as Andernach IV or Gönnersdorf IV values as low as 2.75 % occurred. Following the suggestion that burins and, possibly, borers were indicative of working hard organic materials (cf. Lang 1998, 96-99), this activity was of some importance in the Late Magdalenian assemblages. This assumption is further sustained by the numerous organic remains reflecting the production of bone, antler, and ivory implements at sites with a good organic preservation (Tinnes 1994; Bodu et al. 2006b).

The values from Bois Laiterie and the south-western area of Gönnersdorf fall in the range of Late Magdalenian assemblages. In Bois Laiterie, the ratio of the points was marginally higher than in the Late Magdale-

Fig. 80 A Percentages of LMP given per time and archaeological unit. Circles were set around the main cluster of assemblages attributed to the same archaeological unit. The distribution of all assemblages is given in the overview where also the convex hulls were set per archaeological unit (see p. 281 f.). In the overview, names are only given for sites which are not shown in the main graph. **B** Values of the point-burin index given per time and archaeological unit. The complete distribution is already given and the convex hulls are therefore set in the main view. Besides Hallines and the lower horizon of Andernach, the values of Gönnersdorf, Wildweiberlei, and the lower horizon of Le Grand Canton, sector 2 fall to the bottom of graph B. Abbreviations see **fig. 74**. – For further details see text.


% borers
% borers (of formally retouched artefacts)
variable
variable, occasionally high
low
Late Magdalenian
Final Magdalenian
Magdalenian faciès Cepoy-Marsangy
Early Azilian
Hangest-Conty
Federmesser-Gruppen
Bonnières
Cepoy 1
Saint Mihiel
Hallines
Gouy
Marsangy
LGC 2, up
Cepoy 2
LTG, locus 6
LTG, locus 10
Gönnersdorf, Late Magdalenian
LTG, locus 7
Wildweiberlei
Bois Laiterie
Gönnersdorf SW
LGC, lower
Belloy
Andernach, lower
LGC 1, up
Conty
Le Closeau, in-up
Kettig
Bad Breisig
Étigny
Le Closeau, lower
Pin.III.2
Niederbieber
Le Closeau, locus 25
B
End-scraper-burin index
end-scraper-burin index (n end-scrapers / n burins)
burin-dominated
variable
highly variable
end-scraper-dominated
overview A
Urbar
Le Closeau, locus 46
Pin.III.2
Bad Breisig
Le Closeau, in-up
Kettig
Cepoy 1
Cepoy 2
Le Closeau, locus 4
Saint Mihiel
Étigny
LTG, locus 7
An 2, upper
LTG, locus 6
Bonnières
Belloy
Niederbieber
LGC 2, up
Bois Laiterie
LTG, locus 10
An 3, upper
Andernach, lower
Marsangy
Conty
Wildweiberlei
Hallines
LGC, lower
Gouy
Gönnersdorf, Late Magdalenian
Gönnersdorf SW
Han.III.1
A
kyrs cal. b2k

nian and in the south-western area of Gönnersdorf, the burins were proportionally more frequent than in Late Magdalenian assemblages.

The point-burin index in the inventories of the MfCM is also burin-dominated but to a much lesser extent than within the Late Magdalenian. This greater variability of the index reflects the more regular appearance of pointed implements on these sites. However, the end-scraper-burin index is also higher in this archaeological unit than in the Late Magdalenian, in particular at Cepoy. A high value of this index indicates an end-scraper dominance. However, the proportion of borers was, in general, similar to values from Late Magdalenian. Thus far, no borers were reported from Étigny and the outstanding value from Bonnières-sur-Seine can be explained with the small, selectively excavated assemblage. Nevertheless, Cepoy 1 also yielded a relatively high proportion of borers. Looking at the actual numbers of the formally retouched artefacts (**tabs 14. 27. 38**), the numbers of burins as well as of borers increase occasionally in the MfCM in relation to the Late Magdalenian assemblages. However, the number of end-scrapers usually increases more significantly in the former inventories. In a traceological analysis of selected flints from Gönnersdorf II, Katsuhiro Sano showed that, at least in a longer occupied site such as Gönnersdorf, the use of burins and end-scrapers is relatively similar because, besides hide-working, end-scrapers were also used in working antler or bone. Taking this finding into account, was the increasing number of end-scrapers perhaps also an indicator for an intense working of hard organic material on these sites? In Cepoy 1 were the end-scraper-burin index is high, the number of burins is relatively low as well as the number of LMP in general. Combining these indicators, at least the function of Cepoy 1 can be assumed as focused on the exploitation of animal carcasses, in particular the hard tissue. In general, the inventories of the MfCM tended to produce values that indicate this activity was possibly a major task on these sites. However, the occasionally poor preservation and not yet accomplished analyses prohibited a confirmation of this tendency from the faunal record. In the material from Le Tureau des Gardes as well as in the upper horizon of Le Grand Canton, no organic artefacts were found.

The Early Azilian sites are very heterogeneous. The small inventories of Gouy and Pincevent III.2 were dominated by points rather than burins suggesting that the number of burins was low. Consequently, the high dominance of end-scrapers at Pincevent III.2 is also not surprising but the assemblage of Gouy is burin-dominated which is due to the single end-scraper recovered from the superficial excavation. Moreover, Gouy also provided a high proportion of borers in contrast to the other Early Azilian sites where, usually, no borers were found. Perhaps, this difference can be explained by site specifics and the additional task at this site where the cave walls were engraved (Martin 2007a). Thus, a traceological analysis of this material proposed that besides the processing of hard organic material, also mineral material was scraped and/or engraved (Plisson 2007). That burins were used for engravings can be supported by the results from Gönnersdorf II where a burin facet was found to be used in stone processing (Sano 2012b). However, end-scrapers were more frequently used to process stone material but they were suggested to have been used in the production of stone lamps and mortars (Sano 2012b, 269). According to the same study, all analysed types of artefacts were used to process stone material which could explain the unremarkable values of Pincevent III.2 where an engraved horse head was found (Allain 1976). Besides this single engraving, the structure and hardness of the cortex presumably resulted in relatively few use-wear traces and, possibly, influenced the

Fig. 81 **A** Values of the end-scraper-burin index given per time and archaeological unit. Circles were set around the main cluster of assemblages attributed to the same archaeological unit. The distribution of all assemblages is given in the overview where also the convex hulls were set per archaeological unit (see p. 281 f.). In the overview, names are only given for sites which are not shown in the main graph. **B** Percentages of borers given per time and archaeological unit. The complete distribution is already given and the convex hulls are therefore set in the main view. Besides the *loci* 4, 46, and 25 of Le Closeau, the horizon III.2 of Pincevent, and Bad Breisig, the values of the upper horizon in Andernach 2 and 3, Urbar as well as lower horizon at Hangest-sur-Somme III.1 fall to the bottom of graph B. Abbreviations see **fig. 74**. – For further details see text.

choice of the artefacts used for the engraving. Thus, leaving out only the results from Gouy, the relatively high end-scraper-burin indices and the absence of borers in the Early Azilian assemblages suggest that the processing of hard organic material was of no major importance at these sites, although the point-burin index from *locus* 4 of Le Closeau falls into the upper range of those from MfCM sites. Moreover, organic artefacts were only found in the *locus* 4 of Le Closeau. These pointed rib fragments were suggested to be used in processing animal skins (Bemilli 1998, 402) but again these implements were possibly introduced to the site from elsewhere. However, if the processing of animal skins was an activity performed at the site and the dominant use of end-scrapers was working hides, the relatively high number of end-scrapers and, consequently, the high end-scraper-burin index could be explained.

Even though points were clearly dominant among the LMP in the FMG, these assemblages were generally burin-dominated as highlighted by the point-burin index. The exceptional value of Urbar could be related to a spatial differentiation and a restricted excavation area in which burins were not extensively used and from which borers were absent. A major activity in this area was the use of end-scrapers which reached a high number (n = 98) for the small area. Consequently, the end-scraper-burin index is exceptionally high in this assemblage where also remains of a particularly high number of red deer (MNI = 7) were found suggesting a specialised working area. The end-scraper-burin index can be bisected in a sub-group with almost equal values of end-scrapers and burins (upper horizon of Andernach 2 and 3, Niederbieber) and a sub-group with a clearly end-scraper-dominated retouched artefact inventory (Bad Breisig, Kettig, Le Closeau, greyish deposits). Borers were only present in small proportions in the greyish deposits of Le Closeau, Kettig, and Niederbieber. Thus, assuming that burins and borers were mainly indicators of antler and bone working, this activity was either of no greater importance in the FMG or performed with other types of artefacts. In particular, the borers almost disappeared from these assemblages.

However, in Kettig where an organic projectile was found in a FMG context, the proportions of the LMP are relatively low and the point-burin index is moderately higher than in the Late Magdalenian assemblages. The comprehensive publication of the lithic material (Baales 2002) made a determination of most LMP possible and, thus, the values of this inventory will not significantly change. Consequently, the use of lithic points in this assemblage appears of greater importance than processing hard organic raw material. Even though the Kettig assemblage contained the organic artefacts and had an exceptional organic preservation for FMG sites, no debris material was found at the site which would indicate a local production of the organic artefacts. Thus, the organic artefacts were possibly discarded at Kettig but produced elsewhere.

Although the values from the lower horizons of Hangest-sur-Somme III.1 and Conty were close to the range of the FMG assemblages, these assemblages contained end-scrapers similar in proportion to burins within Late Magdalenian inventories. From Conty, only a fragment of a Lyngby axe-type artefact has been published thus far (Fagnart 1997, 112-118). Except for the engraving, burins were probably not needed in the production of this piece and, thus, a high point-burin index does not seems surprising. However, burins remained the most numerous artefacts besides the LMP in this inventory and, consequently, this artefact group was also dominant in the end-scraper-burin index. The borers were of a proportion which came close to the lower range of the Late Magdalenian assemblages. In conclusion, this inventory was similar to the typical Late Magdalenian inventories and suggests rather the regular processing of hard organic material.

In summary, the development from the high values of borers in the Late Magdalenian to the low values of the FMG as well as from the clearly burin-dominated Late Magdalenian assemblages to the less burin- and more end-scraper-dominated inventories of the FMG does not appear to be a gradual process. The values from the MfCM sites and the Early Azilian which fall into the transitional period contained occasionally higher proportions of borers than Late Magdalenian inventories and scatter over a wider range than the FMG or the Late Magdalenian sites. However, the three developmental processes resulted in incongruent limits of the sub-periods in these developments. The increasing proportion of end-scrapers was the first registered change followed by a congruent increase of points and borers. The variability of the end-scraper-burin index becomes greater followed by increase in the variability of the point-burin index. The next change is the realtively sudden disappearance of borers followed by the disappearance of the burin-dominated and the establishment of only point-dominated and mainly end-scraper-dominated assemblages. Finally, the ratio of points in relation to burins decreases again. At the onset, an increasing diversity seems to indicate a connected development, this impression is lost within the period of highest diversity. In the FMG assemblages, the diversity decreases and a stabilisation is again observable but the proportion of end-scrapers differentiates two types, with the inventories from the lower horizons of Hangest-sur-Somme III.1 and Conty possibly three types of assemblages that might be a relevant factor in the organisation of the settlement system (see p. 557).

The appearance of large variation between the assemblages raises some questions. For example, why did borers become redundant? Were they no longer of use or were they replaced in their function? This question leads to the challenge of whether the function of artefacts such as burins and/or end-scrapers changed in this period. A comprehensive compilation and evaluation of the already accomplished use-wear studies (Plisson 1985; Moss 1986; Plisson 2002; Vaughan 2002; Beyries/Janny/Audouze 2005; Janny et al. 2006; Plisson 2007; Sano 2009; Sano 2012b) supplemented by further analyses of inventories such as Cepoy 1, Bonnières-sur-Seine, or Conty could provide an answer for some of these questions but this endeavour exceeds the possibilities of this project.

Another set of questions refers to the diversity of the assemblages. One possible explanation for the increased variety is that the single assemblages became more specialised and the range reflected sites with supplementary functions. This development would suggest that a progression of the Late Magdalenian behaviour of spatial differentiation of the activities might have occurred. In contrast, if the diversity of the inventories showed no increasing specialisation several explanations are possible. A general explanation would be that the sites were visited for a major task but that besides this task, further activities were also performed at the site. According to this model, special task camps disappeared from the settlement system and were replaced by sites with a more residential character and a special purpose. Another explanation can be found in the accumulation of material over a longer time at the sites. This long duration of use and changing functions during this time could create diverse assemblages with very different compositions. In this case, the use of a location for special purpose in a seasonal round seemed improbable for these sites because the purpose for their use was unstable.

To identify specialised inventories the Simpson diversity index (Sdi) was suggested as useful (see p. 274 f.). This index was also considered to help evaluating the duration of an occupation with more diverse inventories being occupied, usually, for a longer period (Richter 1990). Therefore, the interpretation must take into account the occupation period as an influencing factor.

In the present record, the high degree of similarity of Late Magdalenian and the FMG assemblages (**fig. 82**) seems surprising after the previous results as well as to classic concepts assuming a clear difference of the two archaeological units (see p. 55-74). In fact, some specialised outliers were recorded in the FMG assemblages. From *locus* 25 of Le Closeau, only LMP were recovered and, thus, this inventory yielded an outstanding value (Sdi = 1.0) but whether this concentration represented a single unit or the activity area of a larger unit remains uncertain. The other outlier came again from Urbar, which was previously considered as the excavation of only a specialised activity area. The more continuously or more often used sites such as Gönnersdorf (Sdi = 0.25), the lower horizon of Andernach (Sdi = 0.22), and Niederbieber (Sdi = 0.22) yielded values that indicate the most diverse inventories (**tab. 84**) and, thus, support the suggestion that a greater diversity develops on sites which were used for a longer period. However, the short-termed assemblages

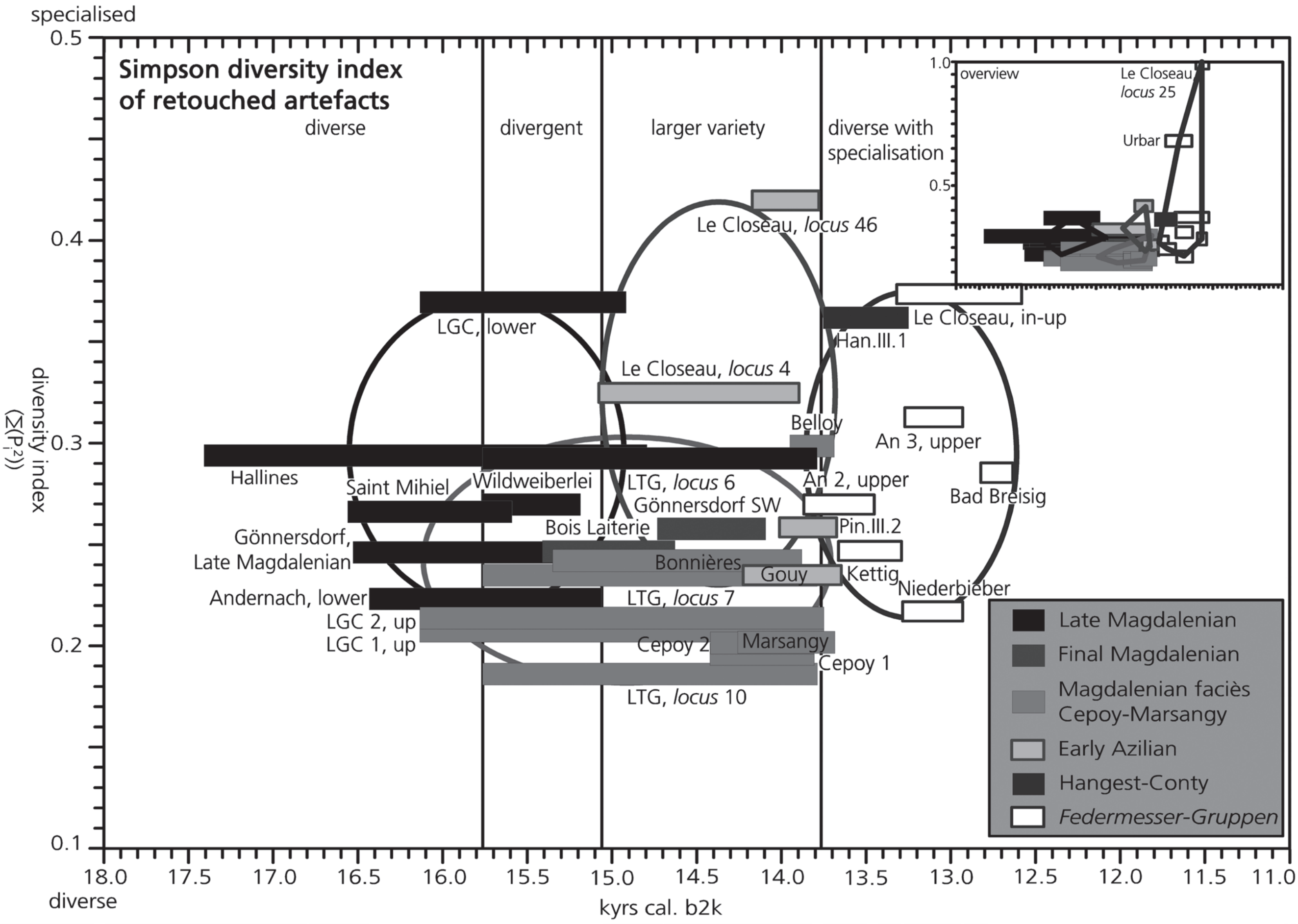


Fig. 82 Values of the Simpson diversity index given per time and archaeological unit. Circles were set around the main cluster of assemblages attributed to the same archaeological unit. The distribution of all assemblages is given in the overview where also the convex hulls were set per archaeological unit (see p. 281 f.). In the overview, names are only given for sites which are not shown in the main graph. Abbreviations see **fig. 74**. – For further details see text.

of the south-western area from Gönnersdorf (Sdi = 0.26) and Bois Laiterie (Sdi = 0.25) also fall in this range, whereas the inventories found in the greyish deposits of Le Closeau (Sdi = 0.37) were assumed to be used over a very long period. These deposits yielded the specialised end of the general FMG range. The LMP in these deposits reached proportions of almost 60 % and indicate a rather special purpose of these concentrations. In particular, the comparison with the Niederbieber concentrations which were interpreted as camps for the preparation and/or postprocessing of a hunting event (Gelhausen 2011b; Gelhausen 2011a) shows the outstanding values of Le Closeau. In Niederbieber, the LMP composed around 30 % of the inventory and the Sdi ranges between a value of 0.20 and 0.48. In the concentrations found in the greyish deposits of Le Closeau, the Sdi ranges between 0.22 (excluding those without any formally retouched artefacts) and 1. Thus, the lower limit of the range is comparable between Niederbieber and Le Closeau but in the latter many more specialised concentrations were found. However, ten concentrations of the greyish deposits yielded a Sdi of 1 but only four of these inventories were dominated by LMP, three by the other artefact group, two by end-scrapers, and one by borers. The suggestion that several concentrations formed supplementary units can thus be considered likely despite the dominance of the LMP in most of the concentrations within these greyish deposits. Nevertheless, the high proportion of the LMP indicates that the occupation at this location had a special purpose. Were these concentrations related to a hunting camp where additional tasks were accomplished? Why were the proportions so high? In comparison, the numbers of LMP ranged between 5 and 80 per concentration in Niederbieber, whereas in the greyish deposits of Le Closeau, the LMP ranged between 0 and 95 pieces per *locus*. Thus, in regard to these similar numbers, an interpretation of the greyish deposits of Le Closeau comparable to Niederbieber seems possible. The different proportion originate in the smaller numbers of the inventories in Le Closeau and, thus, the inventories were frequently formed by only a few or a single retouched artefact groups. However, how far the various *loci* in Le Closeau were related and formed a single occupation episode requires a more comprehensive spatial analyses including inter-concentration refitting attempts. These analyses could further clarify how far the spatial organisations of the greyish deposits in Le Closeau and the one in Niederbieber (Gelhausen 2011c; Gelhausen 2011a) differ from one another.

In comparison to the Late Magdalenian and the FMG assemblages, the inventories of the MfCM produced comparable but tendentially lower values, whereas the values of the Early Azilian vary considerably. The co-occurrence of these two archaeological units results in a large variety of indices.

The values from the MfCM sites range mainly between a Sdi of 0.19 and 0.24, except for the lower horizon of Belloy-sur-Somme which yielded an Sdi of 0.30. For many of the low values such as the ones from Cepoy 1 or the upper horizon of Le Grand Canton, sector 2, the accumulation over a longer period seemed a probable explanation which is in accordance with the archaeological evidence. However, the Sdi of single concentrations of this archaeological unit was also low. For example, the Sdi of Le Tureau des Gardes, *locus* 7 (Sdi = 0.23) fell into the lower range of the Late Magdalenian and Marsangy N19 (Sdi = 0.20) lies below the Late Magdalenian range. If the low values in these single concentrations were to be explained by accumulation over a longer period, a continuous occupation during which diverse activities were performed or repetitive visits to the same spot with different purposes of the visit must be assumed. The quantity of lithic material found in the two concentrations is relatively high: Marsangy N19 falls to assemblage size class 5 and *locus* 7 of Le Tureau des Gardes to class 4 (**tab. 81**). Thus, a longer use of the locale could also be explained the large assemblage size. Moreover, these inventories appear thereby similar to the Late Magdalenian assemblages of the Central Rhineland where many activities were performed in a restricted area leaving a large accumulation of artefacts. However, detailed spatial analyses are necessary to reveal the development of these concentrations and make a distinction between a long continuous or a repetitive occupation possible. The outstanding value of Belloy-sur-Somme is related to an area with an ephemeral lithic scatter and a concentration around a hearth with a possible satellite working area (Fagnart 1997, 65-68). This spatial distribution differs from those observed in Le Tureau des Gardes, *locus* 7 and Marsangy N19 but it is similar to the model of FMG concentrations in Niederbieber (Gelhausen 2011a, 271 f.). Nevertheless, the broad expanse of archaeological material on these sites suggests that the spatial dispersal to the periphery of previous spots of occupation began to occur on these sites.

In Early Azilian inventories, the values from Gouy (Sdi = 0.23) and Pincevent III.2 (Sdi = 0.26) formed a lower group, whereas *loci* 4 and 50 (Sdi = 0.32) and 46 (Sdi = 0.42) of the Le Closeau formed the upper end. Thus, the overlap with the assemblages of the MfCM is minimal. The value for the complete lower horizon of Le Closeau (Sdi = 0.36) is similarly high compared to the greyish deposits. In the lower horizon, the range of the Sdi encompasses values from 0.32 to 0.46. Thus, the range is considerably smaller than in the greyish deposits. In contrast to Niederbieber and the majority of concentrations from the greyish deposits of Le Closeau, the other artefact group was the most numerous group instead of the LMP in the inventories of the lower horizon as well as the areas south of the RN 13. For these concentrations, dominated by the other artefact group, a clear preference of using unstandardised tools can be supported. In addition, several hundred pieces were found with macroscopic use-wear traces showing the intensive use of the lithic artefacts at the site. The differences in the composition of the inventories suggests that the function of the site differed, vertically, from the lowermost to highest horizons and compared to the majority of the greyish deposits. The spatial distribution of the material in the lower horizon with a main activity area where the material was densely scattered and some outlying special activity areas still closely resembled Late Magdalenian spatial organisations (Bodu/Debout/Bignon 2006; Bodu 2010). The single, ephemeral locations in the greyish deposits might also reflect some special working zones but the intensively used main activity areas are absent in these deposits. This different spatial organisation could have further increased the variation between these horizons. A tendency towards more ephemeral activity areas can be detected in the Early Azilian assemblages of Gouy and Pincevent, horizon III.2 which were still relatively diverse. The limited spatial information from Gouy prohibits further consideration about the development of this inventory. However, the restricted area in the small cave, the superficial excavation, and the small assemblage make the accumulation of various episodes improbable as a reason for the documented diversity. Thus, comparable to many Late Magdalenian assemblages, a relatively diverse inventory was already used in a short occupation episode. In Pincevent, horizon III.2, a large, ephemerally scattered area was utilised and, thus, was already more similar to the FMG type of spatial organisation.

Thus, the previously documented difference between the Late Magdalenian, tell-like use of a single restricted area and the suburban-like dispersal of small units over a large space on the FMG sites in the Central Rhineland can also be observed in the Paris Basin. The change between the two different types of using space occurred between Early Azilian assemblages and the FMG occupation of Le Closeau and, more precisely this change occur abruptly within the late phase of the Early Azilian and the MfCM. However, the increased variability of assemblage compositions in these archaeological units can be a first indicator of a less rigid differentiation of site functions that would have had some impact on the organisation of the settlement system (see p. 548-559).

Besides initial variation in the spatial behaviour and the settlement patterns, the increased variability of the retouched artefact inventories, in particular in combination with the dominance of the unspecified others group and artefacts exhibiting macroscopic traces of use, could reflect a less normative production and use of lithic implements. This decreasing conformism to a given standard should be even more apparent on a lower analytical level such as within a single artefact group. Among the LMP, the increased use of points was already mentioned. This group of artefacts was usually attributed to the hunting equipment, in particular the LMP were considered as parts of projectiles. Since these weapons need to be precise in order to be effective and, thus, make hunting a successful subsistence strategy, a relatively high standardisation can be assumed for the different parts of this equipment. Nevertheless, an aim for improvement and a necessity to adapt to fluctuations in the availability and quality of the resources and the prey, leads to a continuous trial-and-error process which causes some diversity in the LMP. Moreover, the choice of the prey can cause some variation in terms of the projectiles used (Ellis 1997). However, when a standard fails to be useful due to a different prey and/or the failure of necessary resources, this process will probably be intensified to prevent alimentary deficiencies. Consequently, the Lateglacial environmental change can be assumed as such an enforcing situation on a wide geographic area. Since the Late Magdalenian societies formed a large information network and the trial-and-error process was probably intensified in several places, testing of new ideas from elsewhere further increased the pool of possibilities. Thus, in these periods high diversity in the LMP can be expected. The diversity of the LMP was specified per assemblage by the number of LMP types present at the site (**tab. 85**). These values were based on a survey of published figures of the LMP and, thus, the result is partially biased by the lack of readable presentations of LMP and occasionally by the lack of spatial information for the LMP making a precise attribution to a sub-assemblage impossible.

According to the current record, the diversity of the LMP is very low in the Late Magdalenian assemblages. Usually, only backed bladelets and blades were identified. In the Early Azilian the values are marginally higher with up to three types occurring in an assemblage. Curve-backed points were always present but angle-backed points were also frequently identified. Usually, the assemblages of the MfCM were similarly diverse with two or three different types of LMP being found in the inventory. In contrast to the Early Azilian, the angle-backed points were the most common type and curve-backed points were more infrequent and less numerous. Backed bladelets or blades occurred in all assemblages except for Cepoy and Étigny in small numbers. However, some of these assemblages (the upper horizon of Le Grand Canton, Marsangy, Belloy-sur-Somme) yielded a greater diversity of LMP types. For the former inventory, the duration of the use and the size of the assemblage could explain some of the diversity. Therefore, this assemblage requires a more detailed spatial analysis. In Marsangy N19, the diversity was also smaller than on the complete site. However, Marsangy N19 was still as diverse as the almost contemporary Belloy-sur-Somme assemblage which was probably represented a single short-termed occupation. The pieces from south-western concentration of Gönnersdorf fall into this usual group of inventories yielding three different types of LMP and likewise the MfCM, these types were backed bladelets, angle-backed points, and a curve-backed point. In contrast, a complete set of LMP types was found in the publications about Bois Laiterie. This diversity indicates that the inhabitants of Bois Laiterie seemed to create or test a range of backed implements. However, in comparison with other inventories from the present record and taking into account the possibility that the site was formed by several hunting episodes, a more detailed spatial analysis of the LMP, in particular of the more recently identified point types (Sano 2009; Sano / Maier / Heidenreich 2011) appears necessary. The FMG assemblages are more diverse usually with three to four and in exceptional cases also five different LMP types occurring on the sites. In larger units such as the upper horizon of Andernach or Niederbieber, the different concentrations contributed to an almost complete set of LMP types. The curve-backed points were the most frequent type followed by backed bladelets and blades and tanged points were the least frequent type followed by simple points. The assemblages from the lower horizon of Conty and Hangest-sur-Somme III.1 produced four types of LMP including curve-backed points as well as angle-backed points but backed blades and couteaux à dos formed the most frequent LMP types.

Besides the diversity of the LMP shapes, the dimensions of the projectile implements play an important role in their use within composite tools requiring some norms to allow for a replacement of defective parts without a discard of the complete projectile. The production of the single LMP is one of the smallest possible analytical levels and very fine differences in the dimensions of the implements are probably beyond the perceptibility of the maker (Eerkens 2000). However, since the function of the complete projectile limits the variability of these implements, the dimensions should spread around an aimed mean. A high standardisation of the equipment would allow for only a small variance, whereas an increased variance reflected a more flexible and possibly different tool kit. Therefore, the variance of the three dimensions of the measured LMP (see p. 275-282) are compared per assemblage and archaeological unit (**fig. 83**).

In general, the length (**fig. 83C**) appeared a more variable dimension than width (**fig. 83B**) or thickness (**fig. 83A**). As long as the implements were inserted into a groove or notch in the shaft, a very restricted standard for the thickness of the implements is necessary. This high standardisation was clearly observable in the assemblages of the Late Magdalenian as well as in the MfCM, Bois Laiterie, and the south-western area of Gönnersdorf. However, in the Early Azilian assemblages of Gouy and Pincevent, horizon III.2 as well as in the lower horizons of Conty and Hangest-sur-Somme III.1, the variance increases considerably. However, the variance of the Gouy assemblage falls as low as that from Étigny if the single *couteau à dos* (**pl. 12, 5**) is excluded. The same applies to Hangest-sur-Somme III.1, lower horizon which produced, without the very big *couteaux à dos* (**pls 13, 7; 14, 2-3. 7**), a variance comparable to Bois Laiterie. In the lower horizon of Conty, the *couteaux à dos* formed a significant part of the record (**pls 12, 10. 12-13; 13, 3-4**) and the variance changes comparable to Hangest-sur-Somme III.1 when these implements were removed. However,

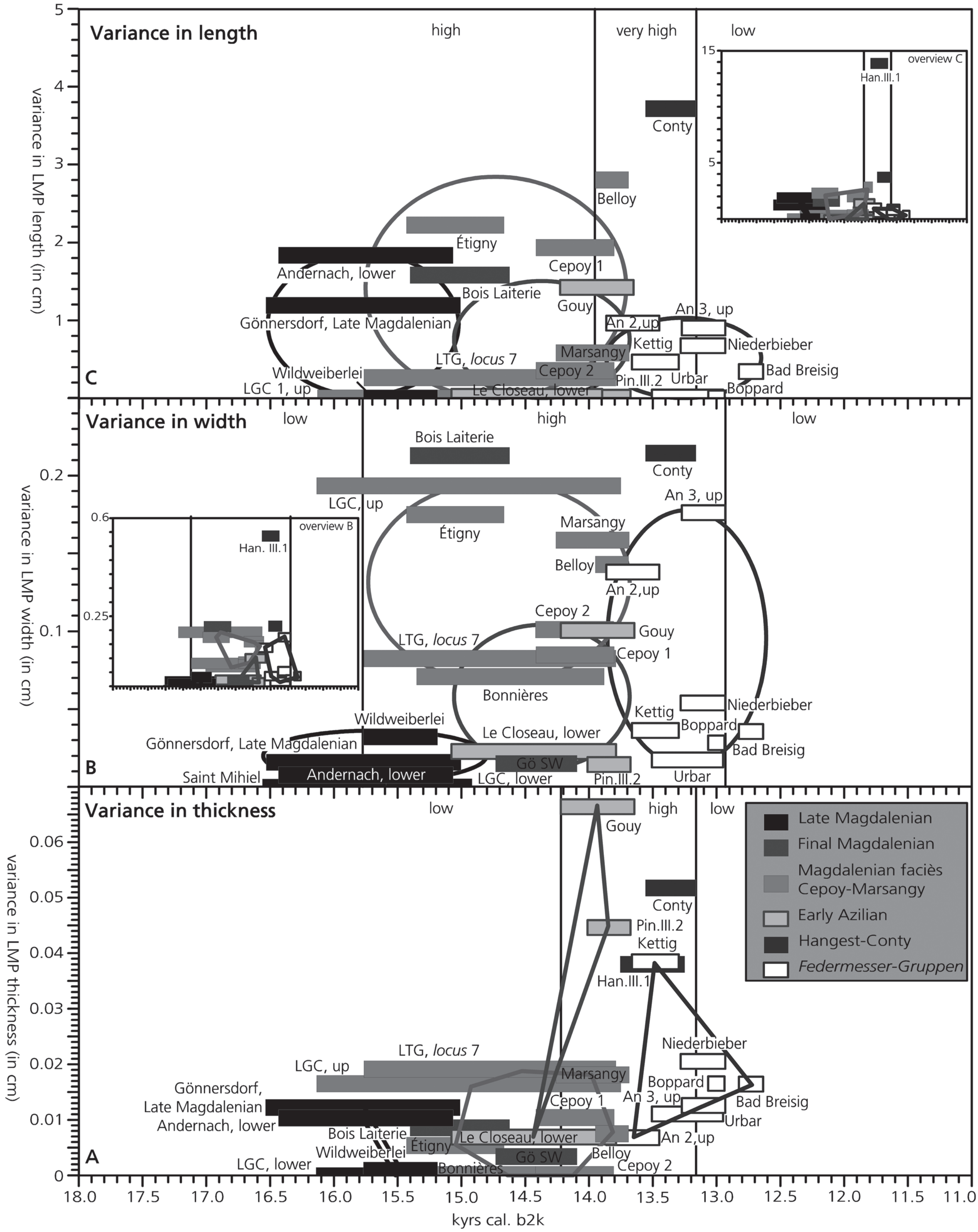


Fig. 83 Variance of the completely preserved thickness (**A**), width (**B**), and length (**C**) of the analysed LMP (see **pls 1-14**) given per time and archaeological unit. Circles were set around the main cluster of assemblages attributed to the same archaeological unit in graphs **B** and **C**. The distribution of all assemblages is given in the overview where also the convex hulls were set per archaeological unit (see p. 281 f.). In the overview, names are only given for sites which are not shown in the main graph. In **A** the complete distribution is already given and the convex hulls are therefore set in the main view. Abbreviations see **fig. 74**. – For further details see text.

in Pincevent, horizon III.2, no *couteau à dos* was found and the outstanding variance remains. The FMG assemblages had generally a higher variance than the Late Magdalenian assemblages but did not exceed the variance of the MfCM inventories by considerable amount. Only the assemblage of Kettig formed an exception with a variance in thickness comparable to the original value from the lower horizon of Hangest-sur-Somme III.1. In Kettig, no *couteau à dos* was found and the microlithic simple points fell into the range of the curve-backed points. However, a single, thick, curve-backed point (**pl. 3, 10**) formed a significant outlier and after removing this piece, the variance of Kettig falls into the usual range of the FMG inventories. Thus, the inventories of the MfCM were the first assemblages in which also wider variances were allowed. In the Early Azilian assemblages, the very strict standardisation did no longer occur and the couteau à dos established a distinct group of implements.

The variance in width was also very standardised in Late Magdalenian assemblages but became considerably more variable with the appearance of the MfCM and, in particular with the co-occurrence of points and backed bladelets. Perhaps, the absence of the narrower bladelets is the reason for the lower variance of width in the Early Azilian assemblages. However, the value of Gouy falls in the lower range of the MfCM but if the *couteau à dos* is excluded again the range is similar to Kettig. In this case the Early Azilian variance in width appeared comparably restricted as the Late Magdalenian one. In the FMG assemblages, the variance of width increases but remains, mainly, in the range of the Early Azilian except for the inventories from the upper horizon of Andernach which were more comparable to the upper range of the MfCM. The LMP from these assemblages formed a very heterogeneous groups of which some very thick pieces were considered as knives (Kegler 2002). Thus, in these assemblages the LMP were possibly used for various tasks which allowed variable standardisations of the width. However, this standardisation does not seem to be related to a specific shape. The values for the lower horizon of Conty and Hangest-sur-Somme III.1 were again very high but decreased to values in the range of the Early Azilian assemblages (Conty) and the lower range of the MfCM (Hangest-sur-Somme III.1) without the *couteaux à dos*.

The variance in length is already greater in the Late Magdalenian. However, this impression can be false since the problem of a distinction between broken and complete backed bladelets was difficult because many pieces were intentionally broken. Thus, the unbroken forms had to be considered as complete, even though they may not represent the pieces that were used. If only the preserved lengths of the Late Magdalenian assemblages were considered they again scattered closely around a value of 1.0 except for Saint Mihiel where a large angle-backed point fragment was found besides a small bladelet-like LMP. The variance of length was in general more restricted in the other archaeological units which appears reasonable if these implements were used as a projectile head and need to be in balance with the shaft. In particular, the Early Azilian and the MfCM sites yielded very low values, whereas the FMG assemblages were again more variable. Perhaps, this increasing variance as well as the frequent occurrence of backed bladelets reveals the return of a laterally inserted type of implements. Nevertheless, the variance of length in some assemblages was very high. The variances of Conty, Hangest-sur-Somme III.1, and Gouy id not change as significantly as in the previous results when the *couteaux à dos* were removed from the dataset. Without these heavy implements, the values ranged around the original value of Gouy. The value of Cepoy 1 sank to a value between Cepoy 2 and Marsangy if a single, small, simple point (**pl. 10, 11**) was excluded. Was this small piece a Mesolithic intrusion or reflected a second type of projectile implement or did it show the possible range of lithic implements on this site? A detailed analysis of the LMP inventory with a special focus of potential use-wear might provide some interesting results for this site. In Belloy, a comparably small angle-backed point increased the variance. Without this piece the value fell to the upper range of the FMG assemblages. In Étigny only a few pieces were completely preserved. A single curve-backed point (**pl. 8, 22**) was considerably smaller than the preserved angle-backed point (**pl. 8, 24-25**). Without this piece the variance dropped to a value below the one of Le Tureau des Gardes, *locus* 7. The high value of Bois Laiterie decreased to a comparably low value if the piece, which appears as a mixture of a tanged point and a Magdalenian blade (**pl. 7, 13**), is rejected. However, this piece was identified by the use-wear analysis and the breakage pattern as a projectile head (Sano 2009). These changes in the variance of the last four sites showed that, besides the *couteaux à dos*, two different types of projectiles, one with a lighter lithic implement and one with a heavier lithic implement, were possibly used in these assemblages.

Thus, the variance of length reveals a general difference between the Late Magdalenian and the other assemblages: The latter were more restrictive about the characteristics than the Late Magdalenians. This greater variability in the length is congruent with a general comparison of the LMP from this study with pieces from Thuringia. On average, the Thuringian pieces were over 1 cm shorter and 0.1 cm thinner but as wide as the implements from this study (Bock et al. 2013, tab. 10). This comparison emphasises the importance of the width in Late Magdalenian LMP inventories. Moreover, in some assemblages of the MfCM as well as in Bois Laiterie indications for two different sets of projectile implements were found. However, the suggested variability of FMG assemblages, particularly, in regard to the backed implements (Barton et al. 2009) cannot be, unambiguously, supported. The present data which is based on FMG sites from the Central Rhineland show that the shape diversity and variance of these implements within single assemblages increased. This increasing variability indicates that standardisation of the hunting equipment was less restrictive and the establishment of *couteaux à dos* as independent group as well as the possible presence of two size classes on some sites such as Kettig also suggested a greater repertoire in the equipment of these hunter-gatherers than in the Late Magdalenian.

Based on ethnographic comparisons, the differences in shape and dimension of lithic projectile implements was considered as being related to the size of the prey (Ellis 1997). In the lower horizons of Hangest-sur-Somme III.1 and Conty, aurochs (*Bos primigenius*) were the main prey. Thus, was the larger equipment, in particular the use of large couteaux à dos, related to the hunting and/or processing of this large herbivore and did this specialisation cause the differences in the inventories of mainly red deer (*Cervus elaphus*) hunting communities in the Paris Basin and the Central Rhineland? Moreover, did the variable faunal spectrum of Bois Laiterie cause the high diversity of LMP types? These questions indicate the importance of contextualising the lithic industries with data from the faunal remains.

In summary, the diversity of the assemblages was influenced by the occupation duration and the function of an assemblage but also by the norms of spatial behaviour and the interrelated presettings of the material equipment. In the equipment represented by formally retouched artefacts, the first changes became apparent with an increasing diversity range (**fig. 84**). In particular, the hunting equipment was subject to variation which is reflect in an instability of normed widths. However, although different LMP types already occurred in this period, they remained singular phenomenons. A more frequent appearance of different LMP types accompanied with a clear differentiation in the overall size of these implements that occurred later concomitantly with an increasing importance of end-scrapers in comparison to burins. Shortly after, LMP point shapes also increased in number compared to burins and the proportion of borers began varying considerably. This increasing differentiation of assemblages was thereafter also observable in the general composition of the assemblages with core-dominated inventories appearing regularly besides assemblages dominated by formally retouched artefacts. Later, the general presence of a complete set of formally retouched artefacts vanished and the diversity of this retouched inventories became very variable forming a large range from more specialised to very diverse assemblages. Besides the continued diversity of LMP width, types, and size groups, the proportion of LMP in the retouched inventories decreased, temporally, to a low that was possibly related to the near disappearance of backed bladelets. In a next step, the differentiation of assemblages which were dominated by end-scraper to those which were burin-dominated increased significantly. This

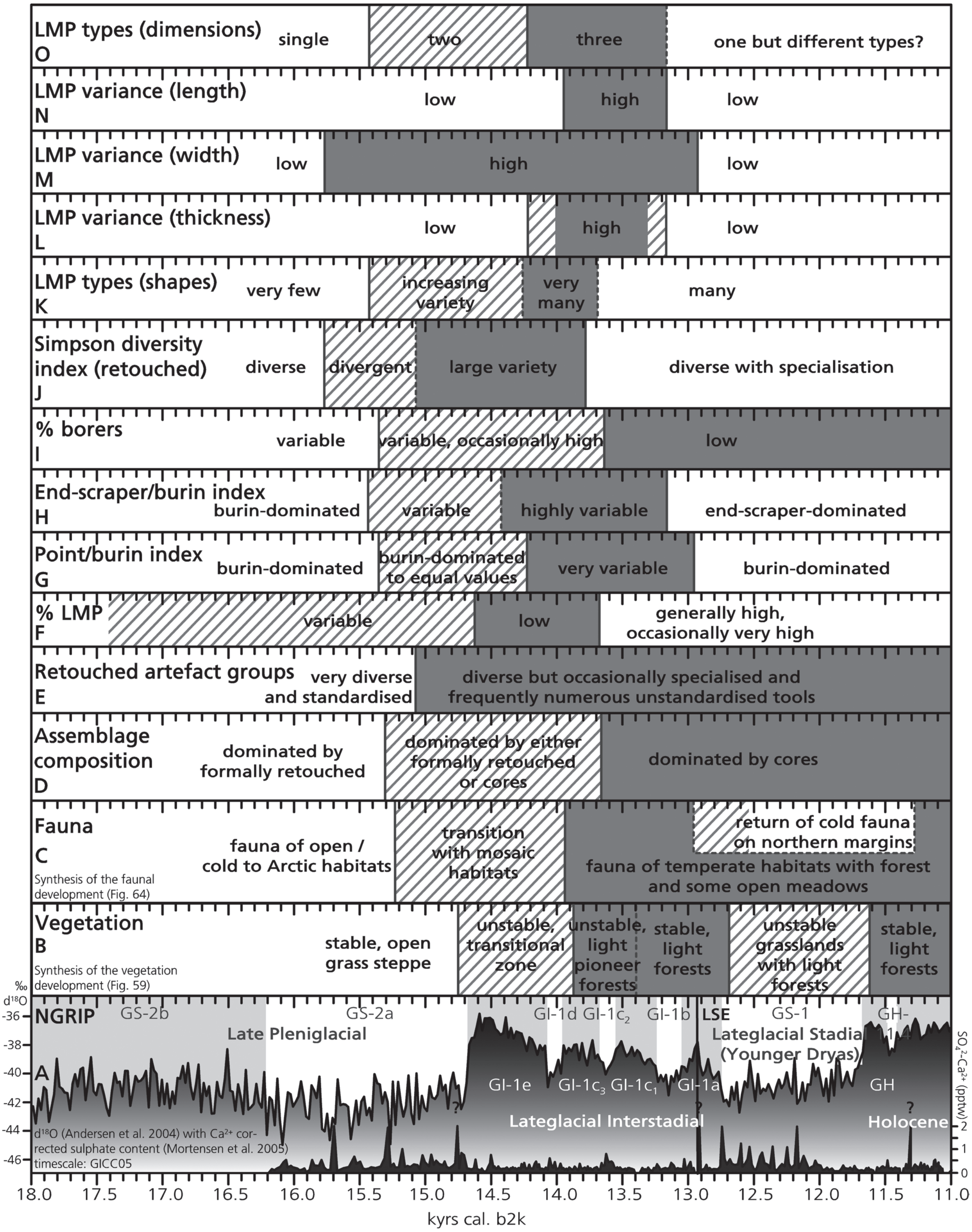


Fig. 84 Developments in lithic assemblages related to the diversity of the lithic inventory (**D-J**) contrasted by the synthesised faunal (**C**; see **fig. 64**) and vegetation development (**B**; see **fig. 59**) as well as the oxygen isotope record of NGRIP (**A**; see **fig. 53**). Hatched areas: transition periods. – For further details see text.

increasing differentiation also affected the relation of points and burins on a site. This increasing variability in the point-burin index was accompanied by the appearance of the highest number of LMP shape types and size types. The thickness of the LMP also began varying and reflected the regular appearance of large *couteaux à dos* in the LMP inventories. At this point, no standard for LMP seemed to exist any more and/or that these implements were used for a range of purposes.

On these almost simultaneously occurring alterations followed the highest variability of thickness as well as length in the LMP, possibly reflecting the search for new standards. In fact, from this point on, the assemblages seem variable in almost all categories and on various levels between the composition of the complete lithic assemblage to the composition of a single LMP. This high variability suggests that no common standard existed in this period.

An establishment of new standards begins with a decrease in the variability of assemblage diversities, followed by a decrease in LMP types and an increase of their proportion followed shortly after by an extreme decrease of borers and the establishment of relatively equal assemblage compositions with only more core-dominated assemblages as the exception. The variance of the thickness in LMP ceases later and the disappearance of exceptionally large *couteaux à dos* follows even later. With the disappearance of these very large LMP, the variance of LMP lengths also ends and, thus, the number of different size classes in the LMP seems to end. Moreover, end-scrapers become more dominant than burins. However, burins remain important and somewhat later they become generally more frequently discarded than points. At this point the variance in the width of LMP also normalises again.

The occasional repetitive appearance of when changes occurred show the interrelation of acquisition, exploitation, and use of lithic resources. Alterations in one of these sectors caused or were influenced by a change in another sector. However, the presentation, in particular of the diversity of the assemblages, also showed the restrictions in the interpretation due to spatial limitations and reveals the importance of spatial organisation on hunter-gatherer sites. Moreover, this finding further emphasises the necessity of spatial analyses for the interpretation of Late Pleistocene assemblages. The results of these analyses make further comparisons and, consequently, considerations about the spatial organisation on a larger scale possible by setting sites into relation to other sites in the same region and allowing for regional models which can be compared with other regions.

However, before the assemblages can be further discussed in regard to their function and, thus, their position in the regional and supra-regional settlement systems, the exploitation of the faunal resources has to be considered. This part of the assemblages is of relevance for considerations about subsistence strategies, duration of the occupation, and the function of the site.

Exploitation of faunal resources

The evidence from faunal resources permits a multitude of analyses to be undertaken, such as hunting specialisation (Gaudzinski/Street 2003), the selection of a specific age structure (Bignon 2006), the seasonality of the hunt (Enloe 1997), hunting methods and equipment (Bratlund 1991; Bratlund 1996b; Leduc 2014a), standardisation in the processing of the animals (Charles 1997b; Bridault/Bignon/Bemilli 2003; Leduc 2014b), and the spatial organisation of these processes (Enloe/David 1989; Street/Turner 2013) as well as the production of artefacts (Tinnes 1994; Álvarez Fernández 1999; Pétillon 2006; Brasser 2012; Leduc 2012). These analyses contribute to the understanding of hunting, subsistence, and exploitation strategies.

However, faunal remains were preserved in only a few Lateglacial assemblages, where the quality of preservation varied considerably. Moreover, the archaeozoological analyses are not accomplished for all of the sites considered in this project. For instance, although species were determined in a preliminary note about the Conty assemblage (Coudret/Fagnart 2006), counts of the skeletal pieces and the individuals was not made available for the present author on time (Auguste 2012). Therefore, the number of the assemblages which can be compared numerically is further limited.

The most apparent difference in regard to the exploitation of faunal resources is the absence of organic tools on most FMG sites. In Late Magdalenian assemblages a variety of organic tools were usually found (Tinnes 1994). In contrast, Early Azilian and FMG assemblages produced only a few fragments of organic implements (**tabs 17. 41**) in well preserved assemblages such as in the lower horizon of Le Closeau (Bodu 1998, 234. 285), Conty (Fagnart 1997, 112-118), and Kettig (Baales 2002). Even though conditions of preservation were considered as a possible reason for this scarcity, the presence of isolated organic implements in well preserved assemblages indicates that this resource decreased in importance and organic implements were no longer produced on a regular basis. Reindeer antler and ivory were substituted as raw material by red deer antler, as shown in Kettig and Conty. Red deer do not usually occur in large herds, such as reported for reindeer. Furthermore, only male red deer grow antlers, whereas antlers are known from both sexes in reindeer. Consequently, a decreasing availability of this resource can be assumed with the disappearance of reindeer herds.

Furthermore, the presence of some of the selected species in the dated assemblages helps to identify changes in the prey selection. Bearing in mind the often unevaluated relation of the faunal remains to the lithic assemblages, these few analysed assemblages can serve as models in the settlement system for other sites with no organic preservation. For a general comparison of the size of the faunal assemblages, a modified version of Gerd-Christian Weniger's classification system (Weniger 1989) was used which took into account the ethologies of the different groups of the hunted mammals (see p. 283 f.). Summing up the classes (**tab. 86**) produced a reference value for the number of hunting episodes and/or the size of the hunting party contributing to the assemblage. This value was of course also influenced by the diversity of the assemblage but, based on the assumption that a coincidental hunt of different large mammals is improbable, animal diversity appears to reflect different hunting episodes, thus justifying a higher value in the sense mentioned above. This value made further considerations about the function of the site and the duration of its use possible and, moreover, allowed a comparison between the very large Late Magdalenian and the smaller FMG assemblages to be undertaken.

The most apparent difference is the choice of prey. Reindeer (*Rangifer tarandus*) was only determined in Late Magdalenian and MfCM inventories, whereas roe deer (*Capreolus capreolus*) was only found in FMG assemblages, at Gouy and Conty. Wildboar (*Sus scrofa*) was typically found in Early Azilian sites as well as Bonnières-sur-Seine and again in late FMG sites of the Central Rhineland. Horse (*Equus* sp.) was the dominant species in the Late Magdalenian assemblages as well as in some MfCM assemblages. Horse also occurs regularly in the Early Azilian and FMG assemblages but are no longer dominant. Besides horses, large bovids (*Bison priscus*/*Bos primigenius*) were the most constantly hunted larger mammals in the Lateglacial. In the older assemblages, these two species were supplemented by reindeer and in the younger assemblages by red deer (*Cervus elaphus*). In Gönnersdorf II, Andernach II, Bois Laiterie, Étigny-Le Brassot, and Marsangy, reindeer and red deer co-occured suggesting a transitional period in which both species were available. If these sites are considered according to their sub-area, this transitional period ended earlier in the Central Rhineland than in the western uplands and northern France. In the FMG assemblages, red deer was occasionally more intensely hunted. In general, the choice of the prey appeared more heterogeneous in the FMG assemblages than in the Late Magdalenian. However, the average for classes found in an assemblage

site	class *Rangifer tarandus*	class *Equus* sp.	class *Bison priscus / Bos primigenius*	class *Cervus elaphus*	class *Alces alces*	class *Capreolus capreolus*	class *Sus scrofa*	sum of classes	Simpson diversity index	% smaller mammals
Saint Mihiel	1	1	1	0	0	0	0	3	0.4167	23.7 (7.8)
Gönnersdorf	1	4	1	1	0	0	0	7	0.2239 / 0.2295*	40.5 / 41.9* (17.7 / 18.2*)
Gönnersdorf I	1	2	1	0	0	0	0	4	0.2850	65.1 (17.5)
Gönnersdorf II	1	3	1	1	0	0	0	6	0.3263	29.1 (21.8)
Gönnersdorf III	1	1	0	0	0	0	0	2	0.2628	21.7 (17.4)
Gönnersdorf IV	0	1	1	0	0	0	0	2	0.5918	0
Andernach, lower horizon	1	2	1	1	0	0	0	5	0.1786	21.7 (4.4)
Andernach II	1	2	1	1	0	0	0	5	0.2016	22.9 (2.9)
Andernach IV	1	1	1	0	0	0	0	3	0.1405	18.2 (9.1)
Wildweiberlei	1	1	0	0	0	0	0	2	0.2000	26.7 (20.0)
Le Tureau des Gardes	2	4	1	0	0	0	0	7	0.4996	3.8 (3.8)
Le Tureau des Gardes, *locus* 6	1	1	0	0	0	0	0	2	0.4150	10.0 (10.0)
Le Tureau des Gardes, *locus* 7	0	1	1	0	0	0	0	2	0.7813	0
Le Tureau des Gardes, *locus* 10	1	2	1	0	0	0	0	4	0.5022	3.3 (3.3)
Étigny-Le Bras-sot, south	p	0	0	p	0	0	0	×	×	×
Bois Laiterie	1	1	1	1	1	0	0	5	0.1174	63.6 (18.2)
Le Grand Can-ton, sector 1, upper horizon	p	p	0	0	0	0	0	×	×	×
Le Grand Can-ton, sector 2, upper horizon	1	4	1	0	0	0	0	6	0.7371	0
Bonnières-sur-Seine	0	1	0	1	0	0	1	3	0.3878	0
Le Closeau, lower horizon	0	1	1	1	0	0	1	4	0.2769	9.1 (9.1)
Le Closeau, *locus* 4	0	1	1	1	0	0	1	4	0.2188	12.5 (12.5)
Le Closeau, *locus* 46	0	1	0	1	0	0	1	3	0.2857	7.1 (7.1)
Gönnersdorf SW	0	1	0	1	1	0	0	3	0.3600	0
Marsangy	1	1	0	1	0	0	0	3	0.3333	0
Gouy	0	0	0	p	0	p	p	×	×	×
Pincevent III.2	0	0	p	p	0	0	0	×	×	p
Bonn-Oberkas-sel	0	0	p	p	0	0	0	×	×	×
Irlich	0	0	0	p	0	0	0	×	×	×

Tab. 86 Classes and indices of faunal assemblages. For the classes see **tab. 55**. **p** presence of a species at a site meaning that it was already determined in a preliminary study; **×** values that cannot be calculated. The class columns were coloured comparably to the ones of **tab. 63** with the darkest background for the highest number and the lightest for the lowest number. The sum of classes counts the different classes together to give an impression of the size of the assemblage. % smaller mammals based on MNI and in relation to total MNI. In parentheses are values without small carnivores. Simpson index is the sum of the square-results of dividing the MNI of each species by the total MNI. Sub-assemblages in these columns are set in shaded light grey. ***** in parentheses index without Gönnersdorf SW; ****** according to the conditions of preservation and partially the spatial distribution, the smaller mammals found at the site were younger intrusions.

site	class *Rangifer tarandus*	class *Equus* sp.	class *Bison priscus / Bos primigenius*	class *Cervus elaphus*	class *Alces alces*	class *Capreolus capreolus*	class *Sus scrofa*	sum of classes	Simpson diversity index	% smaller mammals
Andernach 2-FMG, upper horizon	0	1	1	1	1	1	0	5	0.2018	9.5 (9.5)
Hangest-sur-Somme III.1 lower horizon	0	p	p	0	0	0	0	×	×	×
Kettig	0	1	1	2	0	0	0	4	0.1720	21.7 (8.7)
Conty, lower horizon	0	0	p	p	0	p	0	×	×	×
Urbar	0	1	1	2	0	0	0	4	0.6296	0
Le Closeau, greyish deposits	0	1	0	1	0	1	0	3	0.2857	14.3 (0)
Niederbieber	0	1	1	3	3	1	1	10	0.1910	12.5 (8.3)
Niederbieber 1	0	1	0	1	1	1	1	5	0.1600	20.0 (0)
Niederbieber 2 (18+19+20)	0	1	0	1	2	0	0	4	0.2778	16.7 (16.7)
Niederbieber 3	0	1	0	0	1	0	0	2	0.3333	33.3 (33.3)
Niederbieber 4+17a	0	1	1	1	0	0	0	3	0.3878	0
Niederbieber 5	0	0	1	1	0	0	0	2	0.3750	0
Niederbieber 6+10a	0	1	0	1	2	0	0	4	0.5000	0
Niederbieber 7	0	0	0	1	0	0	1	2	0.3333	33.3 (33.3)
Niederbieber 10	0	0	0	1	0	0	1	2	0.3750	0
Niederbieber 11	0	0	1	1	0	0	0	2	0.5000	0
Niederbieber 12	0	0	1	0	0	0	0	1	1.0000	0
Niederbieber 13	0	0	1	1	0	0	0	2	0.5000	0
Niederbieber 14	0	1	0	1	0	0	0	2	0.5000	0
Niederbieber 15	0	0	0	1	0	0	0	1	1.0000	0
Niederbieber 17	0	1	1	0	0	0	0	2	0.5000	0
Andernach 3-FMG	0	0	0	p	0	0	0	×	×	×
Boppard	0	0	0	p	0	0	p	×	×	×
Bad Breisig	0	1	0	1	0	1	0	3	0.4400	0**

Tab. 86 (continued)

per archaeological unit consistently produced a value of 3 meaning that, usually, 3 different species of the selected mammals were introduced to a Lateglacial concentration.

The comparison of the summed value of the classes indicated that a general value between 2 and 4 for a single concentration appeared to be typical (**tab. 86**). Thus, a value of 2 to 4 can be considered as the norm of hunting per occupation unit in the Lateglacial. The Late Magdalenian assemblages ranged between a value of 2 and 6 with an average for the sub-assemblages of 3.2. Except for the upper horizon in sector 2 of Le Grand Canton, values between 2 and 4 were found in the MfCM sites resulting in an average of 3 for the sub-assemblages. Similarly, the two Early Azilian assemblages from the lower horizon of Le Closeau yielded values of 3 and 4. The FMG assemblages had again a wider range of values between 1 and 5 with an average of 2.9 for the sub-assemblages.

However, on larger sites such as Niederbieber, Gönnersdorf, Le Tureau des Gardes, and the upper horizon of Le Grand Canton, sector 2, these smaller values accumulated producing higher ones. In comparison, these accumulated values appeared particularly different. The FMG sub-assemblages had relatively even values between 2 and 4, whereas the Late Magdalenian assemblages showed a clearer differentiation between concentrations yielding a value of 2 or 3 and those with a value of 4 to 6. For instance, Gönnersdorf III and IV yielded the typical value 2, whereas concentrations I and II reached values of 4 and 6. Concentration II in the lower horizon at Andernach also produced a value of 5, whereas in Andernach IV only a value of 3 was found. Whether this difference on Late Magdalenian sites was due to a shorter occupation of those parts of the sites with the lower values or due to complementary concentrations remains to be discussed in the context of the settlement system.

In Bois Laiterie, only a single concentration was recovered which yielded a value almost as high as Gönnersdorf II. However, this value was due to five different classes, whereas in Gönnersdorf II only three classes formed this high value. Thus, not only the differences in the sum of the classes, but also the diversity of the assemblages forming this sum is different between the archaeological units. High values in the Late Magdalenian as well as in some of the MfCM sites were attained by the typical three different classes of which one usually yielded a higher value. In contrast, in the FMG assemblages as well as at Bois Laiterie, values of five were only reached when five different classes were present. This difference implies that Late Magdalenian assemblages were possibly more specialised than FMG inventories. This result can be tested by the application of the Simpson diversity index (see p. 284 f.) and will be discussed later in more detail. The high value of Bois Laiterie raises the question whether this assemblage was created during a single, longer episode in which different provisions reached the site or whether the paved construction was used during several revisits in which different animals had been hunted.

In contrast to the Late Magdalenian, concentrations with values as high as 5 or higher are almost absent from the sub-assemblages of the FMG, the Early Azilian, and, probably, the MfCM. The upper horizon of Le Grand Canton, sector 2 yielded a value as high as Gönnersdorf II but this material originated from a much larger area and was more dispersed. Nevertheless, without a spatially differentiated presentation of the faunal material, concentrations comparable to Gönnersdorf I or II cannot be entirely excluded for this site. In Niederbieber, only concentrations 1 and 6+10a yielded higher values of 5 and 4. Although the value of area 2 was also higher, it resulted from two, possibly three different clusters (cf. Gelhausen 2011c). Comparably, in Kettig as well as in the upper horizon of Andernach 2, several concentrations formed again the higher values and, thus, each concentration yielded a smaller value. The value of 4 from Urbar can be considered as a higher value because the assemblage came from a very restricted excavation area. Perhaps, this area was the main faunal processing zone of the site. If the complete site had been excavated the value could remain the same but could also possibly increase. Moreover, this assemblage yielded indications for an occupation during the cold season. Niederbieber 1 was also assumed to be an occupation during the cold season based on the close relation to Niederbieber 4 and the seasonal indicators from this concentration. Following this line of evidence, larger assemblages in the FMG concentrations seemed to develop during the cold season. In contrast, the sites with higher values from two or three concentrations such as Kettig and the upper horizon of Andernach 2 yielded indications for a settlement during warmer seasons. In contrast, Niederbieber 2 produced a higher value which was probably formed by two or three concentrations but also contained indications of winter occupation and, even though Niederbieber 4 contained indications for a cold period occupation, the assemblage provided no higher value. Consequently, the results from Niederbieber 2 and 4 contradict a simple seasonal explanation. In Niederbieber, assemblages with higher values were the only ones at the site containing remains of elk, except for the special task camp in concentration 3. In the larger Andernach inventory, elk was also determined. Thus, were assemblages containing elk more probable to also contain material of other hunting episodes? Could this explanation also be applied to the diverse inventory from Bois Laiterie? Thus far no elk remains were found in Urbar nor in Kettig and, perhaps, assemblages containing elk bones were only indicative of better conditions of preservation.

The problem of very poor preservation prohibited the visibility of accumulated faunal remains such as in the greyish deposits of Le Closeau. The very few faunal remains from all these concentrations created only a typical value of 3. Most Niederbieber concentrations which contained faunal remains produced a typical value of 2 or 3, only concentrations 12 and 15 had a very small value of 1. Some of these values have to be seen critically because the conditions of preservation at this site deteriorated drastically after the removal of the protecting cover of pumice (Gelhausen 2011a). Consequently, the accumulated value of 10 for Niederbieber must be regarded as a minimal value. Moreover, the generally lower average value in FMG assemblages than in the other archaeological units must also be seen critically. Thus, bone preservation played an important role in Niederbieber as well as in the greyish deposits of Le Closeau.
As well as poor preservation due to taphonomic processes, the faunal material at many FMG sites often consisted of only small, calcined pieces. An ethnographic example described an ideal of »nothing is wasted« (Pasda/Odgaard 2011) in a successful episode of caribou hunting in the harsh hinterland environments of Western Greenland. In this ideal, the complete animal was exploited and the bones were smashed and cooked to extract the bone grease. This process also meant that very small fragments could be disposed near the dwelling (Pasda/Odgaard 2011, 42) since they were no longer attractive to vermin or other predators. As a result, the faunal material found at these sites was mainly composed of small bone fragments. A possible explanation for the necessity of conforming to this ideal was that »The heavy exploitation of fat resources may be the only means of survival in any community where there is dietary stress.« (Pasda/Odgaard 2011, 37). In fact, the study in Western Greenland also found evidence for deviation from this ideal in the case of sufficient surplus, for instance due to communal hunting episodes and/or modern equipment[52]. Transferring this example to the North-West-European Lateglacial, many very small faunal fragments were found in the pits from Gönnersdorf and Andernach (Street 1993; Bergmann/Holzkämper 2002; Street/Turner 2013). Probably, these pieces are evidence of conforming to a »nothing is wasted« strategy in these assemblages. In the upper horizon of Le Grand Canton, the fragmented state and the under-representation of some skeletal elements were interpreted comparably (Bridault/Bemilli 1999, 55). In the faunal assemblage of Kettig, the under-representation of bone grease rich material in combination with the presence of supposed cooking stones was also suggested as possibly indicative of the cooking of bones (Baales 2002, 204 f.). However, cooking does not usually alter the appearance of the material in the same way as burning and small, burnt or calcined pieces were often found on FMG sites. Burning of small faunal waste also required no additional disposal of the material elsewhere to keep vermin and predators away from the site. An increase of small faunal material being finally discarded in a fire was already observed in the Early Azilian assemblages of Le Closeau (Bignon/Bodu 2006, 408. 414). If these pieces reflect a similar type of exploitation behaviour as do the small pieces in the pits of Gönnersdorf and Andernach, then the method of extracting bone grease had changed between these sites. Perhaps the evidence from the upper horizon of Le Grand Canton, sector 2 was still in accordance with the Late Magdalenian behaviour found at Gönnersdorf and Andernach, shifting the possible alteration in bone grease extraction between the MfCM occupation of this site and the Early Azilian in Le Closeau. However, if burning material was necessary for site hygiene, then the »nothing is wasted« strategy was no longer practised at Early Azilian and FMG sites, since the boiled bones did not require this special treatment. Based on the present evidence, the question whether a change in the bone grease extraction method or an abandonment of grease extraction paired with a persistent unwillingness to »take out the rubbish« led to an increase of burnt bone fragments cannot be answered. A detailed reanalysis of the fragmented faunal assemblages might therefore be of some inter-

52 The study also indicates that only some older hunters in Greenland still conform to this ideal, whereas modern hunters again leave much more waste at the hunting sites.

est as well as, perhaps, the results of the archaeozoological analysis of the well preserved faunal assemblage from Conty (cf. Auguste 2012).

Following the example from Western Greenland, an abandonment of this strategy would show a period of sufficient surplus, whereas conforming reflected a buffering mechanism against nutritional uncertainties. Besides a more intense exploitation of the usual prey, a broadening of the prey spectrum could also safeguard against these uncertainties. At this point the impression that Late Magdalenian assemblages appeared in general more specialised than FMG sites has to be discussed.

A previous study on hunting specialisation of Magdalenian assemblages suggested that the diversity index of Simpson calculated for the faunal assemblages is a useful indicator in the distinction between specialised hunting camps and residential sites (Gaudzinski / Street 2003). Moreover, the relation of this diversity to the total MNI was supposed to be further indicative of the type of site from which the assemblage originated (**tab. 58**). However, in different environments the resulting values of this index diverge probably in relation to the total MNI of the assemblage due to the diversity and density of the available species in general. In small assemblages reflecting possibly only a single hunting episode, this difference is not identifiable due to the small numbers. In assemblages reflecting a longer use such as base camps or repetitively visited sites such as agglomerations of various groups or hunting camps, a difference between the site types as well as between the different environments can generally be expected due to the diversity and the total number of hunted species brought to the site. The characteristics for each site type are likely to alter due to the different function and tasks performed at the site. In different environments, the intensity of these characteristics are assumed to differ due to varying possibilities of exploitation. In particular, these possibilities relate to the necessary adaptations of the subsistence strategy to species with different social structures inhabiting the environments. In a more uniform grassland with a lower species diversity and larger group sizes, a single species, for instance horse, was probably hunted more frequently than any species with a smaller group size in a diverse forest environment. Thus, this index was calculated for the assemblages which were published with sufficient details to base the discussion on a common value (**tab. 86**). A relation of this index to the total MNI of the sites is used later in the discussion about the Lateglacial settlement system.

For some northern French Magdalenian assemblages, a specialisation was already suggested due to the predominance of reindeer or horse in the faunal assemblages, in particular for Le Tureau des Gardes (Gaudzinski / Street 2003). This finding is replicated in the present project. However, the positioning of these assemblages in a chronological succession reveals the Late Magdalenian results clearly contrast with those of the MfCM (**fig. 85**). The Late Magdalenian assemblage form two clearly separated groups. The two large Central Rhineland assemblages as well as the smaller one from the Wildweiberlei form a dense set of diverse faunal inventories, even though horse appeared frequently at the sites. Based on the other archaeological evidence, these values reflect probably some type of base camp or residential site to which prey from various other places was introduced. The northern French assemblage from Le Tureau des Gardes, *locus* 6 and the assemblage from Saint Mihiel in the western uplands resulted in almost identical, more specialised values. A detailed archaeozoological analysis has not been published so far for the former assemblage. In Saint Mihiel, only few traces of human use were identified, including engravings on antler, due to the poor surface preservation of the material. However, almost 500 antler remains were probably accumulated by humans, possibly as a type of raw material cache to be used later for the production of antler spalls (cf. Stocker et al. 2006). Since both assemblages were not recovered from a comprehensive excavation, the attribution to a different group must be considered as provisional and, in the future, should be further tested with additional inventories. In analogy to Lewis Binford's settlement system models (Binford 1980), the clear difference between the two groups (**fig. 85**) support the idea of a clear functional differentiation of at least two types of sites in the Late Magdalenian, the base camp and the hunting camp. A variety of faunal mate-

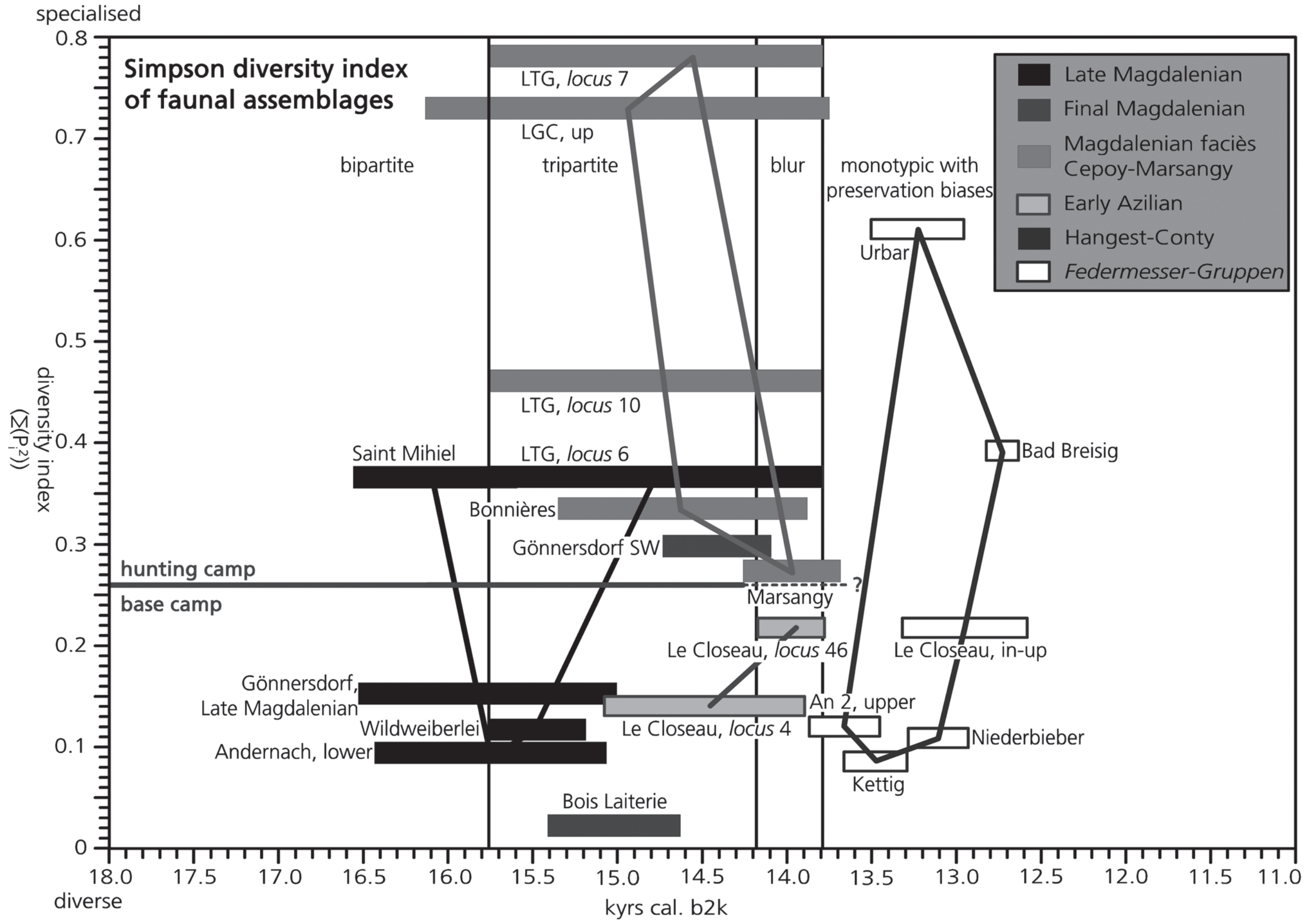


Fig. 85 Values of the Simpson diversity index given per time and archaeological unit. The convex hulls (see p. 281 f.) were set around the main cluster of assemblages attributed to the same archaeological. It was not possible to form a convex hull for the two Early Azilian assemblages, nevertheless, they are connected by a line for better comparability. An approximate limit between more base camp-type assemblages (i. e. diverse) and more hunting-camp-type assemblages (i. e. specialised) was set to the middle between the two Late Magdalenian groups of assemblages. Abbreviations see fig. 74. – For further details see text.

rial was brought to base camps and these resources were occasionally intensely processed, clearly shown by the preserved state of the material, modifications as well as the spatial dispersal (Street/Turner 2013). At hunting camps, one species was found almost exclusively. According to the concept of a hunting or butchering site, indications for dismembering and portioning of the prey should be found but the remains should mainly relate to waste material. However, in Saint Mihiel a considerable amount of useful antlers and a large number of long bone fragments as well as some indications of art were found (Stocker et al. 2006). Thus, the site appeared not as a pure hunting or butchering site. Accordingly, Claude Stocker and colleagues interpreted the excavated portion of the site as a consumption zone with a potential butchering area in the unexcavated vicinity (Stocker et al. 2006, 36). Moreover, the difference of the diversity indices of Saint Mihiel and the single Gönnersdorf concentrations is considerably smaller than the difference to the complete Gönnersdorf assemblage. In particular, Gönnersdorf IV yielded a high value indicating a specialisation similar to that found in the MfCM assemblages. Was Gönnersdorf IV a specialised hunting camp or was the specialisation a result of a small assemblage and provision from other areas of the site? According to the spatial analysis (Sensburg/Moseler 2008) and the faunal remains (Street/Turner 2013) in this part of the site, the former can be rejected and the latter considered more probable.

In general, the MfCM assemblages can also be divided in two groups. The more diverse group yielded values comparable to those of the hunting camp-type inventories of the Late Magdalenian. In addition, the values of Le Tureau des Gardes, *locus* 7 and the upper horizon of Le Grand Canton formed a very specialised group (**fig. 85**). However, different conditions of preservation on a site as well as a greater preservation probability of various elements from different species were considered as an important factor influencing the diversity of the faunal assemblages from Le Tureau des Gardes (Bridault 1996; Lang 1998, 89f.). In fact, the differential preservation of faunal elements has been discussed as an important factor in the formation of assemblage compositions for several decades (Poplin 1976). Differentiating conditions of preservation were found at several Lateglacial sites such as Gönnersdorf, Andernach, or Le Closeau but at these sites the composition of the faunal assemblage did not seem to be affected. Moreover, based on an analysis of the faunal material from the upper horizon of Le Grand Canton and the *loci* 5, 6, and 10 of Le Tureau des Gardes, Olivier Bignon doubted that this taphonomic factor alone could have resulted in the apparent under-representation of other mammal species at these sites (Bignon 2006, 187). Nevertheless, differential preservation could be an explanation for the further distinction of these assemblages from the already specialised group of assemblages. Alternatively, these sites were only in use for short periods and/or were located near reliable and productive hunting grounds for which an additional provision was not necessary. The number of artefacts and activities identified on these sites contradict a very short-termed episode and the diversity of the assemblage also makes an accumulation of several short-term episodes an improbable scenario. In contrast, favourable hunting patches which were recurrently visited but also used for a variety of other purposes (cf. Müller et al. 2006), could explain the number and diversity of artefacts and activities found in Le Tureau des Gardes and Le Grand Canton. In combination with differential conditions of preservation, this location near favourable hunting patches could have resulted in the assemblage appearing more specialised. In contrast, the outstanding inventory of Le Tureau des Gardes, *locus* 7 encompassed only a small assemblage (MNI=8). Thus, an interpretation comparable to Gönnersdorf IV (see above) is also possible. Most diverse is the youngest assemblage from Marsangy which is only 0.05 higher on the index than the Early Azilian *locus* 46 from Le Closeau. However, the very poor state of preservation of the faunal assemblage prohibited the calculation of a more precise MNI for the different species. In better preserved assemblages, this value could become more specialised but also more diverse. In the latter case, for example, the Marsangy inventory would resemble the Early Azilian assemblage of Le Closeau, *locus* 4.

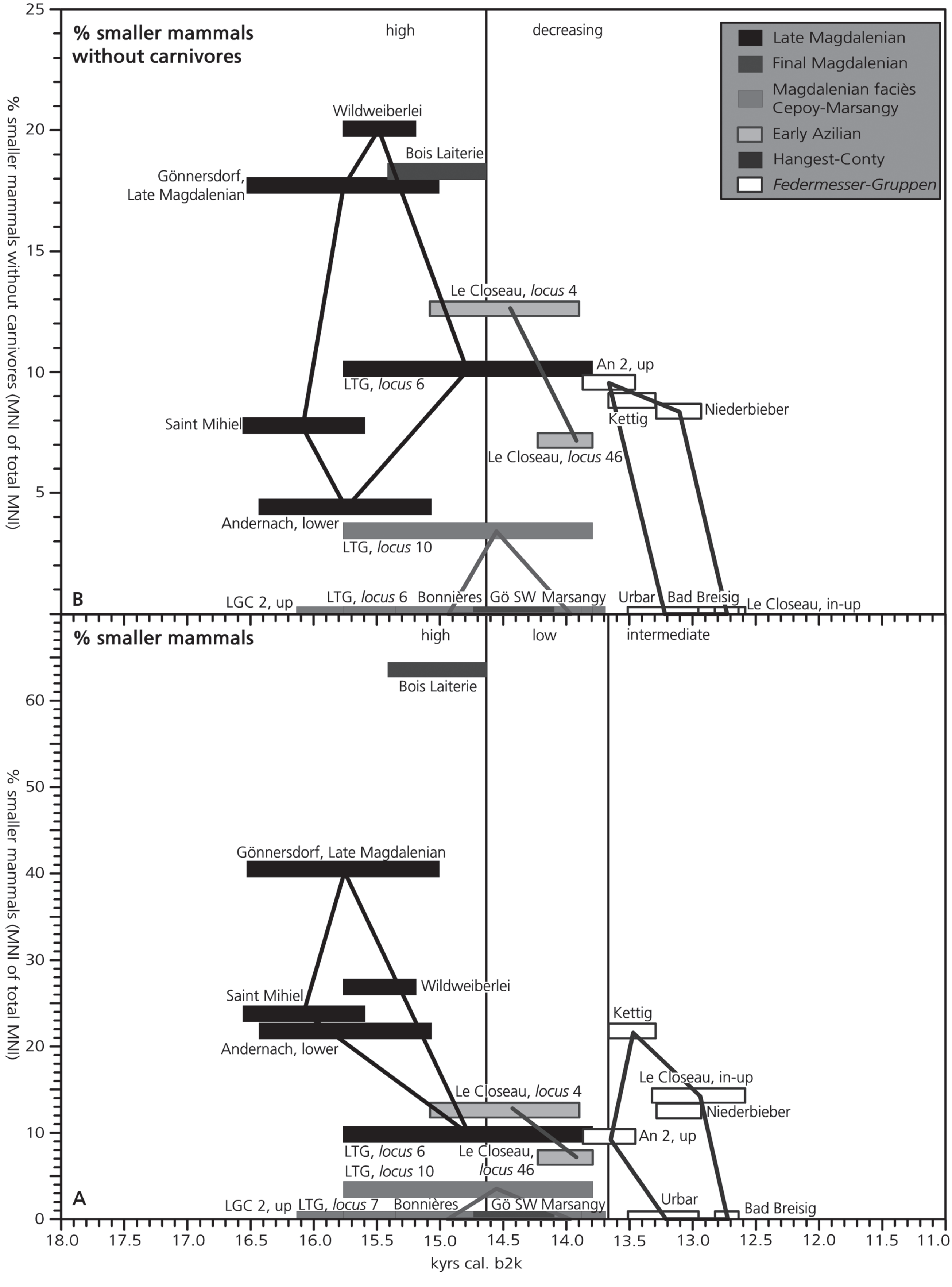
The Early Azilian inventories formed in general a third group with a wide range of values. In comparison to the diverse Late Magdalenian assemblages, species diversity increased slightly in *locus* 4 of Le Closeau and decreased in *locus* 46 of the same site. In fact, this difference is inverse to the previously described assumptions of the influence of conditions of preservation on diversity at this site. Conditions of preservation were mediocre in *locus* 4, whereas very good preservation was described for the more specialised *locus* 46 (Bignon/Bodu 2006). Sample size was approximately the same in both assemblages but the proportion of the determined pieces varied. However, the number of individuals per species and the total MNI decreased significantly in both *loci* in comparison to the majority of MfCM assemblages. The larger and possibly younger assemblage of *locus* 46 was comparable to the small assemblage of Marsangy and together these values resulted in an indistinct separation of the more diverse group of the MfCM and the Early Azilian assemblages. Moreover, the assemblage from the south-western area of Gönnersdorf produced a value which was slightly higher than the one from Marsangy, placing this part of the site into the group of more specialised camps of the Late Magdalenian. However, the attribution of animals to the assemblage was difficult due to the diffuse outlines of this younger phase of occupation at the site and, therefore, the MNI for this site is low. This area can possibly be interpreted as comparable to Gönnersdorf IV. In comparison, the spatial structure of the south-western corner was very different from Gönnersdorf IV and since the south-western area was the only evidence of a younger phase, the question arises which other concentration provided for this part. Bois Laiterie yielded an outstandingly diverse value as was already indicated by the distribution of the selected species. In fact, the value falls clearly below those from large camp sites of the Late Magdalenian, interpreted as base or residential sites, and the value of Wildweiberlei assemblage which was also found in a small cave. The most probable explanation is that this relatively large faunal assemblage was formed during several occupation events which fell into the period of a changing environment, rather than a single long-term settlement in a hyper-mosaic landscape.

The Simpson index decreases even further in the majority of FMG assemblages. However, three outliers were observed: Urbar, Bad Breisig, and Le Closeau. The two former assemblages represented partial inventories. For the latter, the calculation of MNI was biased again by the poor preservation and the low numbers of preserved and determinable faunal remains. Therefore, these highly specialised inventories in the FMG are probably the result of poor preservation. Niederbieber 1 yielded a value lower than Kettig and the upper horizon of Andernach 2. The other concentrations at Niederbieber ranged approximately between a value comparable to that from Marsangy to just below the value for Bad Breisig indicating, perhaps, that a hunting camp-type also existed in the FMG. This scatter was in accordance with the hypothesis that a more diverse environment, inhabited by generally smaller, non-migratory groups of prey, also resulted in a more generalised subsistence strategy which was reflected in a more diverse faunal assemblage.

Besides an increasing diversity within the large mammal spectrum, the incorporation of smaller species such as smaller mammals, fish, or birds into the diet was considered as a step to broaden the food spectrum (broad spectrum revolution) in areas experiencing resource imbalance either due to decreased environmental productivity or to increased population demand (Zeder 2012). As in larger mammal communities, the social structure and the territoriality of potential smaller prey can also differ between different environments but most of these communities are fast growing and their group sizes can vary considerably at local levels, buffering and overprinting the environmental fluctuations (Campbell et al. 2005; Barrio et al. 2013). Consequently, smaller mammal communities commonly found in large and fast growing groups was considered important as a supplementary resource in times of environmental instability and crisis (Munro 2003) and population pulses (Stiner et al. 1999). Ruth Charles pointed further to the complete use of fur-bearing mammals and carnivores (Charles 1997b) and Werner Müller emphasised the importance of non-alimentary parts of small mammals besides their nutritional value (Müller 2004). Furthermore, Anne Bridault and Laure Fontana showed the increasing importance of smaller mammal species during 13,000 and 12,000 years ^{14}C-BP (*c.* 15,890-13,730 years cal. b2k) in a study on Lateglacial environmental changes based on the faunal compositions in mountainous regions (Bridault/Fontana 2003).

For these reasons, the proportion of small mammals in the studied assemblages was considered with and without carnivores (**fig. 86; tab. 86**).

In general, a development from high to low values is observable in both sets (**fig. 86**). In detail, decreasing proportions first occurred in the inventory of Le Tureau des Gardes, *locus* 6. At this site, selective preservation as well as the small number of remains in the assemblage could explain the difference to the other Late Magdalenian assemblages. If the carnivores are removed from all assemblages, the value of *locus* 6 is located in an intermediate position. Nevertheless, the Early Azilian values were generally lower than those of the Late Magdalenian except for Le Tureau des Gardes, *locus* 6 which in both calculations was lower than the results from *locus* 4 of Le Closeau. If the carnivores are removed, the Early Azilian values appeared almost unaltered and rank in the lower part of the Late Magdalenian range. In the MfCM assemblages, smaller mammals with and without carnivores were very infrequent. These assemblages usually rank below the Late Magdalenian range and were also distinctly lower than the Early Azilian assemblages. At the majority of FMG sites, no smaller mammals were preserved. Those with smaller mammals fell approximately into



% smaller mammals without carnivores
high
decreasing
Late Magdalenian
Final Magdalenian
Magdalenian faciès Cepoy-Marsangy
Early Azilian
Hangest-Conty
Federmesser-Gruppen
Wildweiberlei
Bois Laiterie
Gönnersdorf, Late Magdalenian
Le Closeau, locus 4
An 2, up
LTG, locus 6
Kettig
Niederbieber
Saint Mihiel
Le Closeau, locus 46
Andernach, lower
LTG, locus 10
B
LGC 2, up
LTG, locus 6
Bonnières
Gö SW
Marsangy
Urbar
Bad Breisig
Le Closeau, in-up
% smaller mammals without carnivores (MNI of total MNI)
% smaller mammals
high
low
intermediate
Bois Laiterie
Gönnersdorf, Late Magdalenian
Wildweiberlei
Saint Mihiel
Kettig
Andernach, lower
Le Closeau, in-up
Le Closeau, locus 4
Niederbieber
An 2, up
LTG, locus 6
Le Closeau, locus 46
LTG, locus 10
A
LGC 2, up
LTG, locus 7
Bonnières
Gö SW
Marsangy
Urbar
Bad Breisig
% smaller mammals (MNI of total MNI)
kyrs cal. b2k

the range of the Early Azilian assemblages from Le Closeau. Only Kettig reached values of the lower range of the Late Magdalenian inventories, but after the carnivores had been removed, all FMG assemblages became comparable to the value from Le Tureau des Gardes, *locus* 6.

Thus, the two graphs are relatively similar suggesting that the impact of carnivores usually changed in a way comparable to that of the smaller mammals. If all these mammals were hunted, this tendency would suggest, as Charles had pointed out (Charles 1997b), carnivores were treated in a similar way to other mammals (cf. Street/Turner 2013, 161-176). However, comparable conditions of preservation would also result in a linked trend. Exceptions to linked percentages hint occasionally at non-taphonomic causes. For example, one exception is the outstanding value of smaller mammals in Bois Laiterie which becomes comparable to Late Magdalenian inventories when the carnivores are removed. Some of these smaller carnivores such as badger (*Meles meles*) can be assumed to have taken shelter in the cave and, perhaps, reached the site without human influence. A comparable strong decline of the values can be seen in Saint Mihiel and the lower horizon of Andernach as well as Kettig and the greyish deposits of Le Closeau. The assemblage from Kettig sank to a value comparable to the other FMG assemblages after the proportion of carnivores was removed (**tab. 86**). In this case, several smaller carnivores such as red fox (*Vulpes vulpes*), weasel (*Mustela* sp.), and marten (*Martes* sp.) had increased the value. An attribution to natural intrusions at the open air site cannot be completely excluded for these remains. In Le Closeau, the strong decrease was due to the conditions of preservation. Since only a small number of individual animals could be determined in the greyish deposits, a single badger had increased the proportion of the smaller mammals significantly. Thus, in both cases natural rather than human agents could be the reason for the varying values. In contrast, in the lower horizon of Andernach and at Saint Mihiel the decrease is due, in particular, to high proportions of arctic fox (*Alopex lagopus*). At Gönnersdorf, this species was heavily exploited, particularly in concentration I (Street/Turner 2013, 161-176). Presumably, this exploitation was also important in the lower horizon of Andernach (cf. Álvarez Fernández 1999). The values of the assemblages without carnivores were lower than the Early Azilian assemblage of Le Closeau, *locus* 4. Thus, the introduction of other small mammals such as hare (*Lepus* sp.) was not as clearly displayed in these assemblages as, for example, in Gönnersdorf and the Wildweiberlei. Nevertheless, the different values of smaller mammals with and without carnivores in these assemblages indicate that humans could have been an important agent in the creation of these values, even though the small size of the excavations at these sites have to be kept in mind.

Consequently, the question must be discussed whether differential preservation as well as restricted excavations were major agents in creating the observed development. In fact, the preservation was usually good at Late Magdalenian sites and these assemblages yielded the largest proportion of smaller mammals. The higher proportions found in poorly preserved inventories such as in the greyish deposits of Le Closeau or the beaver bone in Niederbieber 3 can be considered critically because they were frequently based on a single individual. However, the proportions did not necessarily increase with better conditions of preservation, such as were found in Le Closeau, *locus* 46 and the upper horizon of Andernach 2. Thus, the observed development towards lower proportions of smaller mammals found in the assemblages of the Lateglacial Interstadial seemed not directly related to preservation. However, the impression of slightly increased values towards the late Lateglacial Interstadial could be the result of generally poor conditions of

Fig. 86 Percentages of smaller mammal MNI from the total determined MNI given per time and archaeological unit. **A** All smaller mammals. – **B** Smaller mammals without carnivores. The convex hulls (see p. 281 f.) were set around the main cluster of assemblages attributed to the same archaeological. It was not possible to form a convex hull for the two Early Azilian assemblages, nevertheless, they are connected by a line for better comparability. Abbreviations see **fig. 74**. – For further details see text.

preservation and small assemblages of bones identified to species. Moreover, the distribution of the values for smaller mammals (**fig. 86A**) recorded at Late Magdalenian sites seems to decrease in association with the extent of the concentration recovered by excavation. In contrast, the widely excavated south-western area of Gönnersdorf contained no smaller mammals suggesting some spatial differentiation where this type of fauna occurred on Magdalenian sites. In addition, the incompletely excavated FMG sites, Urbar and Bad Breisig, yielded no material attributed to smaller mammals, whereas the more complete FMG sites contained smaller mammals in proportions similar to lower ones of the Late Magdalenian. Perhaps this difference indicates that the distribution of faunal material was spatially more distinct at FMG sites than previously thought possible. Consequently, the excavated portion of the site had some effect on the outcome of faunal analyses.

Furthermore, surfaces of the organic material were frequently affected by post-depositional processes making archaeozoological analyses of human modifications on these remains difficult. Besides restricting the comparability of processing methods and behavioural standards, the lack of traces of butchering produces problems when identifying human introductions in contrast to a natural background fauna. The previously mentioned burnt faunal material can only partially help to solve the problem because depending on the attention paid to the setting of the site and the discard process, carelessly swept floors could contain elements which were disposed of in the fire without being introduced as waste by humans. Perhaps recurrently appearing species can possibly be considered as an indicator of human intervention, assuming that a regular appearance at these sites was not a random event. An example of this is the frequent occurrence of arctic fox at Late Magdalenian sites. However, at several of these sites the exploitation of arctic fox has been clearly attested and based on this knowledge, the assumption that foxes were also exploited as a resource at other sites becomes more credible. On the other hand, several species could regularly occur at human settlements where they scavenge on debris. In these cases, their presence was not part of a random process but also not a result of direct human impact. In particular, badgers fall into this uncertain category on Lateglacial Interstadial sites because these omnivorous animals appear regularly in the faunal lists (**tabs 15. 39**). No modified remains of this species were thus far identified, although their fur could be good alternative to furs of arctic foxes. In contrast, beavers (*Castor fiber*) are more likely to be human introductions based on the general habitat and behaviour of this species (Pinto/Santos/Rosell 2009) as well as the frequent appearance of their remains among burnt bone material. Nevertheless, various difficulties restrict the identification of exploitation of small mammals, in particular at FMG sites. Due to these problems all smaller mammals and carnivores were incorporated in the calculation of the values. Consequently, if some of these remains resulted from natural intrusions which had to be excluded, the proportion of smaller mammals in the potential prey assemblages would decrease further. This phenomenon would result in an even clearer manifestation of the general trend of a decreasing importance of smaller mammals in the Lateglacial Interstadial.

According to the hypotheses related to the broad spectrum revolution, the decreasing proportion of small mammals in the development indicated less alimentary pressure either due to an increasing productivity of the environment or a decrease of the population density or both. However, conditions became more favourable for the Lateglacial hunter-gatherers allowing for this decreasing exploitation intensity. In accordance with the finding that a »nothing is wasted« ideal (cf. Pasda/Odgaard 2011) was probably conformed to in the Late Magdalenian and in some MfCM assemblages but possibly no longer in the Early Azilian and the FMG, an increasing alimentary security can be assumed for the hunter-gatherer communities in the Lateglacial Interstadial.

However, the transition in faunal exploitation strategies began much earlier (**fig. 87**). A first step was the appearance of red deer, elk, and wild boar in the various assemblages, followed afterwards by an increasing variety in the diversity of faunal assemblages, in particular due to the occurrence of some hyper-specialised

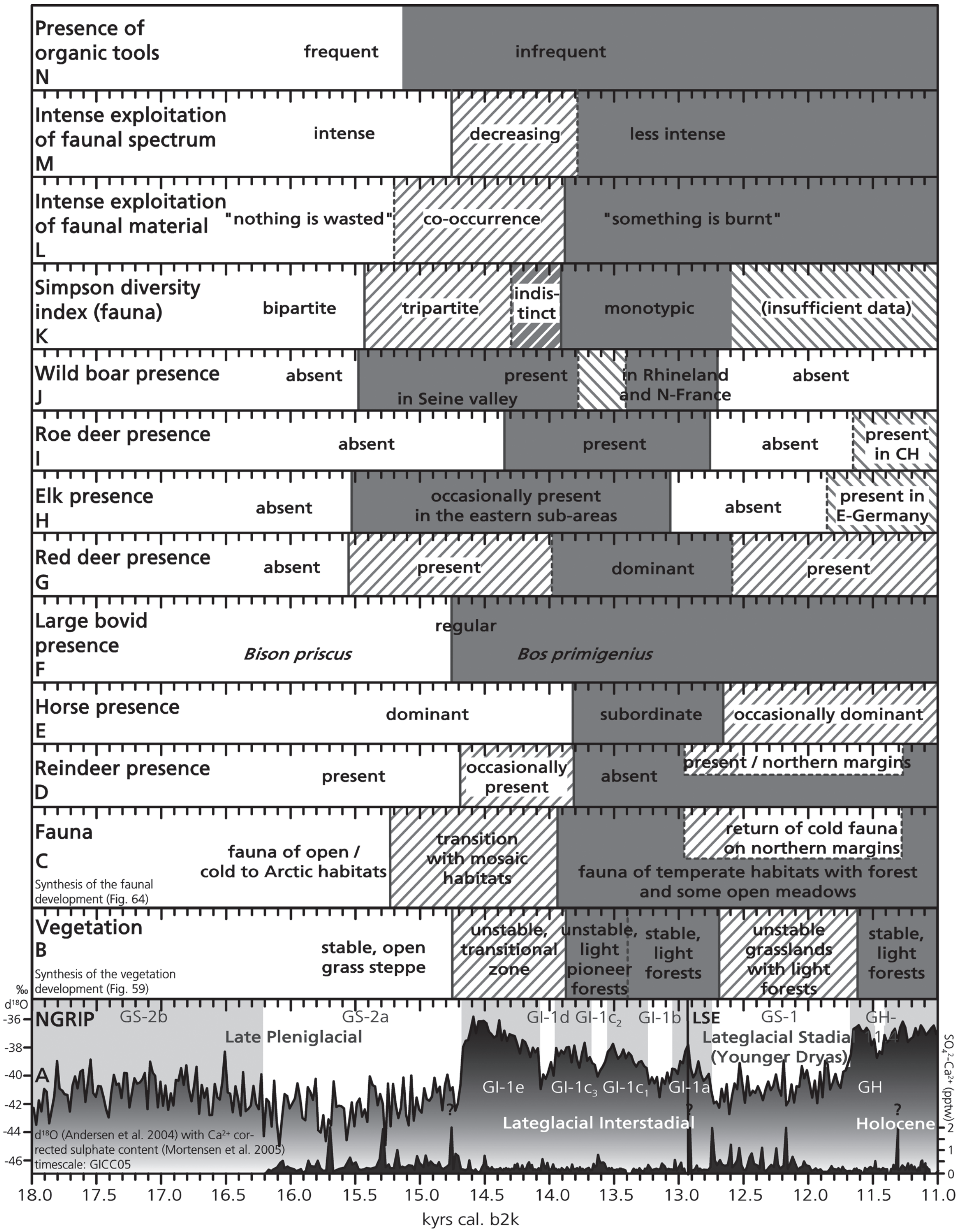


Fig. 87 Developments in faunal assemblages related to faunal exploitation (**D-N**) contrasted by the synthesised faunal (**C**; see **fig. 64**) and vegetation development (**B**; see **fig. 59**) as well as the oxygen isotope record of NGRIP (**A**; see **fig. 53**). Hatched areas indicate transition periods. – For further details see text.

sites. Later the first assemblages with increased numbers of burnt bones appeared almost concomitant with the disappearance of frequently made organic tools. The next wave of changes was the replacement of bison (*Bison* sp., usually *Bison priscus*) by another large bovid (*Bos* sp.), often determined as aurochs (*Bos primigenius*), reindeer becoming only a sporadic visitor in the studied sub-areas, and a decrease of smaller mammal faunas, in particular carnivores in the faunal assemblages. Later roe deer (*Capreolus capreolus*) appears in the archaeological assemblages and, shortly after, the differentiation of diverse and more specialised faunal assemblages becomes indistinct. The next cluster of changes begins with red deer becoming dominant in some assemblages. Thereafter, mainly diverse assemblages are found and the few, very specialised assemblages were found to be incomplete for various reasons. Perhaps, due to preservation, the ideal of »nothing is wasted« could no longer be proven by the evidence of very small, fragmented bones on these sites. However, the trend of burnt material, mentioned previously, could indicate that this ideal was no longer conformed to or that this method of most intense exploitation had changed. At the same time, reindeer disappeared as well as assemblages in which horses were the dominant prey. Wild boar was for a short period not determined in an assemblage of the study area but was possibly present in eastern Germany (see **tab. 80**), appearing again in the assemblages of Niederbieber, Boppard, and Saleux 114 (Fagnart 1997; Coudret/Fagnart 2006). The later disappearance of elk followed by roe deer and wild boar from the archaeological assemblages can only partially be attributed to a change in the faunal composition because the number of assemblages with organic preservation further decreases in this period. Thus, during the Lateglacial Stadial and the early Holocene, the dataset of the study area becomes in some parts insufficient to evaluate further developments in faunal exploitation.

After considering the changes in the exploitation strategies, it becomes apparent that it is necessary to consider these values in the context of the organisation, the length of the occupation, and the function of the sites. However, having presented all this information further assumptions about the settlement system and the changes therein become possible.

Changes in the Lateglacial settlement behaviour

In the previous sub-chapter, the functions of the studied assemblages were already considered in some detail. These results are combined in the following and compared to the idealised models suggested previously (see p. 269 f. and p. 286 f.).

Different levels in the spatial behaviour of Lateglacial hunter-gatherers can be analysed based on the archaeological material. Besides the position of the items and, hence, the spatial organisation within a concentration and on a site, the overall composition and the amount of material help to suppose the main tasks accomplished at a site and, consequently, the general purpose of a site and the duration of its use. In combination with the spatial organisation and seasonal indicators, the duration can be further differentiated into sites which were used repetitively and those which were used more continuously. In a regional comparison of quasi-contemporaneous sites which were characterised in regard to their function and the duration of their use, the spatial behaviour in a limited territory and, thus, the regional settlement system can be modelled. This model is further contributed by the information about the raw material acquisition which allows for further assumptions on the regional to super-regional spatial organisation of the studied groups. Moreover, detailed comparisons of the archaeological types can help sustain an information exchange between different regions and, thus, the spatial extent of information networks. These information networks were considered as the main fundament of the social organisation in prehistoric groups (Clarke

1968; Gamble 1983). Hence, besides reflecting a change in the material output of human behaviour, the above presented analyses also allow for the identification of social changes.
The importance of the spatial organisation became particularly apparent in the last chapter by several outliers in the record which were best explained with specific task zones being excavated such as at Hallines, the upper horizon of Le Grand Canton, sector 1, or Urbar. Even though zoning of a site was found in all studied archaeological units, the intensity of some outliers suggested that the zoning was usually more restrictive on Late Magdalenian than on FMG sites. However, detailed intra-concentration analyses were not possible in the present project but were in some cases accomplished previously (Julien et al. 1999; Bodu/Debout/Bignon 2006; Sensburg 2007; Sensburg/Moseler 2008; Bodu 2010; Gelhausen 2011a; Jöris/Street/Turner 2011). These concentration units were considered as single occupation episodes and the base for assumptions about the diversification of lithic assemblages by function and duration (cf. Löhr 1979; Richter 1990). This concept appears valid for the ephemeral FMG inventories which were positioned at some distance to one another and, thus, preserved the abandonment of the archaeological material almost unaltered. In one case, the horizontal distribution appeared so well preserved that the last sitting position of a single stone knapper was possibly identifiable (Baales 2003b; Gelhausen 2010). This almost undisturbed pattern can be assumed to result from a relatively short-termed event because in a longer occupation, the position where material was originally dropped would be altered by the intentional (cleaning) or unintentional moving (kicking) or transformation (trampling, burning) by the inhabitants. In contrast, large installations such as the concentrations of Gönnersdorf were often cleaned up (Sensburg 2007) and possibly reused in a tell-like manner during several occupation events (Jöris/Street/Turner 2011). In this case, the question arises which duration of use was reflected by the diversity of the lithic inventory: The number of times in which the installation was revisited or the time of a single visit. According to the original Löhr model (Löhr 1979), the cleaning of the site during a visit was considered and assumed to occur in sites which were settled for a longer period. However, if the purposes of the visits were different, possibly depending on the period of the year when the installation was visited and the cleaning up was related to a certain site hygenie to not attract predators or vermin which could destabilise the installation, the interpretations based on this model could be ambiguous. Thus, the relation between concentrations on a site are an important matter in the characterisation of the sites. Moreover, the possible contemporaneity of two or more concentrations on a site further throw up the discussion of social organisations within groups: Were there larger agglomerations or were two or three parties occasionally joining forces? As previously mentioned, questions relating to the contemporaneity are difficult to answer even with a detailed spatial analysis because the interpretation of the results often allows for conflicting models (cf. Cziesla 1990; Jöris/Street/Turner 2011). Nevertheless, although these questions and interpretation problems cannot be solved in this study, the change in the use of space as an interesting factor of standardisation of life spaces can be recorded independent of whether this material accumulation was the result of a single or a few, longer occupation events or several short events. Comparing the layout of the different sites with multiple concentrations in the present record already reveals some clear differences: The large, tell-like used installations on the here studied Late Magdalenian sites are usually clearly separated although the archaeological material sometimes scatters between these areas. However, some works and special dump zones were spatially restricted in the relatively large areas. Frequently, material was transferred between these installations either as part of the differentiation of working zones or as raw material supply from abandoned structures (Terberger 1997;Street/Turner 2013). The concentrations of the Early Azilian in Le Closeau were comparably organised but revealed some satellite concentrations which were separated by several metres from the main activity area (**fig. 88**; cf. Jöris/Terberger 2001; Bodu/Debout/Bignon 2006). The connection between these concentrations were not as frequent as on Late Magdalenian sites. In contrast, the sites of the MfCM along river banks showed the

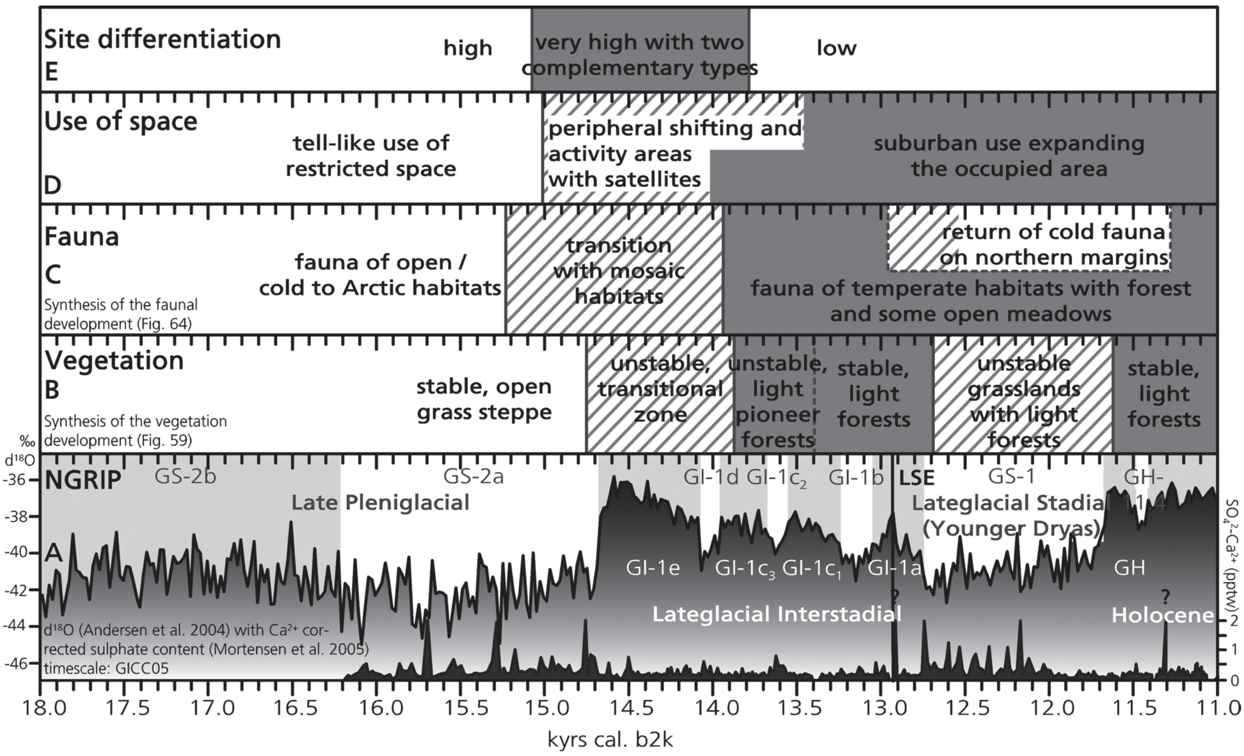


Fig. 88 Developments in the Lateglacial assemblages related to settlement behaviour (**D-E**) contrasted by the synthesised faunal (**C**; see **fig. 64**) and vegetation development (**B**; see **fig. 59**) as well as the oxygen isotope record of NGRIP (**A**; see **fig. 53**). Hatched areas: transition periods. – For further details see text.

gradual shift of much lighter installations to the periphery of a previously used area. This spatial behaviour was also found on Late Magdalenian sites along lake shores in Switzerland where one installation consisted usually of only one or two stone-filled hearths (Leesch/Cattin/Müller 2004; Müller et al. 2006; Leesch et al. 2010). Material from previous installations was occasionally reused on these sites resulting in often complex spatial interrelations on these large and often densely scattered sites. The early FMG assemblage from the upper horizon of Andernach 2 appears as a reminiscence of the peripheral moving of activity areas because in the late MfCM sites such as Belloy-sur-Somme and late Early Azilian sites such as Pincevent III.2, more separate, small concentrations already appear which conform to layout comparable to the single concentrations at the FMG site Niederbieber (Gelhausen 2011a). In Niederbieber, this uniformity of the concentrations reminds of suburban areas planned on a drawing board. Many of the single FMG concentrations also conform to this general layout. In Niederbieber, only very few connections between the various concentrations were found. In combination with the highly similar layout, the concentrations give an independent impression rather than reflecting different spots used in a single, longer-termed occupation. Thus, the number of revisits was perhaps readable from the number of concentrations. In this case, the complete site of Niederbieber could be comparable to a single Late Magdalenian concentration of Gönnersdorf in regard to the number of visits on the site.

Based on the above named differences in the formation of the sites, the diversity of the formally retouched artefact inventories as indicator for the function and duration of the occupation (cf. Löhr 1979; Richter 1990) must be considered in relation to the size of the inventory. In addition, the diversity of the faunal assemblages in relation to the size was considered as an indicator for the function of a site (cf. Gaudzinski/Street 2003) and the duration of its use (**tab. 58**). The distinction between high and low values indicating frequency and diversity remain again a matter of definition and the present database.

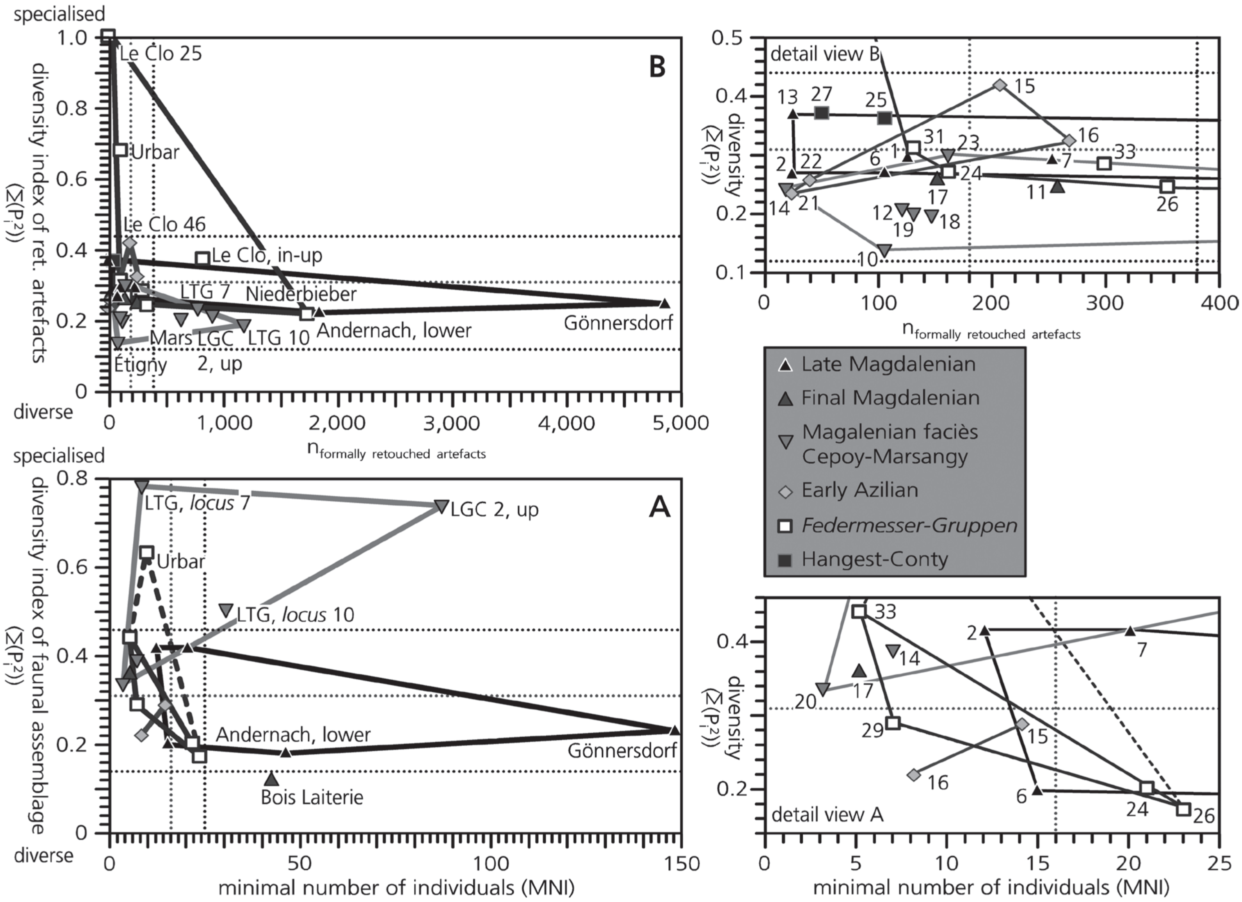


Fig. 89 Diversity of faunal assemblages (**A**) and formally retouched artefacts (**B**) in contrast to the minimal number of individuals determined in the assemblages given per site and archaeological unit. The distribution of all assemblages is given in the main view where also the convex hulls were set per archaeological unit (see p. 281 f.) which are also indicated in the detail view. Numbers for the sites are used in the detail views according to **tab. 82**. Black dotted lines: limits of observable breaks in the data beyond which the values can be considered as extreme; grey dotted lines: sub-division of the usual values into low and high values. For abbreviations see **fig. 74**. – For further details see text.

In the comparison of the faunal assemblages (**fig. 89**A), an important observation is that the convex hulls of Late Magdalenian and MfCM assemblages are almost exclusive and that the convex hull of the FMG overlaps the ends of both types of inventories. The dichotomy of the Late Magdalenian and the MfCM assemblages cannot be explained by a difference in function alone. The Late Magdalenian sample includes Saint Mihiel and *locus* 6 of Le Tureau des Gardes which were considered as specialised hunting sites (Bridault/Lang/Rieu 1997). In fact, these assemblages fall into the lower range of the MfCM hull which is formed by the poorly preserved material of Marsangy and the problematic inventory of Bonnières-sur-Seine. The other assemblages represented some hyper-specialised sites of which the upper horizon in Le Grand Canton, sector 2 and the *locus* 10 of Le Tureau des Gardes were also very large. In these cases, differential conditions of preservation alone appear unreliable as an explanation but in combination with many visits and extremely standardised hunting patterns, they form a probable scenario of the hyper-specialisation. In regard to the very standardised purpose and behaviour of visiting a site, these assemblages appear to be produced by typical Magdalenians. The Late Magdalenian assemblages range between diverse and semi-diverse inventories but except for Gönnersdorf and the lower horizon of Andernach no outstandingly large assemblages were found. For Gönnersdorf as well as for Andernach, this significant amount of diverse faunal material brought to the site seems indicative for a longer use, possibly by several revisits but certainly also by longer stays on these sites. Larger assemblages were not found in the FMG. They were a bit more specialised and generally smaller than the Late Magdalenian sites. However, the sites of Kettig and the upper horizon of Andernach 2 were comparably diverse as the Wildweiberlei assemblage, whereas the partially excavated assemblage from Bad Breisig was approximately as specialised as Saint Mihiel and Le Tureau des Gardes, *locus* 6. Nevertheless, the value of the greyish deposits in Le Closeau ranged between those two values indicating either a less strict differentiation between the FMG sites or, more probable, the impact of poorer preservation in these deposits. Moreover, if in Bad Breisig, as in Urbar, only a specialised part of the site was excavated, the high value must be questioned. If the single concentrations of Niedebieber are taken into account, they yielded usually smaller assemblages than Bad Breisig but comparable specialised inventories. Perhaps, the clear distinction between specialised and diverse sites became indistinct in the FMG inventories. The Early Azilian assemblages of the lower horizon of Le Closeau range among the more diverse inventories but as with the FMG, these inventories were rather small. In general, the tendency towards smaller inventories becomes apparent in the Early Azilian and, perhaps, later MfCM. In summary, the Late Magdalenian yielded two general groups of data with a more specialised group and a diverse one which was usually formed by very large assemblages. The diverse group is also present among the FMG inventories but the distinction to more specialised inventories became possibly unclear. In contrast, the diverse group was also found in the Early Azilian but the more specialised group was absent, whereas the MfCM assemblages yielded only specialised, occasionally hyper-specialised and no diverse inventory. Supposing that the two types of sites were necessary to form a complete settlement cycle in the Lateglacial, the Early Azilian and the MfCM sites probably formed two complementary sets of sites.

The diversity of the formally retouched inventory (**fig. 89B**) does not reflect the specialisation of the MfCM sites nor the diversity of the Early Azilian sites but rather points to the contrary. The Early Azilian assemblages appear more specialised and the MfCM sites are more diverse. Thus, these inventories appear again as complementary sets. However, the specialisation of the Early Azilian sites results from the undefined other formally retouched artefacts group. In addition to a significant amount of macroscopically splintered material which indicate intense use or trampling, this specialisation shows the decreasing reliance on standardised implements in these inventories. The numbers of formally retouched artefacts found on a small group of MfCM sites (Le Tureau des Gardes, *loci* 7 and 10, the upper horizon of Le Grand Canton 2, and Marsangy) suggested along with the faunal inventories a longer use of the site. In particular, the relation of the formally retouched artefacts to cores (see **fig. 79**) proves the large amount of material used at these sites. This relation also indicated that the exploitation of lithic resources played an important role besides the specialised hunting events. Perhaps, this purpose also contributed to the diversity of the formally retouched inventories with the production of rejected implements rather than used material. Among the FMG inventories, Urbar as well as the *locus* 25 of Le Closeau form highly specialised outliers. Besides sustaining the special task character of these inventories, these high values reflect the small size of the assemblages. Exceptionally large FMG assemblage were produced by the accumulations in Niederbieber and the greyish deposits of Le Closeau. The former yielded approximately as many retouched artefacts as the lower horizon in Andernach. However, the Gönnersdorf assemblage was considerably larger pointing to the exceptional position of Gönnersdorf also among the Late Magdalenian inventories. The comparison of the diversity of the smaller Late Magdalenian assemblages indicated little differences between these assemblages. This lack of difference also between the potential hunting camps and the sites with a more residential character reveals the very standardised tool set of the Late Magdalenian which was brought to all site types. Thus, diversity of the formally retouched artefacts could possibly not serve for a functional or temporal differentiation of these sites. In fact, contrasting the diversity indices of the analysed inventories (**fig. 90**) to understand the use of the sites, the Late Magdalenian assemblages formed again two groups with Gönnersdorf, the lower horizon

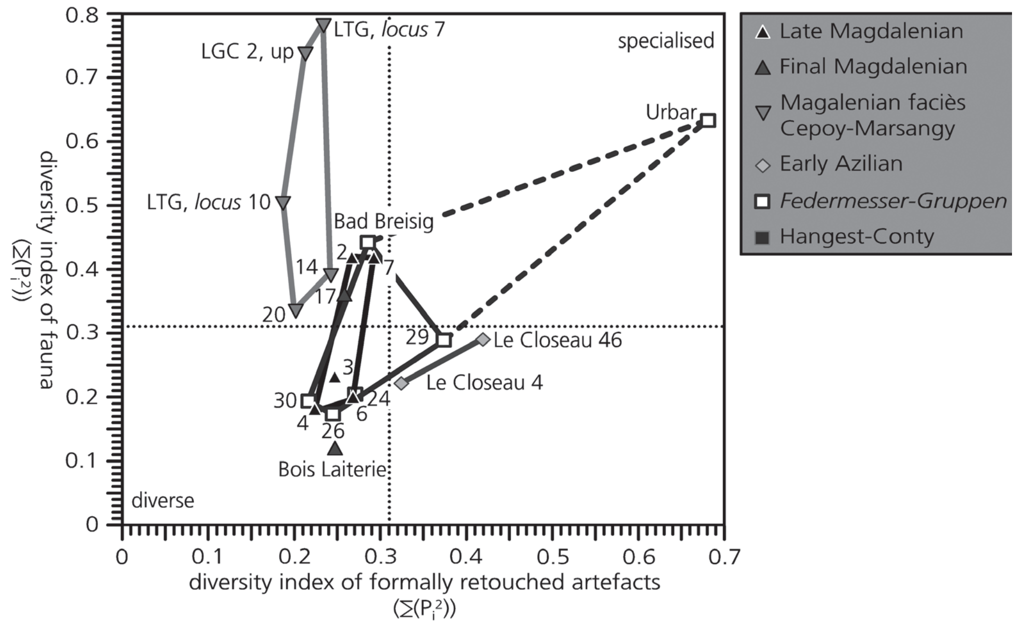


Fig. 90 Diversity of faunal assemblages in contrast to formally retouched artefacts given per site and archaeological unit. The convex hulls were set per archaeological unit (see p. 281 f.). Numbers for the sites are used according to **tab. 82**. Black dotted lines: limits of observable breaks in the data beyond which the values can be considered as extreme (see **fig. 89**). For abbreviations see **fig. 74**. – For further details see text.

of Andernach, and the Wildweiberlei assemblage falling into the diverse sector and the assemblages of Saint Mihiel and *locus* 6 of Le Tureau des Gardes as well as the assemblage from the south-western area of Gönnersdorf falling into the diverse artefact but more specialised faunal assemblages. In this sector, all MfCM assemblages were located, whereas the Early Azilian assemblages of Le Closeau as well as the greyish deposits of Le Closeau fall into the opposite sector with a high diversity in the faunal assemblages but a low diversity in the retouched artefacts. Thus, the site types become further differentiated in this period. The FMG assemblages reveal an almost congruent pattern with the Late Magdalenian inventories. However, the more specialised fauna and diverse artefacts sector is only represented by Bad Breisig. Although this site shows high similarities with the MfCM sites, for instance in regard to the importance of cores, the inventory was not completely excavated which could lead to the increased specialised values. Moreover, the assemblage of Urbar yielded a completely outstanding position in the specialised fauna and specialised artefact assemblages sector showing this assemblage to be biased by the excavated area.

The duration of the use whether recurrent or continuous can also be measured by the evident structures (**tabs 19. 32. 43**) found on the sites. The hearths indicated by stone setting or stone filling as well as those indicated by the colouring or other transformation of the underlying sediment or the accumulation of burnt material prove the existence of fire on a site. However, the former show some effort in the construction of the fireplace, whereas these efforts were not detectable in the other types of hearths. Some efforts in maintaining and use of these latter hearths were visible by the distribution of burnt material showing occasional clearings and allowing for the assumption of a longer use. Nevertheless, in several of the Niederbieber concentrations only a single dense cluster of the burnt material suggested a short-term use of the fireplace. Previously, the use of open fires as places of waste disposal were suggested and, perhaps, explain the increasing proportion of burnt material on Lateglacial sites (see **tabs 11. 35**; cf. Kind 1985). These various types of hearths can be moved easier than large pavements and/or pits. In contrast, the occasionally massive installations of pavements are more sustainable and make reuse of the same installation after some

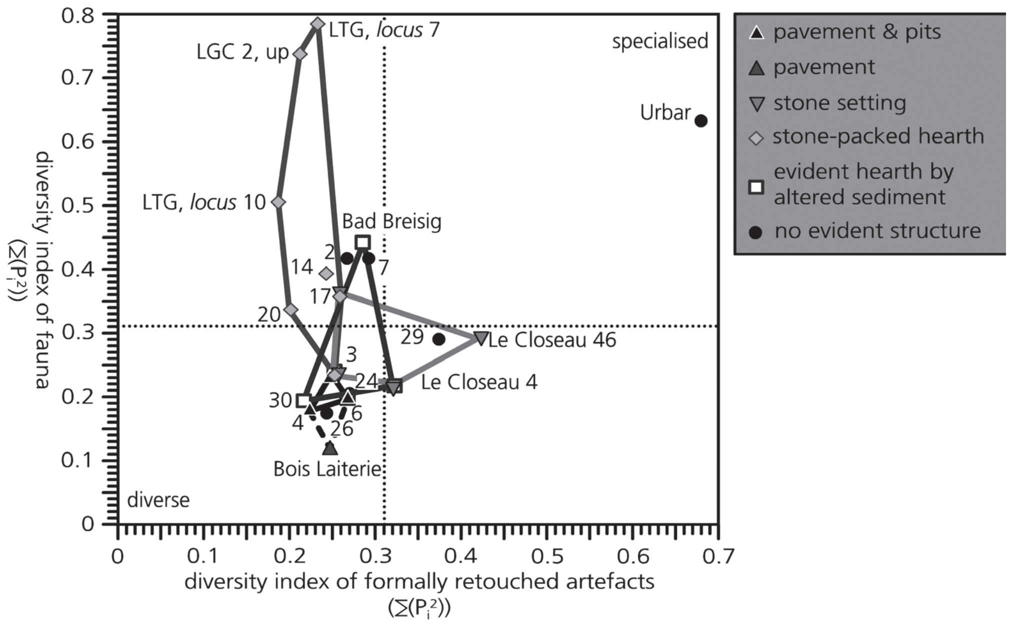


Fig. 91 Diversity of faunal assemblages in contrast to formally retouched artefacts given per site and evident structures. Some sites such as Gönnersdorf yielded several types of evident structures. The convex hulls were set per evident structure type (see p. 281 f.). Numbers for the sites are used according to **tab. 82**. Black dotted lines: limits of observable breaks in the data beyond which the values can be considered as extreme (see **fig. 89**). For abbreviations see **fig. 74**. – For further details see text.

time has passed possible. In fact, pavements often in combination with several pits were only found on very diverse sites (**fig. 91**). Stone-filled hearths were found in very diverse retouched artefact assemblages but seemed independent of the diversity of the fauna. In contrast, stone settings were related to a variety of assemblages, usually of intermediate diversity in regard to the faunal assemblages as well as the retouched inventories. In Gönnersdorf, these structures co-occur but otherwise they are exclusive. Hearths which became evident due to colouration of the sediment appeared also at a variety of sites.

Finally, comparing the seasonal indicators known for the sites (**fig. 92**), the dichotomy of the Early Azilian sites and the MfCM sites is further sustained. Although in all assemblages providing seasonal evidence, this evidence suggested an almost yearly use of the sites, in MfCM inventories the evidence was stronger for the light season, whereas for Early Azilian sites the evidence was more numerous for the dark season. Thus, in the transitional period, the spatial differentiation between hunting and more residential camps appeared stricter than in the Late Magdalenian. In the more solid winter camps, the hunter-gatherers lived on a variety of prey species and the tasks performed necessitated no standardised lithic inventory. During the lighter months, lighter dwellings or no structures were need and a few hearth constructions were sufficient. In this period, regular hunting episodes were performed besides which intense lithic production was performed. In the FMG this seasonal differentiation is no longer visible.

Based on the previous assumption of how the archaeological material would differentiate site types and additional assumptions on the general availability of faunal resources, a hypothetical model can be developed to propose which position sites would take in this model (**fig. 93**) and compare this model with the results of this study (**figs 90-92**).

In general, assuming that the group size of inhabitants of a base camp and their daily tasks did not change, the diversity of the formally retouched inventories should be comparable for all base camps. However, the territorial and reproduction behaviour of the prey influences the duration for which a base camp could be used. Different attributes can be used to describe the faunal compositions (uniform – diverse; migratory –

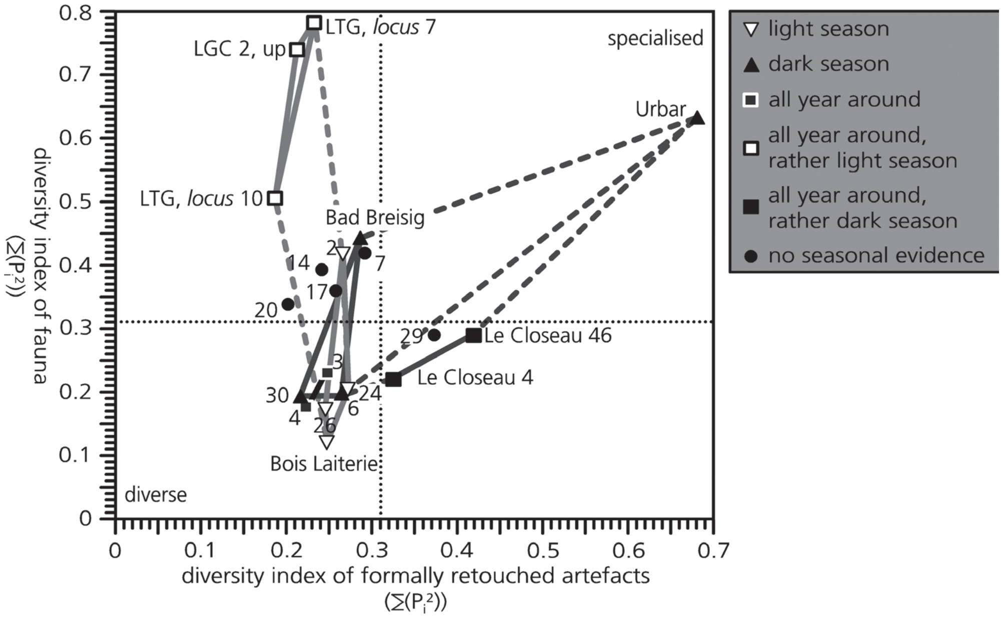


Fig. 92 Diversity of faunal assemblages in contrast to formally retouched artefacts given per site and seasonal indicator. The convex hulls were set per season (see p. 281 f.). Numbers for the sites are used according to **tab. 82**. Black dotted lines: limits of observable breaks in the data beyond which the values can be considered as extreme (see **fig. 89**). For abbreviations see **fig. 74**. – For further details see text.

nonmigratory; large herds – small groups). These attributes are often combined in two groups which are mainly assumed to correspond to an open environment (uniform, migratory, large herds) and a forested environment (diverse, nonmigratory, small groups). Assuming that the intensity of lithic tool use alters with the duration of the site use, base camps in forested areas with more diverse faunas would produce higher diversity values for the faunal assemblage but smaller diversity for the retouched artefact inventories than base camps in more uniform landscapes.

In a landscape characterised by animals which are faithful to their habitat, prey animals can be found there all year round but the supply of prey animals is limited. Thus, the occupation duration for base camps in these areas are limited due to the supply. In contrast, in landscapes with large-scale migration movements, new groups of the same species can replace the hunted ones but often these movements are seasonally restricted. However, if the landscape was characterised by a uniform faunal composition over a large area, the possibilities for the rest of the year were limited to either follow the herds or to supplement the seasonal resources with species available during other seasons. Consequently, if a base camp existed in a uniform environment it could be occupied for a longer period with a succession of seasonally available faunal resources. The seasonal variation between the site types from different environments becomes probably most evident in hunting camps. Seasonally migrating animals are usually caught at a specific place during the migration period, whereas species which are residential in an area can be hunted all year round in a favourable place. Favourable places such as watering places are usually visited by various species. Thus, hunting small numbers of a special prey in favourable place allows for an opportunistic supplement with other species. In contrast, the chance of hunting supplementary species when hunting a migratory herd at a topographically suitable hunting spot is improbable and, in particular, if a larger number of animals is hunted the processing of the wanted species consumes more time making additional work unprofitable. Consequently, a hunting place in a diverse environment can result in slightly higher diversity of the faunal assemblage than hunting camps where the focus was set on a single herd species. The total numbers of determined individual (MNI)

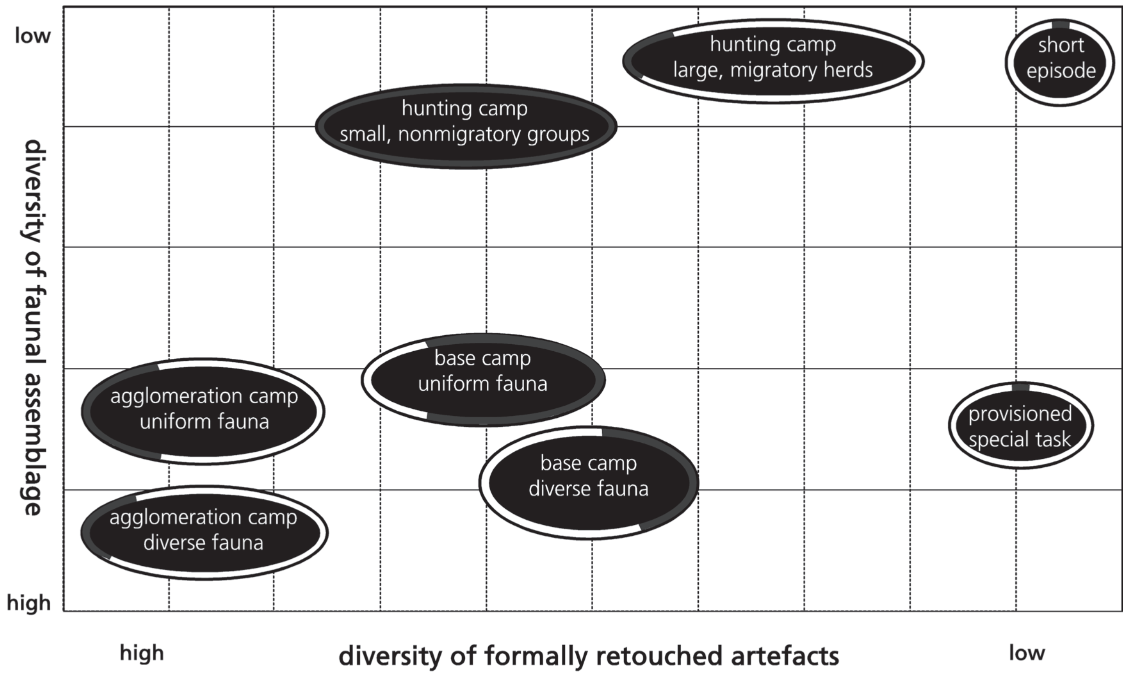


Fig. 93 Hypothetical distribution of different site types in relation to the diversity of the lithic formally retouched artefacts and the faunal assemblage. In addition, the presumable seasonal indicators from these site types are given as grey shaded area in an idealised annual cycle. – For further details see text.

should further differentiate these hunting spots. Places focused on large herds should also produce larger numbers of animals than those focused on smaller groups. Moreover, at mass hunt sites accomplishing tasks unrelated to this event is improbable. However, the time to process numerous animals would also require some space for other activities such as sleeping or eating (cf. Stocker et al. 2006). However, at more opportunistic hunting sites additional tasks could be embedded and, thus, an increased diversity of the lithic inventories seems possible. Nevertheless, repetitive, short stops could also result in more specialised inventories. Besides the base and the hunting camps, agglomeration camps were regularly considered. This type is partially difficult to distinguish from repetitively visited base or hunting camps where also more diverse material could be accumulated (cf. discussions on Niederbieber, Gelhausen 2011a; Gelhausen 2011b; or Rekem, Caspar / De Bie 1996; De Bie / Caspar 2000).

In general, larger agglomerations of groups from different territories should result in a more diverse faunal composition. Depending on the uniformity of the environment between the different territories, this diversity could be only a bit higher (very uniform landscape) to significantly higher (mosaic landscape) than at a single base camp. However, if this agglomeration were continuous for a longer period of time people would have to exploit the local faunal resources. Therefore, the meeting of several groups occurred probably in seasons when large herds were hunted or these meetings were set in particularly favourable places and / or these camps were only sustained for a short duration. In the latter case, sites with a very high diversity but a very limited occupation period as shown by the seasonal indicators could be assumed to represent an agglomeration camp rather than a repetitively visited base camp. In addition, in areas where agglomeration as well as base camps are present, the seasonality of the two types should be exclusive.

Thus, the connection with the seasonality shows which influence the faunal composition in the landscape can have on the human mobility patterns. The more diverse but resident, small group species of the forested environment had a generally smaller faunal biomass per square kilometre than the less diverse, often migratory and larger herd fauna of the open grasslands. This difference required a higher mobility of the

Lateglacial forest hunters to provide the necessary faunal resources. Thus, these hunters had to either move their residential site frequently (high residential mobility) or cover increasing distances to the base camp from hunting grounds (high logistical mobility; cf. Kelly 1991; Kelly 1992).
Comparing this hypothetical model with the results of the present study, the differences between Early Azilian and MfCM sites match the assumptions on base and hunting camps in areas with non-migratory species very well. The inventories of the Late Magdalenian were closer in the faunal diversity and almost identical in the diversity of the lithic inventory. However, the slight decrease in the diversity of the faunal as well as the lithic inventory on the supposed hunting camp sites resembled more the distribution of sites in a uniform landscape. Furthermore, in comparison with the hypothetical model, Gönnersdorf and the lower horizon of Andernach are more similar to the base camps in uniform landscapes with an almost annual occupation than to the agglomeration camps (see **tab. 60**).
According to this model, Bois Latierie was also best explained as a base camp in a mosaic landscape. However, based on the faunal data and also the diversity in the LMP spectrum, this assemblage could also represent a palimpsest of a revisited hunting camp during a period of extreme environmental changes. The south-western area of Gönnersdorf could also represent a site continuity in the period of change but in contrast to the previous occupation of the site, the main purpose could have changed to a short hunting camp. The FMG assemblages were of more interest because in these inventories base and special task sites seemed less distinct.
The assemblages of the lower horizons of Conty and Hangest-sur-Somme III.1 cannot yet be tested against this model. However, due to their lithic inventories (see p. 525), these sites were occasionally separated from the group of FMG values. Since Conty and Hangest-sur-Somme III.1 were possible hunting camps specialised in aurochs, the results promise to be interesting.
Finally, besides these direct evidences from the inventories of the studied sites, the interrelation of various areas can be considered based on the acquired raw materials. Analyses locating the precise source/acquisition area of raw materials were mentioned to be desirable and might become easier to accomplish in the future (Pettitt/Rockman/Chenery 2012; Frahm et al. 2014). They are particularly desirable in regard to this project because a gap in the raw material acquisition distances was observed and if this gap proved valid, it suggested a specific territorial behaviour in which people moved between acquisition sites over a minimal distance. This pattern was independent of the archaeological group and, thus, seemed to sustain the major changes during this period. The possible minimal distance incorporated the local exploitation zones around the sites and a type of untouched transition zone which related approximately to another full exploitation zone. This pattern also occurs when exchange and, thus, the meeting of two groups is excluded due to the amount of the regional or exogenous raw material. Consequently, this pattern can also be related to the settlement behaviour of a single group. Moreover, this pattern seemed independent whether a group was sent to the next mineral source for logisitical reasons such as raw material procurement or the complete group moved their residence. Thus, movements related to the exploitation of a mineral resource seemed optimal within 5-10 km around a site. For sources further away logistical or residential moves had to be considered and these moves seemed only reasonable for sources which were at least another exploitation zone away (**fig. 94A**). Perhaps, this distance could be explained by recovery cycles of the exploited vegetation and the fauna around the sites. Nevertheless, since the decision where to move next was made at least with each residential move, a relatively small territory could be completely exploited with a few moves (**fig. 94B**). These distant moves made a recovery of the ecotope in an exploited zone possible before the next human visit. This behaviour would add to a potential seasonal cycle a fluctuation for environmental sustainability. In addition, this behaviour allowed the intense use of a favourable area, for instance with a high resource concentration such as vegetation and fauna diversity due to water availability in river valleys (cf. Butzer

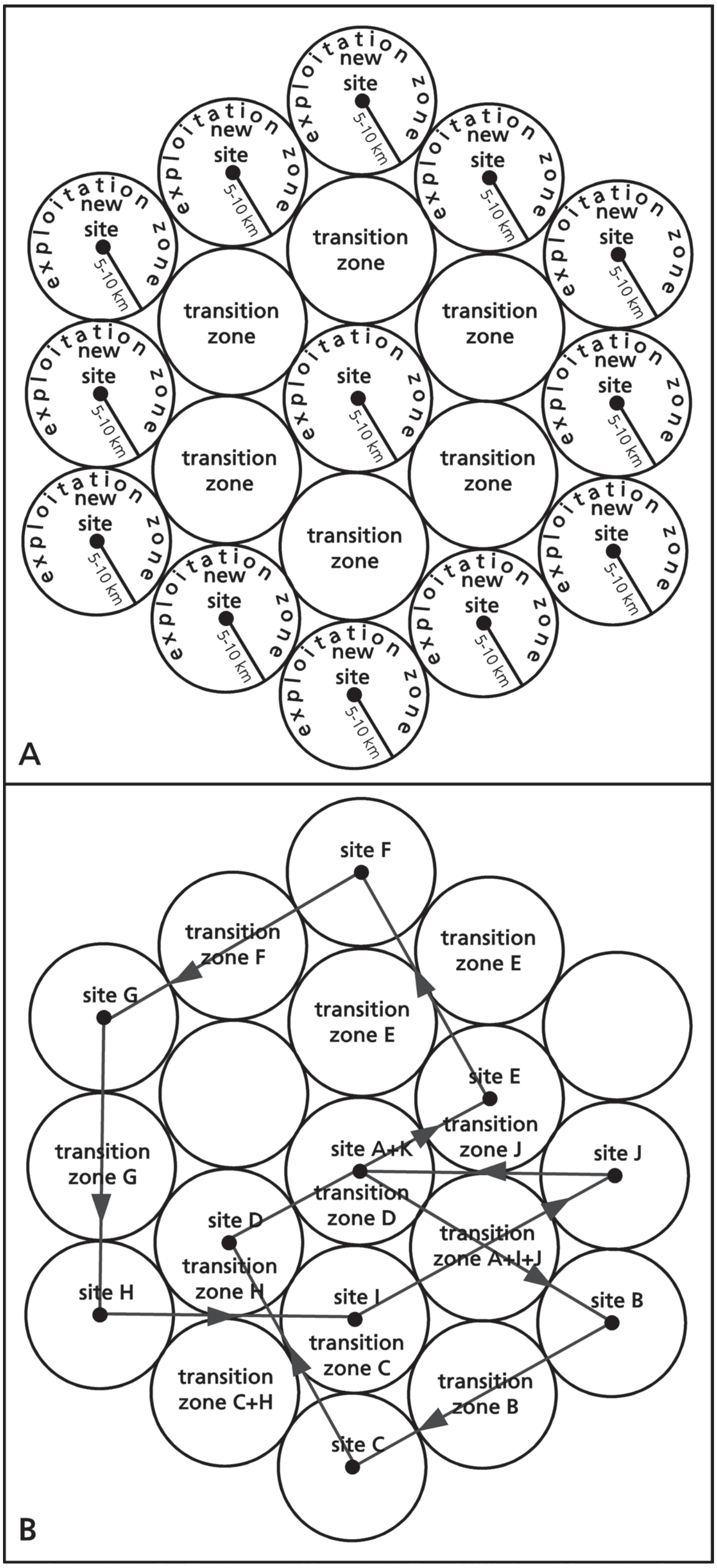
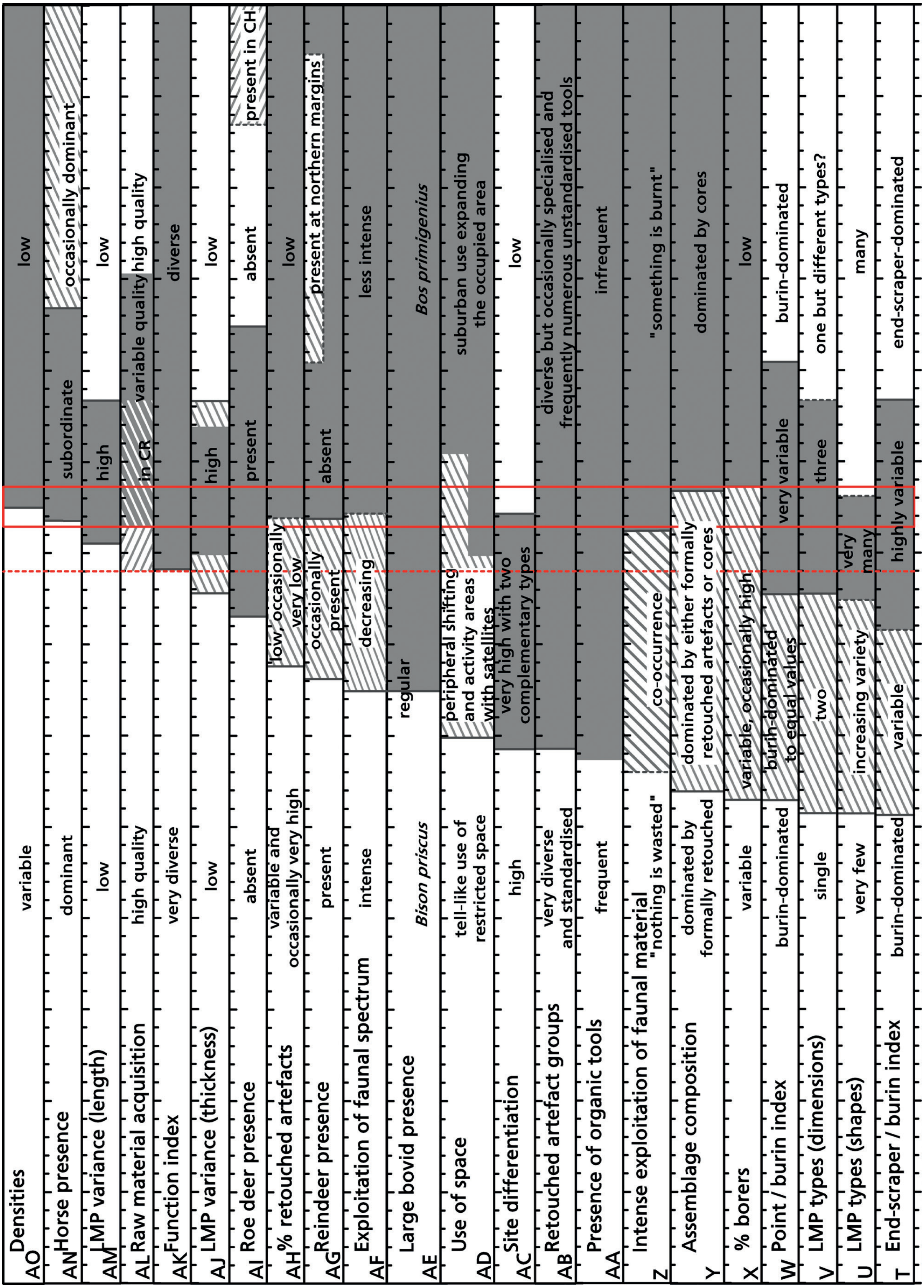


Fig. 94 Hypothetical model of site movements based on a gap in the distances of mineral raw material sources. **A** Possibilities of moves from one site to the next over a transitional zone; **B** use of a territory with the type of moves described in A. Grey line: connection of the successive sites A-K along the straight way between the sites.

1982, figs 12-2 and 14-2). If these observations can be further verified in the future, they provide further implications about the Lateglacial exploitation strategies and the prehistoric understanding of ecological sustainability.
Moreover, the precise spatial location of acquisition sites in relation to the studied sites allows for further suggestions about the territorial and settlement behaviour of Lateglacial groups and, thus, the social organisation of space. In particular, the loss of »long distance« acquisitions indicates that the very large information networks which were sustained during the Late Magdalenian disappeared. Eventhough these connections seemed not very intense, they probably served a wide-span buffering network (cf. Stein Mandryk 1993). Their disappearance can reflect a decreasing need of these security patterns. Nevertheless, distant contacts were still identifiable in the acquisition distances and suggest that contacts at a regional distance were probably sustained.

CHRONOLOGY OF CHANGES IN LATEGLACIAL NORTH-WESTERN EUROPE

The comprehensive presentation of the climatic and environmental developments, in particular in regard to their chronology, was necessary to allow for a synthesis of these results with the developments of the human society in the same temporal framework. Considerations about the impact of climatic and environmental changes on human behaviour are only possible within a consistent and reliable synthetic approach. In the analyses performed at a single site, the indicators of environmental development can be found within the same horizon as the archaeological remains and, thus, a quasi-contemporaneity can generally be assumed after the exclusion of natural intrusions. Comparisons of contemporary or even causally related behaviour across wider geographical areas often lack this direct correlation and other means of chronological correlation are required. As shown in the previous chapters, this correlation on a common (calendar) timescale is necessary to consider two locally distinct developments as quasi-contemporary.
Even though the methodological problems such as the necessity of radiocarbon calibration or the biasing conditions of preservation should be considered as possible reasons for mistrusting the temporal successions in detail, approximate coincidences must be assumed valid based on the coherency of the present chronological framework. However, a problem with evaluating the limits in the archaeological record remained for sites formed by numerous repetitive visits. Limits based on these sites often have a significant standard deviation, even if the limit was only set when at least two sites of overlapping dating showed the changes in the attributes. Nevertheless, the number of analysed attributes (n = 37) helps to further sustain the observations.
To establish the process of change from the Late Magdalenian to the FMG, the previously presented summary graphs were joined to a single graph (**fig. 95**). The analysed archaeological attributes were then ordered chronologically according to the first limit within an attribute. In a second graph, all limits were used to create a cumulative presentation of the appearance of the changes (**fig. 96**).
The chronological order according to the first limit already reveals a generally gradual character of the process of change in the studied period of time. The appearances of first limits in the 37 assembled attributes range over more than 3,500 years. This finding indicates that adapting behavioural patterns was common in Lateglacial hunter-gatherer societies and gradual evolution appeared to have been the norm. Moreover, another important observation of this plot is that many alterations in the archaeological record were not directly related to climatic or environmental changes. Thus, even though the changes appeared gradually, chain reactions were not straightforwardly detectable. A classic causal chain that climate change was promptly followed by environmental variation which again forced humans to react directly was not found.


AO Densities
variable
low
AN Horse presence
dominant
subordinate
occasionally dominant
AM LMP variance (length)
low
high
low
AL Raw material acquisition
high quality
in CR
variable quality
high quality
AK Function index
very diverse
diverse
AJ LMP variance (thickness)
low
high
low
AI Roe deer presence
absent
present
absent
present in CH
AH % retouched artefacts
variable and occasionally very high
low, occasionally very low
low
AG Reindeer presence
present
occasionally present
absent
present at northern margins
AF Exploitation of faunal spectrum
intense
decreasing
less intense
AE Large bovid presence
Bison priscus
regular
Bos primigenius
AD Use of space
tell-like use of restricted space
peripheral shifting and activity areas with satellites
suburban use expanding the occupied area
AC Site differentiation
high
very high with two complementary types
low
AB Retouched artefact groups
very diverse and standardised
diverse but occasionally specialised and frequently numerous unstandardised tools
AA Presence of organic tools
frequent
infrequent
Z Intense exploitation of faunal material
"nothing is wasted"
co-occurrence
"something is burnt"
Y Assemblage composition
dominated by formally retouched
dominated by either formally retouched artefacts or cores
dominated by cores
X % borers
variable
variable, occasionally high
low
W Point / burin index
burin-dominated
burin-dominated to equal values
very variable
burin-dominated
V LMP types (dimensions)
single
two
three
one but different types?
U LMP types (shapes)
very few
increasing variety
very many
many
T End-scraper / burin index
burin-dominated
variable
highly variable
end-scraper-dominated

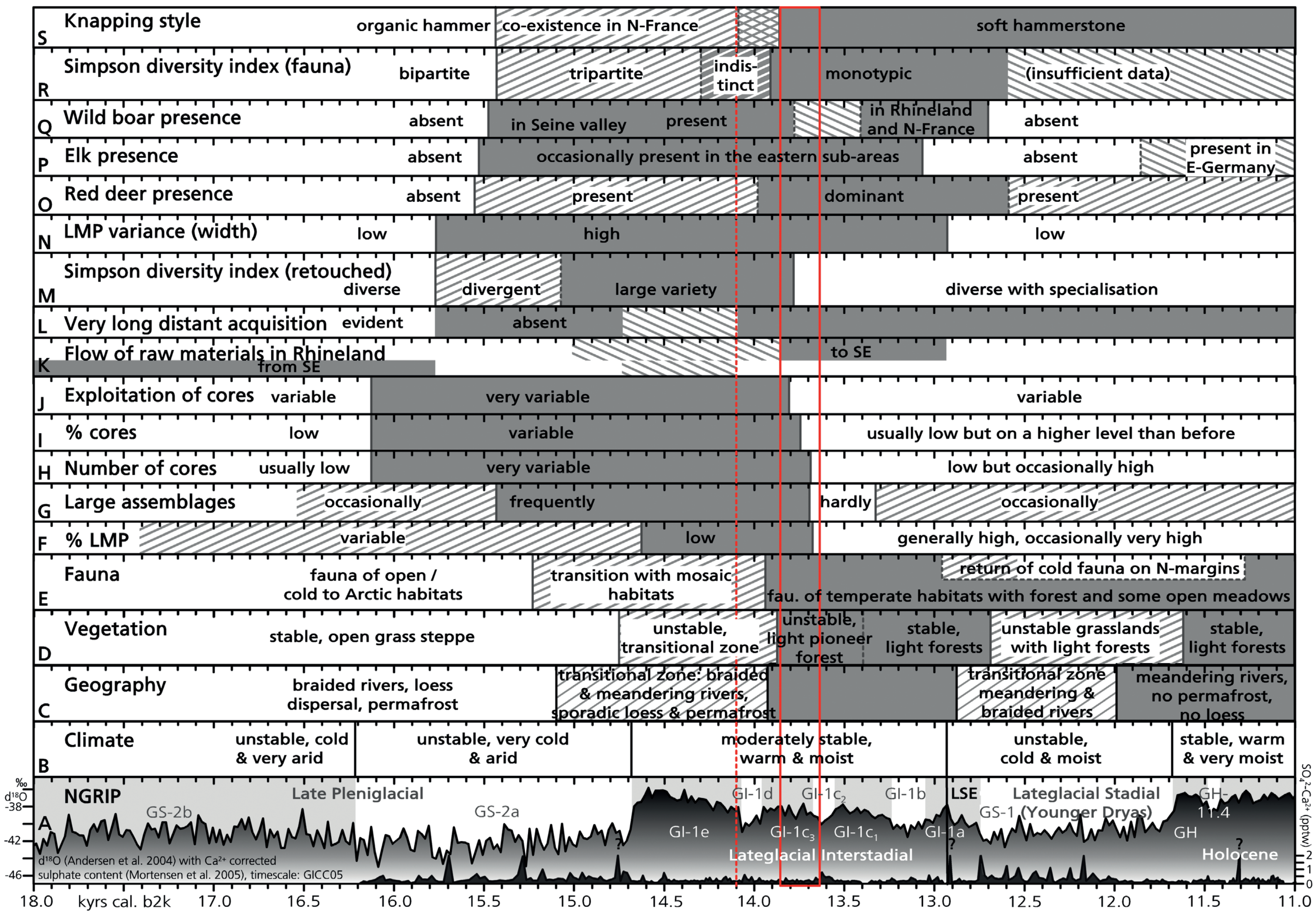


Fig. 95 Synthesis of changes in the archaeological material (**E-AO**) contrasted by the synthesised faunal (**E**; see **fig. 64**) and vegetation development (**D**; see **fig. 59**) as well as the changes in the physical environment (**C**; see p. 365-370), the climatic synthesis and the oxygen isotope record of NGRIP (**A-B**; see **fig. 53**). Hatched areas: transition periods; red lines: phase of rapid and accumulated change; dashed line: beginning of the prelude. – For further details see text.

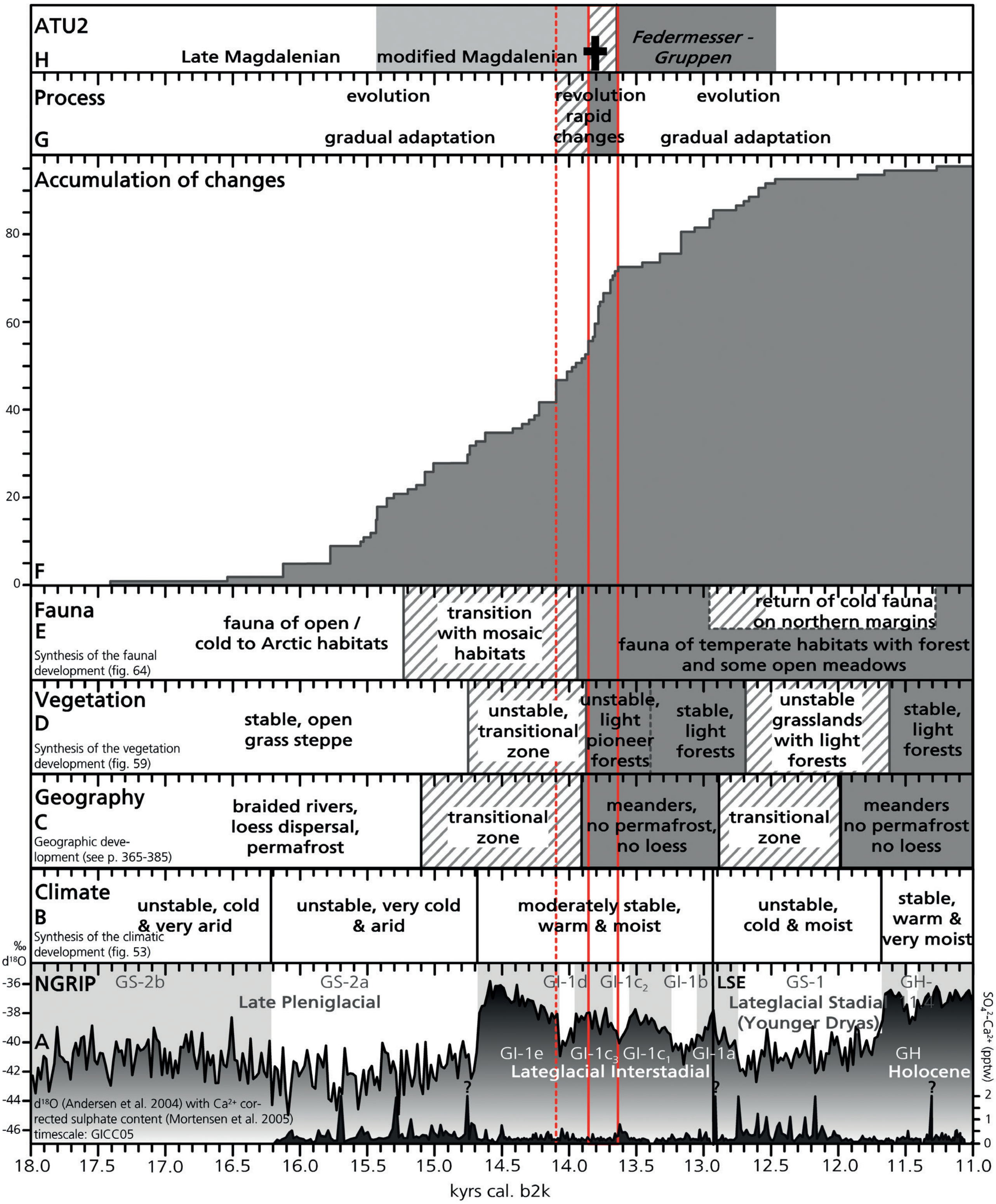


Fig. 96 Quantitative accumulation of changes observed in the archaeological material (**F**; see **fig. 95**), description of the transition process (**G**) and changes of the meso-scale archaeological taxonomic units (ATU2, **G**; see **tab. 62**) contrasted by the synthesised faunal (**E**; see **fig. 64**) and vegetation development (**D**; see **fig. 59**) as well as the changes in the physical environment (**C**; see p. 365-370), the climatic synthesis and the oxygen isotope record of NGRIP (**A-B**; see **fig. 53**). Hatched areas: transition periods; red lines: phase of rapid and accumulated change; dashed line: beginning of the prelude. – For further details see text.

In fact, variation in the archaeological record, in particular in the LMP inventories, occasionally preceded climatic and environmental changes. However, several of the considered lines of evidence were interrelated and, consequently, co-occurring changes in these interrelated characteristics appeared such as the increasing presence of various prey fauna in the inventories followed by a change in the diversity index or the appearance of a new knapping style accompanied by variations in the shape and dimensions of the LMP.
If the plot is examined for the main changes in the climatic record, the most significant change was the onset of the Lateglacial Interstadial. With this change only the first decrease of reindeer in the archaeological record coincided. The counting error of the ice-core record is approximately 200 years at this point. In a range of 200 years around this onset, changes in only two further attributes before and three attributes after the decrease of reindeer are observed. Thus, the onset of the Lateglacial Interstadial was no prominent break in the behavioural evolution. Reindeer, a species adapted rather to arctic environments, can be assumed to have reacted sensitively to the amelioration process and to have followed a more cold climate habitat further north. As reindeer possibly became rarer, it was only hunted in an opportunistic way. Some decades after the decreasing importance of reindeer, the proportion of the formally retouched artefacts dropped to a significant low. Whether this development was related to climate change remains uncertain and even a direct connection to the disappearance of reindeer can be questioned because the decrease of formally retouched artefacts was connected to the appearance of numerous sites with an intense blank production. These sites seem related to the frequent hunting of horses which were also previously hunted but, with the decreasing presence of reindeer, became the main focus prey. The hunt of these smaller, possibly semi-residential groups of animals made a different type of hunting camp possible on which additional tasks such as lithic raw material exploitation could be performed besides the hunting and butchering of the prey. However, shortly before the onset of the Lateglacial Interstadial, the proportion of smaller mammals was already decreasing. This change was possibly due to increasing alimentary security based on the development of more mosaic landscapes.
Some changes in the archaeological record appeared around the onset of GI-1d when cold and dry conditions returned, probably initiating the aeolian dispersal of coversands north of the study area (**fig. 42**). Perhaps due to the more severe impacts occurring northwards, no changes were found in the vegetation or faunal record. In the Central Rhineland assemblages, the quality of the acquired raw materials became more variable as well as the knapping style, whereas the variability in the function index decreased. Furthermore, connections over very long distances and those from the Central Rhineland to the Southeast were no longer identifiable. Together these changes suggest a deterioration in the standards of the well-connected Magdalenian groups. Nevertheless, all these changes are closely related to the end of the age range of the south-western area of Gönnersdorf and the beginning of the age range from the upper horizon of Andernach but no unambiguous equivalence in records from northern France. In the following centuries, changes again appeared more gradual.
A more gradual change in the climate record was the onset of the Lateglacial Stadial. Some changes were possibly related to this climatic fluctuation but the poor database at this transition makes such correlations difficult.
Analysing the plot in regard to the vegetation record, a non-congruent reaction to the climatic developments was highlighted. For instance, the transitional zone from a grass steppe to a light forest environment preceded the onset of the Lateglacial Interstadial in the isotope records of Greenland. The onset of this vegetation zone coincides with the settlement of the south-western area of Gönnersdorf and a possible reestablishment of long distance relations if the jasper pieces from this area were attributed to this later occupation. Moreover, approximately concurrent with this period, steppe bison disappeared from the archaeological inventories and was substituted by aurochs. This correlation of the presence of two differently adapted spe-

cies with changes in the vegetation seems unsurprising and can be interpreted comparably to the decreasing presence of reindeer. In addition, decreasing proportions of smaller mammals in faunal assemblages correlate with this onset and raises the question of whether plants were substituted for the smaller mammals. The preservation of vegetation remains from this period is poor and makes a pursuit with this hypothesis fruitless for the moment. The next change in the vegetation record was the wide-spread establishment of pioneer forests. This change was concomitant with several changes in the archaeological record such as the abandonment of the regular use of organic hammers in the knapping process, the establishment of generally diverse faunal inventories, the disappearance of clear evidences for conforming to a »nothing is wasted« ideal, the appearance of more uniform site types, proportions of smaller mammals becoming almost insignificant, the final disappearance of reindeer from the study area, the dominant acquisition of qualitatively poorer raw materials, and a decreasing importance of horse. However, the burial sites found in the Central Rhineland also originate from the onset of this period. The majority of change to a more boreal fauna occurred shortly before or possibly in many places concomitant with this vegetation change. Changes accomplished shortly before the shift in the vegetation were mainly relate to a new succession in the faunal record. For instance, red deer became a dominant species with the accomplishment of the faunal shift. At approximately the same time, the more suburban use of space on a site appeared and, in particular, the high variances of length and thickness of the LMP are very probably related to this faunal change. The earlier onset of the transitional fauna zone was also closely related with the appearance of burnt faunal material. The later establishment of stable light forests in the study areas was only accompanied by the appearance of wild boar in the assemblages from the Central Rhineland and northern France.
The numerous limits observed around the transition to a generally more forested environment were possibly the result of a temporally close occurrence of changes in the fauna and plant environment as well as the rapidity of this establishment after the cold phase within the early Lateglacial Interstadial. Further changes occurred within the 250 years following the establishment of first pioneer forests with a more boreal fauna and, thus, almost 75 % of the observed attributes are affected by these changes marking this as the period of major change in the archaeological record. Besides the number and tempo of changes, the quality of the changing patterns increases. This higher quality can be established by relating the analysed attributes to the provisional hierarchy of archaeological taxonomic units (tab. 62). Moreover, after this period the values typical for FMG are generally established.

In summary, the number of recorded differences made the establishment of a general development in the archaeological record possible and, besides methodological reasons, the behaviour and, in particular, the resilience of the Magdalenian provides a plausible explanation for the observed succession of these not necessarily related developments (see Discussion, p. 565-574).