Supplementary information

Methods and data

Radiocarbon dating

Plant remains were extracted from the sediment by wet sieving, acidified (10% HCl), cleaned with distilled water and dried in pre-cleaned (distilled water) glass vials at 105°C overnight. The dried samples were then submitted to radiocarbon laboratories, where pre-treatment procedures varied slightly. At the Lund Radiocarbon Laboratory (LuS) plant macrofossil samples with <4 mg dry weight were not pre-treated, while samples >4 mg dry weight were pre-treated as follows: 0.5% NaOH at room temperature for 0.5 hr, followed by HCl at 80°C for 1 hr, rinsing with distilled water and drying at 105°C overnight.

Pollen grains were isolated from the sediment samples following chemical and micro-sieving methods described in detail in [1-3]. The resulting pollen concentrates consisted primarily of bisaccate conifer pollen. Pollen concentrates were rinsed with distilled water and dried at 105°C overnight prior to graphitization at the radiocarbon laboratory.

The insoluble (INS) fraction was pre-treated with 2% HCl at 80°C overnight, followed by 2% NaOH at 80°C for 5 hr. At the Poznan (Poz-) and Uppsala (Ua-) radiocarbon laboratories samples were subjected to an acid-alkali-acid treatment that consisted of 1% HCl for 8-10 hr just below the boiling point, 0.5% NaOH for 1 hr at 60°C, and acidification to pH 3, after which the samples were dried at 105°C overnight prior to graphitization.

The $\delta^{13}C$ results indicate that samples labeled “plant detritus” were mainly composed of limnic plant material ($\delta^{13}C$ -11 to -20 ‰), although some samples also contained terrestrial plant fragments ($\delta^{13}C$ >20 ‰) (Table 2). Limnic plant material from hard water lakes is prone to a hard-water effect since limnic plants take up C from the ambient lake water during photosynthesis. However in the case of Les Echets we judged that this effect is negligible except for Poz-2492, because (i) pollen concentrates from comparable levels resulted in similar age determinations and (ii) the 95% confidence interval of the measurements is larger than the hypothetical hard water error [4].

Because most of the radiocarbon dates of core EC1 are older than the internationally ratified IntCal04 calibration curve [5], we evaluated alternative comparison curves [6] for constructing age models. The use of glacial comparison curves is being debated [7-16]. Both Hughen06 [17] and Fairbanks05 [8] (SI Fig 1) are based on marine radiocarbon dates and thus have the added uncertainty of an imprecisely known and possibly varying marine reservoir effect. Hughen06 is based on tuning of its sediment greyscale with the $\delta^{18}O$ record of the high-resolution ^{230}Th-dated Hulu Cave speleothem [18]. Despite the increased resolution offered by this updated calibration set, it has not yet been securely or independently anchored to known calendar years. The comparison curve of Fairbanks05 is based on independently U/Th dated corals and is therefore not tuned to other records. However, the reliability of the data has been debated [9,13,15]. Both comparison curves possess considerable calendar age uncertainties, quoted as c. 50-100 yr for Fairbanks05 and c. 300-500 yr for Hughen06. Hughen06, obtained from continuous sediment cores, is more evenly spread over time than Fairbanks05, which was derived from individual corals. The resolution of Hughen06 is higher (2-646 yr, average 134) than that of Fairbanks05 (1-3455, average 376). In order to take into account the uncertainties on the calendar as well as the radiocarbon age scales, we re-sampled each data point of the Hughen06 or Fairbanks05 curve assuming normal errors on the radiocarbon and calendar age scales, and repeated this process 10,000 times. From linear interpolations between each sampled data set, we calculated the 1 sd highest posterior densities on the radiocarbon age scale at 50 calendar year resolution.

IRSL dating

Sampling and preparation for infrared stimulated luminescence (IRSL) dating was carried out under subdued red-light conditions. The outer parts of the half-cores were removed and the inner part that was not exposed to daylight was sampled for dating. Altogether, 32 samples were taken from Core EC-1 from which 21 have been investigated so far (Table 2). The polymineral fine grain fraction (4-11 µm) was extracted after chemical pre-treatments (HCl, H_2O_2, Na-Oxalate) by settling using Stokes' law. The silt fraction was used because sufficient amounts of sand size grains were not available in the lacustrine deposits. We did not attempt to extract the quartz fraction from the samples since usually this mineral has poor luminescence properties in areas around young orogenic systems such as the Alps [19,20]. However, previous experience suggests that K-feldspars, which will dominate the investigated IRSL signal from polymineral fine grains, are a reliable natural dosimeter in the Alpine realm [21-23].

Determination of D_E was carried out using the modified single-aliquot regenerative-dose (SAR) protocol [21]. A preheat temperature of 290°C and a cut heat of 200°C were applied. This procedure was crosschecked by preheat and dose recovery tests, applying a dose of the same magnitude as the natural dose. The average ratio of applied/regenerated dose for the investigated samples is 1.04 ± 0.07.

Measurements were carried out using Risø TL/OSL readers. The detection filter was a combination of a Schott BG-39, a Schott GG400, and a Corning 7-59 giving a peak emission at ~410 nm. IRSL was recorded during a 300 s shine-down of IR-diodes. The integral 200-300 s was subtracted from the rest of the IRSL decay curves as late-light and the signal of the first 5 s was used for constructing dose response curves. All samples showed recycling ratios close to 1.00 and low recuperation (3-4%). At least seven aliquots were measured for each sample. The plot of D_E versus stimulation time shows a flat plateau (data not shown), indicating complete bleaching of IRSL prior to deposition. Furthermore, many previous studies have demonstrated that lacustrine samples are usually well bleached [24-30]. Although optical dating of feldspar from some regions seems to systematically underestimate the known age of a sample due to fading of the luminescence signal, previous luminescence dating in the Alpine region [22,31] indicates that feldspars from these areas are not affected by this phenomenon. We can confirm this observation by the results of storage tests carried out for selected samples from Les Echets that do not show any loss of signal within a year.

Dose rate relevant elements of all samples were determined by ICP-MS [32] using updated conversions factors [33]. The validity of the analytic procedures was cross-checked by measuring certified reference material. The samples could not be tested for radioactive equilibrium due to the limited amount of material available for high-resolution gamma spectrometry. However, sediments such as the silts investigated in the present study are usually not significantly affected by radioactive disequilibrium [26,30-34]. The contribution from cosmic rays to the total dose rate was calculated using present day depth [35]. Dose rates were determined using a mean a-value of 0.07 ± 0.02. Past changes in water content are seen as the major source of uncertainty in IRSL dating at Les Echets. Due to the consolidation of lacustrine sediments, it is likely that average moisture in the past was higher than today. To estimate the effect of attenuation of radioactive radiation by water in the sediment pores, we corrected present day moisture measurements for an assumed 80±10% average water content over time. This correction procedure is confirmed by the dating of pre-Eemian sediments from the lowermost part of the core (Preusser, unpublished data).

Age model

Some of the lowermost radiocarbon dates are close to the background limit of the Lund AMS laboratory and might thus not be reliable. AMS laboratories regularly measure samples with no remaining radiocarbon to estimate the background. Samples from the same batch which end up too close (< 2 sd) to this background age are given infinite/"greater than" ages. Two samples were assigned infinite ages (dates LuS6297, >46 k, and LuS6298, >40 k), while samples from the same batch (LuS6299, 38550±1500 ^{14}C BP at 3000 cm depth and LuS6296, 39400±1400 ^{14}C BP at 2830 cm depth) were assigned finite ages. The lowermost date (LuS6154, 39320±600, 3097 cm depth) has not been pretreated and is therefore not considered to be reliable either. This part of the sediment sequence has several sand layers with sharp, erosive upper and lower boundaries, which indicate reworking and redeposition of sediments and likely also sedimentary hiatuses. This observation gives further evidence that the sediments in the lowest part of the analyzed sequence might be older than suggested by the radiocarbon dates. Therefore we assigned 95% prior outlier probabilities (see below) to the lowermost two radiocarbon dates.

The prior outlier probabilities were adapted for the dates at 1653 (IRSL date LEI-7k) and 1605 cm (radiocarbon date LuS6180). When their original outlier probabilities were used in initial runs, the age-depth modelling process would put the dates on the comparison curve, with an inferred long-lasting hiatus around those depths as a result. Because there were no stratigraphical or other indications for a hiatus in that section (as opposed to around 2700 cm [36]), we assumed that the dates were erroneous, and adapted their prior outlier probabilities to 95%.

The age models were constrained by prior information [37,38]: *i*) the depositional setting dictates that the dated depths must be ordered chronologically; *ii*) deposition rates of 5-15 yr/cm are most likely, but other accumulation rates are possible (AlphaM 12, AlphaStd 4); *iii*) the variable stratigraphy suggests that rapid accumulation rate changes and hiatuses could have occurred (Epsilon 2); *iv*) hiatuses are most likely to be short, but could at times last millennia (HiatusA 10^{-4}, HiatusB 10^{-5}); and *v*) every date has a prior probability of being outlying (5% for most dates; 50% for those ^{14}C dates which could not be pre-treated, had a sample weight <1 mg or were possibly altered by a hard-water effect; 95% for dates LUS6180, LEI-7k, LuS6299 and LuS6154; SI Table 1). Outlying dates were not removed but were identified and down-weighted automatically.

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Captions SI

SI Table 1. Radiocarbon dates and outlier probabilities of core Les Echets. *a*: material consisted of plant detritus (pld), plant remains (plr), pollen concentrates (pol), or sediment/insoluble material (sed). *b*: material was treated as follows: HCl followed by NaOH followed by HCl (aba), NaOH followed by HCl (ba), HCl followed by NaOH (ab), rinsed with distilled water (H2O), or no treatment (-). *c*: prior outlier probabilities, *d*: posterior outlier probabilities Hughen06 run, *e*: posterior outlier probabilities Fairbanks05 run. Mean posterior outlier probability 33.6% for Hughen06, 37.1% for Fairbanks05.

SI Table 2. IRSL dates and outlier probabilities of core Les Echets. *a*: prior outlier probabilities, *b*: posterior outlier probabilities Hughen06 run, *c*: posterior outlier probabilities Fairbanks05 run. Mean posterior outlier probability 6.8% in Hughen06 run, 6.6% in Fairbanks05 run.

SI Fig 1. The Hughen06 (green [25]) and Fairbanks05 (red [26]) comparison curves from 40 to 26 ka. Shown are 1 standard deviation error envelopes, taking calendar age uncertainties into account.

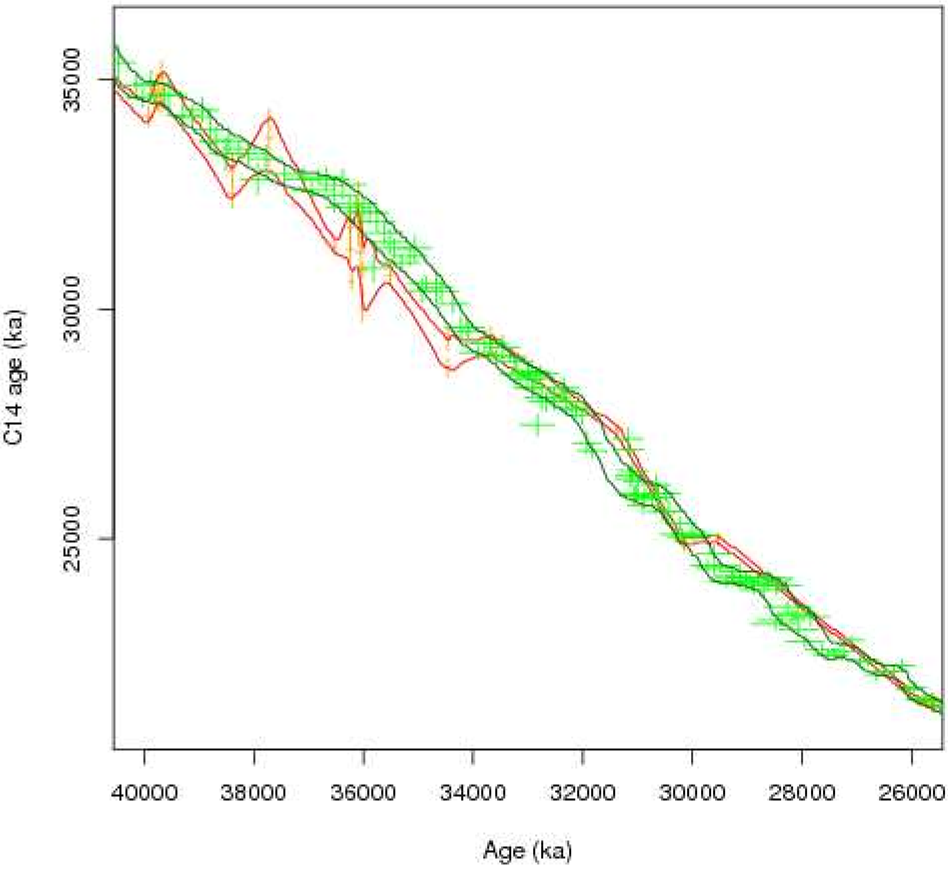
SI Table 1

Lab id.	depth (cm)	material[a]	weight (dry, mg)	treatment[b]	^{14}C age (BP ± sd)	prior[c] (%)	Hugh06[d] (%)	Fair05[e] (%)
Poz2492	566	pld	19	aba	17090 ± 90	50	67.9	66.4
LuS6151	1120	pld	3	--	15310 ± 160	50	92.9	94.9
LuS5988	1300	pld	1	--	17100 ± 400	50	66.0	77.4
LuS6180	1605	pld	2	--	20030 ± 140	95	95.5	96.4
LuS6152	1670	plr	8	ba	22625 ± 120	5	2.3	18.3
LuS6179	1740	plr	5	ba	22210 ± 120	5	3.0	61.1
LuS6072	1770	plr	8	ba	23175 ± 105	5	3.9	6.5
Poz2493	1829	plr	48	aba	23890 ± 150	5	0.5	30.1
LuS6387	1896	pol	4	H2O	23500 ± 150	5	0.9	4.7
LuS6178	1953	plr	8	ba	24490 ± 170	5	5.4	36.2
LuS6069	1987	plr	2	--	21090 ± 170	50	100.0	100.0
LuS6177	2022	plr	15	ba	23820 ± 140	5	1.2	54.1
LuS6070	2031.5	plr	13	ba	24945 ± 120	5	79.1	39.2
LuS6289	2052	plr	9	ba	24350 ± 250	5	0.5	1.3
Ua16654	2080	plr	1.5	aba	24310 ± 470	5	0.3	0.5
LuS6176	2113	plr	10	ba	24725 ± 140	5	0.2	1.0
LuS6073	2171.5	plr	2	--	24455 ± 210	50	63.5	74.4
Ua16739	2185.5	plr	2.3	aba	26115 ± 195	5	1.1	2.4
LuS6291	2300	sed	>50	ab	27700 ± 250	5	1.6	0.7
Ua16770	2312	plr	0.5	aba	21245 ± 220	50	100.0	100.0
LuS6292	2354	sed	>50	ab	30850 ± 350	5	99.5	99.3
LuS6386	2378	pol	4	H2O	23200 ± 150	5	100.0	100.0
LuS6293	2384	sed	>50	ab	30150 ± 400	5	41.0	17.6
LuS6294	2412	sed	>50	ab	28600 ± 300	5	1.0	0.7
LuS6353	2424	pol	12	H20	28800 ± 300	5	0.7	0.5
LuS6295	2440	sed	>50	ab	29450 ± 300	5	0.6	0.4
Ua16660	2474	plr	2.4	aba	30005 ± 190	5	6.0	7.4
LuS6352	2486	pol	6	H2O	26950 ± 200	5	100.0	100.0
LuS5990	2508	plr	2	--	27600 ± 500	50	96.9	96.7
LuS6385	2510	pol	4	H2O	29750 ± 200	5	0.9	0.7
Ua16658	2547	plr	1.8	aba	31170 ± 850	5	0.4	0.5
Ua16824	2562	plr	2.5	aba	31200 ± 350	5	0.1	1.9
LuS6300	2582	pol	13	H2O	27400 ± 200	5	100.0	100.0
LuS6354	2622	pol	12	H2O	31200 ± 350	5	0.5	0.6
Ua16749	2630	plr	1.7	aba	30815 ± 340	5	0.6	0.5
Ua16850	2668	plr	2.3	aba	32010 ± 225	5	0.1	1.6
LuS6384	2706	pol	4	H2O	31950 ± 250	5	0.5	0.7
LuS6355	2730	pol	12	H2O	31800 ± 350	5	0.6	0.9
LuS6020	2735	sed	10	ab	32700 ± 400	5	0.8	1.0
LuS5991	2748	plr	2	--	27450 ± 700	50	100.0	100.0
Ua17108	2815.5	plr	2.3	aba	35300 ± 365	5	8.6	9.2
LuS6296	2830	sed	>50	ab	39400 ± 1400	5	1.3	1.5
LuS6018	2840	sed	10	ab	40000 ± 800	5	1.0	1.6

SI Table 2

Lab id.	IRSL age (yr ± sd)	depth (cm)	prior[a] (%)	Hughen06[b] (%)	Fairbanks05[c] (%)
LE1-1k	24900 ± 3200	549	5	2.8	2.2
LE1-2k	24300 ± 3100	655.5	5	1.3	1.0
LE1-3m	21200 ± 2700	829.5	5	0.3	0.3
LE1-5m	23000 ± 3000	1132.5	5	0.4	0.4
LE1-6k	24300 ± 3200	1393	5	0.3	0.3
LE1-7k	23800 ± 3000	1653	95	58.9	57.1
LE1-8k	32400 ± 4300	1810	5	0.4	0.5
LE1-9k	28700 ± 3700	1895.5	5	0.3	0.2
LE1-10k	28000 ± 3800	2000	5	0.3	0.3
LE1-12m	28700 ± 3800	2104.5	5	0.3	0.2
LE1-15k	40600 ± 6300	2241.5	5	0.7	0.8
LE1-16m	33000 ± 4400	2314	5	0.3	0.2
LE1-21k	33500 ± 4400	2551	5	0.2	0.3
LE1-22m	40000 ± 5300	2653.5	5	0.3	0.4
LE1-24m	37500 ± 5000	2707.5	5	0.3	0.3
LE1-26k	44500 ± 6000	2793.5	5	0.5	0.4
LE1-28k	68200 ± 9000	2851	5	8.8	8.0
LE1-29m	65200 ± 9200	2910.5	5	2.6	2.7
LE1-30k	83600 ± 11800	2930	5	28.2	27.7
LE1-32k	90500 ± 13000	2985	5	38.6	37.9
LE1-33m	76900 ± 12100	3050.5	5	3.7	4.0

SI Fig. 1


35000
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