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Hominin occupation of the Chinese Loess Plateau since about 2.1 million years ago

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Supplementary Information

I. The loess-palaeosol timescale

(1) The loess-palaeosol timescale

The Chinese loess-palaeosol sequence is the longest, most continuous, and detailed terrestrial Quaternary sequence in the world. Research over the last 30 years has shown that palaeomagnetic dating is the most appropriate method for dating long sections of loess and palaeosols from the last ~2.6 Ma. Based on palaeomagnetic dating and astronomical tuning methods, the age of each unit in the Chinese Loess Plateau is given below in SI Table 1[7, 10, 14]. Recent research indicates that although the first-order chronological framework for Chinese loess sequences has been established, there still remain issues concerning age determination of the loess-palaeosol unit in which a given geomagnetic reversal is recorded[19]. Time delays of geomagnetic polarity reversals in Chinese Quaternary loess are estimated to be ca 10 to 30 kyr[20]. Because of this uncertainly, we cite ages of each layer to only two decimal places.

SI Table 1. The loess-palaeosol timescale according to Ding *et al*. (Chiloparts)[10] and Heslop *et al*.[14]. The Wucheng, Lishi, and Malan Formations were proposed by Liu *et al*.[7] in their investigations of the Luochuan sequence.

Loess formation	Palaeosol -loess unit	Age (ka BP)		Loess formation	Palaeosol -loess unit	Age (ka BP)	
		Ding *et al.*	Heslop *et al.*			Ding *et al.*	Heslop *et al.*
Malan Loess	S0	0-11			S15	1,263-1,281	1,223-1,249
	L1	11-73			L16	1,281-1,297	1,249-1,263
	S1	73-128	79-126		S16	1,297-1,318	1,263-1,296
	L2	128-190	129-196		L17	1,318-1,350	1,296-1,311
	S2-1	190-219	196-226		S17	1,350-1,365	1,311-1,363
	S2-2	234-245	234-250		L18	1,365-1,390	1,363-1,386
	L3	245-307	250-290		S18	1,390-1,411	1,386-1,405
	S3	307-336	290-342		L19	1,411-1,441	1,405-1,448
Lishi Loess (upper)	L4	336-360	342-386	*Wucheng* Loess	S19	1,441-1,453	1,448-1,458
	S4	360-412	386-417		L20	1,453-1,467	1,458-1,470
	L5	412-479	417-503		S20	1,467-1,492	1,470-1,484
	S5-1	479-531	503-556		L21	1,492-1,505	1,484-1,514
	S5-2	549-579	568-575		S21	1,505-1,525	1,514-1,530
	S5-3	585-621	581-625		L22	1,525-1,540	1,530-1,541
	L6	621-684	625-693		S22	1,540-1,571	1,541-1,573
	S6	684-710	693-713		L23	1,571-1,588	1,573-1,600
	L7	710-760	713-765		S23	1,588-1,648	1,600-1,614

	S7	760-787	765-788		L24	1,648-1,711	1,614-1,767
	L8	787-819	788-807		S24	1,711-1,734	1,767-1,774
	S8	819-865	807-865		L25	1,734-1,801	1,774-1,807
	L9	865-943	865-952		S25	1,801-1,828	1,807-1,820
	S9-1	943-958	952-964		L26	1,828-1,891	1,820-1,885
	S9-2	971-989	977-984		S26	1,891-1,946	1,885-1,949
	L10	989-1,018	984-1,012		L27	1,946-2,089	1,949-2,095
	S10	1,018-1,049	1,012-1,034		S27	2,089-2,119	2,095-2,125
	L11	1,049-1,061	1,034-1,044		L28	2,119-2,130	2,125-2,135
	S11	1,061-1,076	1,044-1,055		S28	2,130-2,146	2,135-2,147
	L12	1,076-1,102	1,055-1,071		L29	2,146-2,177	2,147-2,172
***Lishi* Loess (lower)**	S12	1,102-1,120	1,071-1,080		S29	2,177-2,217	2,172-2,204
	L13	1,120-1,158	1,080-1,162		L30	2,217-2,249	2,204-2,230
	S13	1,158-1,208	1,162-1,175		S30	2,249-2,260	2,230-2,240
	L14	1,208-1,220	1,175-1,182		L31	2,260-2,271	2,240-2,341
	S14	1,220-1,240	1,182-1,190		S31	2,271-2,307	2,341-2,369
	L15	1,240-1,263	1,190-1,223		L32	2,307-2,493	2,369-2,540
					S32	2,493-2,547	2,540-2,596
					L33	2,547-2,600	2,596-2,600

(2) Dating by sedimentation rates

i) As an independent check on the Chiloparts timescale, the age of the loess-palaeosol units in the Shangchen (SC) section was calculated from estimates of its sedimentation rate. Dating a sedimentary section by estimating its sedimentation rate is a valid method when there are control points of ages measured by an independent dating method.

ii) Three methods were used to determine sedimentation rate age (SRA) for the segment between S15 and L28: 1) the average sedimentation rate of the total section, 2) the average sedimentation rate of each segment based on the position and age of palaeomagnetic reversal boundaries, and 3) the average sedimentation rate of each segment above the base of the Olduvai Subchron, with the compaction rate added to the sedimentation rate calculation for the segment below the Olduvai base (see SI Tables 2 and 3). Compared with the Chiloparts[10] timescale, the poorest estimate is method 1), with a correlation coefficient of 0.969 and an average error of 10.19%. With this method, even the Olduvai Subchron would be located in S23 instead of the lower part of L25 to the base of S26[7]. For Method 2), the correlation coefficient is 0.988 and the average error is only 2.16%. With this method, the oldest layer with artefacts was above the Réunion Excursion, which was situated within L28. The correlation coefficient of method 3) is 0.989 and the average error is 2.23%. Although the age (2.102 Ma) of the base of S27 estimated by this method is similar to that (2.119 Ma) of the Chiloparts timescale, the age of oldest layer with artefacts is 2.153 Ma, which is older than the age of the Réunion Excursion (2.128-2.148 Ma). Overall, Method 2) appears the most applicable.

If we use Method 2), the age of the oldest stone artefact horizon between S27 and L28 (see Extended Data Figures 8-9), which is situated 3.00-3.95 m below the base of the Olduvai Subchron and 1.64-0.69 m above the top of the Réunion Excursion, is ca 2.06-2.10 Ma. That is similar to the age estimated by Chiloparts, i.e. 2.09-2.12 Ma, but there is a time delay of ~20 or 30 ka. Sedimentation rate is also affected by the compaction rate of sediments, as discussed below.

SI Table 2. Calculation of sedimentation and compaction rates of layers below L15 in the Shangchen section (SC)

Reversal boundary	Age (Ma)	Polarity Chron	Depth (m)	Thickness (m)		Sedimentation rate (m/Ma)			Compaction rate		
						segments		total average	segments		total average
Brunhes base	0.781		9.71								
		C1r.1r (Matuyama)		13.79		B-J	66.618				
Jaramillo top	0.988		23.50								
		C1r.1n (Jaramillo)		3.40		J	40.476				
Jaramillo base	1.072		26.90						J/B-J	0.608	
		C1r.2r-C1r.2n-C1r.3r		36.04		J-O	51.048				
Olduvai top	1.778		62.94						J-O/J	1.261	
		C2n (Olduvai)		5.50	64.34	O	32.934	46.446			
Olduvai base	1.945		68.44						O/J-O	0.645	
		C2r.1r		4.64		O-R	25.355				0.381
Réunion top	2.128		73.08						O-R	0.770	
		C2r.1n (Réunion)		0.33		R	16.500				
Réunion base	2.148		73.41						R	0.651	
		C2r.2r		0.64		R- base[1)]	25.355				
SC section base	2.166		74.05						R- base[2)]	0.770	

1) and 2) Because the Réunion Excursion was very short-lived the recorded strata thickness may be incomplete and its compaction rate could be abnormal. Therefore, the sedimentation rate and the compaction rate of the layers below the top of Réunion Excursion are those used between the Olduvai Subchron and Réunion Excursion.

SI Table 3. Sedimentation rate age of main layers below L15 of the Shangchen section (SC) and correlation with Chiloparts

Loess-palaeosol sequence	Depth (m)		(1) By total section		(2) By segments of section		(3) By segments + compaction rate[1)]		Chiloparts (Ma) (by Ding *et al*., 2002)[10]		
	SC Top (m)	SC Base (m)	SC Top (Ma)	SC Base (Ma)	SC Top (Ma)	SC Base (Ma)	SC Top (Ma)	SC Base (Ma)	Ding Top (Ma)	Ding Base (Ma)	Loess-palaeosol layer
Top, L5 mid	0.00		0.569		0.574		0.574		0.447		Top, L5 mid
S15	38.20	40.50	1.403	1.454	1.293	1.338	1.293	1.338	1.263	1.281	S15
S16	41.30	42.40	1.471	1.495	1.354	1.376	1.354	1.376	1.297	1.318	S16
L17	42.40	43.40	1.495	1.517	1.376	1.395	1.376	1.395	1.318	1.350	L17
S18	45.20	46.00	1.556	1.574	1.430	1.446	1.430	1.446	1.390	1.411	S18
S19	47.00	48.40	1.596	1.626	1.466	1.493	1.466	1.493	1.441	1.453	S19
S20	49.80	50.80	1.657	1.679	1.521	1.540	1.521	1.540	1.467	1.492	S20
L21	50.80	51.70	1.679	1.698	1.540	1.558	1.540	1.558	1.492	1.505	L21
S21	51.70	52.70	1.698	1.720	1.558	1.577	1.558	1.577	1.505	1.525	S21
L22	52.70	53.70	1.720	1.742	1.577	1.597	1.577	1.597	1.525	1.540	L22
S22	53.70	55.00	1.742	1.771	1.597	1.622	1.597	1.622	1.540	1.571	S22
S23	56.70	57.90	1.808	1.834	1.656	1.679	1.656	1.679	1.588	1.648	S23
S24	59.90	61.60	1.878	1.915	1.718	1.752	1.718	1.752	1.711	1.734	S24
L25	61.60	65.50	1.915	2.000	1.737	1.856	1.737	1.856	1.734	1.801	L25
S26	68.10	69.30	2.057	2.083	1.935	1.971	1.935	1.989	1.891	1.946	S26
L27	69.30	70.16	2.083	2.102	1.979	2.013	1.989	2.033	1.946	2.089	L27
S27	70.16	71.50	2.102	2.131	2.013	2.066	2.033	2.102	2.089	2.119	S27
L28 ~SC base	71.50	74.05	2.131	2.187	2.066	2.166	2.102	2.232	2.119	2.130	L28
the oldest artefact layer[2)]	71.44	72.39	**2.130**	**2.153**	**2.063**	**2.101**	**2.099**	**2.153**			
coefficients of correlation (r^2) between sedimentation rate age and Chiloparts			0.9657	0.9715	0.9872	0.9888	0.9906	0.9864			
			average	0.9686	average	0.9880	average	0.9885			
error (%) of sedimentation rate age vs. Chiloparts age			10.35	10.03	2.12	2.20	2.31	2.59			
			average	10.19	average	2.16	average	2.45			

Notes: 1) compaction rate is only used for horizons below the Olduvai Subchron; and 2) the oldest artefact layer within the lower S27 and the upper L28 is situated 3.00-3.95 m below the base of the Olduvai Subchron and 1.64-0.69 m above the top of the Réunion Excursion.

iii) Estimates of layer age based on sedimentation rate are likely to undershoot the true age of the lowest layers because loess and palaeosol of different ages have different porosity (density) and compaction rates. This can be seen by comparing the length of time taken for loess/palaeosols of different ages to disintegrate in water (SI Table 4).

SI Table 4. Disintegration rates (in seconds) of loess and palaeosol samples of different ages from the Shangchen section when soaked in water.

Sampling layer	Lithology	Average age （ka BP）	Start of distintegration (s)	Start of collapse (s)	Complete Disintegration (s)
L8	Loess	800	10	19	60
L15	Loess	1,250	24	50	90
S27	Palaeosol	2,100	45	300	360
S27	Palaeosol	2,100	50	240	330

When loess and palaeosol samples are soaked in water, they quickly disaggregate completely, which indicates that diagenesis has not caused cementation in the loess and palaeosol sequence. Such sediments disintegrate, collapse, and slide to the bottom of gullies soon after being soaked by surface water and groundwater. Therefore, no loose slope wash of loess occurs in steep loess sections. Generally, loose loess slope wash can only remain on gentle slopes or at the bottom of gullies, and its thickness on gentle slopes is small.

Loess and palaeosols of different ages differ greatly in their decomposition and collapse rates, which indicates that they have different porosity (density) and compaction rates. The older the underlying loess and palaeosol, the greater thickness and pressure of the overlying younger loess and palaeosol, which leads to a decreased porosity and increased density, and to compaction in older loess, which makes it more difficult for older loess to disintegrate and collapse. This indicates that the loess identified as S27 and associated with the oldest stone artefacts is old loess. However, the present thickness of old loess does not represent its original thickness at deposition, but probably much less due to compaction. Thus, compaction rates must be considered when the lowermost sediments of the Shangchen section are dated using sedimentation rates. Therefore, it is more appropriate to take compaction rate into the account when calculating the average sedimentation rate, or to estimate it using a palaeomagnetic age that is the nearest to the loess horizon.

As shown in SI Table 5 below, the older the loess, the higher the dry unit weight, the lower the void ratio, and the smaller the coefficient of compressibility, which is consistent with the experimental results presented above, which indicates again that we must consider the compaction rate of sediments when we estimate sedimentation rate and sedimentary age from the present sedimentary thickness.

SI Table 5. Average value of main physical parameters of loess and palaeosol samples of different ages from the Chinese Loess Plateau[7, 33, 34].

Geological era of loess sample	Depth (m) of sampling	Dry unit weight (g/cm^3)	Void ratio (%)	Coefficient of compressibility (cm^2/kg)	Reference
Q_3 (Late Quaternary)	—	1.29	1.10	0.038	7. Liu *et al.*, 1985
Q_{1-2} (Mid-early Quaternary)	—	1.41	0.85	0.008	
Q_3 (Late Quaternary)	3.00	1.23	1.22	0.056	33. Liu *et al.*, 1966
Q_2 (Mid Quaternary)	6.00	1.52	0.79	0.003	
Q_{1-2} (Mid-early Quaternary)	10.00	1.66	0.64	0.001	
Q_3 (Late Quaternary)	—	1.33	—	—	34. Zhu & Ding, 1994
Q_2 (Mid Quaternary)	—	1.62	—	—	
Q_1 (Early Quaternary)	—	1.83	—	—	

In conclusion, we use the chronological framework of Chiloparts[10] for dating the loess-palaeosol sequence and stone artefacts at the Shangchen locality because it is internationally recognized as a timescale for the Chinese Quaternary by international organizations on Quaternary stratigraphy and geochronology (see e.g. http://www.quaternary.stratigraphy.org.uk/charts/ (2016)[18]. With the Chiloparts timescale, the oldest stone artefact horizon (the upper of L28) is ~2.12 Ma, which is slightly younger than the Réunion Excursion (2.13-2.15 Ma), and is entirely consistent with the facts of our palaeomagnetic measurements. Therefore, it is reasonable that the oldest stone artefacts at the Shangchen locality are dated to ~2.12 Ma.

II. Main methods and results

(1) Grain size

Grain size was measured with a Malvern Mastersizer-2000 laser diffraction particle size analyzer. Grain size distributions for loess and palaeosol samples from the Shangchen (SC) section are shown in Extended Data Figure 1, and are similar to those of the loess-palaeosol sequence at Lingtai which is located south of the Xifeng section, and is one of the standard sections in east Gansu Province[31].

(2) Mineralogy

The bulk mineralogy and elemental composition of loess and palaeosol samples from SC were analyzed using general chemical and XRD (X-ray diffraction) methods at the Guangzhou Institute of Geochemistry, CAS. Loess is characterized by higher concentrations of montmorillonite and calcite than palaeosols, but concentrations of illite and kaolinite are higher in palaeosols. These characteristics are the same as for the Luochuan loess section[7].

(3) Geochemistry

In Extended Data Figure 1 we compare major elements between the SC loess sections (average of 26 samples from this paper) and Luochuan (average of 36 samples, adapted from Liu *et al.*[7]) which have high geochemical similarities. The characteristics of partition mode of Rare Earth elements in loess and palaeosol samples from SC indicate they are the same as those from Luochuan.

The above three pieces of evidence indicate that the SC loess-palaeosol sequence has the same constituent and sedimentation source as other standard loess-palaeosol sequences from the Chinese Loess Plateau, and also indicate that the SC loess and palaeosol are aeolian sediments that are suitable for palaeomagnetic dating.

(4) Palaeomagnetism

(i) Sampling

The Shangchen section is developed continuously along the same gully and hill. We divided the sampling into five subsections (i.e. offset sections), including four Subsections (I, II, III, and IV) along the same gully and one Subsection (KW) at the foot of the hill. Marker layers, such as L9, L15, and L25 were used to link these sub-sections (see Figure 2 in main text and Extended Data Figures 4 and 5 for details). After removing weathered surface sediments and cleaning sections back to undisturbed loess, discrete powder samples were collected at a stratigraphic sampling interval of 5-10 cm. Oriented block hand-samples were collected at an average sampling interval of ca 10 cm for the whole section. Sampling intervals are not constant in each segment. Sampling intervals and their percentages are 1-5 cm (32.2%), 6-10 cm (47.8%), 11-20 cm (11.2%), and 25-130 (8.8%). Larger sampling intervals (ranging from 25 to 130 cm) were used in the upper section because this segment is young and is constrained by several marker layers, such as S5, L9, and L15, and some segments contain carbonate nodule layers that cannot be used for palaeomagnetic dating. Each block hand-sample was cut into 2 × 2 × 2 cm cubic specimens in the laboratory. A total of 722 specimens were subjected to palaeomagnetic measurements. Other samples collected from some short parallel sections were measured across key polarity reversals such as the Matuyama-Brunhes boundary. These results from parallel sections are the same as those in the main section, and hence we have not presented extra data on magnetic susceptibility and polarity from them.

(ii) Rock magnetism

Powder samples were air-dried and were later ground in the laboratory to measure magnetic parameters. Magnetic susceptibility was measured using a Bartington Instruments MS2 susceptometer at frequencies of 0.47 and 4.7 kHz, respectively. Magnetic susceptibility of loess in north China is usually accepted as a palaeoclimate proxy of the East Asian summer monsoon[7, 10, 31, 35]. The magnetic susceptibility profile generally has high and low values in interglacial palaeosol and glacial loess horizons, respectively. Thus, palaeoclimate boundaries determined from the magnetic susceptibility profile correlate well with field observations in most loess-palaeosol sequences.

Representative samples from several loess and palaeosol horizons were selected for thermomagnetic and hysteresis measurements. Thermomagnetic curves (M-T) and hysteresis loops were measured using a variable field transition balance (VFTB) at the Key Laboratory of Western Environmental Systems (MOE), Lanzhou University. All four representative samples undergo a clear drop in magnetisation at ca 580 °C (see Extended Data Figure 2**a**), which indicates that the major remanence carrier is magnetite in both the loess and palaeosol samples. The magnetisations of samples from L8, L15, and S26 decrease during heating between 580 °C and ~700 °C, which suggests the presence of hematite in the sediments. A slight hump at ca 200-300 °C in the heating runs is indicative of maghemite grains of pedogenic origin[36, 37]. Hysteresis loops (Extended Data Figure 2**b**) for the palaeosol samples are generally narrower than those of the loess samples, probably indicating the presence of more low-coercivity magnetic grains in the weathered soils. Hysteresis loops of the latter four samples exhibit clear evidence of wasp-waisted characteristics, which indicates contributions from both superparamagnetic grains and high-coercivity magnetic minerals[38, 39]. These magnetic characteristics of loess/palaeosol samples from the Shangchen section are consistent with previous investigations of the Lantian loess-palaeosol[3, 40] and other classic loess-palaeosol sections from the Chinese Loess Plateau[41-43].

Anisotropy of magnetic susceptibility (AMS) was measured using a MFK1-FA Kappabridge instrument with a magnetic field of 400 A/m and frequency of 976 Hz and precision of 2×10^{-8} SI at the Guangzhou Institute of Geochemistry, CAS. The AMS data were processed according to the method of Jelínek[44]. The AMS of an oriented sample can be described as a three-dimensional ellipsoid by using three orthogonal principal axes, i.e., the maximum, intermediate, and minimum principal axes (κ_{max}, κ_{int}, κ_{min}). A total of 694 oriented specimens from the main section and some short parallel sections were used to detect possible disturbances of the sediment fabric. Most of the 694 specimens have a prevalent oblate magnetic fabric with foliation exceeding the lineation, with κ_{max} inclinations lying near-horizontal, and with κ_{min} inclinations mostly perpendicular (Extended Data Figure **2a**). These results indicate a primary sedimentary fabric that remains undisturbed throughout the section. The rock magnetic data described here indicate that the samples from Shangchen are typical of Chinese loess-palaeosol sequences, which are suitable for palaeomagnetic dating.

(iii**) Magnetostratigraphy**

Progressive thermal demagnetization was performed on oriented specimens. Most of the 722 specimens were heated from room temperature to 585°C, with 145 specimens up to higher temperatures and 40 up to 690°C. All remanence measurements were made using a 2 G-Enterprises three-axis cryogenic magnetometer (2G755R and 2G760 U-channel) in a magnetically shielded space at the Palaeomagnetism Laboratory, Institute of Geology and Geophysics, CAS, and at the palaeomagnetic laboratory at the South China Sea Institute of Oceanology, CAS. All results from each sampled unit and from the same oriented hand-sample or from nearby horizons are comparable. The ChRM component was determined using principal component analysis (PCA) calculated by a least-squares method[45]. We employ unanchored PCA fitting to process the demagnetization data[46]. The natural remanent magnetization (NRM) of specimens often consists of at least two magnetic components. The component isolated at <250 °C is often considered as a viscous remanent magnetization and can be easily eliminated. The stable ChRM component of most specimens can be isolated from 250 to 585 °C, except very few specimens from the bottom of the section, which were given a stable ChRM component above 585 °C. A few specimens that were thermally demagnetized up to 690 °C were characterized by a sub-stable component above 585 °C. However, no apparent difference was found between them and those from 250 to 585 °C. Specimens with a ChRM maximum angular deviation (MAD) less than 15° (N = 694, ~96.1% of 722 specimens) were used to construct the palaeomagnetic stratigraphy (see data list in Source Data), while 28 specimens (~3.9% of 722 specimens) with greater MAD values were abandoned.

The ChRM directions yield a mean of D = 2.9°, I = 54.0° (k = 14.96, and α_{95} = 3.10) for the 151 normal polarity specimens, and D = 182.0°, I = -52.1° (k = 40.90, and α_{95} = 1.00) for the 543 reversed polarity specimens. D, I, k, and α_{95} are the declination and inclination of the palaeomagnetic direction, precision parameter, and half angle of the 95% confidence cone of Fisher[47], respectively. The reversal test was positive within an angular difference of 2.00° between the mean directions of each polarity, which is less than the critical angle of 4.23° at the 95% confidence level and thus passed an A-class reversal test[48]. Equal area projections for all specimen directions are shown in Extended Data Figure 2**b**. Orthogonal projections of demagnetization data for 15 representative specimens are shown in Extended Data Figure 3, among which (a), (b), (d), (e), (i), (k), (m), and (n) have normal polarity, and all the others have reversed polarity. There are almost no intermediate directions recorded in the polarity transition zones throughout the section. In Figure 3 of the main text, a vertical line at 0^{o} is used to define the locations of reversal boundaries. A reversal is defined by at least three successive data points. In our magnetostratigraphy of the Shangchen section the Matuyama-Brunhes boundary (~0.78 Ma) is recorded in mid-lower S7, the Jaramillo Subchron (0.99-1.07 Ma) is recorded in units S10-S12, the Olduvai Subchron (1.78-1.95 Ma) is recorded in units L25-S26, and the Réunion Excursion (2.13-2.15 Ma) is recorded in unit L28. Furture work is needed to demonstrate the existence of the Punaruu Excursion (~1.12 Ma) in the study area (see “e1” in Figure 3 of main text). One normal polarity data point, which occurs just below the Matuyama-Brunhes boundary, cannot be identified as an independent polarity event (see Figure 3 of main text).

Based on marker layers (including L9, L15, and L24-L25) and reversal boundaries of palaeomagnetic zones, the five subsections (I, II, III, IV, and KW) have been linked to establish the comprehensive main section with a timescale at the Shangchen locality (see Extended Data Figures 4, and 5 for the distribution and linking method of the subsections). This linking method is a well-established and effective approach to investigating offset sections[29].

(iv) **Magnetism as a check on the stratigraphic integrity of stone artefacts**

An innovative aspect of the research programme was that the magnetic properties of loess and palaeosol samples were used to check that stone artefacts were in undisturbed loess/palaeosol deposits and not in re-deposited sediments or slope wash. The underlying rationale is that in-situ loess/palaeosol and slope wash have completely different palaeomagnetic signatures.

In the field, bulk palaeomagnetic loess samples of slope wash were difficult to collect because of their loose structure mixed with weeds, roots and other debris. Most of them can only be sampled using small plastic boxes. However, original, in-situ loess and palaeosol can not only be cut out as intact palaeomagnetic samples (10 x 10 x 10 cm, or bigger) in the field but also can be subsampled to standard palaeomagnetic measurement samples (2 x 2 x 2 cm) in the laboratory.

The magnetic fabric of re-deposited slope deposits showed very disordered axial directions because of its modification by rolling, sliding and transporting. In contrast, the magnetic fabric of primary loess and palaeosol is indicative of the original polarity at the time of deposition.

The palaeomagnetic polarity and characteristic remanent magnetism of slope deposits are usually positive or disordered, or undetectable because most of them were formed in modern times after the inception of gully incision. However, the magnetic polarity and stable characteristic remanent magnetic direction of loess and palaeosol are detectable with only a very small error, because they represent the palaeomagnetic polarity at the time of deposition. Excellent negative palaeomagnetic polarity data were shown at several key horizons such as S22, S23, S24, S27 at the same level and above stone artefacts. Therefore, they are absolutely not slope deposits, and these artefacts are therefore definitely in undisturbed deposits.

III. Archaeological field procedures

The Shangchen section is a homogenous aeolian loess (dust) profile (see Extended Data Figures 1 and 4), without coarse grains or stone inclusions, and without sediment elements from other modes of deposition, such as alluvial and diluvial deposits, or slope wash. The section is on the loess tableland, which sits above surrounding landforms. This is a stone-free landscape, and there is no natural background of gravel or stream deposits, and no clasts occur at the base of gullies. The nearest mountains are around 5-21 km away.

Most of the examined sections have slopes of between 50° and 80°. Steeper intervals are inaccessible unless they occur at the base of a section or adjacent to a road or path. In some cases, foot- and hand- holds were cut to aid examination of a section. Our investigations focused on the lower slopes (i.e. below S15) because they were more accessible than the upper parts of sections.

All stone objects, whether flaked or unflaked, that were found embedded in a section were photographed and recorded before removal. Some were found when digging into a section to collect palaeomagnetic samples.

There are five kinds of original horizons bearing stone artefacts:

1. Artefacts found in natural loess/palaeosol sections. Most of the stone artefacts reported in this paper were found embedded firmly in loess/palaeosol sections under a thin weathered crust. Only a small part of stone artefacts (usually less than 3 cm) protruded from the sediment when they were first found. They were then extracted following normal procedures step by step (see e.g. Extended Data Figure 6).

2. Artefacts found in natural loess/palaeosol sections during palaeomagnetic sampling. Several artefacts were found during palaeomagnetic sampling of S22, S23, S24, and S27. Stratigraphic inspection and analysis of palaeomagnetic samples adjacent to and above these artefacts indicate that these artefacts are in undisturbed, *in-situ* deposits. Details are in Extended Data Figure 4**c**.

3. Artefacts found in the man-made roadside section through S27. These are described in Extended Data Figure 7.

4. Artefacts found in an excavation (Subsection KW) in layers S27 and L28 ~500 m northeast of Subsection IV (see Extended Data Figures 8-10 for details).

5. Artefacts found in slope wash on gentle slopes or at the base of gullies. This slope wash was avoided in our palaeomagnetic sampling. Some stone artefacts (ca 100) were found in slope wash and at the bottom of gullies. They were labeled strictly as "surface" in field records and on the stone surface in order to be distinguished from those found *in situ* in original horizons. None of these stone artefacts are listed in this paper.

Examples of field procedures and their results are shown in the following figures:

Extended Data Figure 4. Landscape in which palaeomagnetic sampling and artefact collecting were carried out at the SC locality.
Extended Data Figure 5. Distribution and linking method of sections at the Shangchen locality.
Extended Data Figure 6. Stone artefacts found during sampling of S22 and S24.
Extended Data Figure 7. Artefact collection at the Shangchen section from S27.
Extended Data Figure 8. The stratigraphic partition, grid lay-out, and distribution of artefacts and fossils at the exploratory trench (Subsection KW) in S27 and L28.
Extended Data Figure 9. The excavation of the exploratory trench (the Subsection KW) in layers

S27 and L28 at Shangchen locality.

Extended Data Figure 10. Selected artefacts and fossils from the exploratory trench (Subsection KW) in S27 and L28.

Supplementary Information Video 1 (SI Video 1) is a video with 3D animation of an artefact (SC2012-0507-3) from S27.

Supplementary Information Video 2 (SI Video 2) is a video with 3D animation of an artefact (SC2012-0507-2) from S27.

Supplementary Information Video 3 (SI Video 3) is a video with 3D animation of an artefact (SC 20120502-6) from S23.

IV. Stone artefacts from Shangchen locality

SI Table 6. Stone artefacts from Early Pleistocene palaeosol and loess units between S15 and L28 at the Shangchen locality. See S1-1 Table 1 for the age of each loess and palaeosol unit. The artefacts found above S15 are not included in this paper.

Artefact number	Layer	Length (mm)	Width (mm)	Thickness (mm)	Weight (g)	NPF	NSF	ND	Rock type	Artefact type
SC081016-3	S15	50.1	44.0	17.2	41	3		2	quartzite	scraper
SC 20120504-1	S16	84.2	46.3	24.4	82	2		2	quartzite	end scraper or notch
SC 20120514	S16	64.1	40.8	27.8	83	3	3	3	quartzite	scraper; possible notch
SC-A 070915-1	L17	150.5	107.2	44.2	764	7		4	quartzite	biface or pick
SC080708-06	S18	82.2	70.2	49.5	216	7		5	quartzite	core
SC080708 WS4	S18	57.5	43.9	16.1	48	3		2	quartzite	flake fragment
SC-W4-2 0707	S18	66.5	35.4	23.1	55	NC		NC	quartzite	fragment
SC 20120502-8	S18	98.7	117.8	58.1	820	3		1	quartzite	flat core
SC-W4 0707	S18	30.6	24.2	14.5	12	NC		NC	quartzite	small fragment
SC 20120502-11	S18 top	62.9	50.9	22.1	78.6	2		2	quartzite	fragment
SC-W5-3 0707	S19	80.4	43.9	40.8	106	3		1	quartzite	core fragment
SC0709-3 WS5	S19	41.6	38.8	28.4	41	3		1	quartzite	cortical fragment
SC0707-W5-1	S19	55.1	35.8	22.4	45	4		2	quartz	core fragment
SC-07-09	S19	75.9	55.4	42.2	285	1		1	quartzite	flat core; transverse break
SC-E 070918-1 WS4-5	S19	56.9	50.3	42.1	126	5		3	quartzite	fragment; broken end of large tool
SC0709-1 –WS5	S19	109.3	86.6	46.0	655	N		N	quartz	hammerstone
SC080708-07 WS5	S19	49.6	43.5	39.4	112	N		N	quartz	manuport
SC0707-W5-2	S19	68.5	58.9	29.6	116	10		2	quartzite	point
SC 20120502-12	S20	66.6	45.2	32.5	87	3		NC	sandstone	fragment
SC0709-2 WS6	S20	91.1	69.9	32.5	264	2		1	quartz	borer(1)
SC W6-2 0707	S20	39.4	33.2	15.9	20	2		1	quartzite	flake fragment
SC-E-070918-9	S20	28.2	18.2	17.5	12	7		5	quartz	flaking debris
SC0707-W6-1	S20	126.1	109.8	77.1	1,019	3	4	3	quartzite	pick
SCW6-3 0707	S20	44.7	26.7	11.6	14	1		1	quartzite	scraper (retouch noted)
SC 20120502-10	L21	55.4	41.1	16.0	40.5	2		2	quartzite	scraper
SC-E-S 070918-18-5	S21	29.0	21.5	17.8	12	3		3	quartz	small fragment; no cortex
SC-E-S 070918-7 WS 6-7	S21	105.6	64.9	47.2	139	N		N	quartzite	hammerstone
SC-E-5 070918-6 WS 6-7	S21	131.0	71.2	52.6	639	N		N	quartzite	manuport
SC-E-S 070918-4 WS1	S21	66.5	58.6	38.9	225	N		N	quartz	manuport
SC-E 070918-2	S21	38.5	30.2	9.6	13	1	3	2	quartzite	scraper
SC 20120503-1	S21	133.8	123.0	112.7	2,060	4	1	3	quartzite	core

SC-A 070915-2 WS7	S21	33.1	42.2	11.4	19	2		1	quartzite	flake
SC 20120502-7	S21 lower	115.7	89.2	43.4	660	1		1	quartzite	flake fragment
SC 20120502-5	L22	82.2	61.9	50.2	292	N		N	quartzite	hammer
SC 20120503-11	L22	52.3	33.5	15.1	31	1		1	quartzite	notch
SC-E-E 070917-12	S22	83.7	53.9	34.5	155	8		3	quartzite	biface
SC-W8-1 0707	S22	44.9	28.4	19.0	23	4		2	quartz	bipolar fragment
SC 091101-4	S22	64.9	51.3	22.4	86	2		2	quartzite	borer[1]
SC080711-8	S22	50.6	25.9	18.5	21	4		NC	quartzite	fragment
SC 080708-02	S22	145.4	98.8	68.7	1,219	4	3	5	quartzite	core
SC080708-03	S22	82.1	43.6	64.9	360	4	3	1	quartzite	core
SC080711-13	S22	63.9	53.5	40.3	190	3	4	3	quartzite	core, no cortex
SC-E-E 070917-7	S22	74.8	55.4	48.6	348	1	2	2	quartzite	core
SC080711-6	S22	59.0	42.5	38.2	103	1	2	2	quartzite	flake
SC-FW 080710-4	S22	49.0	35.9	13.3	24	3		3	quartz	flake fragment, no cortex
SC 20120503-12	S22	44.0	38.6	15.0	40	2		2	quartzite	flake fragment; salami slice[2]
SC 091101-7	S22	76.0	49.7	32.0	122	6		3	quartzite	flake tablet
SC-080711-1	S22	42.0	47.7	17.4	37	2		1	quartzite	flake
SC 20120502-9	S22	39.8	27.7	16.8	18	N		N	quartzite	fragment
SC 20100610-S22	S22	58.7	58.0	60.0	277	N		N	quartzite	manuport
SC080708-01	S22	85.8	70.6	63.1	475	N		N	quartzite	hammer[3]
SC 20091101-12	S22	74.4	56.4	31.3	177	N		N	quartzite	manuport
SC 20091101-5	S22	77.5	60.8	46.5	290	N		N	sandstone	manuport
SC 20120502-4	S22	103.4	96.3	46.7	880	N		N	quartzite	manuport
SC080-708-05	S22	70.3	59.3	19.6	110	2		2	quartzite	notch
SC080711-20	S22	66.9	38.1	25.1	81	5		4	quartzite	notch
SC-E-E 070917-14	S22	62.7	43.5	24.1	51	4		2	quartzite	flake
SC 091101-6	S22	72.6	58.9	19.7	103	2		2	quartzite	flake
SC 20100610-S22-b	S22	22.3	23.4	11.1	8	1		1	quartz	scraper, bipolar
SC080708-11	S22	46.4	34.0	21.5	30	3		3	quartz	scraper
SC080711-6	S22	52.7	43.8	12.9	33	3		3	quartz	scraper
SC-E-E 070911-1	S22	55.9	28.4	12.5	27	1	5	3	quartzite	scraper
SC-E-E 070917-6	S22	76.7	62.8	30.8	152	1		1	quartz	scraper
SC-E-E 070917-9	S22	82.4	56.7	22.2	125	4		2	metamorphic	scraper
SC-FW080710-3	S22	79.0	50.6	29.5	104	6		2	quartz	scraper
SC-FW 080710-13	S22	58.5	57.5	39.1		4		4	quartzite	core
SC 20120503-10	S22	65.6	37.9	17.1	61	4		1	quartzite	scraper
SC 20100610-S22-a	S22	21.3	17.6	8.7	4	2		2	quartz	scraper; possible notch
SC070926-1	S23	89.8	53.5	25.9	141	4		3	quartzite	flake fragment
SC 20120502-6	S23	71.3	46.5	21.1	72	2		1	quartzite	flake, salami slice[2]
SC080710-1	S24	150.3	148.8	91.7	2,841	2		2	quartzite	core
SC0807 11-01	S24	52.5	34.4	19.2	30	2		1	quartzite	flake fragment

SC080712-1-a	S24	46.0	31.1	12.1	17	1		1	quartz	scraper
SC080712-1-b	S24	39.0	48.2	18.3	36	3		1	quartzite	flake fragment
SCW 9-10	S24	97.3	75.7	42.5	204	3		2	quartz porphyrite	notch,
SC080708 L25	L25	24.3	22.6	19.7	12	3		3	quartz	flaking debris
SC2012 0504-2	L25	94.4	67.4	42.2	380	N		N	quartzite	hammer(3)
SC-E-S 070918-8	L25	49.5	29.3	17.6	24	NC		NC	quartzite	fragment
2010-06 SC-L25	L25	62.8	62.9	33.9	156	1	3	2	quartz	scraper
SC-D2	S26	116.4	56.8	37.1	426	1		1	quartzite	cobble
SC-D2a	L27	115.1	58.4	38.2					quartzite	cobble
SC-B D2-2	L27	54.6	39.2	26.3	168	4		4	quartzite	bipolar fragment
SC 20120516-1	S27	62.5	47.3	49.7	241	4		1	quartz	core
SC20120507-1	S27	152.4	145.4	82.6	1,908	4		1	quartzite	core
X2013 0712-D1	S27	60.2	46.9	26.4	97	2	1	2	quartzite	core/scraper
SC2012-0507-3	S27	92.0	53.0	31.8	143	5		2	quartzite	flake tool
SC 2012 0507-2	S27	84.8	47.8	28.0	108	4	1	2	quartzite	pointed piece
SC 20120518-1	S27	60.4	56.5	46.1	238	1	`	1	quartzite	core
Excavation of S27 and L28										
SC-K4	S27/L28	225.0	133.0	100.0	3,770	4	N	2	quartzite	core
SC-K5	S27/L28	56.0	36.0	15.0	35	1	2	2	quartzite	flake tool
SC-K30	L28	85.5	77.0	38.0	205	2		2	quartzite	pointed piece
SC-K46	L28	29.0	21.0	5.0	4.6	2		3	quartzite	scraper
SC-K53	L28	81.2	55.0	19.0	80.8	2		2	quartzite	flake
SC-K54	L28	34.0	29.0	9.5	8.2	2		2	quartzite	scraper
SC-K55	L28	29.0	26.5	13.0	7.9	2	1	3	quartzite	point
SC-K57	L28	19.0	16.0	4.0	3.3	2	2	3	quartz	scraper

Notes:

For layers, S = palaeosol, and L = loess.

Measurements are in mm for size and g for weight. NPF = number of primary flake removals; NSF = number of secondary flake removals; ND = number of directions of flaking; Columns 7 (NPF) and 9 (ND): NC = not clear; N = none.

(1) Borer is a tool that can make a hole, and can also be called an awl.

(2) Salami flakes are defined by Hurcombe[49]: “They are round, and have a continuous arc or ring of cortex from the platform and extending down around their circumference, with the flake scar from the previous removal forming a neat round dorsal scar. They signify the opening stages of a pebble core reduction strategy by being the second or at most third flake off a cobble, and could either alter the angle of the platform created at the top of a cobble, or widen it to encompass more of the cobble’s breadth”.

(3) Two hammerstones had possible percussion damage on one side.

SI Table 7. Details of selected artefacts from L28/S27, S27, L27, L25 and S23 shown in Figure 4 of main text.

Number in Figure 4	Specimen number	Layer	Rock type	Length (mm)	Breadth (mm)	Thickness (mm)	NF	ND	Artefact type
4a	SC 20120507-3	S27	quartzite	92.0	53.0	31.8	7	2	flake tool
4b	SC 20120507-2	S27	quartzite	84.8	47.8	28.0	5	2	pointed piece
4c	SC 20120516-1	S27	quartzite	62.5	47.3	49.7	4	1	core
4d	SC 20120507-1	S27	quartzite	152.4	145.4	82.6	4	1	core
4e	SC-B D2-2	L27	quartzite	54.6	39.2	26.3	4	2	bipolar fragment
4f	SC 20120502-6	S23	quartzite	71.3	46.5	21.1	2	1	flake
4g	2010-06 SC	L25	quartz	62.8	62.9	33.9	4	2	scraper
4h	SC-K5	S27/L28	quartzite	56.0	36.0	15.0	3	2	flake tool
4i	SC-K4	S27/L28	quartzite	225.0	133.0	100.0	4	2	core
4j	SC070926-1	S23	quartzite	89.8	53.5	25.9	5	4	flake fragment

Notes:

Measurements are in mm. NF: number of flake removals; ND: number of directions of flake removals.

4a) SC 2012-0507-3 (S27): There are four primary and three secondary flake removals from two directions. Two of the flake removals are 61.3 x 3 and 41.0 x 22.7 mm; the others are less clear. Percussion was bipolar. The piece is fresh, and one edge is sharp. The cortex on the base is 37.7 x 27.8 mm. See also Extended Data Figure 7 for photographs of its extraction from the section.

4b) SC 2012 0507-2 (S27): There are four primary flake removals and one secondary one at the base. Two primary removals with clear edges of 80.6 x 34.6 and 25.9 x 23.7 mm. Percussion was bipolar, and the edges are sharp. The cortex on the base is 35.5 x 25.1mm.

4c) SC 20120516-1 (S27). The piece is fresh and there are four flake removals, 40.2 x 36.7; 41.7 x 36.7; 44.8 x 18.3; and 23.3 x 21.7 mm. Percussions were by hard hammer.

4d) SC 20120507-1 (S27) The flake removal scars are clear and 61.3 x 77.9; 76.3 x 41.1; 64.9 x 56.4; and 41.4 x 29.5 mm. Flaking angles were c. 80^{o}. See Extended Data Figure 7 for photographs of its extraction from the section.

4e) SC-B D2-2 (L27). There are four primary flake removals, and two secondary ones. Flaking was bipolar, and the piece was fresh.

4f) SC 20120502-6 (S23). This piece is a thin slice that was struck from the face of a flat core. There is a clear flake removal across the ventral face, and a hinge fracture on the dorsal face. Cortex remains along the outer edge; the opposing edge is sharp. The piece is fresh.

4g) 2010-06 SC (L25). The piece is fresh, with one sharp edge. Two secondary removals are 21.3 x 12.1 and 22.8 x 19.9 mm. Percussion was by hard hammer.

4h) SCK-5 (S27/L28): The piece is fresh and with one twisted edge. There are three secondary flake removals on this edge. See Extended Data Figure 10d for a photograph.

4i) SCK-4 (S27/L28): There are four flake removals from two directions. The flake removal scars on this core are clear and measured 102.5 x 45.4; 84.5 x 53.6; 80.1 x 46.5; and 73.4 x 58.5 mm. See Extended Data Figure 10a for a photograph.

4j) SC070926-1 (S23): There are four primary and one secondary flake removals, from four directions. Two of the flake removals measured 35.0 x 32.8 and 28.8 x 28.7 mm. This is probably a fragment of a larger flake. There is cortex on the dorsal face, but not on the other two.

SI Table 8. Details of selected artefacts found in S22

Number	Specimen number	Rock type	Length (mm)	Breadth (mm)	Thickness (mm)	NF	ND	Artefact type
a	SC-E-E 070917-14	quartzite	42.7	62.5	24.1	4	2	flake
b	SC-080711-1	quartzite	42.0	47.7	17.4	2	1	flake
c	SC080711-6-a	quartz	52.7	43.8	12.9	3	2	scraper
d	SC-FW080710-3	quartz	79.0	50.6	29.5	6	2	scraper
e	SC-W8-1 0707	quartz	44.9	28.4	19.0	4	2	bipolar fragment
f	SC080711-20	quartzite	66.9	38.1	25.0	7	4	notch
g	SC-E-E 070917-6	quartz	76.7	62.8	30.8	1	1	scraper

Notes:

Measurements are in mm. NF: number of flake removals; ND: number of directions of flake removals.

a) SC-E-E 070917-14. A flake with cortex on one face and three flake removals on the dorsal side 26.3 x 27.4, 23.6 x 26.2, and 28.8 x 28.2 mm. The cortex measured 42.7 x 23.2 mm, and 15.1 x 14.8 mm on the platform.

b) SC-080711-1. A broken flake with a small area of cortex on the platform at the tip 15.3 x 8.9 mm.

c) SC080711-6-a. A flake with three flake removals; two were 47.8 x 27.8 and 36.9 x 12.7mm. There is possible edge damage along the basal side. There is some cortex (8.2 x 7.6 mm) on the platform, and some (36.4 x 20.2 mm) on the dorsal side

d) SC-FW080710-3. A pointed piece that had been flaked extensively, with five flake removals on one face and one on the other, and only a small area of cortex c. 20 x 12 mm. The upper edge has some damage that may indicate use as a scraper.

e) SC-W8-1 0707. A fragment resulting from bipolar flaking. There are four flake removals from two opposite directions. Three of the removals measured 30.6 x 16.7, 19.9 x 15.7, and 13.5 x 13.4 mm. The break occurred after extraction from the section.

f) SC080711-20. There were five primary flake removals around the edge, and a secondary one on the obverse. One flake removal 11.1 x 15.0 resulted in a notch, 5.7 mm deep. The obverse side is cortex.

g) SC-E-E 070917-6. This piece is classed as a scraper because of the fine alternate retouching on the tip, shown in the enlarged view. The retouch is 13.3 mm deep.

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