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Age limits on the Late Quaternary evolution of the upper Loire River☆

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Abstract

The Loire River is one of the largest rivers in Europe, draining a basin area of southern France which exceeds 100,000 km^2. Despite its significance, the Loire remains poorly studied and has a very limited amount of chronological control on the deposited sedimentary record of fluvial activity. These factors, coupled with the availability of a set of 10 radiocarbon dates on younger (c., < 5 ka) Loire terraces, have encouraged us to commence an intensive programme of optical dating on terraces from the upper Loire. We have obtained relatively good agreement between single-aliquot regeneration (SAR)-based age estimates and AMS dates, and have extended the chronology of the terraces back into the middle Weichselian. Our data indicate that the key shift in fluvial style from a braided gravel-bedded system through to a sand and silt dominated system occurred at around the time of the Pleistocene–Holocene transition. © 2000 Published by Elsevier Science Ltd.

1. Introduction

Although a large number of studies have used proxy records from Western Europe, and particularly Central France, to establish the nature of climate change over the last 140 ka (e.g., Guiot et al., 1992; Pons et al., 1992; Reille and Beaulieu, 1995; Siffendine et al., 1996), few have attempted to analyse the impact of such changes on the landscape. Yet this is important for assessing how climate and land use changes may impact future landscapes. Studying the response of large rivers to climate change provides a useful starting point for investigating the regional response of landscapes, since rivers are an important, near-ubiquitous component. The ultimate aim of this study is to provide a detailed chronology for the terraces of the Loire and Arroux rivers, in particular for those terraces that are near to or beyond the age range of radiocarbon dating. Chronological control of these terraces is vital for interpreting the response of the Loire River system to late Quaternary climate change.

The Loire River is the longest river in France and flows 1012 km from the source at Mont Gerbier de Jonc in the Massif Central northwest across the Paris Basin before discharging into the North Atlantic south of Nantes at St Nazaire. It drains an area of 115,112 km^2 and has a mean discharge of 32 km^3 pa (Manickam et al., 1985; Stanner and Bordeau, 1995). Relatively little research has been carried out on the Loire river or its deposits (e.g., Dacharry, 1981). Late Pleistocene fluvial deposits have been mapped for the Loire (Mangin, 1961–62) but lack any rigorous chronological and assumed to correlate with periglacial conditions associated with ‘Wurmian’. Recently, there has been more research into the terraces of the Allier, the largest of the Loire tributaries which joins the Loire at the town of Nevers tributary (e.g., Kroonenberg et al., 1988; Lenselink et al., 1990; Veldkamp and Kroonenberg, 1993).

The study area sampled in this project is located in the middle Loire valley, centred around the confluence of the Loire and Arroux rivers near Digoin (Fig. 1). This section of the Loire was chosen as hydrological changes are thought to be best expressed in the middle course of a river where each substantial change in discharge and sediment load is reflected in the transformation of the channel pattern, sediment type (facies) and deposition rate (Williams et al., 1998). In addition, the middle Loire is upstream from any potential impacts of Quaternary glacio eustacy or other basinal processes such as subsidence. The drainage basin is geologically heterogeneous, consisting of deformed Proterozoic and Paleozoic crystalline and sedimentary rocks, around which are wrapped a succession of Mesozoic and late Cenozoic marine and continental strata (Joly, 1984). Volcanic rocks cover upland reaches of the Massif and Morvan (the extension of the Massif Central northward into Burgundy) regions

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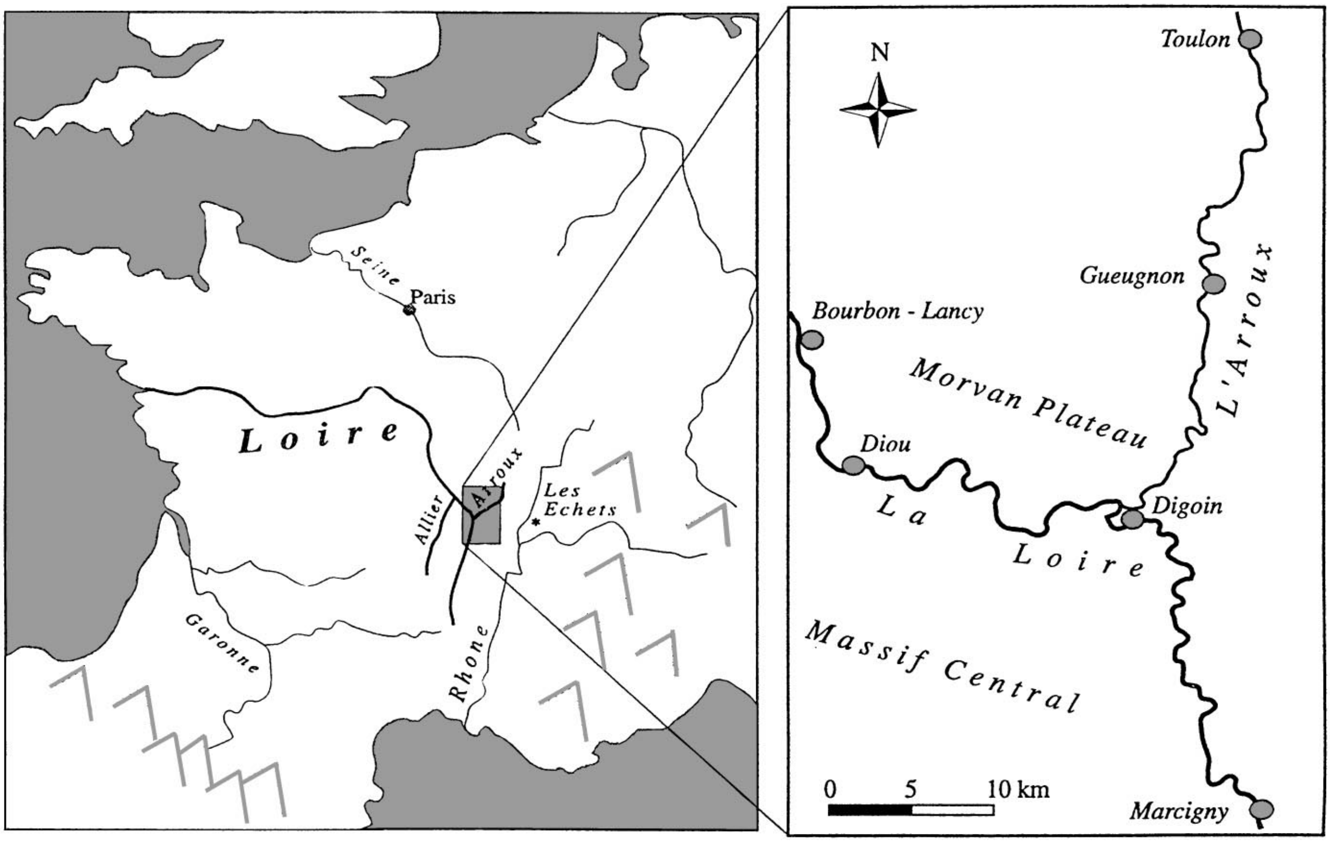

Fig. 1. Location of the study area (from Straffin et al., 1999).

and consequently many of the fluvial sediments are rich in quartz and potassium feldspars.

Seven distinct allostratigraphic units within and capping the valley walls of the Loire and Arroux rivers were identified representative of the preserved Middle Pleistocene–Holocene alluvial history. Analysis of the well-preserved surface morphology and corresponding facies architecture reveals a distinct trend from braided to meandering channel planforms, coupled with decreases in channel width and sinuosity through time. Soil profile development, gravel lithology and clast size were also used to differentiate individual depositional units. We attempted to collect samples representative of all the terrace units.

2. Experimental procedures

Samples were collected by hammering (labelled) opaque, PVC cylinder (5 cm diameter × 20 cm length) into freshly cleaned, vertical exposures of sediment. The bulk sample was initially left overnight in dilute HCl to remove carbonates and to assist in the disaggregation of clay. The samples were then wet sieved at various fractions (90–125, 180–212, 212–425 and 425–600 μm). Quartz and other light mineral grains were separated from denser minerals using sodium polytungstate ($\rho = 2.75\ \mathrm{g\,cm^{-3}}$). In order to remove all remaining non-quartz material (in particular any feldspars), the samples were etched for 1 h in concentrated (c. 48%) hydrofluoric acid (HF) and then left in 35% fluorosilicic acid (H_2SiF_6) for 48 h. The refined quartz was rinsed thoroughly and stored in sealed containers. Sample aliquots were made up by mounting the refined quartz grains as monolayers onto aluminium discs (10 mm diameter × 1 mm thickness) with Silkospray.

Equivalent dose (D_E) measurements were made on a TL/OSL-DA-15 RISØ system. Aliquots were stimulated by exposure to a blue/green-filtered halogen (c. $20\ \mathrm{mW\,cm^{-2}}$ at sample (Bøtter-Jensen, 1997)), while OSL emissions were detected using an Electron Tubes 9635Q photomultiplier (PMT) filtered with two U-340 filters.

The basic SAR procedure adopted during this study is similar to the approach most recently described (Murray and Wintle, 2000). Five or six aliquots of each sample were prepared and analysed. Best estimates of equivalent doses (D'_E) were used to establish a regeneration dose sequence which typically ranged sequentially from 0.5 D'_E, 1 D'_E, 1.5 D'_E. The initial regeneration dose (0.5 D'_E) was then repeated to confirm the validity of the sensitivity correction (a so-called 'recycling ratio'). The distribution of the D_E estimates for each sample was then evaluated and graphically summarised.

OSL measurements of preheated aliquots were made at the elevated temperature of 125°C for either 60 or 100 s. The first second of OSL stimulation was used for both the natural, regenerated and test-dose response OSL. A background signal was estimated from the last 10 s and subtracted from the initial signal. For the test-dose signal, this background was estimated from that of the previous natural or regenerated OSL signal. This minimised sensitivity due to any continuing underlying decrease in the residual OSL signal, left over from the main dose and sitting underneath the (small) test-dose signal (Murray and Wintle, 2000). A 280°C, 10 s preheat was routinely used in the aforementioned studies and is also adopted here for all SAR analyses.

All dose rate and radioisotope concentration estimates are based on portable 4-channel NaI γ-spectrometry (Aitken, 1985).

One of the major advantages of single-aliquot analysis is that a separate D_E estimate is obtained for each aliquot measured. The scatter in estimates for a particular sample can yield important information about its bleaching history. This has implications for the dating of fluvial samples, where bleaching may often have been heterogeneous.

By plotting the D_E estimate for each aliquot against its natural OSL intensity it is possible to assess the bleaching history of a sample (e.g., Li and Wintle, 1992; Clarke, 1996). In a well-bleached sample, although the natural intensities may be variable, the D_E estimates should be the same within errors. In contrast, poorly or heterogeneously bleached samples will exhibit variability both in D_E and natural intensity due to remnant doses from previous depositional phases (Clarke, 1996).

In situations where the single-aliquot data indicate a mixture of well-bleached and poorly bleached grains, the true D_E is thought to lie towards the bottom end (best-bleached) of the range of D_E derived from the single-aliquot analysis (Duller, 1996; Olley et al., 1998, 1999).

In this study a modified approach was adopted (following Colls, 1999) in which standardised

$$t = r\sqrt{\frac{N-2}{1-r^2}}$$

(mean $= 0$; SD $= 1$) plots of D_E versus signal intensity are examined to test for partial bleaching. Using the standardised plots it is possible to readily visualise the covariance within the dataset and test for the significance of any trend in the D_E versus OSL intensity relationships by examining the statistical significance of the resulting Pearson's Correlation Coefficient (r). The significance of the trends was estimated by establishing the correlation coefficient (r) for each data set and generating a test statistic (t) (after Norcliffe, 1982). Comparison of the value for this test statistic to a one-tailed Student's-t distribution (using N-2 degrees of freedom) allows the identification of statistically significant relationships.

The individual D_E estimates and statistical measures are provided in Table 1. A summary of 'behavioural' categories is provided in Table 2. Samples in category A exhibit no apparent relationship between signal intensity and D_E, which implies the samples are well- (or at least uniformly) bleached. In contrast, samples in category B do show a statistically significant correlation ($r^2 > 0.55$) between the signal intensity and D_E, which is suggestive of partial bleaching. The third class of sample (C) contains those samples which are well bleached with the exception of a single outlier (estimate > 3 SD from mean) aliquot which tends to strongly bias the correlation.

The D_E estimates were divided by the dose rates to obtain optical ages (Table 3). Errors on the ages were derived from uncertainties in both D_E and dose rates (added in quadrature).

3. Results

It is clear that although some samples ($\sim 32\%$) exhibit evidence of partial bleaching, the majority do not. This is an important observation as it suggests, at least for the Loire samples in this limited (typically $N = 6$ aliquot) analysis, that optical resetting in fluvial environments is more complete than often assumed.

Three grouped D_E estimates are provided for each of the Loire samples; the minimum, the mean and the weighted mean values (Table 2). For some samples there is little difference between the three estimates (e.g., 14/1, 21/1). For other samples the difference is substantial (e.g., 1020/2, 16/2). Which of these D_E estimates was used as the 'best estimate' for age calculation depended upon the bleaching characteristics identified. The mean estimate was used for the well-bleached samples of group A. The minimum estimate was taken as the 'best estimate' for samples of category B which exhibit clear evidence of partial bleaching (e.g., Duller, 1996). It is noted that the minimum estimate may still represent an overestimation and the resulting optical ages should probably be viewed as a maximum estimate for such samples. For samples of category C, the weighted mean estimate was used as this tends to minimize the influence of any outlier estimates.

The optical age estimates generated are stratigraphically sensible in terms of the sequence of terrace units (Fig. 2). We have further confidence in the chronostratigraphy as the sample collected from the modern river point bar indicated residual ages for two separate grain sizes to be of the order of 300 years (Table 4); implying low residual signal levels at deposition. Additionally, for the units where more than a single sample was collected (6, 8, and 9), all agree at 1 SD. Further, the age estimates for the youngest terraces (T2, T3, and T4) are in good

Table 1
SAR D_E estimates and summary statistics[a]

Site[b]	Unit	Sample [grain size (μm)]	SAR D_E estimates (Gy)						Summary statistics						Median mean	CV (%)	R^2	t
			1	2	3	4	5	6	Min.	Max.	Med.	Mean$_{wtd}$	Mean$_{unwtd}$	SE				
1	Moder n	19/1 (90–212	2.15 ± 0.02	1.97 ± 0.01	1.62 ± 0.01	2.16 ± 0.01	4.47 ± 0.03	3.1 ± 0.02	1.62	4.47	2.16	1.85	2.29	± 0.34	0.94	57	0.17	0.91
1	Modern	19/1 (425–600)	1.18 ± 0.02	2.5 ± 0.07	1.33 ± 0.01	1.97 ± 0.03	2.47 ± 0.04	3.59 ± 0.03	1.18	3.59	2.22	1.39	1.93	± 0.29	1.15	64	0.24	1.12
2	T2	1026/2 (90–125)	3.55 ± 3.93	2.66 ± 0.06	2.04 ± 0.02	3.28 ± 0.03	17.84 ± 0.14	3.28 ± 0.03	2.04	17.84	3.28	2.76	5.44	± 2.22	0.6	219	0.90	6.00
3	T2	1021/1 (90–125)	4.62 ± 0.03	6.33 ± 0.07	6.48 ± 0.06	4.88 ± 0.03	5.77 ± 0.04	5.5 ± 0.04	4.62	6.48		5.23	5.59	± 0.27	1.01	14	0.66	2.78
4	T3	21/1 (212–425)	16.74 ± 0.24	19.1 ± 1 0.08	16.14 ± 0.17	15.26 ± 0.12	16.8 ± 0.08	19.65 ± 0.19	15.26	19.65		15.5	17.28	± 0.56	0.97	11	0.19	0.97
5	T4	1020/2 (90–125	43.8 ± 0.5	84.8 ± 0.6	92.4 ± 0.8	115.7 ± 0.7	57.5 ± 0.5	216 ± 1.5	43.8	216		74.6	101.7	± 22.4	0.9	83	0.86	4.96
6	T5	14/1 (90–212)	69 ± 5.8	57.6 ± 4.9	53.6 ± 2.9	44.8 ± 3.8	58.3 ± 6.4	64.7 ± 4.5	44.8	> 69		54.2	58	± 3.1	1	16	0.01	0.20
7	T5	15/1 (425–600)	104.1 ± 3.3	132.8 ± 1.8	92.8 ± 2.8	123.8 ± 3.2	91.5 ± 5.4	125 ± 3.9	66.2	> 150		92.6	103.6	± 7.7	1	22	0.03	0.35
7	T5	15/2 (425–600)	> 148	90.3 ± 2.2	86.7 ± 2.8	81.1 ± 1.7	127.3 ± 5	109.7 ± 2.2	81.1	> 148		96.7	107.2	± 8.5	0.8	20	0.60	2.45
8	T5	1024/1 (90–125)	112.8 ± 2.1	83.7 ± 1.3	91.6 ± 1.4	90.8 ± 1	136 ± 1.7	135.3 ± 2.0	83.7	136		100.1	106.3	± 8.5	0.9	23	0.01	0.20
8	T5	18/1 (90–212)	109.5 ± 10.6	87.8 ± 13.5	139.6 ± 8.6	101.7 ± 33.2	107.3 ± 7.2	92.1 ± 6.1	87.8	139.6		94.4	91.7	± 5.9	1.1	20	0.68	2.91
9	T5	1025/2 (90–125)	117 ± 2.2	147 ± 3.2	77.2 ± 1.7	60.9 ± 1	86.2 ± 0.7	64.7 ± 0.9	60.9	147		77.6	92.1	± 12.2	0.9	43	0.02	0.29
9	T5	20/1 (212–425)	102.6 ± 0.7	137.6 ± 2	112.4 ± 0.9	119.4 ± 1.7	89.8 ± 3.1	111.3 ± 1.1	89.8	137.6		97.1	99.6	± 5.2	1.1	17	0.04	0.41
10	T6	1022/1 (90–125)	109.9 ± 0.3	184.4 ± 0.4	132.4 ± 0.4	160.4 ± 0.4	199.4 ± 0.7	121.5 ± 0.4	109.9	199.4		136.9	151.3	± 13.1	1	26	0.07	0.55
11	T6	1023/2 (90–125)	462.9 ± 13.3	> 500	303.7 ± 6.3	500	379 ± 7.6	434.1 ± 6.3	303.7	> 500		418.3	429.9	± 24.8	0.9	17	0.43	1.73
11	T6	17/1 (425–600)	267.7 ± 13.3	> 500	> 500	289.3 ± 4.3	206.9 ± 19.8	299.7 ± 15	206.9	> 500		353.5	343.9	± 40.4	0.8	12	0.40	1.63
12	T7	31/1 (90–180)	> 500	248.9 ± 1.3	491.7 ± 3.4	299.7 ± 1.7	342 ± 1.5	342.7 ± 2.7	248.9	> 500		328.5	370.8	± 33.2	0.9	28	0.18	0.94
13	T8	16/1 (212–425)	> 500	> 500	436.3 ± 2.1	413.8 ± 3.3	439.8 ± 2.7	412.8 ± 2.3	412.8	> 500		444.7	450.4	± 12.9	0.9	3	0.00	0.06
13	T8[c]	16/2 (90–212)	21.5 ± 0.9	54.3 ± 0.9	221.8 ± 6	47.8 ± 1.8	44 ± 1.7		21.5	221.8		36.1	69.1	± 25.7	0.7	226	0.73	3.29

[a] Summary statistics: Mean$_{wtd}$ = weighted mean, Mean$_{unwtd}$ = unweighted mean, SE = standard error, CV = coefficient of variation.

[b] See text and Table 3 for additional details.

[c] This sample was collected from a unit suspected as being influenced by quarrying activities, it exhibits clear evidence of partial bleaching and is rejected.

Table 2
Status & classification of partial bleaching for Loire samples

Category	Samples	Description	R^2
A	102/1, 1022/1, 20/1, 14/1, 15/1, 21/1, 1025_2, 1024/1, 19/1 (90–212 & 425–600 μm) 31/1, 17/1, 1023/2	No evidence of partial bleaching	< 0.55
B	16/2, 1020/2	Evidence of partial bleaching	> 0.55
C	18/1, 15/2, 1026/1	Correlation biased by single outlier (> 3 SD)	> 0.60

agreement with radiocarbon dates (Table 4). This provides strong support for the accuracy of the OSL dates for these units, and it is possible to infer similar optical-dating accuracy for the older terraces for which there is no independent age control. Some specific comments are provided below.

3.1. *Younger* (*Holocene*) *terraces*

Units T2–T4 are the younger (mid-to-late Holocene), independently dated, units. These deposits generally consist of sand-dominated, meandering channel facies which are thought to reflect a shift (amelioration) in regional climates following the Last Glacial (Weichselian) period (Straffin et al., 2000). A warmer Holocene climate would have resulted in enhanced vegetation growth and soil development, reductions in peak storm flow velocities, and a more channelised, sand-dominated river regime.

3.2. *Older* (*pre-Holocene*) *terraces*

Terrace unit T5 is a widespread, gravel-dominated facies for which there is no independent radiocarbon age control. Optical ages for this unit consist of a single, relatively young (c. 11.1 ka) age, and a cluster of 6 ages spanning the period of the last glacial maximum (LGM) (17.8–23.2 ka). The deposition of this unit during glacial times is supported by the presence of frost wedge casts, the style of channel development (primarily reflecting braided channel forms), and the coarse clast size (reflecting enhanced peak storm flows draining a landscape with limited vegetation cover and possibly comprising spring melt flood events). The single 11.1 ka estimate is interesting as it correlates well with the timing of the Younger Dryas stadial, and may identify a discrete aggradational period within the latter phases of construction of terrace unit T5.

Ages for terrace unit T6 indicate that deposition occurred during both middle (c. 40 ka) and earliest (c. 80 ka) Devensian time. As with unit T4, the sedimentary sequences are gravel dominated and as such a glacial phase (marine oxygen isotope stages 4 and 3) age is highly consistent. Unit T7 is less well preserved in the study area and is thought, based on lithological and pedological criteria, to be last interglacial in age (Straffin et al., 2000). The age of 91.5 ka for this unit places it within the later phases of the last interglacial period (c. marine oxygen isotope stage 5a).

The age estimate of 123 ka for terrace unit T8 is somewhat controversial as the unit is mixed sand and gravel dominated and exhibits well developed ice wedge features which are normally associated with cold (periglacial) conditions. An age of 123 ka places the deposit within marine isotope stage 5e — at the peak of the last interglacial period. It is possible that the deposit is actually interglacial in age and underwent periglacial modification during a subsequent (Weichselian) cold period, but it is necessary to briefly consider alternative explanations for the potentially problematical age estimate. It is noted that the mean D_e for sample 16/1 is 425 Gy, a value well beyond the conventionally accepted D_e range of quartz. The SAR growth curves do not however indicate any evidence of dose saturation.

An alternative, somewhat controversial view, drawing from nearby palaeoenvironmental data could also be argued. Pons et al. (1992), analysing nearby lacustrine sequences suggest that the last interglacial period was punctuated by a number of cold periods which have also been controversially identified in some high-latitude ice cores (Williams et al., 1998) and other environmental archives (e.g., Adams et al., 1999). While these cold events are much debated, the sedimentological and chronological data for terrace unit T8 could be argued to provide some support for the concept. A more detailed age assessment of unit T8 will be required to clarify this issue.

4. Conclusions

We have successfully used the SAR analysis protocol to derive D_Es and optical ages for fluvial sediments from the Loire River. A combination of a residual age for a modern sample of c. 300 years, general agreement with a limited ^{14}C age data set for the same units, and the ability to objectively test for partial bleaching gives us considerable confidence in our results. It appears that partial bleaching is only significantly observed in approximately one third of the sampled fluvial deposits. It is interesting to note that partial bleaching is observed in a range of fluvial sedimentary facies (e.g., well-sorted sands, gravelly sands, sandy gravels) and it is not possible from this data set to anticipate the extent of bleaching based on sedimentological criteria.

The dating results indicate that the Loire and Arroux rivers responded (accreted) to climatic changes contemporaneously during both warm and cold climate periods

Table 3
Best estimates of ages for the Loire and Arroux terraces

Site	Latitude	Longitude	Unit	Sample, ID	Sampling depth (m)	Grain size, (μm)	$[K_2O]$ (%)	[U] (ppm)	[Th] (ppm)	D_{cosmic}	Dose rate (Gy ka^{-1})	D_E (Gy)	Age estimate (ka)
1	46°21′58″N	003°59′44″E	Modern	19/1	—	90–212					5.23 ± 0.15[a]	1.9 ± 0.3	0.35 ± 0.07
				19/1		425–600					4.67 ± 0.15[a]	1.4 ± 0.3	0.30 ± 0.06
2	46°22′29″N	003°59′49″E	T2	1026/2	1.3	90–125	2.90 ± 0.14	5.86 ± 0.41	23.82 ± 1.66	0.18 ± 0.01	6.10 ± 0.16	2.7 ± 2.2	0.5 ± 0.4
3	46°29′08″N	003°57′13″E	T2	1021/1	1.5	90–125	3.45 ± 0.14	8.70 ± 0.57	35.96 ± 2.34	0.15 ± 0.00	8.28 ± 0.20	5.6 ± 0.3	0.68 ± 0.04
4	46°28′41″N	003°53′32″E	T3	21/1	1.8	212–425	3.95 ± 0.12	2.50 ± 0.08	11.47 ± 0.35	0.15 ± 0.01	4.75 ± 0.09	15.4 ± 0.6	3.2 ± 0.1
5	46°39′52″N	004°07′07″E	T4	1020/2	3.6	90–125	4.55 ± 0.25	3.42 ± 0.26	13.79 ± 1.05	0.15 ± 0.01	5.98 ± 0.20	44 ± 22	7.3 ± 3.8
6	46°40′21″N	004°07′07″E	T5	14/1	2.0	90–212	4.14 ± 0.13	2.61 ± 0.08	11.14 ± 0.34	0.15 ± 0.01	5.21 ± 0.09	58 ± 3	11.1 ± 0.6
7	46°41′27″N	004°07′53″E	T5	15/1	1.8	425–600	4.34 ± 0.15	2.20 ± 0.28	8.18 ± 0.28	0.15 ± 0.01	4.46 ± 0.01	104 ± 7	23.2 ± 1.8
			T5	15/2	2.6	425–600	3.69 ± 0.10	3.70 ± 0.09	16.69 ± 0.43	0.15 ± 0.01	5.01 ± 0.08	97 ± 8	19.3 ± 1.7
8	46°24′22″N	004°01′10″E	T5	1024/1	1.5	90–125	4.12 ± 0.23	2.49 ± 0.19	12.59 ± 0.96	0.13 ± 0.01	5.26 ± 0.18	108 ± 8	20.6 ± 1.8
			T5	18/1	1.8	90–212	3.91 ± 0.22	2.62 ± 0.20	13.85 ± 1.06	0.13 ± 0.01	5.00 ± 0.20	94 ± 6	18.9 ± 1.4
9	46°24′17″N	004°00′22″E	T5	1025/2	5.6	90–125	4.37 ± 0.23	2.66 ± 0.20	8.34 ± 0.62	0.15 ± 0.01	5.18 ± 0.17	92 ± 12	17.8 ± 2.4
			T5	20/1	7.0	212–425	3.65 ± 0.11	3.10 ± 0.09	11.97 ± 0.35	0.15 ± 0.01	4.70 ± 0.08	100 ± 5	21.2 ± 1.2
10	46°28′48″N	003°53′35″E	T6	1022/1	1.5	90–125	3.03 ± 0.18	1.68 ± 0.13	8.11 ± 0.64	0.16 ± 0.01	3.80 ± 0.14	151 ± 13	39.8 ± 3.7
11	46°20′54″N	004°02′08″E	T6	1023/2	1.8	90–125	4.06 ± 0.24	2.40 ± 0.19	9.80 ± 0.77	0.16 ± 0.01	4.99 ± 0.18	304 ± 6	61 ± 2.5
			T6	17/1	3.2	425–600	3.86 ± 0.23	2.52 ± 0.20	10.78 ± 0.85	0.15 ± 0.01	4.22 ± 0.20	207 ± 20	49 ± 5
12	46°28′31″N	004°00′25″E	T7	31/1	5.0	90–180	3.11 ± 0.11	2.72 ± 0.10	7.16 ± 0.25	0.15 ± 0.01	4.05 ± 0.08	329 ± 33	81 ± 8
13	46°23′29″N	003°57′53″E	T8	16/1	2.5	212–425	3.29 ± 0.12	1.45 ± 0.05	7.59 ± 0.28	0.15 ± 0.01	3.66 ± 0.09	450 ± 13	123 ± 5
			T8[b]	16/2	1.8	90–212	3.13 ± 0.12	1.43 ± 0.06	6.52 ± 0.25	0.15 ± 0.01	3.68 ± 0.09	19 ± 26	5.2 ± 7.0

[a] Dose rate estimates based on averages of other analyses.

[b] This sample was collected from a unit suspected as being influenced by quarrying activities, it exhibits clear evidence of partial bleaching and is rejected.

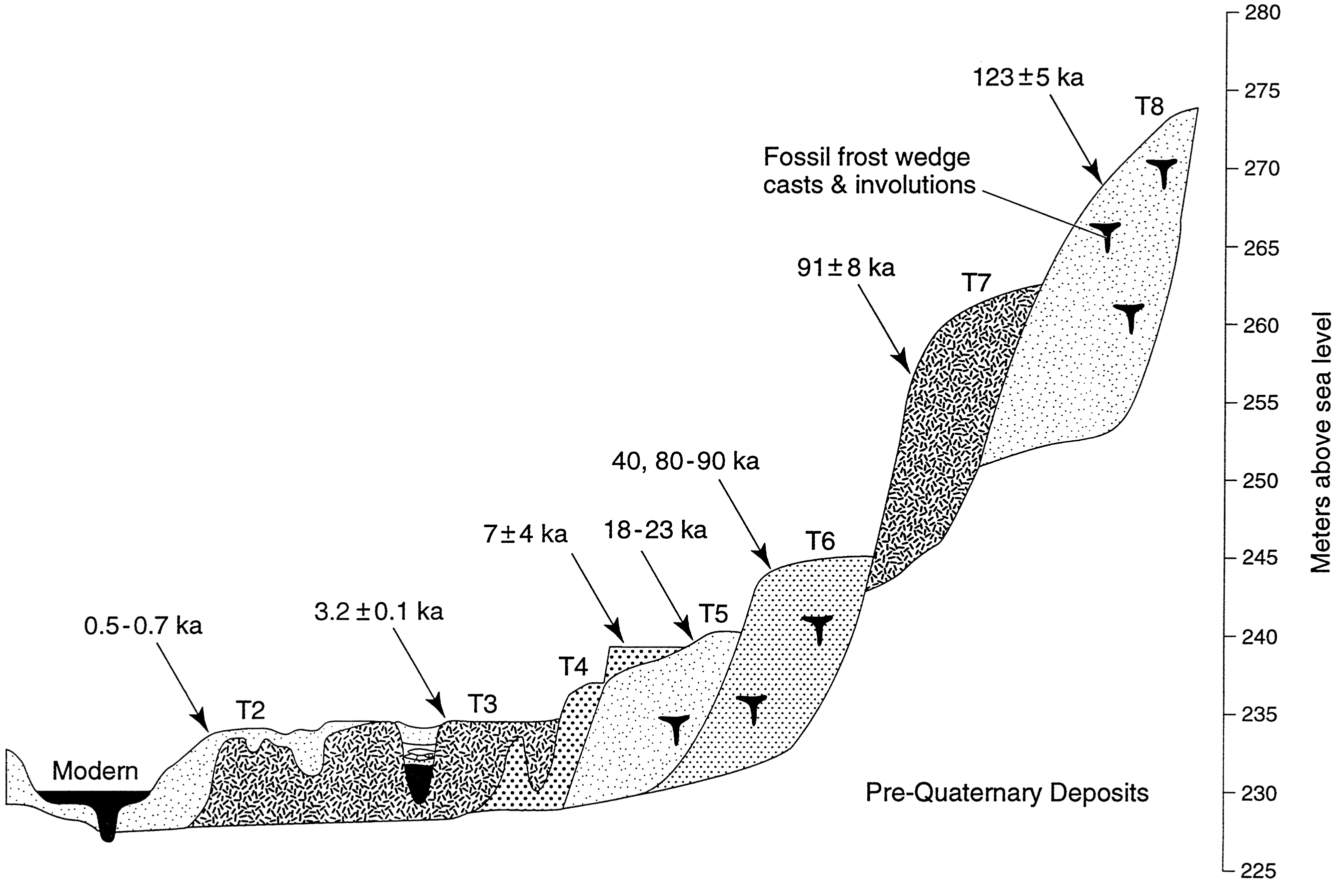

Fig. 2. Summary of terrace stratigraphy and optical ages.

Table 4
Comparison of ^{14}C and optical ages[a]

Unit	^{14}C (kBP)	OSL (ka)
T2	0.12 ± 0.05–1.42 ± 0.06	0.46 ± 0.36–0.68 ± 0.06
T3	2.93 ± 0.05–3.68 ± 0.05	3.23 ± 0.13
T4	5.59 ± 0.06	7.33 ± 3.75

[a] The dates were provided by Eric Straffin and Mike Blum (pers comm.) without detailed stratigraphic information. All radiocarbon ages are uncorrected. All radiocarbon ages are uncorrected.

of the last glacial–interglacial cycle. The most significant transition in the style of fluvial deposition over the period dated is that of the shift from gravel to sand and silt-dominated bedload which occurred at approximately the same time as the shift from glacial (Weichselian) to interglacial (Holocene) climate. This further implies that changing sediment yield and sediment type from upland catchment areas may be the most important control on terrace aggradation/degradation relationships. Detailed evaluations of such relationships will, however, require considerably more analyses.

There is considerable potential for the dating of fluvial systems using SAR and other optical dating methods as they provide the potential to evaluate the fluvial response to changing environmental conditions over a full interglacial–glacial cycle.

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