Quartz OSL dating of late quaternary Chinese and Serbian loess: A cross Eurasian comparison of dust mass accumulation rates

Peric, Zoran; Adolphi, Emma Lagerbäck; Stevens, Thomas; Ujvari, Gabor; Zeeden, Christian; Buylaert, Jan-Pieter; Markovic, Slobodan B.; Hambach, Ulrich; Fischer, Peter; Schmidt, Christoph

Total number of authors:
22

Published in:
Quaternary International

Link to article, DOI:
[10.1016/j.quaint.2018.01.010](https://doi.org/10.1016/j.quaint.2018.01.010)

Publication date:
2019

Document Version
Peer reviewed version

[Link back to DTU Orbit](#)

Citation (APA):

Peric, Z., Adolphi, E. L., Stevens, T., Ujvari, G., Zeeden, C., Buylaert, J-P., Markovic, S. B., Hambach, U., Fischer, P., Schmidt, C., Schulte, P., Huayu, L., Shuangwen, Y., Lehmkuhl, F., Obrecht, I., Veres, D., Thiel, C., Frechen, M., Jain, M., ... Gavrilov, M. B. (2019). Quartz OSL dating of late quaternary Chinese and Serbian loess: A cross Eurasian comparison of dust mass accumulation rates. *Quaternary International*, 502(Part A), 30-44. <https://doi.org/10.1016/j.quaint.2018.01.010>

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Quartz OSL dating of late Quaternary Chinese and Serbian loess: a cross Eurasian comparison of dust mass accumulation rates

Zoran Perić^{1,2*}, Emma Lagerbäck Adolphi³, Thomas Stevens³, Gábor Újvári^{4,5}, Christian Zeeden⁶, Jan-Pieter Buylaert^{5,7}, Slobodan B. Marković², Ulrich Hambach^{8,2}, Peter Fischer⁹, Christoph Schmidt⁸, Philipp Schulte¹⁰, Lu Huayu¹¹, Yi Shuangwen¹¹, Frank Lehmkuhl¹⁰, Igor Obreht¹², Daniel Veres^{13,14}, Christine Thiel¹⁵, Manfred Frechen¹⁵, Mayank Jain⁵, Andreas Vött⁹, Ludwig Zöller⁸, Milivoj B. Gavrilov²

**¹Research Group for Terrestrial Paleoclimates, Max Planck Institute for Chemistry,
Hahn-Meitner Weg 1, 55128 Mainz**

**²Chair of Physical Geography, Faculty of Science and Mathematics, University of Novi
Sad, Trg Dositeja Obradovića 3, 21000 Novi Sad, Serbia**

**³Department of Earth Sciences, Uppsala University, Villavägen 16, Uppsala, SE-75236,
Sweden**

**⁴Institute for Geological and Geochemical Research Research, Centre for Astronomy and
Earth Sciences, Hungarian Academy of Sciences, 1112 Budapest, Budaörsi út 45.
Hungary**

**⁵Centre for Nuclear Technologies, Technical University of Denmark, Risø Campus,
Roskilde, DK-4000, Denmark**

**⁶IMCCE, Observatoire de Paris, PSL Research University, CNRS, Sorbonne Universités,
UPMC Univ Paris 06, Univ Lille, 75014 Paris, France**

**⁷Nordic Laboratory for Luminescence Dating, Department of Geosciences, University of
Aarhus, DTU Nutech, Risø Campus, Roskilde, DK-4000, Denmark**

**⁸BayCEER and Chair of Geomorphology, University of Bayreuth, 95440 Bayreuth,
Germany**

**⁹Institute for Geography, University of Mainz, Johann-Joachim-Becher Weg 21, 55099
Mainz, Germany**

**¹⁰Department of Geography, RWTH Aachen University, Templergraben 55, 52056
Aachen, Germany**

**¹¹School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing
210093, China.**

¹²Organic Geochemistry Group. MARUM-Center for Marine Environmental Sciences and Department of Geosciences, University of Bremen, D-28359 Bremen, Germany

¹³Institute of Speleology, Romanian Academy, Clinicilor 5, 400006 Cluj-Napoca, Romania

¹⁴Interdisciplinary Research Institute on Bio-Nano-Science of Babe-Bolyai University, 400006 Cluj-Napoca, Romania

¹⁵ Leibniz Institute for Applied Geophysics (LIAG) Geochronology and Isotope Hydrology, 30655 Hannover, Germany

*Corresponding author: zoranperic.geo@gmail.com

ABSTRACT: Reconstructing dust Mass Accumulation Rate (MAR) from loess deposits is critical to understanding past atmospheric mineral dust activity and requires accurate independent age models from loess deposits across Europe and Asia. Previous correlations of loess in Europe and China have tended to focus on multi-millennial timescales, with no detailed examination of dust MAR at the two ends of the Eurasian loess belt on shorter, sub-orbital scales. Here we present a detailed quartz optically stimulated luminescence (OSL) chronology from the Serbian Titel Loess Plateau (Veliki Surduk loess core) and the Chinese Loess Plateau (Lingtai section). The luminescence ages pass internal tests and show consistent increases in age with depth, with no obvious major hiatuses. However, as reported before, it seems the quartz OSL technique is only capable of accurate age determination up to accrued doses of ca. 150 Gy (ca. 30-40 ka) due to approaching field saturation of the quartz OSL signal. Two age-depth models were used to reconstruct dust MARs, where one utilises OSL data solely and the other additionally makes assumptions about sedimentation rates. Although short-term fluctuations in MAR are model dependent, general MAR patterns between the two sites are very similar, with peak MAR occurring rather late in the last glacial (ca. 13-25 ka). This suggests that at least broad scale trends in dust activity within the last glacial period may be similar at a continental scale.

Keywords: OSL dating, MAR, Titel Loess Plateau, Chinese Loess Plateau, loess, dust

Introduction

Loess deposits are important continental archives of climatic change and past atmospheric dust activity. Apart from the Chinese Loess Plateau dust deposits, which are some of the most

extensively studied climate archives on the planet (Liu, 1985; Ding et al., 2002; Porter, 2001), a large number of the longest and most detailed loess-palaeosol sequences are situated in the Vojvodina region of Serbia (Buggle et al., 2013). These sequences are also some of the oldest and most complete archives of environmental change on the European continent (Marković et al., 2012) and provide an opportunity to reconstruct past climate and dust dynamics across a wide area of Eurasia from the same type of archives and under a uniform stratigraphic and interpretive framework (Marković et al., 2015). However, the climatic control on the formation of loess-palaeosol sequences in these regions is somewhat different: on the Chinese Loess Plateau, loess-palaeosol formation is closely associated with variations of winter and summer East Asian monsoon climates during the Quaternary (An, 2000; Porter, 2001) while the formation of the loess deposits in the Vojvodina region is controlled by the interplay of continental and Atlantic climates (Obrecht et al., 2016), with two possible predominant dust transport directions: northerly and south-easterly (Marković et al., 2008).

Marković et al. (2011) correlated loess deposits in the Vojvodina region with those in China, and similarities in loess palaeoclimate records at opposite ends of the Eurasian loess belt have been proposed by Marković et al. (2015) based on inter-profile correlation, using pedostratigraphy and magnetic susceptibility (MS) in the middle Danube Basin and the Chinese Loess Plateau. This holds great promise as understanding of loess dust mass accumulation rates (MAR) across such a wide continental area could provide insight into changes in past atmospheric dust activity over a hemispheric scale (Lu and Sun, 2000; Kohfeld and Harrison, 2003; Albani et al., 2015), which is a critical but poorly understood component of the climate system. However, it is uncertain if the similarities observed by Marković et al. (2015) are valid on shorter, sub-orbital or sub-Milankovic timescales, and no study has tested whether there are indeed similarities in dust accumulation rates within glacial stages at the two ends of the Eurasian loess belt. In order to achieve this, detailed independent age models are needed to

calculate dust accumulation rates, as non-independent age models are incapable of resolving changes in accumulation rate within single glacial periods (Stevens et al., 2008; Kang et al., 2015).

Independent high sampling resolution dating of loess sequences is still relatively rare, as reflected in the few loess sites included in the dust MAR compilation of Albani et al. (2015). On the Chinese Loess Plateau, although still relatively unusual, loess sites with independent chronologies sufficiently detailed to examine shifts in dust MAR are numerous enough to permit some analysis of wider Late Quaternary trends on the plateau (Kang et al., 2014; Stevens et al., 2016). In European loess generally, Frechen et al. (2003) summarises a large body of research that used IRSL techniques to undertake relatively high-resolution dating and dust MAR calculation, while Rousseau et al. (2002) provide detailed ^{14}C , OSL, IRSL and TL ages for the Nussloch site in Germany. However, most of these studies utilise luminescence methods that in recent years have been questioned (Roberts, 2008). Recently one Hungarian Carpathian Basin site dated in unprecedented detail using AMS radiocarbon dating of charcoal and small gastropods (Újvári et al., 2017), while in the Lower Danube Basin (Romania) tephra chronology and correlative age modelling using palaeoclimatic proxy data has been applied on several loess sequences (Obrecht et al., 2017; Zeeden et al., in press). However, these studies are still rare and as yet have not been conducted in Vojvodina (Vojvodina Province, southeastern part of the Carpathian Basin). Limited initial TL dating of the loess-palaeosol sequences in Vojvodina was conducted (Singhvi et al., 1989), although in recent years the validity of this method has been questioned. Recently, initial attempts have been made to date loess sequences in the area using quartz based OSL and polymineral post-IR IRSL dating techniques (Fuchs et al., 2008; Stevens et al., 2011). However, these are not dated with sufficient precision for detailed MAR calculation and analysis of climate proxies on fully independent timescales. Thus, this paper attempts to address this by applying a highly detailed

study of quartz OSL ages from the last glacial period at two sites: one on the Titel loess plateau in Europe and one at the Lingtai loess section on the Chinese Loess Plateau (Fig. 1). To the best of our knowledge, the data presented here represents the most detailed luminescence-based age model in European loess to date.

Regional setting, litho- and pedostratigraphy

The analysis we present in this study covers the last glacial cycle loess (L1) unit recovered from a unique loess core taken from the Titel loess plateau (Vojvodina Province, Serbia, southeastern part of the Carpathian Basin) and the L1 unit of the Lingtai section on the Chinese Loess Plateau. The Titel core goes as deep as the penultimate interglacial palaeosol (S2) unit, and the samples recovered from the Lingtai section cover roughly the last climatic cycle loess (L1-S1) units and the top part of the penultimate glacial loess (L2) unit. However, the quartz OSL dating was performed only on the last glacial L1 unit and therefore, the following stratigraphic descriptions will focus only on the L1 loess unit.

The Titel loess plateau

The Titel loess plateau in the Vojvodina region of Serbia (Fig. 1) is considered to contain one of the most detailed terrestrial palaeoclimatic records in Europe, with a thick and apparently continuous record of climate and atmospheric dust deposition from the last five glacial-interglacial cycles (Marković et al., 2015). Due to the scarcity of archives and previous studies, as well as the potential importance of the region as a boundary between continental and Mediterranean climate systems, palaeoenvironmental reconstruction for this region is a major goal (Obreht et al., 2016). Here we present a description of the Veliki Surduk section (45°17'18"N and 20°12'15"E), which lies ca. 100 m from the location of the Titel drill core and is

situated at the southern edge of Mošorin village (Fig. 2) at an elevation of 116 (max) m at the top of the section (Fig. 2).

The modern soil (S0) and the most recent three glacial loess units L1, L2, and L3 and pedocomplexes S1, S2, and S3 are represented at exposures in the Veliki Surduk deep loess gully at the southern edge of the village. Previous stratigraphic studies of loess sections at various exposures in northern Serbia (Vojvodina Province, southeastern part of the Carpathian Basin) focused on pedo- and litho-logical and magnetic susceptibility data, along with variations in amino acid racemization geochronology, all combined with luminescence dating, as the primary basis for correlation (Marković et al., 2011). These results have been used for the establishment of a chronostratigraphy for the various loess-palaeosol units in the Vojvodina region (Marković et al., 2008, 2009). The nomenclature for this chronostratigraphy follows the Chinese loess stratigraphic system, with one exception - use of the prefix “V-“ to refer to the standard Pleistocene loess-palaeosol stratigraphy in Vojvodina (Marković et al., 2008). Recently, a Danubian loess stratigraphic model (Marković et al., 2015) has been developed to correlate the loess-palaeosol units of the Danube Basin with the Chinese stratotype sections of Luochuan. Thus, in this study we use this scheme and Chinese “L and S” labels (e.g. Kukla, 1987; Kukla and An, 1989) without using any regional prefix.

According to the current chronostratigraphic model for Serbian loess (Marković et al., 2015), the penultimate interglacial pedocomplex S2 and glacial loess L2 formed during marine isotope stages (MIS) 7 and 6, respectively. The pedocomplex S1 correlates with MIS 5, which is overlain by the composite loess unit L1, corresponding to MIS 4 through 2. The lower loess sub-horizon (L1LL2) accumulated above the S1 palaeosol. The Middle Pleniglacial pedocomplex is represented in the area by one palaeosol unit or even multiple weakly developed soils (therefore we use the term L1SSX; where ‘X’ represents a number of developed palaeosoils in L1). The youngest loess layer (L1LL1) accumulated during the Late Pleniglacial

period, mostly associated with the late last glacial. Finally, the modern soil (S0) developed during the Holocene (Marković et al., 2015). Table 1 shows the position of the upper and lower boundaries and the thickness of stratigraphic units at the Veliki Surduk drilling site and the Lingtai section. The Holocene soil cover on the loess plateau surface, at the top of Titel loess plateau, is a typical Chernozem. At the top of the Veliki Surduk deep loess gully sequence, the soil profile is 50 cm thick, with a Ck horizon that contains many CaCO₃ nodules (0.5-2.0 cm in diameter) and numerous krotovinas and root channels filled with humic material. The transitional AC horizon is 25 cm thick, porous, and has a silt loam texture and a granular structure. The silt loam Ah horizon is 20 cm thick and has granular structure, along with some carbonate pseudomycelia. The presence of a P (plough) horizon in the uppermost part of the section indicates a strong human influence on this soil due to long term intensive agriculture production.

At the Veliki Surduk deep loess gully sequence the last glacial loess unit (L1) is generally around 10 m to 11 m thick. The lower loess unit (L1LL2) is a light yellow to grey, coarse and porous loess layer; the superimposed weakly developed pedocomplex L1SSX is intensively bioturbated and contains three weakly developed humic horizons. The uppermost loess layer (L1LL1) is porous and especially in its uppermost part heavily bioturbated. Many spherical, soft, carbonate nodules and humic infiltrations in old root channels are found at the contact with the Holocene soil (S0) above. The brownish pedocomplex (S1), which is 220 to 240 cm thick, is comprised of three pedomembers: a brown horizon at the base and two fossil Chernozem type horizons that form the middle and upper part of the pedocomplex. The uppermost humic horizon is relatively weakly developed and characterised by abundant krotovinas. The lowermost part of the pedocomplex and the transition to the underlying loess contain carbonate concretions.

The Chinese Loess Plateau – Lingtai section

The Chinese Loess Plateau is considered to contain the most complete and detailed continental record of Quaternary palaeoclimatic changes (Liu, 1985; Liu and Ding, 1993) and is one of the most investigated climate archives on the planet. The Lingtai section is situated in the southern part of the plateau (107°30'33"E, 35°00'75"N; Fig. 2), about 15 km to the south of the town of Lingtai, Gansu Province, at an elevation of ca. 1340 m above sea level (Ding and Yang, 2000), and is situated on typical loess plateau table land.

The section consists of a 175 m thick loess-palaeosol sequence underlain by 130 m of the Pliocene Red Clay formation. The long-term chronology of the Lingtai section is based on palaeomagnetic reversal stratigraphy, as are the chronologies of many of the records in the Loess Plateau, although several sections have been tuned to an astronomical timescale (Ding et al., 1994, 2002; Lu et al., 1999).

The Lingtai section is one of the longest and most complete sections on the Chinese Loess Plateau, with a total of 33 palaeosol horizons developed sequentially during the Pleistocene representing warm/humid intervals alternating with cold/arid periods during which loess was deposited but remained largely unaltered. The Holocene soil cover on the top of the Lingtai section is a ~75 cm thick horizon, loose in structure with a brownish colour. Like the Titel plateau, it contains a Ck horizon (25 - ~90 cm) with CaCO₃ nodules. The Ah horizon is ~25 cm thick and represents a typical agricultural terrace with strong, recent soil development and numerous root channels filled with humic material.

The last glacial loess unit (L1) is 5.55 m thick and intersected with fine and a few larger roots in the upper ~200 cm of the horizon. The lower loess unit (L1LL2) has a dense structure with many fine, elongated CaCO₃ precipitates. At 540 cm depth, there is a noticeable increase in sand and CaCO₃. The overlying pedocomplex L1SS1 is 220 cm thick, brown in colour with

a few secondary carbonates mainly in fine root channels. From a depth of ~280 cm downwards the deposits show a higher density in the structure.

The palaeosol S1 from the last interglacial is 270 cm thick and has a blackish-brownish colour indicating a high organic matter content (Ding et al., 1999). The lower, transitional part to L2 is clay rich, yellowish brown in colour and shows an increase in sand content. The middle part of the pedocomplex (740-820 cm) is characterised by very dominant Mn precipitates (ca. 0.5 cm in diameter). The uppermost horizon is angular-blocky in structure, clay rich and characterised by abundant krotovinas. Many authors have correlated the Lingtai section with other sections on the plateau using grain size and magnetic susceptibility records (Kukla and An, 1989; Rutter et al., 1991) but to date no independent chronology exists at the site to our knowledge.

Sampling

In order to obtain detailed stratigraphic, climatic and chronological information from the Titel loess plateau, two cores were drilled in the northern area of the plateau, near the village of Mošorin (45°17'46"N 20°11'21"E) at the site called Veliki Surduk. The coring site is located on the eastern side of the loess gully, while the intensely studied outcrop is exposed on the western side. The first core (TLP 1) was drilled to a depth of 22.93 m while the second one (TLP 1A) was drilled to a depth of 21.42 m. The two cores were drilled side by side, just 1 m apart, covering about the same stratigraphic depths. In general, the second core was drilled in order to compensate for core loss at the top and base of the 1 m long core segments of the TLP 1 core, and to provide backup samples in case the material from the first drilling was proved to be insufficient or not suitable for analysis. TLP 1A has a core depth offset of 0.5 m from 1.5 m down compared to TLP 1. The cores were then split lengthwise, one half for luminescence dating and the other one for sedimentology, geochemistry, palaeo- and mineral magnetism.

Luminescence sampling for equivalent dose determination was undertaken in continuous sections of 13-15 cm length in both cores. Samples for dose rate assessment via laboratory gamma spectrometry were taken in 6 cm segments from each end of the section matching the luminescence samples. The sampling was undertaken in the laboratory of the Chair of Geomorphology (member of BayCEER), University of Bayreuth, Germany under subdued red-orange light. In core TLP 1 99 samples were obtained for both equivalent dose and dose rate measurements, while from TLP 1A 89 samples were obtained.

The samples from the Lingtai section were obtained by hammering stainless steel cylinders into the loess profiles at 10 cm intervals. In total, the results from 43 samples are presented here from the uppermost 5.6 m. The sample preparation was carried out in the Nordic Laboratory for Luminescence Dating (Aarhus University), Risø Campus, Denmark, under subdued orange light. The inner material of the cylinders was used for equivalent dose measurement and the outer, light-exposed material for dose rate measurements.

Samples, instrumentation and facilities

In this study, we present the results from a detailed OSL investigation of the 63-90 μm quartz grains from the Titel core TLP 1 and 4-11 μm quartz grains from the Lingtai section, covering the last glacial period. The fraction 63-90 μm from the Titel core proved to be relatively easy to extract and provided sufficient material in most of the samples, while for Lingtai average grain-size is finer and 63-90 μm grains are far less abundant. The 63-90 μm grains were obtained by wet sieving through 90 and 63 μm sieves. For four Titel samples a smaller grain size fraction (40-63 μm) was used as there was insufficient material in the 63-90 μm fraction. Chemical preparation of the bulk samples included 10% hydrochloric acid (HCl) and 10% hydrogen peroxide (H_2O_2) treatments in order to remove carbonates and organic matter, respectively. Samples that showed a stronger carbonate reaction were left in the HCl solution

for 24 h. The 63-90 μm grain size separates were treated with 10% hydrofluoric acid (HF) for 40 min to remove the alpha irradiated surface layer and weathering products and coatings, followed by 10% HCl for 40 min to remove fluorides. After each chemical treatment, samples were washed three times in deionised water. The obtained material was separated using sodium heteropolytungstate dissolved in water (2.58 g cm^{-3} ; LST 'Fastfloat') to provide quartz-rich and K-feldspar-rich fractions. The isolated quartz-rich fraction was treated with concentrated (49%) HF for 20 min to remove any remaining feldspar contamination. The quartz grains were mounted as large 8 mm aliquots on stainless steel cups using silicone oil spray for as an adhesive.

For the extraction of the fine quartz grains from the Lingtai samples, a standard procedure was used (Lowick and Preusser, 2010). All grains were first treated with 32% HCl to remove carbonates followed by a 30% H_2O_2 treatment to remove organic matter, and finally with sodium oxalate ($\text{Na}_2\text{C}_2\text{O}_4$) to avoid aggregation. The 4-11 μm polymineral fine grains were extracted by settling using Stokes' Law, and the quartz fraction was obtained by subsequently immersing these grains in 32% hydrofluorosilicic acid ($(\text{H}_3\text{O})_2\text{SiF}_6$) for 3 to 5 days. Finally, in order to remove fluorides, the grains were rinsed with 32% HCl. The grains were settled on 9.8 mm aluminium discs with acetone using the pipette method.

All the luminescence and dose rate measurements were conducted at the Nordic Laboratory for Luminescence Dating (Aarhus University) and DTU Nutech (Technical University of Denmark, DTU Risø Campus in Denmark). Luminescence measurements for both the Titel and Lingtai samples were conducted on several Risø TL/OSL readers, equipped with calibrated $^{90}\text{Sr}/^{90}\text{Y}$ beta sources (Bøtter-Jensen et al., 2010). The dose rates of the readers ranged between $0.05100 \text{ Gy s}^{-1}$ and $0.24852 \text{ Gy s}^{-1}$ depending on reader beta source and measurement substrate. Quartz stimulation employed blue (470 nm; $\sim 80 \text{ mW cm}^{-2}$) LEDs with the OSL signal detected through a 7 mm Hoya U-340 glass filter. For the determination of the

equivalent dose (D_e) a standard single-aliquot regenerative (SAR) protocol was employed (Murray and Wintle, 2000, 2003) with a preheat temperature of 260°C for 10 s and a cut heat of 220°C. Details of dose recovery tests are given below. The aliquots that failed the OSL IR depletion test (outside 10% of unity) were rejected (Duller, 2003). The initial 0.8 s of the quartz OSL decay curves minus a background of the following 0.8 s was used for calculation of net signal (early background subtraction; based on Cunningham and Wallinga, 2010). Luminescence data analysis was conducted using the Risø Analyst software, version 4.31.9.

Dose rate measurements

The material for dose rate ($\square$) calculation was ground to <200 μm , ignited at 450 °C for 24 h, and cast in wax to retain radon. The material from both Titel and Lingtai was sufficient to cast solid disc-shaped samples (~30 g of dry sample). The discs were then stored for >3 weeks to allow ^{222}Rn to build up to equilibrium with ^{226}Ra , before analysing for >24 h using high resolution gamma spectrometry (Murray et al., 1987). The radionuclide concentrations were converted to dry dose rates using the conversion factors provided by Guérin et al. (2011). The activities of ^{238}U and ^{226}Ra , ^{210}Pb , ^{232}Th and ^{40}K for the Titel and Lingtai samples are presented in Tables 2 and 3, respectively.

The contribution of cosmic rays to the total dose rate was calculated according to Prescott and Hutton (1994). The water content of the Titel samples was estimated to be $15\pm 5\%$ based on field observations and previous research conducted in this area and was assumed to apply throughout the burial period (Schmidt et al., 2010; Antoine et al., 2009). An internal dose rate from U and Th of $0.02\pm 0.01 \text{ Gy ka}^{-1}$ was assumed for coarse grains from Titel (based on Vandenberghe et al, 2008). The water content of the Lingtai samples was estimated to be $20\pm 5\%$ based on analysis of multiple samples taken at the site, and is comparable to typical values for other sites on the southern part of the Chinese Loess Plateau (Stevens et al., 2013).

The total dose rates are given in Tables 2 and 3 for Titel and Lingtai, respectively. For 4-11 μm aliquots an α efficiency value of 0.04 ± 0.02 was used (Rees-Jones, 1995).

Luminescence characteristics

Aliquots for the OSL measurements on the Titel plateau quartz were obtained from samples 168110 (9.5 cm depth) – 168160 (1115 cm depth), covering the L1 unit in the loess-palaeosol sequence. For the Lingtai quartz, aliquots were obtained from samples H18101 (20 cm depth) to H18149 (560 cm depth) also corresponding to the L1 unit in the loess-palaeosol sequence. The SAR-procedural test results for the Titel and Lingtai samples are presented in Tables S1 and S2 respectively.

Most of the measured aliquots showed an OSL IR depletion ratio close to unity with a ~34-51 Gy regenerative dose and with the 110°C TL peak being clearly defined, indicating the purity of the quartz extracts (19% of the aliquots from Titel were rejected based on this criterion). The OSL signals from both sites are bright and generally dominated by the fast component. The natural and regenerated decay curves show a very close match to each other, as well as to the signal from fast component dominated Risø calibration quartz (Figures 4 (A) and 4 (B)).

For the determination of an appropriate preheat temperature, a preheat plateau test was performed on 24 aliquots of the sample 168122 from the Titel loess plateau (309 cm depth), and on 24 aliquots of the sample H18116 (210 cm depth) from the Lingtai section. For the Titel samples, temperatures ranging from 160°C to 300°C were employed for 10 s during the first preheat in combination with a 160°C to 260°C test dose preheat (cutheat). For the Lingtai samples we employed temperatures ranging from 180°C to 300°C for 10 s during the first preheat in combination with 140°C to 260°C test dose preheat. For the Titel quartz, the D_e value did not show any significant sensitivity to preheat temperature up to approximately

260°C. The recycling ratios are close to unity and the recuperation is close to 1% over the 160-300°C first preheat interval. For Lingtai quartz, the D_e is independent of temperature for preheats $\geq 220^\circ\text{C}$. Based on these results, a first preheat temperature of 260°C for 10 s and cut heat of 220°C was chosen for all following measurements. The results of the preheat plateau tests for the Titel and Lingtai samples are summarised in Figure 5.

As 19% of aliquots from Titel quartz were rejected based on OSL IR depletion ratio we further compared D_e values derived from pure blue-light stimulated luminescence with those obtained using a double-SAR protocol (Roberts and Wintle, 2001) for 6 Titel samples (6 aliquots per sample). The measurement sequence included preheating to a temperature of 260°C for 10 s, followed by stimulation using IR LEDs at a temperature of 60°C for 100 s to monitor and deplete the IRSL signal from feldspars. The ‘double-SAR’ protocol used in this study yielded D_e values that are indistinguishable from the D_e values measured with pure blue-light stimulation. The D_e value obtained using the ‘double-SAR’ protocol for sample 168116 was 42 ± 4 Gy while the standard SAR protocol for the same sample yielded a value of 40 ± 4 Gy. This indicated that the feldspar contribution to the (post-IR) OSL signal was negligible and a standard blue-light stimulated SAR procedure was appropriate to measure dose for the Titel samples.

To test the applicability of the luminescence measurement protocol, dose recovery tests (Murray and Wintle, 2003) were performed on 6 aliquots of each of the following Titel samples: 168111, 168113, 168114, 168115, 168116 (~30 Gy given dose) and 168141, 168143, 168158, 168159 (~60 Gy given dose). An additional dose recovery test was performed on samples 168124 and 168139 where doses ranging between ~20 and 250 Gy were employed (24 aliquots per sample; 6 aliquots per dose). The results of these tests are summarised in Figure 6 and show that the measurement protocol is able to accurately (within 10% of unity) measure doses of up to 270 Gy administered before any thermal pretreatment of the sample. However,

we note that this dose might be beyond the reliable range of measurement of natural dose in quartz OSL dating (Buylaert et al., 2007; Roberts, 2008; Chapot et al., 2012; Trandafir et al., 2015). For the Lingtai samples, the dose recovery tests were performed on 4 aliquots on alternate samples (H18121 – H18134 ($n=12$) ~ 120 Gy given dose; H18135 – H18140 ($n=6$) ~ 100 Gy given dose). The average of the measured to given dose ratio for all the Titel samples ($n=11$; 6 aliquots per sample) is 1.05 ± 0.04 and for the Lingtai samples ($n=18$; 4 aliquots per sample) it is 0.99 ± 0.03 , which confirms that the applied SAR protocol is suitable for age determination and a known laboratory dose can be recovered. The frequency distributions of the dose recovery ratio for the Titel and Lingtai samples are shown in Figure 7 (A) and 7 (B) respectively.

For each sample from the Titel plateau (168110 – 168160; $n=51$) a minimum of five replicate D_e measurements were conducted (except for sample 168111 and 168129 where no sufficient quartz grains could be extracted), while for the samples from the Lingtai section (H18101 – H18149; $n=43$ 2-4 replicate measurements were performed. Figure 4 (C) shows a typical dose response curve for sample 168113 from the Titel Loess Plateau. A representative dose response curve for sample H18121 from Lingtai is presented in Figure 4 (D).

The weighted mean D_e values (1 sigma standard error) of the Titel quartz range from 1.4 ± 0.2 Gy for the uppermost sample to 167.8 ± 9.4 Gy for sample 168142 (715 cm depth) (Table 2). The D_e values generally increase with depth, but at ~ 548 cm depth (sample 168134) and below, they reach a stationary value of ~ 120 Gy. This flattening in D_e in quartz from the Titel loess plateau likely represents a saturation (or steady state) of the luminescence dose-response in the field (field saturation).

The D_e values of the Lingtai quartz range from 5.7 ± 0.2 Gy for the uppermost sample to 150 ± 6 Gy for the lowermost sample dated. Similar to Titel, the D_e values demonstrate an

increase with depth up to ~150 Gy, where it reaches field saturation. This value also coincides with the upper limit for quartz dating in Chinese loess as suggested by Chapot et al. (2012).

The samples suffering from field saturation (Titel samples: 168124 – 345 cm depth and below; Lingtai samples: H18140 – 450 cm depth and below) are excluded from age model calculation and further discussion.

Luminescence ages

The luminescence ages, dosimetric information and equivalent doses, for the Titel and Lingtai samples are presented in Tables 2 and 3 respectively. Supplementary Tables S1 and S2 show equivalent dose measurements (D_e , recycling ratio and recuperation), results of dose recovery tests (Dr) and luminescence ages for the Titel loess core.

The ages of the Titel core show a consistent increase with depth ranging from 0.44 ka for the uppermost sample (168110, 9.5 cm depth) to 35.8 ka (168124, 345 cm depth) where the reliable age limit for quartz OSL dating on the Titel loess plateau is probably reached (Figure 8). Even though the samples generally display a constant age increase with depth, a few noticeable irregularities are observed. The most obvious are the changes in ages between samples 168112 to 168114 (between 47.5 and 109 cm depth). The remaining record shows a steady age increase to sample 168124, after which the ages begin to decrease and show larger scatter on an average.

The ages of the Lingtai samples generally increase with depth but in some cases display irregularities (Figure 9). Most notable is the 14 ka difference between sample H18101 (1.60 ± 0.27 ka) and H18103 (15.6 ± 1.5 ka), over a 50 cm depth change. Sample H18104 has an anomalously high age (~22 ka) compared to succeeding samples while sample H18133 has a considerable lower age than the rest of the data would suggest. The highest observed age was ~52 ka on sample H18135 whilst the succeeding samples all show lower ages (H18136 -

49.5±3.6 ka; H18137 - 38.7±3.2 ka; H18138 - 44.7±3.0 ka). The record then continues to display consistent age increases with depth until sample H18141 (35.1±4.5 ka - 460 cm depth).

Age-depth models and dust Mass Accumulation Rate (MAR)

The luminescence data provide the opportunity to develop continuous and fully independent age versus depth models for the two sites. Approaches as to how to derive continuous age-depth models from discrete luminescence age points vary in the literature (Kang et al., 2015; Stevens et al., 2016; Újvári et al., 2014; Zeeden et al., 2018) and as such here we have chosen to apply and briefly compare results from two approaches, which are based on contrasting assumptions. Firstly, we apply a Bayesian modeling approach using the Bacon code of Blaauw and Christen (2011), undertaken at 5 cm depth resolution. Bacon uses Bayesian statistics to reconstruct accumulation histories for deposits, through combining numerical age dates with prior information such as accumulation rate and its variability (memory). Accumulation rates are controlled using a gamma autoregressive semiparametric model with an arbitrary number of subdivisions along the sediment profile (Blaauw and Christen, 2011; here resolution is set to 5 cm). Prior knowledge about accumulation rates can lead to reduced uncertainty and more realistic modeling (Blaauw and Christen, 2011). The priors for accumulation rate and memory (autocorrelation) are modeled by gamma and beta distributions, and the latter defines how much the accumulation rate at a particular depth in a core depends on the depth above it. The section thickness dictates to some degree the flexibility of the age-depth model, which is obtained by millions of Markov Chain Monte Carlo (MCMC) iterations (Blaauw and Christen, 2011). Secondly, an age-depth model of OSL dates was constructed using the model of Zeeden et al. (2018). This method constructs an age-depth model from luminescence ages without making any assumptions over sedimentation rate or process, but requires ages to be consistent with stratigraphy. It involves an inverse model and uses a conservative measure for the random

part of overall uncertainty. Due to the Lingtai dataset size, the dataset was separated into several parts and was later recombined, with the third data point from top considered an outlier. Smoothing of results was undertaken using a Taner low pass filter as implemented in the ‘astrochron’ R package (Taner, 1992; Meyers, 2014; R Core Team, 2017). Cut-off frequencies of 0.2 and 0.1 kyr were used for Titel and Lingtai, respectively (see Supplementary Materials for the documented R code). Modeling results from both approaches are presented in Figure 10.

The lack of abrupt increases in OSL age with depth suggests that no major hiatuses are present in the studied sections. This allows continuous age-depth models to be developed from the OSL ages (Figure 10). While the general age-depth trends between the two models are similar, the model of Zeeden et al. (2018) is much more sensitive to changes in OSL age with depth, which results in a more variable age-depth function, especially at Titel. In contrast, the age depth function resulting from the Bacon model is nearly linear at both sites, indicating relatively constant sedimentation rates, at least within the error limits of the technique (Figure 10). The only exception is a change from relatively higher sedimentation rates to relatively lower ones at around 15 ka at both sites. The results of the different age models are discussed below in light of age-depth model assumptions, the nature of loess deposition, and dust Mass Accumulation Rate (MAR) calculated from the age models.

In order that the results can be reliably compared between regions and other dust archives, as well as for use in estimating past atmospheric dust flux (Albani et al., 2015), we here calculated Mass Accumulation Rate (MAR) (Kohfeld and Harrison, 2003) at the two sites. MAR ($\text{g m}^{-2} \text{a}^{-1}$) is calculated using the following equation:

$$\text{MAR} = \text{SR} \times f_{\text{eol}} \times \text{BD},$$

where SR is sedimentation rate (m a^{-1}), f_{eol} is the proportion of the sediment that is aeolian (assumed = 1), and BD is bulk density of the loess (g cm^{-3}). Estimated bulk density for loess

values vary in the literature and in loess regions (Kohfeld and Harrison, 2003; Stevens et al., 2016; Újvári et al., 2010). Here we measured bulk density directly on all dated samples from Lingtai. While values range apparently randomly from ca. 1.3 to 1.7 g cm⁻³, the majority concentrate around a mean value of 1.5 g cm⁻³, which also matches almost exactly average Chinese Loess Plateau bulk density data in Kohfeld and Harrison (2003) and the average value of 1.52 ± 0.02 g cm⁻³ measured on 33 samples from the S1 soil at Jingbian (Buylaert et al., 2015). Bulk density at Titel was not directly measured so we use estimates obtained from other middle Danube loess at the Dunaföldvár loess section in Hungary, which yielded average values of 1.5 g cm⁻³ (Újvári et al., 2010).

The calculated MAR trends with depth at both sites and from both models are shown in Figure 11. The model of Zeeden et al. (2018) shows much more variability in dust MAR for both sites, which is a consequence of the different assumptions made over loess accumulation rate and the weight given to individual age points in the two models. To what extent the process of true loess sedimentation is reflected in variability in closely-spaced luminescence ages is yet unclear, which makes determining the best choice of model difficult. Loess deposition over a variety of timescales may be considered a random and intermittent process (e.g., due to dust storms, phases of enhanced or reduced accumulation, erosional events, breaks in sedimentation, etc.). However, while some of these may be reflected in luminescence age with depth variability, given the typical uncertainty on luminescence ages of 5-10% it is not possible to constrain the nature of loess deposition on shorter than 1000 a timescales for samples older than 10 ka. In other words, there is currently no way of determining whether luminescence age variability within or close to error estimates on individual ages is real (i.e. low autocorrelation, implying highly temporally variable aeolian environment) or just the artefact of noise imposed by the inherent limitations of the OSL technique. Reassuringly, examination of the smoothed results from the Zeeden et al. (2018) model compared to the Bacon model results reveals

general similarity in longer-term MAR trends for both sites, suggesting that irrespective of shorter-term fluctuations in MAR, the general trends at both sites are captured by both models (Fig. 11). However, the absolute MAR values yielded by the two models vary considerably, as discussed below.

In terms of the trends seen at the sites, we here focus on longer term trends due to uncertainty and discrepancies between modeled MARs on short-term (sub ka scale) timescales. Furthermore, while the MAR values presented here are given without error estimates, this is largely because there is no agreement about how to obtain realistic estimates of dust MAR uncertainty from loess. Apart from potential uncertainties in bulk density estimates and the impact of post-depositional modification, simple Gaussian error propagation from luminescence ages may not be valid as uncertainty may not be strictly Gaussian, or fully random. However, we anticipate that the error on MAR estimates will exceed the luminescence age uncertainty in percentage terms. As such, shorter-term variability in MAR, like the ca. 4-6 ka frequency oscillations seen especially at Lingtai (Fig. 11), cannot be considered as significant here. Generally, both absolute MAR values and trends in the data with age are remarkably similar between the sections (with the exception of the large ca. 15 ka MAR peak in the Zeeden et al. (2018) model output for Lingtai, which is driven by the model relying solely on the luminescence ages themselves, and not surrounding age depth information as with Bacon). Both show a peak in MAR around 25-13 ka, with values at both Titel and Lingtai peaking in the Bacon model around $200 \text{ g m}^{-2} \text{ a}^{-1}$. In the model of Zeeden et al. (2018) peak values are much higher, especially at Titel where MAR peaks at around $650 \text{ g m}^{-2} \text{ a}^{-1}$. However, given the discrepancies in absolute values between the models it is debatable how accurate these peak estimates are and it may be safer to simply state that MAR is generally in the range of $100\text{-}200 \text{ g m}^{-2} \text{ a}^{-1}$ at both sites for the late last glacial. Prior to the last glacial MAR peak, MAR values at both sites are very similar, and both sites show lower MAR values after ca. 13

ka (Fig. 11). These general MAR values are relatively low in comparison to average values for last glacial Central-Eastern European loess (Újvári et al., 2010), although European loess deposits show considerable variation in MAR and the peak MAR values here are more consistent with other studies. Indeed, a recent study that uses extremely detailed AMS ^{14}C dating of charcoal and small gastropods from the Dunaszekcső site in Hungary shows a major and variable dust peak between 24 and 27 ka, with peak MAR values of $2800 \text{ g m}^{-2} \text{ a}^{-1}$ (Újvári et al., 2017). These extremely high values reflect the fact that this is a very short-term peak derived from a ^{14}C age model with much higher resolution than our OSL-based models, which will smooth out such peaks. However, the general MAR values at the sections are similar to last glacial Chinese Loess Plateau MARs (Stevens et al., 2016). The timing of peak MAR at the two sites under study matches broadly (but is slightly later than) the timing of peak MAR identified from analysis of multiple luminescence dated sites across the Chinese Loess Plateau (Fig. 11) in Kang et al. (2015). Stevens et al. (2016) also showed peak dust MAR at Xifeng occurring around 22-27 ka, earlier than in the records here, although due to soil formation driven disturbance the Xifeng record does not extend to the absolute peak MAR intervals presented here (see also Fig. 11). It is unclear whether these differences in peak MAR are an artefact of dating uncertainty, preservation, or whether these are real differences in dust accumulation between sites. The latter may also potentially be related to aspects such as proximity to local dust sources, and in the case of Titel, which is located close to the confluence of two major rivers, to local hydrodynamic conditions. In any case, there is now considerable evidence for a major peak in dust MAR across the Chinese Loess Plateau during the late last glacial period, and the similar age peak at Titel and recent evidence from Dunaszekcső in Hungary (Újvári et al., 2017) suggests that this may be also the case in Central-East and South-East European deposits. However, this must be tested extensively, as in contrast to China, very little sufficiently detailed MAR data exists for European deposits. Note that here we only

consider evidence from age-models derived from ages obtained via fully independent, numerical geochronological techniques, which fully consider the resolution and uncertainty of their approaches, so as to avoid incorporating further assumptions over sediment depositional age. Furthermore, the heavy dependence of MAR on choice of age-depth model requires that a uniform and representative approach is now developed for dust accumulation in loess deposits, in order that this information can be incorporated into atmospheric dust deposition and loading models (Albani et al., 2015). To ensure use of dust MAR data in climate modelling (Albani et al., 2015) we provide grain-size distribution data for Lingtai in Table S3. Grain-size distribution data from Titel are not yet available but will be presented with MAR data when possible. We also include the results of our MAR versus age calculations at the two sites using the two models in Supplementary Table S4.

The remarkable similarity in MAR patterns between the two sites at east end west ends of the Eurasian loess belt suggests that at least broad scale trends in dust activity within the last glacial period may be similar at a continental scale. This is promising with regard to the use of loess deposits to gain a better geographical representation of past continental scale dust activity. The relative constancy in dust MAR at the sites also suggests rather constant levels of dustiness over much of the last glacial, and suggests no major hiatuses are discernible given the resolution of the OSL ages. As such, there seems to be considerable variation in the degree to which sites may show hiatuses in loess accumulation (Buylaert et al., 2008; Kang et al., 2015; Stevens et al., 2008, 2016). A major peak in dustiness during the late last glacial broadly corresponds to increases in dust activity shown in Northern Hemisphere ice cores and marine cores (Hovan et al., 1989; Rasmussen et al., 2014; Ruth et al., 2007). However, given the inconsistencies between loess accumulation timing between loess sections, further refining of the chronologies of dust deposition in general and more standardised approaches to age modelling and MAR

calculation are required before leads or lags or differences in timing between different dust archives can be identified.

Conclusions

Detailed quartz OSL dating conducted on upper last glacial cycle loess at two sites at the extreme ends of the Eurasian loess belt shows that the technique is only capable of accurate age determination for D_e values up to about 150 Gy, with older samples providing minimum estimates due to the effects of signal saturation. However, high sampling resolution dating of the middle to late last glacial phase yields normally internally consistent ages that pass standard luminescence dating checks. Generally, the luminescence ages increase with depth and no obvious jumps in ages suggest major hiatuses are absent from these sites. The resultant age data were converted into age-depth models using two approaches, where one approach makes assumptions over sedimentation rates, and the other is based solely on the OSL data. Dust Mass Accumulation Rates (MAR) were calculated from these models and reveal strong model dependency on short term MAR fluctuations and absolute values. However, general MAR trends are consistent between models and show relatively constant and highly consistent dust MAR patterns over the last 35-45 ka at both the sites, with generally similar absolute MAR values at the sites. A peak in MAR values at both sites is shown around 13-25 ka, suggesting that similar patterns of last glacial dust activity may have occurred at either end of the Eurasian loess belt and that dust activity over this period may show a hemispheric trend.

Acknowledgements:

We thank Warren Thompson and Louise Helsted for help with OSL sample preparation and gamma spectrometry measurements, and to Shugang Kang for providing relative MAR changes from the CLP. We also thank Christian Laag for the assistance during sample

preparation of the Titel loess core at the University of Bayreuth. Jan-Pieter Buylaert thanks the Danish Council for Independent Research | Natural Sciences (FNU) for financial support (Steno grant no. 11-104566). Christian Zeeden is financed through a PSL post-doctoral fellowship.

References

1. Albani, S., Mahowald, N. M., Winckler, G., Anderson, R. F., Bradtmiller, L. I., Delmonte, B., François, R., Goman, M., Heavens, N. G., Hesse, P. P., Hovan, S. A., Kang, S. G., Kohfeld, K. E., Lu, H., Maggi, V., Mason, J. A., Mayewski, P. A., McGee, D., Miao, X., Otto-Bliesner, B. L., Perry, A. T., Pourmand, A., Roberts, H. M., Rosenbloom, N., Stevens, T., and Sun, J., 2015. Twelve thousand years of dust: the Holocene global dust cycle constrained by natural archives. *Climate of the Past* 11, 869–903.
2. An, Z.S., 2000. The history and variability of the East Asian paleomonsoon climate. *Quaternary Science Reviews* 19, 171–187.
3. Antoine, P., Rousseau, D.D., Fuchs, M., Hatté C., Gautier, C., Marković, S.B., Jovanović, M., Gaudeenyi, T., Moine, O., Rossignol, J., 2009. High resolution record of the last climatic cycle in the Southern Carpathian basin (Surduk, Vojvodina, Serbia). *Quaternary International* 198, 19–36.
4. Blaauw, M., Christen, J.A., 2011. Flexible palaeoclimate age-depth models using an autoregressive gamma process. *Bayesian Anal.* 6 (3), 457–474.
5. Buggle, B., Hambach, U., Kehl, M., Marković, S.B., Zöller, L., Glaser, B., 2013. The progressive evolution of a continental climate in SE-Central European lowlands during the Middle Pleistocene recorded in loess paleosol sequences. *Geology* 41, 771–774.

6. Buylaert, J. P., Vandenberghe, D., Murray, A. S., Huot, S., De Corte, F., Van den haute, P., 2007. Luminescence dating of old (>70 ka) Chinese loess: a comparison of single-aliquot OSL and IRSL techniques. *Quaternary Geochronology* 2, 9–14.
7. Buylaert J.P, Murray AS, Vandenberghe, D., Vriend, M., De Corte, F., Van den haute, P., 2008. Optical dating of Chinese loess using sand-sized quartz: establishing a time frame for Late Pleistocene climate changes in the western part of the Chinese Loess Plateau. *Quaternary Geochronology* 3, 99–113.
8. Buylaert, J.P., Yeo, E-Y, Thiel, C., Yi, S., Stevens, T., Thompson, W., Frechen, M., Murray, A., Lu, H., 2015. A detailed post-IR IRSL chronology for the last interglacial soil at the Jingbian loess site (northern China). *Quaternary Geochronology* 30, 194–199.
9. Chapot, M.S., Roberts, H.M., Duller, GAT, Lai, Z.P., 2012. A comparison of natural- and laboratory-generated dose response curves for quartz optically stimulated luminescence signals from Chinese Loess. *Radiation Measurements* 47, 1045–1052.
10. Cunningham, A.C., Wallinga, J., 2010. Selection of integration time intervals for quartz OSL decay curves. *Quaternary Geochronology* 5, 657–666.
11. Ding, Z., Sun, J., Rutter, N.W., Rokosh, D., Liu, T., 1999. Changes in sand content of loess deposits along a north–south transect of the Chinese Loess Plateau and the implications for desert variations. *Quaternary Research* 52, 56–62.
12. Ding, Z.L., Ranov, V., Yang, S.L., Finaev, A., Han, J.M., Wang, G.A., 2002. The loess record in southern Tajikistan and correlation with Chinese loess. *Earth and Planetary Science Letters* 200, 387–400.
13. Duller, G.A.T., 2003. Distinguishing quartz and feldspar in single grain luminescence measurements. *Radiation Measurements* 37, 161–165.
14. Ding, Z., Yu, Z., Rutter, N.W. and Liu, T.S., 1994. Towards an orbital time-scale for Chinese loess deposits. *Quaternary Science Reviews* 13, 39–70.

15. Ding, Z.L., Yang, S.L., 2000. C3/C4 vegetation evolution over the last 7.0 Myr in the Chinese Loess Plateau: evidence from pedogenic carbonate $\delta^{13}\text{C}$. *Palaeogeography, Palaeoclimatology, Palaeoecology* 160, 291–299.
16. Hansen, V., Murray, A., Buylaert, J.-P., Yeo, E.-Y., Thomsen, K., 2015. A new irradiated quartz for beta source calibration. *Radiation Measurements* 81, 123–127.
17. Frechen, M., Oches, E.A., Kohfeld, K.E., 2003. Loess in Europe – mass accumulation rates during the Last Glacial Period. *Quaternary Science Reviews* 22, 1835–1857.
18. Fuchs, M., Rousseau, D., Antoine, P., Hatté, C., Gauthier, C., Marković, S., Zoeller, L., 2008. Chronology of the last climatic cycle (upper Pleistocene) of the Surduk loess sequence, Vojvodina, Serbia. *Boreas* 37, 66–73.
19. Guérin, G., Mercier, N., Adamiec, C., 2011. Dose-rate conversion factors: update. *Ancient TL* 29, 5–8.
20. Hovan, S.A., Rea, D.K., Pisias, N.G., Shackleton, N.J., 1989. A Direct Link Between The China Loess And Marine Delta-o-18 Records - Aeolian Flux To The North Pacific. *Nature* 340 (6231), 296–298.
21. Huntley, D.J., Baril, M.R., 1997. The K content of the K-feldspars being measured in optical dating or in thermoluminescence dating. *Anc. TL* 15, 11–13.
22. Kang, S., Roberts., H. M., Wang, X., An, Z., Wang, M., 2015. Mass accumulation rate changes in Chinese loess during MIS 2, and asynchrony with records from Greenland ice cores and North Pacific Ocean sediments during the Last Glacial Maximum. *Aeolian Research* 19B, 251–258.
23. Kohfeld, K. E., Harrison, S.P., 2003. Glacial–interglacial changes in dust deposition on the Chinese Loess Plateau. *Quaternary Science Reviews* 22, 1859–1878.
24. Kukla, G., 1987. Loess stratigraphy in Central China. *Quaternary Science Reviews* 6, 191–219.

25. Kukla, G., An, Z., 1989. Loess stratigraphy in Central China. *Palaeogeography Palaeoclimatology Palaeoecology* 72, 203–225.
26. Liu, T.S., 1985. *Loess and Environment*. China Ocean Press: Beijing.
27. Liu, T.S., Ding, Z.L., 1993. Stepwise coupling of monsoon circulations to global ice volume variations during the late Cenozoic. *Global and Planetary Change* 7, 119–130.
28. Lowick, E.S., Preusser, F., 2011. Investigating age underestimation in the high dose region of optically stimulated luminescence using fine grain quartz. *Quaternary Geochronology* 6, 33–4.
29. Lu, H.Y., Liu, X.D., Zhang, F., An, Z.S., Dodson, J., 1999. Astronomical calibration of loess paleosol deposits at Luochuan, central Chinese Loess Plateau. *Palaeogeography Palaeoclimatology Palaeoecology* 154, 237–246.
30. Lu, H., Sun, D., 2000. Pathways of dust input to the Chinese Loess Plateau during the last glacial and interglacial periods. *Catena* 40, 251–261.
31. Marković, S.B., Bokhorst, M., Vandenberghe, J., Oches, E.A., Zöller, L., McCoy, W.D., Gaudenyi, T., Jovanović, M., Hambach, U., Machalett, B., 2008. Late Pleistocene loess-paleosol sequences in the Vojvodina region, North Serbia. *Journal of Quaternary Science* 23, 73–84.
32. Marković, S. B. Hambach, U., Catto, N., Jovanović, M., Buggle, B., Machalett, B., Zöller, L., Glaser, B. Frechen, M., 2009. The middle and late Pleistocene loess-paleosol sequences at Batajanica, Vojvodina, Serbia. *Quaternary International* 198, 255–266.
33. Marković, S., Hambach, U., Stevens, T., Jovanović, M., O'Hara-Dhand, K., Basarin, B., Lu, H., Smalley, I., Buggle, B., Zech, M., Svirčev, Z., Sümege, P., Milojković, N., Zöller, L., 2012. Loess in the Vojvodina region (Northern Serbia): an essential link between European and Asian Pleistocene environments. *Netherlands Journal of Geosciences, Geol. Mijnbouw* 91, 173–188.

34. Marković, S.B., Hambach, U., Stevens, T., Kukla, G., Hellere, F., McCoy, W.D., Oches, E.A., Buggle, B., Zöller, L., 2011. The last million years recorded at the Stari Slankamen (Northern Serbia) loess-palaeosol sequence: revised chronostratigraphy and long-term environmental trends. *Quaternary Science Reviews*, 30, 9–10, 1142–1154.
35. Marković, S.B., Stevens, T., Kukla, G. J., Hambach, U., Fitzsimmons, K. E., Gibbard, P., Buggle, B., Zech, M., Guo, Z. , Qingzhen, H., Haibin, W., Dhand, O. K., Smalley, I. J., Gábor, U., Sümegi, P., Timar-Gabor, A., Veres, D., Sirocko, F., Vasiljević, D. A., Jary, Z., Svensson, A., Jović, V., Lehmkuhl, F., Kovács, J., Svirčev, Z., 2015. Danube loess stratigraphy – Towards a pan-European loess stratigraphic model. *Earth Science Reviews* 148, 228–258.
36. Meyers, S.R., 2014. Astrochron: An R Package for Astrochronology, Version 0.7. <https://cran.r-project.org/package=astrochron>.
37. Muhs, D. R., 2007. Loess deposits, origins and properties. *Encyclopedia of Quaternary Science*, 1405–1418.
38. Murray, A. S., Marten, R., Johnston, A. & Martin, P., 1987. Analysis for naturally occurring radionuclides at environmental concentrations by gamma spectrometry. *Journal of Radioanalytical and Nuclear Chemistry* 115, 263–288.
39. Murray, A.S. and Wintle, A.G., 2000. Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. *Radiation Measurements* 32, 57–73.
40. Murray, A. S. & Wintle, A. G., 2003. The single aliquot regeneration dose protocol: potential for improvements in reliability. *Radiation Measurements* 37, 377–381.
41. Obreht, I., Zeeden, C., Hambach, U., Veres, D., Marković, S.B., Böskén, J., Svirčev, Z., Bačević, N., Gavrilov, M.B., Lehmkuhl, F., 2016. Tracing the influence of Mediterranean climate on Southeast Europe during the past 350,000 years. *Scientific Reports* 6, 36334.
42. Obreht, I., Hambach, U., Veres, D., Zeeden, C., Böskén, J., Stevens, T., Marković, S.B., Klasen, N., Brill, D., Burow, C., Lehmkuhl, F., 2017. Shift of large-scale atmospheric systems

over Europe during late MIS 3 and implications for Modern Human dispersal. *Scientific Reports* 7, 58–48.

43. Porter, S.C., 2001. Chinese loess record of monsoon climate during the last glacial–interglacial cycle. *Earth Science Reviews* 54, 115–128.

44. Prescott, J.R. and Hutton, J.T., 1994: Cosmic ray contributions to dose rates for luminescence and ESR dating: large depths and long-term time variations. *Radiation Measurements* 23, 497–500.

45. Rasmussen, S.O., Bigler, M., Blockley, S.P., Blunier, T., Buchardt, S.L., Clausen, H.B., Cvijanovic, I., Dahl-Jensen, D., Johnsen, S. J., Fischer, H., Gkinis, V., Guillevic, M., Hoek, W.Z., Lowe, J. J., Pedro, J. B., Popp, T., Seierstad, I.K., Steffensen, J. P., Svensson, A. M., Vallelonga, P., Vinther, B.M., Walker, M.J.C., Wheatley, J.J., Winstrup, M., 2014. A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy. *Quaternary Science Reviews* 106, 14–28.

46. Rees-Jones, J., 1995. Optical dating of young sediments using fine-grain quartz. *Ancient TL* 13, 9-14.

47. Roberts, H.M., 2007. Assessing the effectiveness of the double-SAR protocol in isolating a luminescence signal dominated by quartz. *Radiation Measurements* 42, 1627–1636.

48. Roberts, H.M., Wintle, A.G., 2001. Equivalent dose determinations for polymineralic finegrains using the SAR protocol: application to a Holocene sequence of the Chinese Loess Plateau. *Quaternary Science Reviews (Quaternary Geochronology)* 20, 859–863.

49. Roberts H.M., 2008. The development and application of luminescence dating to loess deposits: a perspective on the past, present and future. *Boreas* 37, 483–507.

50. Rousseau, D.D., Antoine, P., Hatté, C., Lang, A., Zöller, L., Fontugne, M., Othman, D.B., Luck, J.M., Moine, O., Labonne, M., Bentaleb, I., Jolly, D., 2002. Abrupt millennial climatic

changes from Nussloch (Germany) Upper Weichselian eolian records during the Last Glaciation. *Quaternary Science Reviews* 21, 1577-1582.

51. Ruth, U., Bigler, M., Röthlisberger, R., Siggaard-Andersen, M.-L., Kipfstuhl, S., Goto-Azuma, K., Hansson, M. E., Johnsen, S. J., Lu, H., Steffensen, J. P., 2007. Ice core evidence for a very tight link between North Atlantic and East Asian glacial climate. *Geophysical Research Letters* 34, L03706.

52. Rutter, N., Ding, Z. L., Evans, M. E., Liu, T., 1991. Baoji-type pedostratigraphic section, Loess Plateau, north-central China. *Quaternary Science Reviews* 10, 1–22.

53. R Core Team, 2017. R: A Language and Environment for Statistical Computing.

54. Schmidt, E.D., Machalett, B., Marković, S.B., Tsukamoto, S., Frechen, M., 2010. Luminescence chronology of the upper part of the Stari Slankamen loess sequence (Vojvodina, Serbia). *Quaternary Geochronology* 5, 137–142.

55. Singhvi, A.K., Bronger, A., Sauer, W., Pant, R.K., 1989. Thermoluminescence dating of loess - paleosol sequences in the Carpathian basin (East-Central Europe): A suggestion for a revised chronology. *Chemical Geology* 73, 307–317.

56. Stevens, T., Marković, S.B., Zech, M., Hambach, U., Sümegi, P., 2011. Dust deposition and climate in the Carpathian Basin over an independently dated last glacial-interglacial cycle. *Quaternary Science Reviews* 30, 662–681.

57. Stevens, T., Adamiec, G., Bird, A.F., Lu, H., 2013. An abrupt shift in dust source on the Chinese Loess Plateau revealed through high sampling resolution OSL dating. *Quaternary Science Reviews* 82, 121–132.

58. Stevens, T., Buylaert, J.P., Lu, H., Thiel, C., Murray, A., Frechen, M., Yi, S., Zeng, L., 2016. Mass accumulation rate and monsoon records from Xifeng, Chinese Loess Plateau, based on a luminescence age model. *Journal of Quaternary Science* 31, 391–405.

59. Taner, M.T., 1992, in: Attributes revisited (Technical Report, Rock Solid Images, Inc), url: http://www.rocksolidimages.com/attributes-revisited/#_Toc328470897.
60. Trandafir, O., Timar-Gabor, A., Schmidt, C., Veres, D., Anghelinu, M., Hambach, U., Simon, S., 2015. OSL dating of fine and coarse quartz from a Palaeolithic sequence on the Bistrita Valley (Northeastern Romania). *Quaternary Geochronology* 30, 487-492.
61. Újvári, G., Molnar, M., Novothny, A., Pall-Gergely, B., Kovacs, J., Varhegyi, A., 2014. AMS ¹⁴C and OSL/IRSL dating of the Dunaszekcső loess sequence (Hungary): chronology for 20 to 150 ka and implications for establishing reliable age-depth models for the last 40 ka. *Quaternary Science Reviews* 106, 140-154.
62. Újvári, G., Kovács, J., Varga, G., Raucsik, B., Marković, S.B., 2010. Dust flux estimates for the Last Glacial Period in East Central Europe based on terrestrial records of loess deposits: a review. *Quaternary Science Reviews* 29, 3157-3166.
63. Újvári, G., Stevens, T., Molnar, M., Demény, A., Lambert, F., Varga, G., Jull, A.J.T., Páll-Gergely, B., Buylaert, J.P., Kovács, J., 2017. Coupled European and Greenland last glacial dust activity driven by North Atlantic climate. *Proceedings of the National Academy of Sciences* 114, E10622-E10631.
64. Vandenberghe, D., De Corte, F., Buylaert, J.-P., Kučera, J., Van den haute, P. 2008. On the internal radioactivity in quartz. *Radiation Measurements*, 43, 771-775.
65. Zeeden, C., Hambach, U., Veres, D., Fitzsimmons, K., Obrecht, I., Böskén, J., Lehmkuhl, F., in press. Millennial scale climate oscillations recorded in the Lower Danube loess over the last glacial period. *Palaeogeography, Palaeoclimatology, Palaeoecology*. doi.org/10.1016/j.palaeo.2016.12.029.

66. Zeeden, C., Dietze, M., Kreutzer, S., 2018. Discriminating luminescence age uncertainty composition for a robust Bayesian modelling. *Quaternary Geochronology* 43, 30-39. doi.org/10.1016/j.quageo.2017.10.001.

Figure Captions

Figure 1. Eurasian loess distribution (yellow). The locations of the two studied sites are marked with red crosses. Revised from Muhs et al. (2007).

Figure 2. Location of the study site and distribution of loess in Serbia. The drilling site is located 100 m from Veliki Surduk gully site, marked with a red cross (see text for details). Revised from Marković et al. (2008).

Figure 3. Location of the main loess sites in China (black circles). The Lingtai section is marked with the red star. Revised from Buylaert et al. (2015).

Figure 4. (A) Representative natural blue-light stimulated luminescence decay curve for sample 168124 from the Titel loess core (depth 3455 cm). The inset shows the same data together with a decay curve of Risø calibration quartz (Hansen et al., 2015; dashed line), both curves are normalised to their initial intensity and are nearly identical. (B) representative natural blue-light stimulated luminescence decay curve for sample H18127 from the Lingtai loess section (depth 320 cm). The inset shows the same data together with a decay curve of Risø calibration quartz (dashed line), both curves are normalised to their initial intensity. (C) representative SAR dose response curve for sample 168113 (depth 66.5 cm). The recycled point is represented with an open triangle and the zero dose point with an open circle. (D) representative SAR dose response curve for sample H18121 (depth 260 cm). The recycled point is represented with an open triangle and the zero dose point with an open circle.

Figure 5. Equivalent dose as a function of first preheat temperature for sample 168122. (A) Three aliquots were used per preheat temperature and the error bars represent 1 standard error. The dashed line is drawn at the average D_e of the aliquots measured with preheat temperatures between 160 and 280°C. (B) Recycling ratios and recuperation as a function of preheat temperature for the same aliquots as in (A). A dashed line is drawn at an ideal recycling ratio of 1.0. Equivalent dose as a function of preheat temperature for sample H18116. (C) Three aliquots were used per preheat temperature and the error bars represent 1 standard error. The dashed line is drawn at the mean D_e of the aliquots measured with preheat temperatures between 220 and 300°C. (D) Recycling ratios and recuperation as a function of preheat temperature for the same aliquots as in (C). A dashed line is drawn at an ideal recycling ratio of 1.0.

Figure 6. Results of dose recovery test on sample 168139. Six aliquots were measured per dose point. Error bars represent one standard error.

Figure 7. Histogram of the dose recovery ratio for samples from the Titel loess plateau (A) and the Lingtai loess section (B). n represents the number of aliquots.

Figure 8. OSL ages from the Titel loess core plotted against the magnetic susceptibility record measured on the same core (TLP-1). Magnetic susceptibility was measured in 2 cm intervals just after the cores were split using an MS3 Magnetic Susceptibility Meter (MS2E Core Logging Sensor) from Bartington Instruments. The dashed lines represent the boundaries of the investigated stratigraphic units. The red solid line represents the proposed reliable age limit for quartz dating at the site.

Figure 9. OSL ages from the Lingtai loess section plotted against the low frequency magnetic susceptibility record (sampling in 5 cm intervals) from the same site. The dashed lines represent

the boundaries of the investigated stratigraphic units. The red solid line represents the proposed reliable age limit for quartz dating at this site.

Figure 10. Age modelling results and OSL ages from A), C) Titel and B), D) Lingtai. A) and B) show results of Bayesian modelling using the Bacon model of Blaauw and Christen (2011). The results are based on over 15 and 19 million Monte Carlo iterations and yield mean 95% confidence age ranges of 2257 and 2199 a for Titel and Lingtai, respectively. Top panel: Time series of the log-posterior for the sub-sampled MCMC (left), prior (green) and posterior (gray) for accumulation rates with priors $\text{acc.shape} = 1.5$ and $\text{acc.mean} = 100$ (center) and prior and posterior for the memory (right), $\text{mem.strength}=4$ and $\text{mem.mean}=0.7$. C) and D) show results of an age-depth modelling method proposed for specifically treating luminescence data (Zeeden et al., 2018). The original data and uncertainty are plotted as diamonds with error bars, with age estimates shown as a dark line, 1-sigma uncertainty as dark grey shade, and 2-sigma uncertainty as lighter grey shade. Mean age and uncertainty were linearly interpolated between the age depth points used in the modelling.

Figure 11. Dust Mass Accumulation Rate (MAR) as a function of age at the sites. A) MAR values for Titel obtained via the Bacon model (blue line) and by the smoothed (orange) and unsmoothed (grey) model of Zeeden et al. (2018). Note the results from the Zeeden et al. (2018) model are plotted on a separate y-axis (right hand side) for clarity; B) Same as in A) but for Lingtai MAR results; C) MAR values from the Bacon model from Titel (red line) and Lingtai (black line) plotted against MAR values from Xifeng (grey line) obtained by Stevens et al. (2016) using linear regression and relative MAR changes from the Chinese Loess Plateau (yellow line) indicated by the relative frequency of quartz OSL age from 15 sites, as summarized in Kang et al. (2015); D) same as C) but MAR results from the smoothed model of Zeeden et al. (2018).

Table Captions

Table 1. Position of unit boundaries and thickness of stratigraphic units at the Veliki Surduk coring site and the Lingtai section.

Table 2. Summary of depth information, sample codes, dry beta and gamma dose rates, radionuclide activities, total dose rates, weighted mean D_e values and luminescence ages for the Titel samples. The grain size range of extracted quartz was 63-90 μm for all samples except for samples 168110, 168117, 168121 and 168122 (40-63 μm). n represents the number of aliquots. Error terms are given as 1 standard error.

Table 3. Summary of depth information, sample codes, dry alpha, beta and gamma dose rates, radionuclide concentrations, total dose rates, weighted mean D_e values and luminescence ages for the Lingtai section. Grain size range of quartz extract was 4-11 μm for all samples. n represents the number of aliquots. Error terms are given as 1 standard error.

Table 1. Position of unit boundaries and thickness of stratigraphic units at the Veliki Surduk coring site and the Lingtai section.

Stratigraphic unit		Upper/lower boundary (m)		Thickness (m)	
Titel	Lingtai	Titel	Lingtai	Titel	Lingtai
S0	S0	0.00/0.60	0.00/0.75	0.60	0.75
L1	L1	0.60/10.90	0.75/6.30	10.30	5.55
L1LL1	L1LL1	0.60/3.15	0.75/2.20	2.55	1.45
L1SSX	L1SS1	3.15/7.60	2.20/4.20	4.45	2.00
L1LL2	L1LL2	7.60/10.90	4.20/6.30	3.30	2.10
S1	S1	10.90/13.25	6.30/9.00	2.35	2.70

Table 2. Summary of depth information, sample codes, dry beta and gamma dose rates, radionuclide activities, total dose rates, weighted mean D_e values and luminescence ages for the Titel samples. The grain size range of extracted quartz was 63-90 μm for all samples except for samples 168110, 168117, 168121 and 168122 (40-63 μm). n represents the number of aliquots. Error terms are given as 1 standard error.

Depth (cm)	Sample code	Beta $\square$ (Gy ka ⁻¹)	Gamma $\square$ (Gy ka ⁻¹)	²³⁸ U (Bq kg ⁻¹)	²²⁶ Ra (Bq kg ⁻¹)	²¹⁰ Pb (Bq kg ⁻¹)	²³² Th (Bq kg ⁻¹)	⁴⁰ K (Bq kg ⁻¹)	Total $\square$ (Gy ka ⁻¹)	D_e (Gy)	n	Age (ka)
9.5	168110	2.01±0.03	1.44±0.04	34±4	41.7±0.7	59±5	45±0.8	501±10	3.25±0.16	1.4±0.2	10	0.4±0.1
28.5	168111	1.71±0.02	1.18±0.03	26±3	39.0±0.6	42±3	40±0.5	442±8	2.72±0.13			
47.5	168112	1.65±0.08	1.15±0.04	29±18	41.6±1.3		44±1.4	443±18	2.63±0.15	19.5±1.3	26	7.4±0.7
66.5	168113	1.50±0.02	1.03±0.02	29±2	34.6±0.4	35±3	37±0.4	384±7	2.38±0.11	37.3±2.0	26	15.6±1.2
109	168114	1.51±0.06	1.06±0.03	26±12	37.6±1.0		41±0.9	404±15	2.71±0.14	36.8±1.9	26	13.6±1.0
127	168115	1.46±0.08	1.05±0.04	22±15	37.5±1.2		41±1.0	389±17	2.34±0.13	44.0±2.6	24	18.8±1.6
181	168116	1.58±0.07	1.05±0.03	44±14	37.5±1.0		39±1.1	410±14	2.43±0.13	41.7±3.5	24	17.1±1.7
209	168117	1.54±0.05	1.07±0.03	24±9	37.3±0.8		41±0.8	425±13	2.43±0.13	47.8±3.2	24	19.7±1.7
227	168118	1.43±0.04	1.00±0.03	25±8	34.1±0.6		39±0.6	385±10	2.25±0.11	62.6±3.1	17	27.8±2.1
245	168119	1.64±0.06	1.13±0.03	32±11	38.4±0.9		44±0.8	444±13	2.54±0.13	65.6±4.4	24	25.8±2.3
263	168120	1.36±0.10	0.98±0.03	6±21	32.4±1.6		38±1.4	393±23	2.17±0.14	67.8±4.5	24	31.3±2.9
281	168121	1.97±0.07	1.32±0.04	53±14	46.5±1.0		50±1.1	510±14	3.00±0.16	73.6±6.6	18	24.6±2.6
309	168122	1.46±0.05	0.98±0.03	40±18	34.7±1.4		37±1.2	384±20	2.26±0.12	67.3±12.6	6	29.8±5.8
327	168123	1.61±0.07	1.11±0.04	31±12	37.9±1.0		43±1.0	431±17	2.48±0.13	84.8±3.2	39	34.2±2.4
345	168124	2.04±0.03	1.43±0.03	41±3	46.8±0.7	51±4	49±0.6	518±9	3.12±0.16	111.8±9.8	26	35.8±3.7
363	168125	2.12±0.08	1.43±0.04	46±17	47.0±1.3		55±1.3	571±18	3.19±0.17	86.6±7.0	21	27.2±2.7
381	168126	2.24±0.09	1.50±0.05	32±17	48.9±1.3		56±1.2	638±22	3.35±0.18	93.9±6.5	24	28.1±2.5
409	168127	1.95±0.04	1.32±0.04	45±14	46.1±1.1		51±1.1	510±14	2.94±0.15	105.6±6.9	20	35.9±3.1
427	168128	2.11±0.03	1.46±0.03	39±3	46.0±0.7	51±3	50±0.5	544±9	3.20±0.16	98.5±5.3	30	30.8±2.3
445	168129	1.92±0.03	1.37±0.35	42±4	41.3±0.6	49±4	48±0.6	484±10	2.95±0.33			
463	168130	1.70±0.07	1.10±0.03	37±14	35.5±1.2		41±1.1	471±20	2.53±0.14	98.7±8.0	26	38.9±3.9
481	168131	1.64±0.10	1.20±0.04	10±20	41.6±1.6		44±1.4	504±24	2.56±0.15	82.8±7.1	23	32.3±3.5
510	168132	1.53±0.03	1.00±0.03	4±8	32.9±0.7		38±0.7	420±11	2.30±0.12			
529	168133	2.20±0.10	1.45±0.05	75±22	51.7±1.6		56±1.7	539±23	3.25±0.19	108.3±10.9	30	33.4±3.9
548	168134	1.91±0.27	1.34±0.03	44±3	42.3±0.5	46±3	47±0.5	487±9	2.91±0.27	144.9±10.8	27	49.9±6.0
567	168135	2.01±0.03	1.41±0.04	40±4	46.6±0.9	47±4	51±0.7	509±11	3.05±0.16	127.7±7.9	26	41.9±3.5

586	168136	1.59±0.07	1.14±0.04	24±14	37.9±1.1		46±1.1	427±19	2.46±0.14	144.3±13.8	21	58.8±6.6
615	168137	1.91±0.04	1.30±0.04	38±16	44.3±1.2		50±1.3	503±16	2.86±0.15	136.4±11.4	21	47.7±4.8
633	168138	1.55±0.04	1.10±0.03	9±8	35.9±0.6		43±0.6	450±10	2.39±0.12	124.0±11.6	20	51.9±5.7
651	168139	1.85±0.04	1.25±0.04	33±5	40.7±1.0	41±5	44±0.7	487±12	2.77±0.14	153.6±15.9	14	55.6±6.5
669	168140	1.78±0.06	1.24±0.04	28±12	43.8±0.9		48±0.9	483±12	2.70±0.14	149.6±17.7	9	55.5±7.3
687	168141	1.79±0.04	1.26±0.05	35±5	40.3±1.1	47±6	42±0.8	452±13	2.72±0.14	157.3±17.7	9	57.9±7.3
715	168142	1.88±0.04	1.34±0.04	32±5	40.8±1.0	52±5	44±0.8	472±12	2.86±0.15	167.8±9.4	9	58.6±4.6
733	168143	1.87±0.02	1.29±0.03	39±3	42.2±0.6	43±3	45±0.5	486±8	2.81±0.14	95.6±10.9	11	34.0±4.3
751	168144	1.25±0.04	1.77±0.04	34±5	39.5±1.0	47±5	43±0.7	445±12	2.69±0.14	97.9±7.6	21	36.4±3.5
769	168145	1.94±0.03	1.38±0.03	45±3	43.0±0.7	51±4	47±0.6	488±9	2.94±0.15	125.6±11.4	15	42.7±4.5
787	168146	1.91±0.03	1.35±0.03	40±4	41.7±0.6	47±4	48±0.6	483±10	2.89±0.15	82.5±8.6	15	28.5±3.3
815	168147	1.82±0.06	1.24±0.04	40±20	43.6±1.6		48±1.4	474±24	2.71±0.15	121.6±7.7	17	44.8±3.9
869	168148	1.86±0.09	1.38±0.04	22±19	40.8±1.5		48±1.4	487±23	2.87±0.17	126.1±16.4	16	44.0±6.3
887	168149	1.18±0.07	1.32±0.04	32±13	39.3±1.0		46±0.9	467±16	2.24±0.13	114.9±11.7	18	51.3±6.1
915	168150	1.81±0.06	1.27±0.36	36±12	39.2±1.0		47±1.0	480±17	2.72±0.34	129.5±16.0	13	47.6±8.4
933	168151	1.95±0.04	1.32±0.04	34±4	43.2±0.9	42±5	47±0.7	514±12	2.88±0.15	91.5±13.1	17	31.7±4.9
951	168152	2.06±0.03	1.40±0.03	42±3	44.9±0.6	47±3	49±0.5	540±9	3.05±0.15	91.9±17.2	12	30.1±5.9
969	168153	2.10±0.03	1.46±0.03	38±3	44.4±0.5	51±3	50±0.5	544±9	3.13±0.16	120.5±20.3	13	38.5±6.8
987	168154	1.95±0.06	1.28±0.38	48±12	43.2±0.9		48±0.9	520±13	2.85±0.36	91.0±19.5	10	32.0±8.0
1015	168155	2.01±0.03	1.38±0.03	39±3	43.7±0.6	47±3	48±0.5	521±9	2.99±0.15	95.3±25.2	9	31.9±8.6
1033	168156	1.94±0.04	1.34±0.04	40±5	44.1±0.8	45±5	47±0.7	501±12	2.89±0.15	154.3±25.8	11	53.4±9.4
1051	168157	1.97±0.43	1.33±0.04	45±5	49.5±1.1	50±5	49±0.8	520±13	2.91±0.40	131.5±13.6	11	45.1±7.8
1069	168158	2.03±0.04	1.38±0.04	41±5	48.3±1.0	52±5	52±0.8	546±13	3.00±0.16	134.8±12.9	11	44.9±5.0
1087	168159	1.97±0.04	1.32±0.04	43±5	46.2±1.0	40±5	50±0.7	529±13	2.90±0.15	159.0±13.1	11	54.8±5.5
1115	168160	0.66±0.02	0.44±0.01	14±2	14.6±0.5	16±3	17±0.4	177±6	1.02±0.05	50.0±7.9	6	48.9±10.0

Note: D_e and dose rate results for samples (168111, 168129 and 168132) are not yet available. The missing ^{210}Pb values are not available because not all gamma spectrometers can measure the 40 keV peak of ^{210}Pb .

Table 3. Summary of depth information, sample codes, dry alpha, beta and gamma dose rates, radionuclide concentrations, total dose rates, weighted mean D_e values and luminescence ages for the Lingtai section. Grain size range of quartz extract was 4-11 μm for all samples. n represents the number of aliquots. Error terms are given as 1 standard error.

Depth (cm)	Sample code	Alpha $\square$ (Gy ka ⁻¹)	Beta $\square$ (Gy ka ⁻¹)	Gamma $\square$ (Gy ka ⁻¹)	²³⁸ U (Bq kg ⁻¹)	²²⁶ Ra (Bq kg ⁻¹)	²¹⁰ Pb (Bq kg ⁻¹)	²³² Th (Bq kg ⁻¹)	⁴⁰ K (Bq kg ⁻¹)	Total $\square$ (Gy ka ⁻¹)	D_e (Gy)	n	Age (ka)
20	H18101	0.254±0.011	2.39±0.05	1.60±0.06	43±6	42.5±1.0	47.9±7.0	56±1.0	660±17	3.58±0.58	6.1±0.2	6	1.6±0.3
60	H18102	0.217±0.011	2.18±0.05	1.40±0.06	28±6	41.2±1.3	37.5±7.1	49±1.0	623±18				
70	H18103	0.230±0.010	2.14±0.05	1.43±0.05	24±6	40.1±1.2	44.0±6.3	50±0.9	589±16	3.53±0.20	54.8±4.	6	15.6±1.5
80	H18104	0.227±0.009	2.27±0.05	1.47±0.05	32±6	40.3±0.9	38.1±6.2	53±0.9	649±16	3.50±0.20	75.6±1.8	9	21.6±1.4
90	H18105	0.217±0.009	2.21±0.05	1.41±0.05	26±5	41.1±1.1	34.3±5.8	51±0.9	639±16	3.49±0.20	53.7±1.0	6	15.4±1.0
100	H18106	0.215±0.012	2.29±0.06	1.43±0.07	40±7	41.3±1.4	32.5±7.8	52±1.1	674±19	3.62±0.21	62.9±2.0	6	17.4±1.2
110	H18107	0.257±0.010	2.37±0.05	1.61±0.06	38±6	41.5±1.0	50.8±6.4	56±1.0	650±16	3.68±0.21	55.2±1.3	4	15.0±1.0
120	H18108	0.232±0.006	2.27±0.03	1.48±0.03	29±3	41.1±0.6	40.5±3.6	53±0.6	640±10	3.74±0.22	55.9±0.5	6	15.0±1.0
130	H18109	0.252±0.012	2.55±0.06	1.65±0.07	33±7	42.5±1.2	46.9±7.9	57±1.1	732±20	3.82±0.23	68.9±3.0	6	18.1±1.4
140	H18110	0.226±0.011	2.26±0.05	1.46±0.06	32±6	41.1±1.1	35.2±7.1	54±1.0	648±17	3.71±0.22	64.1±1.5	5	17.3±1.1
150	H18111	0.256±0.010	2.45±0.05	1.61±0.06	33±6	45.9±1.2	49.5±6.4	55±1.0	681±17	3.75±0.22	82.9±1.2	9	22.1±1.4
160	H18112	0.249±0.007	2.38±0.04	1.57±0.04	25±4	44.0±0.8	44.6±4.4	56±0.7	666±12	3.97±0.24	75.1±2.0	6	18.9±1.3
170	H18113	0.259±0.008	2.48±0.04	1.65±0.04	40±5	43.3±0.8	46.5±5.0	59±0.8	696±14	3.87±0.22	75.9±1.2	9	19.6±1.2
180	H18114												
200	H18115	0.230±0.011	2.24±0.05	1.47±0.06	29±7	41.0±1.4	38.3±7.3	54±1.1	633±18	3.66±0.22	83.4±3.1	6	22.8±1.7
210	H18116	0.275±0.011	2.70±0.05	1.77±0.06	38±6	47.5±1.0	47.1±6.9	64±1.0	764±18	4.10±0.24	115.2±2.2	12	28.1±1.8
220	H18117	0.240±0.007	2.38±0.04	1.54±0.04	25±4	41.7±0.9	43.5±4.8	54±0.7	676±13	3.95±0.23	98.2±1.3	6	24.9±1.6
230	H18118	0.256±0.010	2.39±0.05	1.61±0.06	38±6	40.6±0.9	50.2±6.4	56±0.9	661±16	3.80±0.22	86.9±4.2	3	22.9±1.8
240	H18119	0.270±0.011	2.65±0.05	1.75±0.06	36±6	43.2±1.0	48.9±7.1	62±1.1	751±18	3.94±0.22	99.4±0.9	5	25.2±1.5
250	H18120												
260	H18121	0.263±0.014	2.50±0.07	1.67±0.08	34±9	43.8±1.4	45.4±9.5	62±1.4	700±22	3.83±0.23	118.0±3.5	6	30.8±2.2
270	H18122	0.273±0.013	2.69±0.06	1.76±0.08	38±8	46.0±1.3	46.9±8.7	64±1.2	767±21	4.26±0.25	116.6±2.8	6	27.4±1.8
280	H18123	0.254±0.011	2.47±0.06	1.62±0.06	33±7	43.6±1.4	47.0±7.5	57±1.1	697±19	3.94±0.23	113.2±2.8	12	28.7±1.9
290	H18124	0.255±0.013	2.50±0.06	1.64±0.07	28±7	42.8±1.2	46.5±8.3	58±1.2	708±20	3.73±0.22	123.0±2.3	5	33.0±2.1
300	H18125	0.264±0.011	2.43±0.05	1.65±0.06	28±6	41.2±1.3	56.2±7.0	55±1.0	662±18	3.76±0.22	133.7±2.4	9	35.5±2.3
310	H18126	0.244±0.012	2.47±0.06	1.60±0.07	35±7	41.2±1.2	39.7±8.1	59±1.2	713±19	3.88±0.22	118.2±3.3	6	30.5±2.0
320	H18127	0.242±0.012	2.41±0.06	1.57±0.07	43±7	41.6±1.4	40.1±7.9	57±1.1	691±20	3.72±0.22	125.1±2.2	6	33.7±2.2
330	H18128	0.251±0.013	2.50±0.07	1.63±0.08	31±8	41.0±1.6	46.5±8.8	57±1.3	713±22	3.74±0.22	125.7±2.1	6	33.6±2.2

340	H18129	0.276±0.011	2.58±0.05	1.74±0.06	44±7	44.5±1.1	51.1±7.1	63±1.1	713±18	3.67±0.21	139.7±5.4	6	38.0±2.8
350	H18130	0.237±0.014	2.52±0.07	1.56±0.08	29±8	47.7±1.7	34.1±8.9	58±1.3	740±23	3.67±0.21	148.3±5.4	6	40.4±2.9
360	H18131												
370	H18132	0.256±0.010	2.51±0.05	1.65±0.06	29±6	43.2±1.0	42.5±6.4	61±1.0	713±17	3.88±0.22	144.8±3.0	6	37.3±2.4
380	H18133	0.245±0.014	2.38±0.07	1.57±0.08	32±8	39.1±1.6	46.8±8.8	55±1.3	670±22	3.88±0.22	122.2±8.5	6	31.5±2.9
390	H18134	0.257±0.015	2.56±0.07	1.67±0.08	39±9	42.8±1.4	43.2±9.8	61±1.4	733±23	3.10±0.18	151.0±2.2	6	48.7±3.0
400	H18135	0.252±0.007	2.53±0.04	1.64±0.04	36±4	43.0±0.8	42.1±4.4	60±0.7	725±12	3.10±0.18	160.5±2.7	6	51.7±3.3
410	H18136	0.266±0.015	2.58±0.07	1.70±0.09	39±9	43.9±1.9	47.9±10	61±1.5	726±24	3.10±0.18	153.4±6.1	6	49.5±3.6
420	H18137	0.254±0.009	2.53±0.04	1.65±0.05	36±5	42.4±0.8	42.1±5.6	61±0.9	724±14	3.75±0.22	145.4±8.4	6	38.7±3.3
430	H18138	0.255±0.012	2.53±0.06	1.65±0.07	35±7	42.3±1.4	43.3±7.7	60±1.1	722±20	3.75±0.22	167.9±5.0	6	44.7±3.0
440	H18139	0.222±0.006	2.20±0.06	1.44±0.04	27±16	38.2±1.2		58±1.3	633±22	3.75±0.22	164.3±2.6	6	43.8±2.8
450	H18140	0.255±0.011	2.36±0.05	1.60±0.06	44±6	40.7±1.0	48.8±7.0	57±1.0	649±17	3.30±0.19	139.0±3.4	6	42.1±2.7
460	H18141	0.245±0.007	2.37±0.05	1.56±0.04	50±18	44.5±1.4		61±1.5	670±20	3.30±0.19	115.7±13.0	3	35.1±4.5
470	H18142	0.254±0.012	2.48±0.06	1.64±0.07	33±7	40.7±1.4	45.0±7.6	59±1.1	705±19	3.30±0.19	151.4±2.5	3	45.9±2.9
480	H18143	0.222±0.006	2.36±0.05	1.50±0.04	37±14	37.5±1.1		58±1.2	702±20	3.79±0.22	125.9±8.9	6	33.2±3.1
490	H18144	0.261±0.009	2.52±0.05	1.67±0.05	34±6	42.7±0.9	47.3±6.2	60±0.9	709±16	3.79±0.22	133.6±3.1	6	35.2±2.3
500	H18145												
510	H18146	0.234±0.014	2.24±0.07	1.49±0.08	33±8	37.9±1.6	42.6±8.9	54±1.3	627±21	3.48±0.20	134.5±1.6	3	38.7±2.4
520	H18147												
540	H18148	0.214±0.016	2.27±0.07	1.44±0.09	23±9	37.1±1.5	28.2±10	56±1.4	673±23	3.47±0.20	142.2±2.0	3	41.0±2.6
560	H18149	0.212±0.006	2.14±0.06	1.40±0.04	53±21	35.0±1.6		56±1.7	621±22	3.66±0.21	150.3±5.9	3	41.0±3.0

Note: D_e , dose rate and age results for missing samples H18102, H18114, H18120, H18131, H18145 and H18147 are not yet available.

SUPPLEMENTARY FILES

Supplementary R script file: An annotated R script documents the age-depth calculations using the method of Zeeden et al. (2018), as well as the smoothing of results.

Table S1. Equivalent dose measurements (D_e , recycling ratio and recuperation), dose recovery tests (Dr) and luminescence ages for the Titel loess core. n represents the number of aliquots.

Sample code	Depth (cm)	D_e (Gy)	Recycling ratio	Recuperation (% natural)	n D_e	Dr	n Dr	OSL age (ka)
168110	9.5	1.4±0.2	1.060±0.047	0.25±0.20	10			0.4±0.1
168111	28.5					1.091±0.038	6	
168112	47.5	19.5±1.3	0.953±0.048	0.27±0.31	26			7.4±0.7
168113	66.5	37.3±2.0	1.002±0.034	-0.22±0.41	26	1.069±0.051	6	15.6±1.2
168114	109	36.8±1.9	0.960±0.034	0.20±0.28	26	1.009±0.026	6	13.6±1.0
168115	127	44.0±2.6	0.990±0.040	0.27±0.28	24	1.074±0.034	6	18.8±1.6
168116	181	41.7±3.5	1.037±0.071	0.51±0.16	24	1.044±0.046	6	17.1±1.7
168117	209	47.8±3.2	1.002±0.033	0.02±0.06	24			19.7±1.7
168118	227	62.6±3.1	0.982±0.032	0.34±0.09	17			27.8±2.1
168119	245	65.6±4.4	0.958±0.020	-0.31±0.28	24			25.8±2.3
168120	263	67.8±4.5	0.978±0.071	0.28±0.89	24			31.3±2.9
168121	281	73.6±6.6	0.944±0.032	0.90±0.81	18			24.6±2.6
168122	309	67.3±12.6	0.963±0.017	0.31±0.15	6			29.8±5.8
168123	327	84.8±3.2	0.988±0.044	-0.16±0.48	39			34.2±2.4
168124	345	111.8±9.8	0.974±0.034	-0.04±0.20	26	1.035±0.076	24	35.8±3.7
168125	363	86.6±7.0	0.955±0.052	1.18±0.56	21			27.2±2.7
168126	381	93.9±6.5	0.952±0.036	-0.03±0.35	24			28.1±2.5
168127	409	105.6±6.9	1.038±0.048	0.05±0.18	20			35.9±3.1
168128	427	98.5±5.3	0.951±0.028	0.09±0.26	30			30.8±2.3
168129	445							
168130	463	98.7±8.0	0.998±0.029	-0.30±0.64	26			38.9±3.9
168131	481	82.8±7.1	0.943±0.034	0.02±0.06	23			32.3±3.5
168132	510							

168133	529	108.3±10.9	0.956±0.045	-0.26±0.45	30			33.4±3.9
168134	548	144.9±10.8	0.938±0.024	0.11±0.08	27			49.9±6.0
168135	567	127.7±7.9	0.917±0.026	0.32±0.12	26			41.9±3.5
168136	586	144.3±13.8	0.983±0.032	-0.15±0.18	21			58.8±6.6
168137	615	136.4±11.4	0.923±0.012	0.25±0.09	21			47.7±4.8
168138	633	124.0±11.6	0.943±0.020	-0.02±0.48	20			51.9±5.7
168139	651	153.6±15.9	0.913±0.033	0.05±0.09	14	1.023±0.048	24	55.6±6.5
168140	669	149.6±17.7	1.012±0.036	-0.09±0.20	9			55.5±7.3
168141	687	157.3±17.7	1.032±0.019	0.11±0.12	9	1.109±0.045	6	57.9±7.3
168142	715	167.8±9.4	1.027±0.018	0.00±0.18	9			58.6±4.6
168143	733	95.6±10.9	0.014±-0.152	-0.15±0.09	11	1.145±0.097	6	34.0±4.3
168144	751	97.9±7.6	0.973±0.014	0.22±0.12	21			36.4±3.5
168145	769	125.6±11.4	0.953±0.025	0.07±0.09	15			42.7±4.5
168146	787	82.5±8.6	0.975±0.032	-0.05±0.27	15			28.5±3.3
168147	815	121.6±7.7	0.951±0.019	0.24±0.12	17			44.8±3.9
168148	869	126.1±16.4	0.953±0.029	0.09±0.13	16			44.0±6.3
168149	887	114.9±11.7	0.947±0.020	0.31±0.13	18			51.3±6.1
168150	915	129.5±16.0	0.964±0.056	0.11±0.25	13			47.6±8.4
168151	933	91.5±13.1	1.019±0.034	0.13±0.20	17			31.7±4.9
168152	951	91.9±17.2	0.981±0.029	0.56±0.22	12			30.1±5.9
168153	969	120.5±20.3	0.943±0.015	0.04±0.05	13			38.5±6.8
168154	987	91.0±19.5	0.970±0.041	-0.15±0.17	10			32.0±8.0
168155	1015	95.3±25.2	0.863±0.026	0.28±0.59	9			31.9±8.6
168156	1033	154.3±25.8	0.989±0.043	0.14±0.18	11			53.4±9.4
168157	1051	131.5±13.6	0.968±0.034	0.89±0.74	11			45.1±7.8
168158	1069	134.8±12.9	0.965±0.023	-0.07±0.13	11	1.016±0.029	6	44.9±5.0
168159	1087	159.0±13.1	0.972±0.026	-0.16±0.17	11	1.077±0.043	6	54.8±5.5
168160	1115	50.0±7.9	0.968±0.020	0.24±0.17	6			48.9±10.0

Note: D_e , optical ages and test results (recycling ratio and recuperation) for missing samples (168111, 168129 and 168132) are not available at this moment.

Table S2. Equivalent dose measurements (D_e , recycling ratio and recuperation), dose recovery tests (Dr) and luminescence ages for the Lingtai loess section. n represents the number of aliquots.

Sample code	Depth (cm)	D_e (Gy)	Recycling ratio	Recuperation (% natural)	n D_e	Dr	n Dr	OSL age (ka)
H18101	20	6.1±0.2	0.945±0.051	0.97±0.28	6			1.6±0.3
H18102	60							
H18103	70	54.8±4.	0.980±0.021	0.77±0.01	6			15.6±1.5
H18104	80	75.6±1.8	0.997±0.007	0.58±0.04	9			21.6±1.4
H18105	90	53.7±1.0	0.973±0.013	0.72±0.08	6			15.4±1.0
H18106	100	62.9±2.0	0.960±0.006	0.73±0.12	6			17.4±1.2
H18107	110	55.2±1.3	0.964±0.027	0.63±0.10	4			15.0±1.0
H18108	120	55.9±0.5	0.963±0.024	0.42±0.02	6			15.0±1.0
H18109	130	68.9±3.0	0.943±0.019	0.69±0.08	6			18.1±1.4
H18110	140	64.1±1.5	1.013±0.018	0.81±0.23	5			17.3±1.1
H18111	150	82.9±1.2	0.979±0.020	0.47±0.05	9			22.1±1.4
H18112	160	75.1±2.0	0.970±0.015	0.77±0.17	6			18.9±1.3
H18113	170	75.9±1.2	0.993±0.012	0.54±0.02	9			19.6±1.2
H18114	180							
H18115	200	83.4±3.1	1.067±0.009	0.57±0.11	6			22.8±1.7
H18116	210	115.2±2.2	0.964±0.012	0.67±0.04	12			28.1±1.8
H18117	220	98.2±1.3	0.973±0.014	0.54±0.04	6			24.9±1.6
H18118	230	86.9±4.2	0.930±0.038	0.69±0.20	3			22.9±1.8
H18119	240	99.4±0.9	0.938±0.010	0.77±0.03	5			25.2±1.5
H18120	250							
H18121	260	118.0±3.5	0.943±0.003	0.95±0.02	6	0.984±0.026	4	30.8±2.2
H18122	270	116.6±2.8	0.940±0.000	1.00±0.06	6	0.945±0.009	4	27.4±1.8
H18123	280	113.2±2.8	0.943±0.007	0.84±0.03	12			28.7±1.9
H18124	290	123.0±2.3	0.930±0.017	1.02±0.03	5	1.007±0.021	4	33.0±2.1
H18125	300	133.7±2.4	0.952±0.005	0.92±0.04	9	1.015±0.015	4	35.5±2.3
H18126	310	118.2±3.3	0.977±0.009	1.07±0.04	6	1.011±0.012	4	30.5±2.0

H18127	320	125.1±2.2	0.960±0.006	0.99±0.03	6	0.981±0.013	4	33.7±2.2
H18128	330	125.7±2.1	0.960±0.026	0.94±0.02	6	0.998±0.003	4	33.6±2.2
H18129	340	139.7±5.4	0.987±0.009	0.75±0.03	6	0.977±0.024	4	38.0±2.8
H18130	350	148.3±5.4	0.987±0.009	0.73±0.01	6	0.772±0.258	4	40.4±2.9
H18131	360					1.063±0.011	4	
H18132	370	144.8±3.0	0.970±0.006	0.98±0.02	6	1.032±0.009	4	37.3±2.4
H18133	380	122.2±8.5	0.955±0.024	1.00±0.14	6			31.5±2.9
H18134	390	151.0±2.2	0.983±0.007	0.95±0.04	6	1.000±0.010	4	48.7±3.0
H18135	400	160.5±2.7	0.967±0.009	0.92±0.02	6	1.043±0.012	4	51.7±3.3
H18136	410	153.4±6.1	0.987±0.003	0.89±0.05	6	1.030±0.013	4	49.5±3.6
H18137	420	145.4±8.4	0.983±0.007	0.73±0.02	6	1.032±0.013	4	38.7±3.3
H18138	430	167.9±5.0	0.967±0.007	0.74±0.03	6	1.058±0.014	4	44.7±3.0
H18139	440	164.3±2.6	0.970±0.010	0.72±0.02	6	1.042±0.008	4	43.8±2.8
H18140	450	139.0±3.4	0.987±0.003	0.79±0.02	6	1.057±0.011	4	42.1±2.7
H18141	460	115.7±13.0	0.973±0.045	0.95±0.02	3			35.1±4.5
H18142	470	151.4±2.5	0.960±0.010	0.71±0.02	3			45.9±2.9
H18143	480	125.9±8.9	0.977±0.057	1.99±0.38	6			33.2±3.1
H18144	490	133.6±3.1	1.005±0.010	1.00±0.08	6			35.2±2.3
H18145	500							
H18146	510	134.5±1.6	0.967±0.012	1.18±0.09	3			38.7±2.4
H18147	520							
H18148	540	142.2±2.0	1.047±0.028	0.78±0.40	3			41.0±2.6
H18149	560	150.3±5.9	0.957±0.007	1.11±0.05	3			41.0±3.0

Note: D_e , optical ages and test results (recycling ratio and recuperation) for missing samples (H18102, H18114, H18120, H18131, H18145 and H18147) are not yet available.

Table S3. Grain-size distribution data for the Lingtai loess section.

Sampling Average Depth	Volumetric Mean	Volumetric Median	Fraction <5.5 μm	Fraction Silt: 5.5 to 63 μm	Fraction 5.5 to 16 μm	Fraction 16 to 44 μm	Fraction 44 to 63 μm	Fraction 63 to 160 μm
0.01								
0.06	21.63410989	14.80147954	27.94031089	67.58495032	24.32178016	33.79499767	9.468172487	4.456191099
0.11	21.60013136	14.18616559	27.48244428	68.54957511	23.61908456	35.00327678	9.927213769	3.947172388
0.16	20.88872806	14.87121342	28.49087577	67.75488782	23.89227536	34.27189909	9.590713371	3.739575972
0.21	20.82028827	14.57393066	28.07905009	68.17502221	23.76726872	35.00998414	9.397769341	3.745499735
0.26	22.27942054	14.02257905	26.9157902	68.19358574	23.86978675	34.52001329	9.803785704	4.877744348
0.31	23.8858242	15.88182324	25.59747072	68.30634606	23.46566478	34.53257312	10.30810816	6.054260046
0.36	20.81987805	12.41323798	28.76404664	67.50634735	23.7793645	34.19028237	9.53670048	3.722824718
0.41	20.83361594	14.63406928	28.0067068	68.30613733	23.9611825	34.88488555	9.460069278	3.68673687
0.46	22.36387527	16.0744465	26.54560131	68.97734568	22.86202448	35.74990751	10.36541369	4.467004852
0.51	21.92690005	14.04325906	27.27804049	68.33086471	23.5363368	34.61195414	10.18257377	4.379481665
0.56	22.39382418	15.56709419	24.20797661	71.516735	24.14140306	37.33534143	10.03999051	4.271851158
0.61	21.57196245	14.59852472	26.41398466	69.19506458	25.5514773	33.76799326	9.87559403	4.388776705
0.66	22.64550714	16.18420004	25.78139839	69.36664114	23.81728014	35.32942097	10.21994002	4.833316811
0.71	21.06016228	14.85215728	27.34013405	68.69346409	25.1133791	34.05804559	9.522039395	3.95924919

0.76	22.0523511	16.12266694	24.22352022	71.63611873	25.2187941	36.46027652	9.95704811	4.135105539
0.81	21.80973769	13.7782925	25.08082054	70.83098196	25.26941688	35.92101604	9.640549039	4.080099796
0.86	20.35692532	12.81756224	27.69395097	68.72850731	25.86674448	33.66586225	9.195900581	3.577012301
0.91	23.07019257	15.22333798	23.79837257	71.38970127	23.98153224	36.53917288	10.86899615	4.810351622
0.96	22.10573491	13.71008186	25.13477583	70.51161517	25.06643106	35.07220517	10.37297894	4.351674619
1.01	21.60076104	13.7480211	25.18154085	70.92539627	25.10193948	35.88273339	9.940723408	3.890986646
1.06	21.73174575	16.03959689	24.18676667	71.95752556	25.09768886	37.16780039	9.692036315	3.854461874
1.11	22.66936264	15.99981133	23.03057146	72.7322562	24.21476865	37.8395166	10.67797096	4.236879952
1.16	20.76968699	14.85109992	26.16928041	70.08234165	26.42453385	34.58139767	9.076410124	3.747369079
1.21	21.69528536	16.10035956	23.85883585	72.39089423	25.5315757	37.19602376	9.663294777	3.749343142
1.26	20.07303379	13.43189668	27.91807345	68.69558756	27.15515893	32.87819618	8.662232441	3.375763781
1.31	20.57931353	14.73733086	25.9902696	70.39621802	26.3840734	34.93015284	9.081991771	3.613405213
1.36	20.78887728	14.00875482	24.19508266	72.52211804	26.69875325	37.17622327	8.64714152	3.281918291
1.41	19.29452851	13.29700307	26.63919367	70.44216742	28.48650959	33.84320128	8.112456549	2.918638911
1.46	18.77408592	11.79762074	28.15044487	69.01128929	28.83224733	32.27609724	7.902944727	2.838265834
1.51	19.20944545	11.90159179	28.74276664	67.89635625	28.23229664	31.55304707	8.111012539	3.360068722
1.56	20.46677878	12.45188032	25.84856245	70.58386317	27.17110119	34.78283462	8.629927358	3.566376565
1.61	21.15054651	13.69697179	24.33711662	72.23352307	25.85289465	37.0438702	9.33675821	3.428896857
1.66	21.28606849	16.29445262	23.96709659	72.6086918	25.81436184	37.44784925	9.346480713	3.423601416

1.71	18.92052515	11.70036662	28.54945984	68.48724083	28.07209851	32.63374586	7.781396459	2.963059025
1.76	20.68127618	16.3018929	23.94510199	73.21690817	25.84525795	38.46223241	8.909417809	2.837907656
1.81	19.16014011	13.28026997	27.46180124	69.78874698	27.55577666	34.37839367	7.85457665	2.749227353
1.86	18.78073267	11.38248465	28.02943409	69.29737213	28.05352037	33.67406925	7.569782518	2.672986159
1.91	18.40904967	11.56937101	28.5470122	69.15409292	27.85839894	33.64765696	7.648037026	2.298894876
1.96	19.95432582	14.87020439	26.60122995	70.57943151	26.07998464	35.69214497	8.807301905	2.819338538
2.01	19.28252687	13.20278528	28.15193677	69.12155877	26.48221982	34.46491531	8.174423638	2.726323791
2.06	18.16196236	11.87445527	29.69710528	68.22300852	27.1900306	33.38629663	7.64668129	2.079766024
2.11	19.96485664	14.50742984	26.30461561	71.35154705	25.5967738	36.82447635	8.930296892	2.343510203
2.16	18.22994733	13.11451046	28.04561104	71.01118831	26.48473253	36.02512123	8.501334557	0.943200644
2.21	18.94921201	14.75108274	26.46945472	72.36315334	26.02945384	37.4059587	8.927740803	1.167391944
2.26	19.13345454	12.99157472	27.80720256	69.91781875	26.37225301	35.50593846	8.039627284	2.274597532
2.31	19.68995881	14.44853326	25.85418085	72.05595941	25.96550815	37.56558035	8.524870907	2.089859742
2.36	18.79825902	12.52614548	26.71886072	72.01681421	26.48206791	36.81621028	8.718536021	1.264325067
2.41	18.38590541	12.07719853	28.28688296	69.72956733	27.50280901	34.4517646	7.774993717	1.983549712
2.46	18.80484518	13.30569972	27.81424539	70.21342296	27.17110612	35.18669197	7.85562487	1.972064935
2.51	20.74350749	14.09344438	26.04010236	70.8034228	24.95199449	36.25439871	9.597029594	3.156291363
2.56	18.65794828	13.38166839	27.98995191	69.64093875	27.18487574	34.69371822	7.762344788	2.369109347
2.61	17.89930013	11.39548355	28.35003065	70.42299368	27.75384619	34.62112009	8.048027398	1.226975663

2.66	20.31473734	14.28402008	25.47701344	71.58551271	25.97330287	36.74393782	8.868272018	2.937473853
2.71	21.61266566	15.38758419	23.48339633	73.4192834	24.49006432	38.1831998	10.74601929	3.097320271
2.76	20.27467334	14.16669868	25.45288489	71.86857997	25.74785827	36.87517105	9.245550658	2.678535138
2.81	22.12506855	16.80801335	22.74636521	73.96331827	24.0395545	38.64399388	11.27976989	3.290316512
2.86	19.79359235	14.76619876	26.04442852	71.415865	26.46800128	36.10923367	8.838630058	2.53970648
2.91	19.25043893	13.19611148	27.8509518	69.53615036	26.84706662	34.75396688	7.935116859	2.611550094
2.96	20.23852504	14.41469371	25.85459955	71.35427771	25.84510584	36.35102442	9.158147447	2.791122738
3.01	20.15885809	14.61066254	25.94862239	71.2003648	26.19555023	36.13112747	8.873687105	2.850832171
3.06	18.97101402	13.4147735	27.73608762	69.82232478	27.5019312	34.21988409	8.100509488	2.44146517
3.11	17.7345872	12.11086147	29.79638827	68.29284291	27.87217048	33.23805772	7.182614704	1.91076882
3.16	18.20188252	11.46956461	29.01991156	69.13464183	27.00362871	34.50942819	7.621584927	1.845446616
3.21	18.01396915	11.86046855	28.99716148	69.12935672	28.13101378	33.46717731	7.531165634	1.873481801
3.26	17.60666298	12.21290305	29.59737774	68.64907784	28.46284704	32.9956456	7.1905852	1.753544426
3.31	21.60780415	16.28751102	24.78956079	71.3519529	24.99015889	36.25431529	10.10747872	3.858308707
3.36	19.72172151	13.1310104	26.42372968	70.67061896	26.68390515	36.03468395	7.952029856	2.905547527
3.41	18.909883	12.82695111	26.67222217	71.42696239	27.27384927	35.92986412	8.223248994	1.900815443
3.46	19.03890196	12.91008046	27.69942729	70.10689752	26.27464656	35.5294164	8.302834557	2.193675187
3.51	19.61094931	14.05746227	26.88905018	70.68624617	25.83444503	36.08991594	8.761885201	2.424703655
3.56	17.62038615	12.04181372	29.5541807	68.88445714	27.9925528	33.64836244	7.243541903	1.56136216

3.61	17.94185553	11.78734259	29.59115438	68.69126012	27.21502837	34.00940745	7.466824306	1.717528118
3.66	21.52084324	15.62670564	23.81797409	73.16371775	24.63209058	38.1945045	10.33712267	3.018166891
3.71	16.47499287	10.68574885	31.21952808	68.08300963	28.26423306	32.93045298	6.888323596	0.697462287
3.76	18.53323275	13.5435969	28.83289571	69.39106555	26.48482477	34.73319108	8.173049705	1.775898423
3.81	16.0200724	11.01221379	31.42607307	67.94324484	29.37319004	32.14768316	6.422371644	0.630682092
3.86	17.64527174	11.59181666	29.12140695	69.70995265	27.28303825	34.89074101	7.536173396	1.168640405
3.91	19.2647647	12.57179322	26.92840318	71.09606319	26.31909877	36.17999064	8.596973776	1.975518796
3.96	19.07207019	13.3111707	28.55172773	69.2330181	26.12028816	34.68579665	8.426933288	2.214365485
4.01	18.36848057	13.45441833	28.56834657	69.44852178	26.64573204	35.05316846	7.749621279	1.983131652
4.06	19.6763735	14.82941382	26.80318068	70.9115034	25.78781624	36.42807849	8.695608678	2.284882875
4.11	19.60304381	14.48554275	26.41855224	71.64882058	25.43677253	37.44457988	8.767468161	1.932627178
4.16	18.34441798	13.01269978	27.57749751	71.33933553	26.69346917	36.24599288	8.399873474	1.083166959
4.21	20.74309635	13.80126945	24.83473156	72.46023467	25.57390551	37.19630953	9.690019633	2.704550975
4.26	19.47447107	14.63485216	26.49474708	71.78733243	25.66540779	37.08799147	9.033933179	1.717920484
4.31	20.06485155	14.34186696	25.70980176	71.79393572	25.86205764	36.84134239	9.090535694	2.496262513
4.36	21.09995677	13.82421202	24.70389473	71.93194843	25.75057289	36.76790463	9.413470909	3.363989431
4.41	22.11921663	15.68170592	24.0427321	72.16120168	24.54238735	37.10888937	10.50992496	3.794638964
4.46	19.53520591	12.81642234	26.68490331	70.81887036	27.13628958	35.23554058	8.447040199	2.495653248
4.51	20.00106803	12.83517477	27.15230681	69.79300404	26.59349365	34.25096205	8.948548336	3.053568156

4.56	20.94035292	13.6848755	24.78757487	72.09336257	25.37290425	37.08623726	9.634221059	3.119049326
4.61	20.06686844	14.73589466	25.5432401	71.72031096	26.94226282	35.94378784	8.834260301	2.7360034
4.66	18.31246994	11.95182627	28.38251898	69.36754548	29.09803381	32.72064524	7.548866426	2.249393316
4.71	20.48106479	14.46730746	25.49212844	71.38854622	26.34772088	35.95537938	9.085445966	3.119037494
4.76	18.1753352	11.84751722	28.54878718	69.3819354	28.63019231	33.16322384	7.588519251	2.069277423
4.81	21.1728807	14.60290247	24.67860769	71.99875005	25.4563005	37.05806235	9.484387203	3.321712834
4.86	20.13287613	14.56291165	25.58612731	71.57818392	26.49464084	36.35093709	8.732606	2.835532836
4.91	19.8902781	12.52829497	25.95952481	71.02620587	27.29577474	35.33528315	8.395147971	3.014198178
4.96	20.72331269	14.29909715	25.39417152	71.2048892	26.07367744	36.03155003	9.099661723	3.400655686
5.01	19.0835486	13.5275306	27.36871424	69.92281056	28.18967446	33.70921111	8.023924982	2.708373882
5.06	20.46380651	14.76379714	25.63200358	70.91529846	26.89249495	35.4189186	8.603884912	3.451816741
5.11	19.2875386	13.06915476	26.66126411	70.57371533	27.91872717	34.67239845	7.982589709	2.765020556
5.16	19.31561172	13.34479074	27.11970724	69.98633994	28.02114916	33.82776711	8.137423673	2.893933359
5.21	21.38743845	13.71402236	24.67801214	71.46931112	25.54252982	36.40269785	9.524083454	3.852540882
5.26	20.32840429	12.59938582	26.3937898	69.92599026	26.95192552	34.96363286	8.010431883	3.679348714
5.31	19.71414676	13.11179464	27.14894462	69.57589629	27.34038359	33.93773417	8.297778532	3.275086783
5.36	20.08467131	14.70107481	25.75596577	71.27816917	26.62006723	36.08212886	8.57597308	2.965865059
5.41	21.16498572	13.87119671	24.91130776	71.42355935	25.63938992	36.33438263	9.449786799	3.665120322
5.46	19.88461837	12.56517781	26.27833473	70.76632651	27.02611451	35.25975506	8.480456944	2.954825096

5.51	19.85487549	12.56202679	26.20830691	70.82435585	27.08013281	35.42598826	8.318234787	2.966913473
5.56	21.3380484	16.1298062	23.82177214	72.30887438	25.61838292	37.87144822	8.819043241	3.869353483
5.61	21.67399606	15.77625433	24.0781665	72.32077765	24.67188794	37.57020159	10.07868812	3.600887906
5.66	21.25802354	13.81403862	24.9759254	71.49142591	25.4580285	36.64366658	9.389730835	3.531499337
5.71	20.36532947	14.30779965	25.47722135	71.6546233	26.03559379	36.59485258	9.024176928	2.867603484
5.76	22.73733511	17.70770961	22.75043283	73.17468682	23.81150051	38.32707737	11.03610895	4.074830597
5.81	21.98918996	15.68194002	23.97510778	72.18062849	24.60719746	37.28101495	10.29241608	3.843939039
5.86	20.80025501	13.78405115	24.99545888	71.94284707	25.37597046	37.29256089	9.274315726	3.061553022
5.91	22.17473002	15.56672821	23.70172904	72.32689784	24.65242008	37.39604736	10.2784304	3.970496515
5.96	22.76002553	17.61259138	22.52351261	73.34003765	23.84520555	38.7444963	10.7503358	4.136404943
6.01	19.89276111	12.54649738	26.43677795	70.61729843	26.81746733	35.46433518	8.335495915	2.945356487
6.06	20.85979767	13.68701426	24.20285508	73.02510763	25.96702525	37.65749918	9.400583192	2.768409708
6.11	20.09995085	14.28725386	25.31201562	71.91953908	26.15766957	37.15175661	8.610112902	2.768445303
6.16	19.64803005	12.71181386	26.31674791	70.81471654	27.32943501	35.29113452	8.194147009	2.868535555
6.21	21.24356677	14.55961137	24.40441275	72.3969977	25.64035001	36.99430876	9.762338932	3.19725025
6.26	21.63029707	15.92701236	24.13579811	72.34665138	24.91736299	37.50322696	9.926061423	3.516571938
6.31	23.07791303	17.06118898	21.53518259	74.27873717	23.72705884	39.64827568	10.90340264	4.185782751
6.36	23.80826225	16.54321695	21.25782682	74.21661232	23.13414142	39.66352998	11.41894092	4.524232888
6.41	22.43959106	15.99466646	23.02889774	73.06596655	24.14696472	38.42816258	10.49083925	3.904165126

6.46	23.38196597	17.08418131	21.84864461	73.82731356	23.50974582	39.29118758	11.02638016	4.322366514
6.51	19.92685627	12.88952001	27.06639204	69.75595377	26.82285142	34.32436468	8.608737677	3.177192481
6.56	23.28193605	16.87735351	21.33150488	74.4543102	23.47769583	40.28801813	10.68859624	4.213360344
6.61	18.71454528	13.28866553	27.36178431	70.44468987	27.69036696	35.23780385	7.516519066	2.193525816
6.66	18.02416393	11.84056088	28.70841337	69.13731156	28.65846301	33.63502911	6.843819434	2.154032624
6.71	18.42774537	12.57394928	26.44716683	72.72949048	26.97479133	37.47413324	8.280565908	0.82334269
6.76	18.10628641	13.31442211	27.28477721	71.22968026	28.03166942	35.92547187	7.272538977	1.485542531
6.81	20.93317555	15.55977222	23.30927447	74.37648731	24.90134761	39.75864847	9.716491229	2.314110051
6.86	15.99816749	11.0543442	31.25023051	67.88786209	29.98754387	31.77328886	6.127029358	0.861907408
6.91	17.58282018	11.4156122	29.16050273	68.78430298	26.75022075	34.50743018	7.526652052	2.055194286
6.96	22.37506529	17.62486358	22.29994481	74.07104616	23.97290205	39.4213211	10.67682301	3.629009028
7.01	15.86880284	10.87770224	30.57338109	68.90701541	30.36893388	32.51074984	6.027331688	0.519603498
7.06	17.03516887	11.60839299	28.68144255	70.58093505	28.26048212	35.58310792	6.737345012	0.737622402
7.11	17.56116284	13.54294755	28.97038592	70.18478157	26.62139303	36.17121287	7.392175671	0.844832512
7.16	17.67995266	11.78664992	29.93711689	68.53707819	26.88329357	34.54477729	7.10900733	1.525804926
7.21	16.4821351	10.37298685	30.58014016	68.70042003	28.4295365	33.61363407	6.657249454	0.719439812
7.26	22.38376734	15.95569461	23.67147079	72.65738365	23.44949404	38.43127975	10.77660986	3.669871946
7.31	22.33049083	16.00573187	23.3895219	72.49756054	23.78865872	37.98912164	10.71978018	4.112917561
7.36	19.24608712	13.25284708	28.78928084	68.23326755	25.86197083	34.07183114	8.299465585	2.977348443

7.41	16.52958241	10.73369114	31.57178072	67.6079618	28.00656398	32.46887663	7.132521189	0.820257481
7.46	19.43756029	13.29688527	27.14547934	70.44393479	25.87338628	35.83100585	8.739542662	2.410585873
7.51	16.0548756	11.10859479	31.73917756	67.33034343	29.26589213	32.07219571	5.992255599	0.930479009
7.56	16.13115033	11.04820567	32.29069479	66.97929705	28.17696709	32.0984336	6.703896358	0.730008165
7.61	15.46780339	9.731830894	33.49707294	65.91427949	28.76006993	31.03203953	6.122170028	0.588647573
7.66	20.96786299	16.13205174	25.65161676	71.50110327	23.8232975	37.24574772	10.43205805	2.847279968
7.71	20.51031157	14.64980985	26.27733528	71.13912391	23.94930108	37.35985828	9.829964553	2.583540802
7.76	16.18607644	10.91248249	31.95974649	67.25405372	28.25430753	32.364399	6.635347191	0.786199792
7.81	18.26720639	12.78844461	28.9577399	69.25674809	26.59339491	34.92140772	7.741945454	1.785512012
7.86	14.11584756	9.218921932	36.24130823	63.3845673	30.13981961	28.19911168	5.045636009	0.374124475
7.91	15.84865696	10.62467741	32.3961741	66.85172456	29.04169049	31.44784989	6.362184183	0.752101332
7.96	17.65612269	11.76509881	29.96124567	68.50470177	26.92545619	34.37413292	7.205112663	1.533995443
8.01	16.86956022	10.76255773	32.16095484	66.5282662	27.1143921	32.25594408	7.157930023	1.310778962
8.06	19.72694927	14.58484865	26.65327027	70.93347966	25.43732882	36.52381729	8.972333546	2.413250078
8.11	23.92620755	19.45705371	22.05382403	73.32040278	21.64714329	39.34374926	12.32951023	4.625615166
8.16	20.51574935	14.7250178	25.2223481	72.12449736	25.17408938	37.6793157	9.271092286	2.653128937
8.21	20.18455325	14.24732283	26.78815975	70.70065277	24.48946406	36.2079927	10.00319601	2.511187485
8.26	21.18247108	14.64227051	26.10219588	70.44611069	24.10706997	36.12460564	10.21443508	3.451564309
8.31	15.12256332	7.832343209	36.82093444	61.94223815	28.80219432	27.02900377	6.111040059	1.236752693

8.36	25.47626715	18.63295818	21.45554655	72.19719379	21.1953388	37.88753993	13.11431506	6.346912062
8.41	20.63392582	14.03905395	25.81925795	71.18413093	25.07674954	36.38957693	9.717804459	2.996611123
8.46	23.96153763	16.64035877	22.30142346	72.75565768	22.39659498	38.19535436	12.16370833	4.94224116
8.51	24.33321832	19.51665217	22.03189122	72.9088669	21.86851556	38.49576742	12.54458393	5.05849301
8.56	20.60189458	14.80904387	27.94658018	68.63347639	24.37306076	34.09487864	10.16553698	3.419943435
8.61	20.54473732	14.2215462	26.18585032	70.56985041	25.11767592	35.97655086	9.475623622	3.244299275
8.66	26.23921581	20.87697927	20.21496252	73.64098164	20.1793723	39.18740478	14.27420456	6.143593389
8.71	27.14513669	20.67949299	20.29169297	72.07689993	20.00168972	37.42218006	14.65303016	7.630655812
8.76	20.30423284	14.5421724	27.58323397	69.68704298	24.22902745	35.63366278	9.824352745	2.729643862
8.81	18.84187646	13.2921177	28.60143026	69.21318521	26.26438729	34.11856353	8.8302344	2.185384522
8.86	22.60257464	15.73584404	25.75582574	69.24450755	23.02501011	35.20912849	11.01036895	4.99966671
8.91	20.0532079	14.56500728	26.29781626	70.94233314	25.75546812	35.61869117	9.56817385	2.759850595
8.96	21.04221233	13.83212264	26.29240987	70.33889893	24.16821562	36.49115435	9.679528964	3.367754565
9.01	21.04889179	14.52917961	27.18401355	68.9915085	24.6233066	34.03050957	10.33769233	3.824343024
9.06	21.69405536	15.83783769	24.5929347	71.73199145	24.29335531	36.78374131	10.65489484	3.675073847
9.11	23.97304646	19.64897092	21.48572459	73.92490974	22.37039784	39.43784467	12.11666724	4.588884305
9.16	23.82364576	17.48886918	23.27864551	71.68619635	23.09936448	36.22422576	12.36260612	5.031763078
9.21	22.63340542	17.72402662	23.45202316	72.57509879	23.15475996	37.9392186	11.48112023	3.972878044
9.26	23.42174542	17.42480058	23.18638352	71.9291484	22.95597714	37.17007966	11.8030916	4.88446808

9.31	24.60852861	16.6390706	22.88790839	71.46734071	22.33069639	35.95327854	13.18336578	5.644381367
9.36	25.69978127	18.27137727	20.52623334	73.70132128	21.41858521	38.47060029	13.81213578	5.771135895
9.41	25.48330962	18.95857237	21.62262973	72.44197584	21.49194805	37.57299738	13.37703041	5.92537333
9.46	21.90236732	14.20697342	25.76002548	69.76162196	25.4015882	33.15228941	11.20774435	4.478169259
9.51	25.28120596	19.05128387	22.008878	71.92862665	21.64047972	36.64653103	13.6416159	6.062116101
9.56	25.79850297	18.35555476	20.80097888	72.99906743	21.31672139	38.2731398	13.40920624	6.199152706
9.61	27.71349308	23.66124385	18.95331871	73.82042208	19.60106383	39.12980036	15.0895579	7.220907942
9.66	24.44983551	16.51411883	22.15418829	72.36029076	22.49473171	37.12139979	12.74415927	5.485301987
9.71	26.09644604	18.46105755	20.86026649	72.43121912	21.52388188	37.47915756	13.42817968	6.706203011
9.76	25.55062328	18.54665765	20.80499474	73.1217699	21.5673314	38.31696169	13.23747681	6.072425425
9.81	24.70810386	19.53035134	21.89583029	72.44103184	22.26503239	37.24252168	12.93347778	5.663081692
9.86	24.94857184	18.91999745	21.00781112	73.55709122	21.8767014	38.80488648	12.87550334	5.434579413
9.91	23.80832705	16.98360942	22.92484796	72.1385442	22.50510103	37.72800579	11.90543738	4.936204562
9.96	23.43286529	17.71495823	23.35989216	71.70068232	23.41994039	36.6284571	11.65228483	4.938831255
10.01	25.00205012	19.42458342	22.09153476	72.05067303	21.94018175	37.14426166	12.96622962	5.856223801
10.06	23.04040796	17.66117187	23.24773892	72.48223186	23.3461134	37.75853088	11.37758758	4.269189256
10.11	24.63573306	18.23884929	19.89507618	75.58551811	21.54452977	41.25141829	12.78957005	4.519405704
10.16	22.46051737	15.30544865	24.51045725	71.37692975	23.44210135	36.67910653	11.25572187	4.112492813
10.21	23.30811595	15.00910024	24.35129226	70.64529842	23.14193257	35.7410673	11.76229854	5.002630145

10.26	23.00845201	17.40712978	22.90665408	72.99545373	23.20507522	38.22456608	11.56581243	4.097771272
10.31	23.74556103	16.68617334	22.40829624	73.13535523	22.57504408	38.43351062	12.12680053	4.455727212
10.36	22.56152007	17.8553645	23.443557	72.82901756	23.52707947	37.99107187	11.31086622	3.727271475
10.41	23.97874132	19.39632647	21.3977802	74.29037817	22.20033112	39.74966954	12.34037751	4.311585887
10.46	22.56027227	17.39230016	21.67500837	74.85003288	24.11358647	39.86497701	10.8714694	3.474958747
10.51	22.84293981	17.1420559	21.5731829	74.95061229	23.70632222	40.58895437	10.6553357	3.474947047
10.56	20.14963559	14.74941938	26.99721536	70.29037817	25.32442378	35.55280616	9.413148234	2.712212948
10.61	19.47580921	12.83819587	27.58165765	69.93964712	26.1488224	34.61885687	9.171967846	2.478695229
10.66	21.94954258	16.9192533	22.09283197	74.89297251	24.70449628	39.9751103	10.21336593	3.013924959
10.71	19.90015017	12.9965361	27.69410982	69.32200089	26.31309562	34.06438174	8.944523528	2.983889293
10.76	20.34436406	14.43837414	26.19986871	70.7983492	25.49828097	36.09483434	9.205233885	3.001533457
10.81	18.94183244	13.55552905	28.12860506	69.32771225	27.26087746	33.55199196	8.514842833	2.543682686
10.86	19.13103473	12.71941455	26.80600202	71.52311121	26.77556668	35.26328521	9.484259321	1.670886766
10.91	20.72510138	14.26164119	25.8199626	70.73928362	25.53809481	35.96669868	9.234490131	3.440753784
10.96	18.56784683	12.45370432	28.57148629	69.89991598	26.83646387	33.75416267	9.309289443	1.528597724
11.01	19.45172976	13.10498982	27.85563907	69.4092326	26.45369983	33.95142576	9.004107014	2.735128323
11.06	19.5923992	13.24080599	28.24683106	68.80629925	26.31019743	33.72993774	8.766164079	2.946621411
11.11	20.01367659	14.86284932	26.17435318	70.9599456	26.53745003	35.34788533	9.074610239	2.865701222
11.16	20.2077581	12.54693729	27.0234671	69.79542239	26.05714437	34.57255704	9.165720981	3.180968605

11.21	19.79763419	12.84347641	27.17710949	69.86378491	26.62527151	34.25171124	8.986802157	2.9591056
11.26	20.24771338	14.86088351	26.78154595	70.0373101	25.83117308	34.95201137	9.254125645	3.18114395
11.31	19.55711833	13.40964885	28.5290121	68.42137307	26.37118412	33.10029084	8.949898113	3.049582981
11.36	21.36111746	15.88797232	23.10517116	73.66781495	25.80071167	38.17018199	9.696921293	3.22689133
11.41	20.17110972	12.54663132	27.86544528	69.01542835	25.0840374	34.20824349	9.723147462	3.119126372
11.46	20.30781681	12.61792651	27.75487053	68.85704656	25.36549092	34.00005674	9.491498905	3.387975636
11.51	20.65950927	14.43812312	25.90460338	70.82138475	25.82674739	35.39104169	9.603595669	3.273925904
11.56	20.90153909	14.11651127	25.86499304	70.69450769	25.17456195	35.75617825	9.76376749	3.44049927
11.61	20.76932447	14.65365086	27.00913058	69.26387156	25.10377498	34.47190005	9.688196522	3.726111999
11.66	20.91715129	14.08686609	25.75392066	70.89589781	25.22386836	35.51413265	10.1578968	3.350181534
11.71	23.7101337	19.0577577	20.22452167	76.01981103	22.42051957	41.83607297	11.7632185	3.755667296
11.76	23.20882094	16.99178116	21.62400781	74.16009784	23.47519191	39.55787378	11.12703215	4.215878974
11.81	22.91982273	17.80119004	23.0370922	72.56009903	23.74296455	37.76250221	11.05463227	4.402630935
11.86	22.591104	15.96895371	23.13993269	72.69051706	24.00700489	37.75867695	10.92483522	4.16955025
11.91	23.22096681	17.07084769	21.98457567	73.77808015	23.39970903	38.92350172	11.45486941	4.237344179
11.96	22.69852049	15.13072605	23.97273742	71.54877296	23.62454374	36.76282071	11.16140851	4.478489618
12.01	24.83774602	18.20794012	18.82843747	76.45966118	22.02471997	42.28076374	12.15417747	4.711671278
12.06	22.06700165	13.94877588	26.54611636	68.84813407	24.09438119	34.09174358	10.6620093	4.604415984
12.11	23.9123932	17.36914207	24.01775309	70.47028348	22.28863817	36.02579732	12.15584799	5.511210422

Table S4. Loess Mass Accumulation Rate (MAR g m⁻² a⁻¹) calculated for Titel and Lingtai based on modelling output.

Titel				Lingtai			
Bacon		Inverse (Smoothed)		Bacon		Inverse (Smoothed)	
Age	MAR	Age	MAR	Age	MAR	Age	MAR
0.5	90.7	3.9	127.9	5.5	114.5	7.8	64.7
1.4	86.7	6.2	12.7	6.2	110.6	8.8	52.0
2.2	84.9	8.5	-1.2	6.9	115.6	9.9	55.7
3.1	86.1	10.8	191.8	7.5	112.8	10.9	64.1
4.0	84.7	13.1	492.3	8.2	111.7	11.9	86.1
4.9	86.9	15.4	647.6	8.9	112.5	12.9	136.3
5.7	88.0	17.8	520.3	9.5	114.5	13.9	204.0
6.6	95.6	20.1	249.1	10.2	113.5	14.9	249.8
7.4	114.3	22.4	88.0	10.8	113.0	16.0	244.6
8.0	114.6	24.7	121.6	11.5	117.2	17.0	206.9
8.7	115.0	27.0	210.2	12.1	132.2	18.0	187.6
9.3	135.0	29.3	206.9	12.7	136.6	19.0	214.3
9.9	154.6	31.6	137.1	13.3	157.2	20.0	258.1
10.4	156.0	33.9	122.3	13.7	168.5	21.0	265.0
10.9	155.2			14.2	173.6	22.1	218.5

11.3	155.5	14.6	179.0	23.1	161.4
11.8	155.8	15.0	190.0	24.1	148.5
12.3	156.1	15.4	194.7	25.1	185.1
12.8	152.7	15.8	196.4	26.1	221.1
13.3	153.2	16.2	188.9	27.1	207.7
13.8	155.5	16.6	181.2	28.2	151.2
14.2	154.8	17.0	178.4	29.2	104.3
14.7	156.3	17.4	179.9	30.2	107.2
15.2	163.0	17.8	180.5	31.2	147.1
15.7	189.3	18.3	183.8	32.2	176.2
16.1	186.6	18.7	175.3	33.2	164.2
16.5	187.5	19.1	179.9	34.3	125.3
16.9	186.5	19.5	192.2	35.3	97.1
17.3	186.3	19.9	184.4	36.3	100.6
17.7	190.0	20.3	180.7	37.3	126.6
18.1	191.8	20.7	182.1	38.3	152.8
18.5	186.4	21.1	171.5		
18.9	184.8	21.6	175.2		
19.3	188.2	22.0	166.7		

19.7	175.2	22.4	165.0
20.1	163.2	22.9	171.7
20.5	161.6	23.3	164.5
21.0	163.2	23.8	169.3
21.5	165.5	24.2	175.2
21.9	161.6	24.7	185.3
22.4	143.8	25.1	176.3
22.9	133.2	25.5	180.7
23.5	134.6	25.9	171.4
24.0	140.0	26.3	169.7
24.6	158.2	26.8	169.3
25.0	154.6	27.2	160.4
25.5	160.6	27.7	166.1
26.0	157.7	28.1	162.9
26.5	157.2	28.6	165.9
26.9	155.9	29.1	174.7
27.4	156.8	29.5	171.4
27.9	165.7	29.9	163.7
28.4	170.2	30.4	157.1
28.8	167.9	30.9	147.1

29.2	172.1	31.4	150.5
30.0	153.9	31.9	160.0
30.2	150.8	32.3	165.7
30.7	152.8	32.8	178.1
31.2	149.5	33.2	171.1
31.7	150.3	33.7	153.9
32.2	149.7	34.1	152.3
32.7	145.3	34.6	152.3
33.2	148.6	35.1	150.4
33.7	149.9	35.6	140.4
34.2	150.3	36.1	143.2
34.7	147.2	36.7	152.0
35.2	151.3	37.2	151.4
35.7	144.8	37.6	164.0
		38.1	162.4
		38.6	173.3
		39.0	168.1
		39.4	161.2
		40.0	154.9

40.4	139.1
40.9	142.8
41.5	153.4
41.9	160.6
42.4	175.5
42.8	173.5
43.3	190.6
43.7	185.5
44.1	171.2
44.5	175.0
45.0	173.4
45.4	179.6
45.8	164.7
46.2	146.0