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Holocene sediment-accumulation rates in the western Loess Plateau, China, and a 2500-year record of agricultural activity, revealed by OSL dating

Helen M. Roberts,[1] Ann G. Wintle,[1] Barbara A. Maher,[2]* and Mengyu Hu[2]*

([1]Luminescence Dating Laboratory, Institute of Geography and Earth Sciences, University of Wales, Aberystwyth SY23 3DB, UK; [2]Centre for Environmental Magnetism and Palaeomagnetism, School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK)

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Abstract: High-resolution optically stimulated luminescence (OSL) dating of a terraced loess section in the western margins of the Chinese Loess Plateau provides evidence of continuous and varying accumulation of dust throughout the Holocene. From 12 030 to 2500 years ago, the sediment-accumulation rate was approximately 0.2 mm/year. After this time, it increased to approximately 0.8 mm/year, during a historically documented period of agricultural expansion in adjacent areas. From 680 years ago, a further increase in accumulation rate, to approximately 3.4 mm/year, is evident. Particle-size analysis indicates that this increase in accumulation rate was associated with anthropogenic addition of sandy sediment, probably for soil improvement. The OSL dating also identifies the period when the terrace was first cut for agricultural use, between 2500 and 2070 years ago.

Key words: Loess Plateau, OSL dating, loess, China, accumulation rates, agriculture, late Holocene.

Introduction

The loess/palaeosol deposits of northern China provide high-resolution proxy-records of climate change throughout the Quaternary period (e.g., Heller *et al*., 1993; Maher *et al*., 1994). Both magnetic-susceptibility changes (Heller and Liu, 1986; Rutter *et al*., 1991; Maher and Thompson, 1995) and grain-size measurements (Ding *et al*., 1994), matched against the orbitally tuned marine oxygen isotope record, provide a timescale for the last glacial/interglacial cycle and earlier. However, a high-resolution timescale has yet to be developed for the Holocene.

Dust deposition in China has continued through the Holocene at a much higher rate than in Europe, thus providing an archive of palaeoclimatic information that overlaps with historical and meteorological records (Derbyshire *et al*., 1998). A general timeframe for Holocene climatic changes in China has been provided by radiocarbon dating, which relies on the presence of *in-situ*, uncontaminated organic material (Head *et al*., 1989; Zhou *et al*., 1992; 1994; 1998). However, relatively few dates are available owing to a lack of suitable dating material.

This lack of radiocarbon dates has impeded attempts to determine dust-deposition rates through the Holocene. It is thus timely and appropriate to use a dating method that can be applied to the minerogenic, rather than the organic, component of the Chinese loess/soil sequences. Dating of grains of feldspar or quartz by optically stimulated luminescence can potentially provide a robust chronology. In China, luminescence dating has been applied to aeolian dust deposited in the last glacial cycle, from 74 to 16 ka (e.g., An *et al*., 1991; Fang *et al*., 1997; Forman, 1991; Frechen, 1999; Musson, 1995; Musson *et al*., 1994; Sun *et al*., 1998), with so far few dates from 16 ka to the present day (An *et al*., 1991; Forman, 1991; Lai *et al*., 1999; Zhou *et al*., 1992). In this paper, we report on a new procedure that has enabled us to conduct a high-resolution dating study, allowing calculation of Holocene dust-deposition rates for a site at the western edge of the Chinese Loess Plateau. We also identify the timing of human impact at the site, resulting from phases of agricultural activity.

*Present address: Environment Lancaster, Department of Geography, University of Lancaster, Lancaster LA1 4YB, UK.

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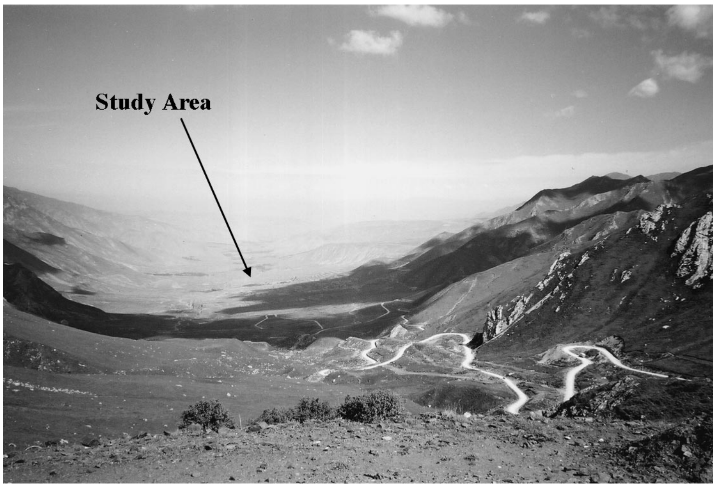

Figure 1 Location of the Duowa section within the Linwusu River valley, Qinghai.

Site and methods

The loess/soil sequence investigated is exposed in a river terrace located in the extreme west of the Chinese Loess Plateau, at Duowa, Qinghai Province (N 35°39′; E 102°38′). The Duowa section occupies the lowest of a series of shallow terraces in the Linwusu river valley, a tributary of the Huang He (Yellow River), at approximately 2000 m altitude (Figures 1 and 2). The natural terraces have subsequently been exploited and modified by farming activity. The 4.6 m sequence predominantly consists of multiple palaeosols interbedded with less-weathered aeolian sediment (Figure 3). Several of the palaeosols are visible with the naked eye and can also be detected by field measurements of magnetic susceptibility (Figure 4). The uppermost soil, intersecting with the terrace surface, is presently used for agriculture, and thus subject to shallow ploughing and manuring. Close to the base of the section, a discrete, 10 cm thick band of dark, sandy, strongly magnetic material is present (Figures 3 and 4). This sub-unit has a sharp contact with the aeolian sediment above and below it.

Sample recovery and preparation

Nineteen samples for luminescence dating were obtained, from the top, middle and base of the palaeosols, as identified by the field magnetic-susceptibility measurements (Figure 4). The section was sampled using thin-walled, cylindrical corers, approximately 20 mm in diameter and 100 mm in length. Two samples were taken at each depth. The sample tubes were sealed at both ends using rubber bungs and tape, to preserve the water content at the time of sampling.

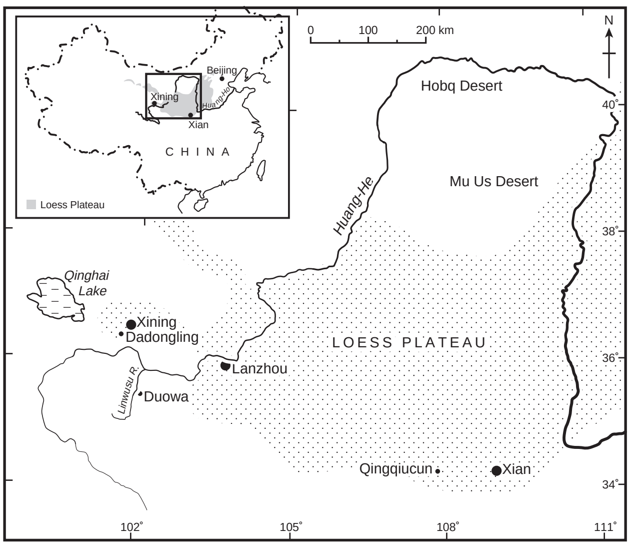

Figure 2 The Chinese Loess Plateau showing the Duowa section, and locations mentioned in the text.

The sampled Duowa sediments were well compacted. Following the removal of material from the ends of the tubes (which had been exposed to light during sampling), the samples were extruded under subdued lighting conditions, using an extrusion rod on a 15 tonne hydraulic press. In the case of weak or damaged sample tubes, the sediments were extracted by gentle hand-drilling using a large-diameter drill-bit.

Samples were also obtained at 5 cm intervals through the sequence for magnetic and particle-size analysis. Particle size was determined by laser analysis. Approximately 10 g of each sample was immersed in 50 ml distilled water and first mechanically shaken for four hours, then subjected to ultrasonic dispersion for 30 minutes. The dispersed sample suspensions were then injected into a Coulter Counter LS 130. Particle-size classification was according to the Wentworth scale. The methods and results of the magnetic analysis, and the palaeoclimatic information thence obtained, will be discussed in a later paper.

The luminescence samples were weighed and then dried in an oven at 50°C until a constant mass was recorded. The 'as sampled' water content could then be determined, for use in the estimation of the dose-rate. They were then treated with 20 vols hydrogen peroxide, to remove organic material, and then 50% v.v. hydrochloric acid at 50°C (Porat, personal communication), to remove carbonates and surficial iron-coatings. The samples did not contain sufficient quartz of an appropriate grain size to permit its isolation and use for optically stimulated luminescence dating. Thus, the polymineral fine-grain fraction (4–11 μm) was isolated by settling samples in 20 cm depth of 0.01N sodium oxalate solution. The 4–11 μm fraction was prepared for luminescence measurements by settling in acetone onto 1 cm diameter aluminium discs (2 mg material per disc).

Luminescence equipment and measurement protocol

A new method of optically stimulated luminescence (OSL) dating using polymineral fine-grains (4–11 μm) was employed, as proposed by Banerjee *et al.* (2001). This method uses the OSL signal obtained on stimulation at 470 nm for dating, following a prolonged stimulation at 830 nm to minimize the OSL signal from feldspars. The OSL behaviour of the signal used for dating was similar to that of quartz and, thus, a slightly modified Single-Aliquot Regenerative (SAR) dose protocol (Murray and Wintle, 2000) was employed. The SAR protocol corrects for any sensitivity changes either caused by thermal pretreatments used to

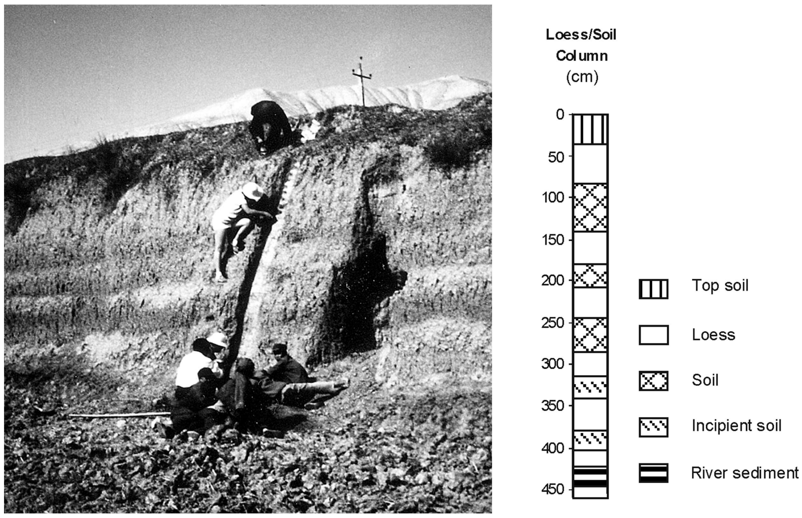

Figure 3 The 4.6 m Duowa section, consisting of multiple palaeosols interbedded with less-weathered loess.

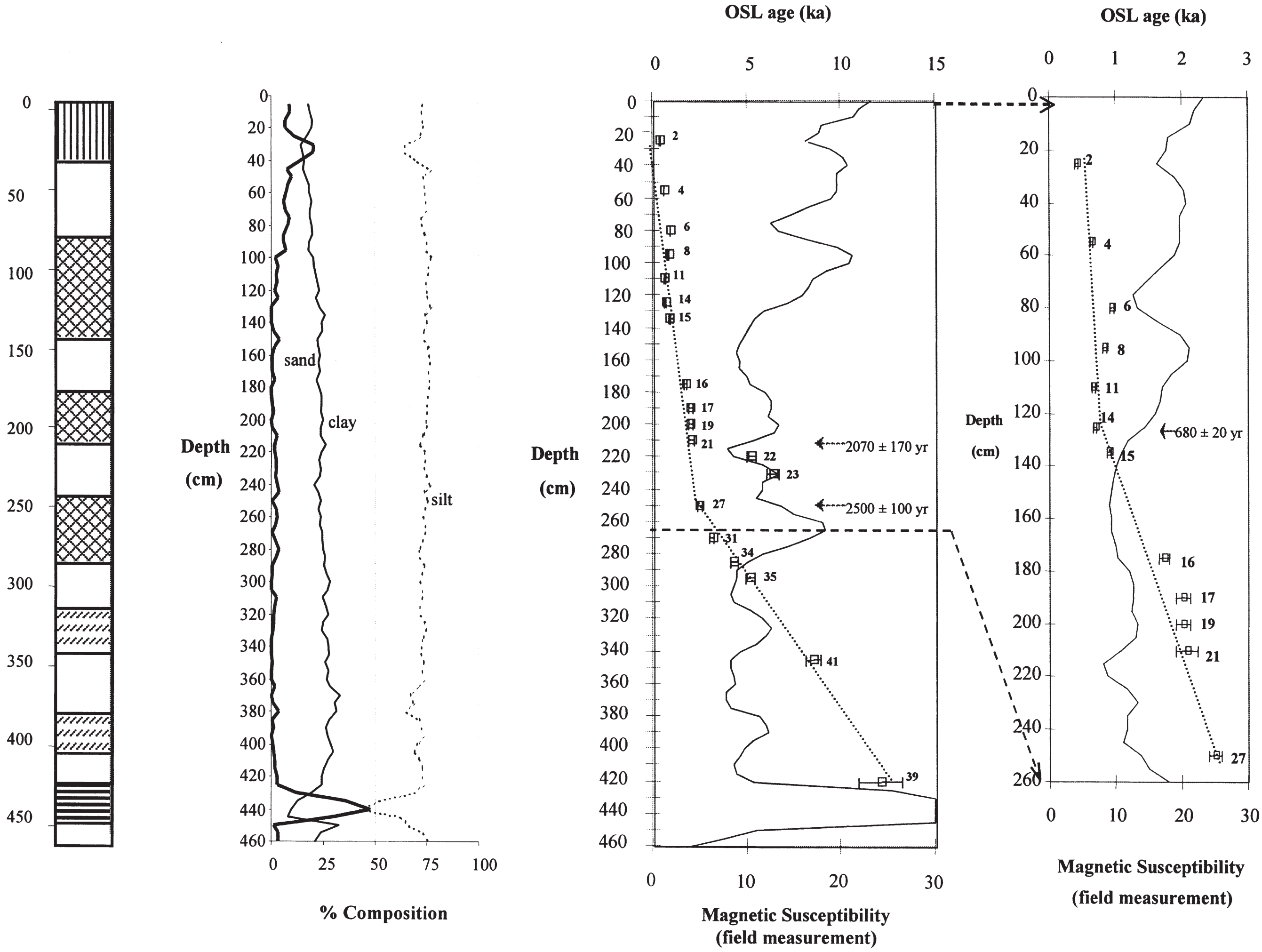

Figure 4 Sequence stratigraphy, particle size, field magnetic susceptibility and OSL ages for the Duowa section. The upper 260 cm of the section is shown in greater detail to the right of the figure. Dotted lines link OSL samples of similar sediment-accumulation rates. See Figure 3 for key to sequence stratigraphy.

isolate the stable OSL signal, or that may have occurred during burial. This method was tested extensively on one sample from the Duowa section prior to use (Roberts and Wintle, 2001).

The modified SAR protocol was then applied to 19 polymineral fine-grain samples from the Duowa section (Table 1). All luminescence measurements were made using an automated Risø TL/OSL reader, equipped with a combined high-power blue LED/infra-red solid state laser diode OSL unit, and a beta source

Table 1 Typical Single-Aliquot Regenerative-dose (SAR) protocol employed (modified from Banerjee *et al*., 2001)

Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7
(Natural)	0 Gy dose	Regenerative dose 1	Regenerative dose 2	Regenerative dose 3	0 Gy dose	Regenerative dose 1
		P/ht (160–300°C), @ 5°C/s, hold 10s 100s 830 nm @ 125°C, @ 5°C/s (to reduce OSL from feldspars) 100s 470 nm @ 125°C, @ 5°C/s (OSL signal used for dating) Test dose P/ht 160°C, @ 5°C/s 100s 830 nm @ 125°C, @ 5°C/s (to reduce OSL from feldspars) 100s 470 nm @ 125°C, @ 5°C/s (OSL signal used for dating)				

for irradiations. The combined OSL unit was employed at 80% of full diode current, providing approximately 17 mW/cm^2 power from the blue LED unit (470 nm), and 370 mW/cm^2 from the IR laser diode (830 nm). All measurements were made at 125°C and detected using three 3 mm Hoya U-340 filters. Between 12 and 24 polymineral fine-grain discs were examined for each sample, with each disc giving rise to a determination of equivalent dose (D_e). This permitted a range of thermal pretreatments to be employed during the SAR protocol (160–300°C, with three discs at each 20°C interval, in the case of 24 discs; 220–260°C, with four discs at each 20°C interval, in the case of 12 discs).

Radioactivity measurements
The radioactivity measurements required for determination of the dose-rate to the sample were conducted on dried, ground bulk material. Thick source alpha counting (TSAC) and beta counting using Risø GM-25–5 equipment were undertaken. The observed homogeneity of the alpha- and beta-activity through the sediment sequence allowed the gamma dose-rate to be estimated using the uranium and thorium determinations (from the TSAC pair count) and the calculated potassium contents. The latter were derived by subtraction, using the measured beta dose-rate and that calculated from the uranium and thorium values. Use of a field gamma detector was not feasible due to the high-resolution nature of the sampling at this section (up to every 5 cm). The cosmic-ray dose-rate was estimated for each sample as a function of depth, using the appropriate altitude (2000 m) and geomagnetic latitude (Prescott and Hutton, 1994). The water content was determined in the laboratory from sealed field samples.

Results

Luminescence dating
The ‘as sampled’ water content, and the alpha and beta activity through the section, are given in Table 2. Table 2 also shows the equivalent dose determination, dose-rate components and the total dose-rate, and, finally, the calculated luminescence ages. The ages are also shown graphically in Figure 4, together with the sequence stratigraphy, field magnetic susceptibility values and the particle-size data. The 470 nm (post-830 nm infra-red [IR] stimulation) OSL ages confirm that the section is Holocene in age. With four exceptions, the ages produced are all in correct stratigraphic order, spanning from 410 years at the top of the section (0.1 m depth) to 12 030 years at the section base (4.2 m). The errors associated with the ages are $<$5%.

The modified SAR protocol proved extremely robust in providing these ages. An example of a typical preheat plateau for material for this section is given in Figure 5 (sample 41), which shows the 24 equivalent dose (D_e) determinations obtained using various thermal pretreatments. The SAR protocol enables corrections to be made for sensitivity changes which occur as a result of thermal pretreatments. The recycling ratio is calculated using the corrected OSL signals for repeated measurements of the same dose (e.g., comparing run 3 and run 7 of Table 1), and shows how effectively the sensitivity correction is working. From Figure 6, it can be seen that sensitivity change is being adequately monitored and corrected for by the SAR measurement protocol (recycling ratios are typically from 0.9 to 1.1).

The four stratigraphically incorrect ages arise from samples 6, 8, 22 and 23; it is probable that the OSL signal was incompletely bleached at the time of deposition of these sediments, thus leading to erroneously high luminescence ages. This is discussed further below.

Particle size
The results of the particle-size analyses are given in Figure 4. Between ~1 m and 4.2 m, the sequence is uniformly dominated by silt (~75%) and clay (~25%), with minimal amounts of sand present. Between 4.30 and 4.45 m, the dark, strongly magnetic layer is additionally differentiated from the remainder of the section by its high sand content (maximum of ~50%). The other notable occurrence of significant amounts of sand is within the top ~1 m of the section, where values reach a maximum of 21%.

Discussion

The OSL data shown in Figure 4 indicate that dust deposition has been at least quasi-continuous throughout the last 12 030 years at this site. That is, although sedimentation may be episodic (associated with dust storms and/or rain-out of dust), over the Holocene period as a whole, the influx and deposition of dust has essentially been a continuous process. The sediment-accumulation rate over the period from 12 030 to 2500 years ago is approximately 0.2 mm/year. This value is consistent with that noted by Chen *et al*. (1995) for the older loess unit L_1 and the palaeosol unit S_1 of the Dadongling loess section near Xining, another site in the western margins of the loess plateau (N 36°35′; E 101°44′; Figure 2). For the period from 2500 to 410 years ago, the average accumulation rate at Duowa then increases more than six-fold, to approximately 1.3 mm/year. Closer examination reveals that this interval of increased sediment accumulation may be further divided into two more periods. Between 2500 and 680 years ago, the accumulation rate was approximately 0.8 mm/year (four times higher than that from the early Holocene to 2500 years ago, as discussed above). This increased sediment-accumulation rate then increases further to approximately 3.4 mm/year, in the period from 680 to 410 years ago.

These OSL-derived accumulation rates show no correlation with sediment lithology; the loess units and the soil units appear to have similar sediment-accumulation rates. Thus, contrary to the

Table 2 Equivalent dose (D_e), water content and dose-rate data, and calculated (post-IR) OSL ages

Sample no.	Depth (m)	D_e (Gy)	n	Water (% dry mass)	U (ppm)	Th (ppm)	K (%)	α* (μGy/a)	β* (μGy/a)	γ* (μGy/a)	Cosmic* (μGy/a)	Total dose rate (μGy/a)	Age# (a)
2	0.10	2.18 ± 0.08	11	5 ± 2	2.8 ± 0.3	11.1 ± 1.1	2.84 ± 0.08	0.608	2.879	1.497	0.345	5.33 ± 0.16	410 ± 20
4	0.55	3.16 ± 0.06	12	5 ± 2	2.7 ± 0.4	10.8 ± 1.2	2.72 ± 0.09	0.571	2.740	1.426	0.267	5.00 ± 0.16	630 ± 20
6	0.80	4.77 ± 0.09	12	5 ± 2	3.0 ± 0.3	8.8 ± 1.0	2.82 ± 0.08	0.571	2.831	1.406	0.248	5.06 ± 0.15	940 ± 30
8	0.95	4.32 ± 0.08	12	5 ± 2	3.2 ± 0.3	9.0 ± 1.1	2.90 ± 0.09	0.595	2.917	1.450	0.243	5.21 ± 0.16	830 ± 30
11	1.10	3.59 ± 0.05	12	5 ± 2	3.1 ± 0.4	10.5 ± 1.2	2.98 ± 0.09	0.630	3.012	1.536	0.238	5.42 ± 0.17	660 ± 20
14	1.25	3.84 ± 0.03	12	5 ± 2	3.2 ± 0.4	10.5 ± 1.2	3.16 ± 0.08	0.639	3.166	1.586	0.233	5.62 ± 0.17	680 ± 20
15	1.35	5.00 ± 0.08	23	5 ± 2	2.6 ± 0.5	12.5 ± 1.5	3.14 ± 0.10	0.628	3.122	1.616	0.230	5.60 ± 0.17	890 ± 30
16	1.75	9.90 ± 0.33	12	5 ± 2	3.6 ± 0.4	10.3 ± 1.3	3.17 ± 0.10	0.677	3.217	1.622	0.218	5.73 ± 0.18	1730 ± 80
17	1.90	11.65 ± 0.51	12	6 ± 2	2.7 ± 0.4	10.4 ± 1.2	3.61 ± 0.10	0.574	3.402	1.613	0.213	5.80 ± 0.17	2010 ± 100
19	2.00	11.67 ± 0.52	11	6 ± 2	2.9 ± 0.4	10.7 ± 1.2	3.54 ± 0.08	0.601	3.381	1.631	0.210	5.82 ± 0.16	2000 ± 100
21	2.10	12.42 ± 0.94	9	7 ± 2	3.3 ± 0.4	10.5 ± 1.2	3.64 ± 0.10	0.644	3.475	1.677	0.208	6.00 ± 0.17	2070 ± 170
22	2.20	29.45 ± 1.00	21	7 ± 3	2.6 ± 0.3	10.7 ± 1.0	3.52 ± 0.08	0.573	3.297	1.586	0.205	5.66 ± 0.18	5200 ± 240
23	2.30	33.74 ± 1.38	12	5 ± 2	3.1 ± 0.3	9.0 ± 1.1	3.07 ± 0.08	0.590	3.046	1.485	0.202	5.32 ± 0.16	6340 ± 320
27	2.50	14.19 ± 0.35	12	7 ± 2	3.0 ± 0.3	11.1 ± 1.1	3.38 ± 0.09	0.626	3.252	1.613	0.197	5.69 ± 0.16	2500 ± 100
31	2.70	17.03 ± 0.47	11	10 ± 2	2.6 ± 0.3	11.6 ± 1.0	3.35 ± 0.09	0.582	3.080	1.538	0.192	5.39 ± 0.15	3160 ± 130
34	2.85	22.65 ± 0.81	11	11 ± 2	3.8 ± 0.4	8.8 ± 1.1	3.18 ± 0.09	0.628	3.002	1.474	0.188	5.29 ± 0.16	4280 ± 200
35	2.95	27.41 ± 0.90	12	11 ± 2	3.4 ± 0.4	10.6 ± 1.2	3.15 ± 0.08	0.629	2.974	1.508	0.186	5.30 ± 0.16	5180 ± 230
41	3.45	46.07 ± 1.05	22	15 ± 5	3.2 ± 0.4	10.7 ± 1.1	3.60 ± 0.09	0.601	3.143	1.534	0.174	5.45 ± 0.23	8450 ± 400
39	4.20	59.38 ± 5.08	10	17 ± 5	2.8 ± 0.4	11.0 ± 1.4	3.28 ± 0.09	0.554	2.817	1.409	0.158	4.94 ± 0.21	12 030 ± 1150

*Central values are given for dose-rates – errors are incorporated into that given for total dose-rate.
#Ages are rounded to the nearest 10 and expressed as years before AD 2000.

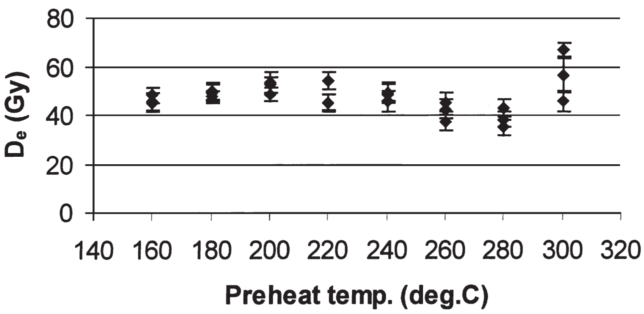

Figure 5 Equivalent dose (D_e) for sample 41 as a function of preheat temperature.

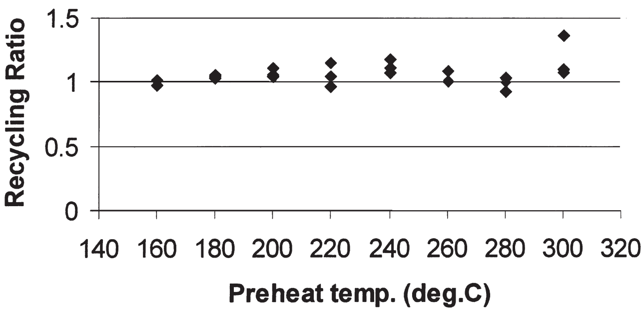

Figure 6 Ratio of corrected signals for run 7 to those of run 3 for each disc as a function of preheat temperature.

expectation of reduced dust accumulation during soil-forming periods, the episodic development of soil horizons appears to proceed contemporaneously with, and be unaffected by, the continuous accumulation of dust. The process of 'upbuilding' soil formation (Johnson and Watson-Stegner, 1987; Almond, 1998) is thus displayed in this section, i.e., soil formation and weathering processes operating in an *upward* sense, as dust continues to accumulate, rather than weathering down through the profile. The uniformity of the particle-size distribution through most of the sequence also suggests that the source(s) of the dust has not changed significantly through time. As neither the accumulation rate nor the source of the sediment appear to vary between the loess and the palaeosols, then climate must be the primary factor controlling soil development.

Significant changes in particle size are observed in the upper metre of the section. The percentage of sand-sized particles is almost negligible (~1–2%) from ~1.0 to 4.2 m depth in the sequence, whereas the top metre displays significantly larger values, from 2% at 1 m depth, to a maximum value of 21% at 0.3 m depth. In their study of a Holocene loess-palaeosol sequence at Qingqiucun, Guanzhong Basin (N 34°13′; E 107°50′; Figure 2), Huang *et al.* (2000) also noted the occurrence of sand-sized particles, reaching values of 2–7 % from a depth of 2.3 m to the surface. This increase in sand-sized particles was attributed to cultivation by arable farming from 7000 years cal. BP to the present day, an activity which has taken place without masking the record of dust deposition and soil formation (Huang *et al.*, 2000). Similarly, we attribute the increase in sand percentage within the top metre of the Duowa sequence to farming activity, but on a more recent timescale, i.e., from approximately 680 years ago to the present day. Given its coarse grain size, the sand is unlikely to reflect aeolian deposition. There is no evidence of sedimentary structures or sharp contacts in this upper portion of the section. The high accumulation rates in this part of the section make it unlikely that the increase in the proportion of coarse material is the result of winnowing.

A possible source of this sandy material is the nearby river and/or its overbank deposits. The dark, sandy layer towards the base of the section (4.35–4.45 m), which forms a discrete, magnetically and sedimentologically distinctive sub-unit of the loess/soil sequence, is probably an overbank deposit arising from a flood event of the adjacent Linwusu river. Both the dark, sandy basal layer and the upper, sand-enriched metre of the section display higher magnetic-susceptibility values than the remainder of the sediments (Figure 4). Optical microscopy of polished grain mounts of the sand fraction from the basal layer and the upper metre shows that their mineralogy is similar; notably, the heavy mineral, tourmaline, is common in both.

Further evidence for farming activity at Duowa can be found in the apparently anomalous luminescence dates for samples 6 and 8, from the base of the sand-enriched upper layer. The ages for these samples are not in stratigraphic order, being up to 50 % larger than those which bracket them. The bracketing dates for the samples above and below them (samples 4 and 11, at 0.55 and 1.10 m, respectively), indicate an extremely high sediment-accumulation rate between 630 and 660 years ago. Thus, we infer that the sand-sized material has been incorporated into the section by humans over the last 680 years, possibly to improve the structure and workability of the soil for agriculture.

The significant sand enhancement in the upper metre of the section thus indicates arable cultivation over the last 680 years. However, this does not necessarily mark the start of cultivation in this area; it may simply mark the introduction of a practice of soil improvement at this site. The OSL data also indicate a major increase in sediment-accumulation rate at Duowa after 2500 years ago, and, again, two loess samples (22 and 23) yield unexpectedly high OSL ages at this point. Since the ages are high, it can be inferred that the OSL signal was incompletely bleached on deposition. Incomplete bleaching could result from deposition during extremely turbid dust storms. However, it seems unlikely that evidence for two such events would be found in adjacent samples, and at no other point, in this densely sampled section. The coincidence of samples 22 and 23 with the four-fold increase in sedimentation rate at 2500 years (from ~0.2 mm/year to ~0.8 mm/year) may, instead, reflect earlier anthropogenic activity. The incomplete bleaching of the OSL signals could result from reworking of the sediments at this point. The most likely agent of reworking is man, since there is no evidence through the sequence of fluvial activity, other than for the dark, sandy unit near the base of the section.

The area is presently under cultivation; the natural sequence of river terraces have been modified to provide flat, horizontal surfaces to conserve soil moisture and nutrients. This practice increases grain yields by between 200 and 400%, as compared to unterraced semi-arid loess hillsides, and may even increase yields ten-fold in times of drought (Bray, 1984). To conserve the topsoil, the terraces are constructed as shown in Figure 7. The uphill plot surface is subjected to downcutting, with addition of this older material to the downhill plot area, prior to redistribution of the topsoil over the new, horizontal land surface. Such a reworking event is likely to result in age overestimation of the magnitude observed for samples 22 and 23. The OSL dates place the time of terrace cutting to between 2500 and 2070 years ago.

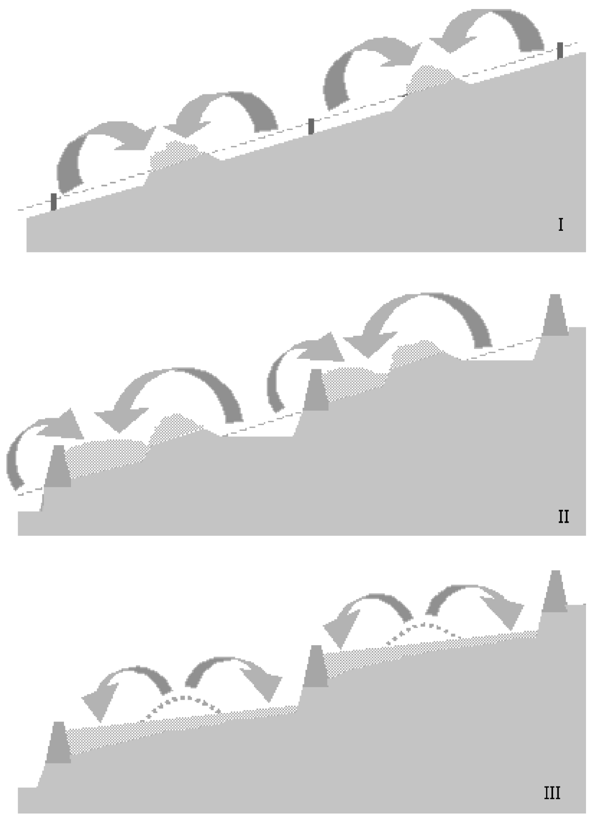

Figure 7 Preservation of topsoil in the terracing of loess (redrawn from Bray, 1984: 127).

Removal of vegetation, terrace-cutting and the introduction of agriculture would result in destabilization of the land surface and provide a new source of dust. If land-surface disturbance was extensive in this region, it could account for the four-fold increase in dust accumulation observed at Duowa. The suggested onset of farming activity here at between 2500 and 2100 years ago is consistent with historical records and studies from neighbouring regions. In the Central Loess Plateau, terracing is believed to have been introduced well over 1100 years ago; by AD 1900, over one-third of the area under cultivation was terraced (Bray, 1984). People have farmed river valleys of the high-altitude, mountainous, marginal areas for more than 2200 years (Bray, 1984). Historical records show large-scale movement of people into marginal areas approximately 2300 years ago (Sun, 2000). Large-scale immigration of Han peoples to the Ordos Plateau, including the Mu Us and Hobq deserts (Figure 2), was reported by Sun (2000), who identifies three main periods of migration and cultivation. The largest of these occurred during the West Han Period, when up to one million people migrated from central China to the Ordos Plateau between 127 and 111 BC (2127–2111 years ago). Analysis of pollen records from Qinghai Lake (in the northeast of Qinghai Province; Figure 2) and Lanzhou (Gansu Province; Figure 2) reveals a significant decrease in the percentage of arboreal pollen at approximately 3000 yr BP (uncalibrated) (Ren, 2000). This was attributed to human activity, including the expansion of agriculture and high-density settlement.

Conclusions

OSL dating of 19 samples from a loess/palaeosol sequence at Duowa, western Chinese Loess Plateau, has provided a high-resolution chronology for Holocene dust accumulation. Use of a new SAR protocol for OSL dating has resulted in dates with high precision. Fifteen dates were in stratigraphic order, from 12 030 to 410 years ago. The remaining four samples gave OSL ages that were too high and are indicative of two periods of disturbance, between 2500 and 2070 years ago, and between 660 and 630 years ago, that have been linked to known agricultural practice in neighbouring areas. At these times, material was reworked and incorporated into the section by human activity; however, the sediments were not adequately exposed to sunlight and the luminescence signal was not, therefore, fully reset.

The OSL dates show three distinct periods with marked differences in accumulation rates. From the early Holocene until 2500 years ago, the accumulation rate was approximately 0.2 mm/year. From 2500 to 410 years ago, the average accumulation rate increased by more than a factor of six to approximately 1.3 mm/year, a period for which there is historical evidence of widespread expansion of areas under cultivation, providing a new source of dust. Closer examination reveals two different sediment-accumulation rates during this period. From 2500 to 680 years ago, the accumulation rate was approximately 0.8 mm/year, while the uppermost part of the section, dated to between 680 and 410 years ago, shows an even higher accumulation rate (approximately 3.4 mm/year). Particle-size analysis demonstrates that this latter period coincides with the addition of sandy material, possibly for soil improvement, a practice that would result in an artificially enhanced accumulation rate.

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