The past in dust: current trends and future directions in Pleistocene geoarcheology of European loess

Chu W.; Nett Janina J.

JOURNAL OF QUATERNARY SCIENCE (2021) **36**(8) 1279–1292 ISSN 0267-8179. DOI: 10.1002/jqs.3388

JQS Journal of Quaternary Science QRA Quaternary Research Association

The past in dust: current trends and future directions in Pleistocene geoarcheology of European loess

WEI CHU[1,2]* and JANINA J. NETT[3]
[1]Faculty of Archeology, Leiden University, Leiden, The Netherlands
[2]Institute of Prehistoric Archeology, University of Cologne, Cologne, Germany
[3]Physical Geography & Geoecology, Department of Geography, Aachen, RWTH Aachen University, Germany

Received 7 September 2021; Accepted 5 October 2021

ABSTRACT: Loess is a main archive of Pleistocene landscapes and environments and therefore has an important connection to the preservation and interpretation of Paleolithic sites. In Europe, anthropogenic sites have been found in loess because of past local occupation. At one extreme, sites are well preserved with minimal disturbance often accompanied by embedded proxies to estimate ecological parameters. On the other hand, loess deposits have undergone post-depositional alterations such as weathering, pedogenesis or bioturbation due to changing environmental conditions or other disturbances that obscure anthropogenic sites. We outline the current state of research and connections between Paleolithic archeology and loess research while introducing a series of subsequent regional case studies as part of a special issue. We also make recommendations for future work to incorporate a wider variety of methods to create more robust inferences on hominin and environmental evolution and their connections. © 2021 The Authors *Journal of Quaternary Science* Published by John Wiley & Sons Ltd

KEYWORDS: Europe; geoarcheology; geochronology; geoconservation; loess; Paleolithic; Pleistocene; proxy data

Introduction

In recent decades, geoarcheology has been shifting from the application of earth science techniques to the archeological record, towards an increased integration of geoscientific methods and concepts to interpret archeological contexts (Pollard, 1999; Rapp and Hill, 2006, p. 22; Goldberg and Macphail, 2009; Fouache, 2013; Canto, 2015; French, 2015; Gilbert, 2016). Whereas sediments were formerly seen as static site repositories, they are now regarded as remnants of past dynamic landscapes and environmental evolution that are intimately connected to their embedded cultural residues and capable of contextualizing but also obscuring behavioral interpretations. This framework has positioned geoarcheology to uniquely inform aspects of prehistory and its connection to the environment that are important for understanding cultural evolutionary trajectories and elaborating the mechanisms that underpin our past and present relationship to global evolution.

The aim of this special issue is to do precisely that through a series of papers exploring the chronostratigraphy, environmental and ecological background and site formation processes of Paleolithic sites embedded in European loess. The articles are organized roughly from north-western to south-eastern Europe, starting with a detailed investigation of Middle Pleistocene loess–paleosol deposits in northern France (Antoine *et al.*, 2021), followed by a study about the impact of katabatic winds on the Neanderthal environment (Lefort *et al.*, 2021), and several studies concentrating on Upper Paleolithic sites (Moine *et al.*, 2021; Molnar *et al.*, 2021; Sümegi *et al.*, 2021; Valde-Nowak and Łanczont, 2021). Finally, we present studies dealing with methodological investigations and paleoenvironmental focus in several loess–paleosol sequences and one lacustrine record in central and south-eastern Europe (Krauss *et al.*, 2021; Ludwig *et al.*, 2021; Marković *et al.*, 2021a; Zeeden *et al.*, 2021).

Loess is a main sediment archive preserving European Pleistocene artifacts and has therefore long played an important role in Paleolithic archeology. The formal description of loess emerged coeval with the notion of Europe's Pleistocene antiquity and the study of both has evolved, often in tandem, ever since (Marković *et al.*, 2016; Ding *et al.*, 2019). While the recognition of the Paleolithic is commonly attributed to early cave excavations and advances in fluvial terrace stratigraphy (Pettitt and White, 2014; de la Torre, 2016; Chauhan *et al.*, 2017), Paleolithic artifacts were also recognized early in Quaternary loess series in Northern France and Belgium. Loess has therefore had an important historical role in forming concepts and definitions of the Paleolithic (Zeuner, 1956; Sommé and Tuffreau, 1978).

Early research on artifacts embedded in the lower eolian sediments covering the Somme Middle Terrace at Saint-Acheul gave rise to the eponymous Acheulean (Commont, 1916) and the development of the *loess cycle* concept in which alternating layers of loess and paleosols marked climate deterioration and amelioration that were correlated to changes in lithic artifacts over time (Bordes, 1954). Loess research further contributed to the idea that Middle Paleolithic hominins and their tool assemblages were influenced by environmental conditions (Bordes, 1953). In France, for instance, caves and rock shelters in the south and east were thought to have been inhabited by semi-sedentary or sedentary cave-dwellers who intensively retouched Mousterian tools to conserve raw materials. On the north-western loess plateaux, by contrast, mobile Levallois makers discarded unfinished tools when moving on to their next site (Blundell, 2020). While

*Correspondence: Wei Chu, as above.
E-mail: w.chu@arch.leidenuniv.nl

such concepts are now regarded as overly simplified, this early practice of linking sedimentary records to hominin ways of life set the stage for Paleolithic research in Europe that continue to be a focus of research today.

While France was a model for many subsequent studies on loess in other loess-rich regions of Europe, Eastern European models of loess were similarly influenced by the Central Asian record. There, the term 'Loessic Paleolithic' has been used to describe Lower Paleolithic sites where lithics are vertically dispersed (1–1.5 m) in pedogenically developed parts of thick loess–paleosol sequences along river terraces (Ranov, 1989, 1995; Schäfer *et al.*, 1998; Davis and Holliday, 2017). This terminology has also been similarly used to describe sites found in the European loess belts of Russia, Ukraine, Germany, Czechia and Poland (Valde-Nowak and Łanczont, 2021).

At a minimum, the history of loess and Paleolithic archeology illustrates that while the two have been inextricably linked, the intimacy of these research strands remains disjointed as no clear consensus has emerged to connect them. In many ways, the absence of true synthetic research between loess research and Paleolithic archeology speaks to the greater uncertainties of how environmental, landscape and hominin evolution are associated. While notable progress has been made, scholars are just beginning to think of new ways of connecting these physical remains of past human culture and environment.

Background: when the dust settles

Loess is an important terrestrial archive for European Paleolithic archeology stretching back to as early as 2.5–1.8 Ma (Pastre *et al.*, 1996). These records are often (semi-)continuous and encompass the same timeframe as current models of Pleistocene hominin presence. However, loess is often a generic term for sediments formed by multi-genetic processes described by a wide range of unstandardized vocabulary (Sprafke and Obreht, 2016). Unsurprisingly, the definition of loess and its formation processes are still not settled (Smalley and Obreht, 2018).

Compared to other prime Pleistocene sedimentary records such as karstic traps and fluvial terraces deposits (Table 1), loess deposits are more locally widespread across Europe, often with greater temporal depth and resolution (Haase *et al.*, 2007; Bertran *et al.*, 2016; Lindner *et al.*, 2017; Lehmkuhl *et al.*, 2021). Where chronological patterns are not entirely clear, these can be potentially refined allowing for broader, landscape-wide interpretations of the archeological record (Zeeden *et al.*, 2018). Indeed, the spatial extent of loess and its effects on preserving human traces is a feature that has been remarked upon previously. Increased sedimentation amplifies opportunities for capture and preservation of artifacts, and hence the greater chance for sites to enter the Paleolithic record (Roebroeks and Speleers, 2002; Hijma *et al.*, 2012; Antoine *et al.*, 2015).

Outside the mid-latitudes of Europe, loess accumulation is often restricted to periglacial incised valleys, coastal capture points or dolines (Fig. 1; Cremaschi *et al.*, 2015; Scott *et al.*, 2019). However, in regions where loess-mantles are no longer present, eolian sediments are also preserved in isolated areas such as fissures or caves (Kovács *et al.*, 2020). These features can often be important repositories of Paleolithic artifacts (Peresani *et al.*, 2008; Pope *et al.*, 2013; Allsworth-Jones *et al.*, 2018a) and can assist in age and landscape correlations when absolute dating is not feasible (Krajcarz *et al.*, 2016a; Allsworth-Jones *et al.*, 2018b). Where caves and rockshelters are abundant, they also inform interpretations of how hominins modulated their responses to open-air sites (Madeyska, 2002; Delpiano *et al.*, 2019). Figure 1 demonstrates the close spatial relationship of European loess deposits, karst and Paleolithic sites.

Loess records are unique insofar as, like other widespread terrestrial records, they can address broad-scale spatiotemporal changes (Ashton and Hosfield, 2010; Antoine *et al.*, 2021), but they can also provide windows into brief moments in time. The fluvial record, which preserves many of the Paleolithic artifacts recovered in Europe, is predominantly composed of coarse-grained deposits that obscure the spatial arrangements of sites. By contrast, the low-energy deposition of Late Pleistocene loess-forming dust is known to finely preserve archeological sites with minimal spatial redistribution that can often be refitted to an impressive degree (Roebroeks *et al.*, 1997; Vallin *et al.*, 2001) and are even occasionally suitable for usewear and residue analyses (Sano, 2012; Pawlik and Thissen, 2017; Wilczyński *et al.*, 2020). Loess records are also excellent repositories of faunal prey, fire features, pits, habitation structures and early hominin burials that provide singular insights into local hominin behavioral patterns (Iakovleva and Djindjian, 2005; Händel *et al.*, 2009; Trinkaus and Buzhilova, 2018; Fewlass *et al.*, 2019). To contextualize these sites and document broader ecological evolution, researchers have developed a range of geochronological and proxy analyses for loess.

Dating methods applied in loess sediments

An array of dating methods are used to determine the timing of loess deposition and the direct ages of artifacts. The most

Table 1. A comparison of main Paleolithic archives in Europe

	Loess	Fluvial	Karstic
Distribution	Widespread across mid-latitudes with thicker deposits in the north-west, eastern Central Europe and western Russia (Bertran *et al.*, 2016)	Widespread, though earlier Pleistocene deposits often absent or altered by the advance of ice sheets in the north (Bridgland *et al.*, 2015)	Widespread though largely concentrated in uplands and the west and south (Goldscheider *et al.*, 2020)
Local preservation	Fine, though often colluviated in areas of rugged terrain, on steeper slopes (Bertran *et al.*, 2016)	Variable, though archeological finds are primarily recovered from coarse-grained gravel deposits (Chauhan *et al.*, 2017)	Fine, though variable according to cave/rockshelter morphology and hydrological regimes
Common absolute dating techniques	Luminescence, electron spin resonance, radiocarbon (Chu, 2018)	Luminescence, electron spin resonance, cosmogenic nuclides, amino acid racemization	Luminescence, electron spin resonance, radiocarbon, U/Th
Frequently used paleoenvironmental proxies	Rock magnetism, geochemistry, color, grain-size, charcoal, (micro)fauna (Obreht *et al.*, 2019)	Pollen, plant macrofossils, charcoal, phytoliths, (micro)fauna (Cordier *et al.*, 2015)	Pollen, plant macrofossils, charcoal, phytoliths, (micro) fauna (aDNA), stable isotopes

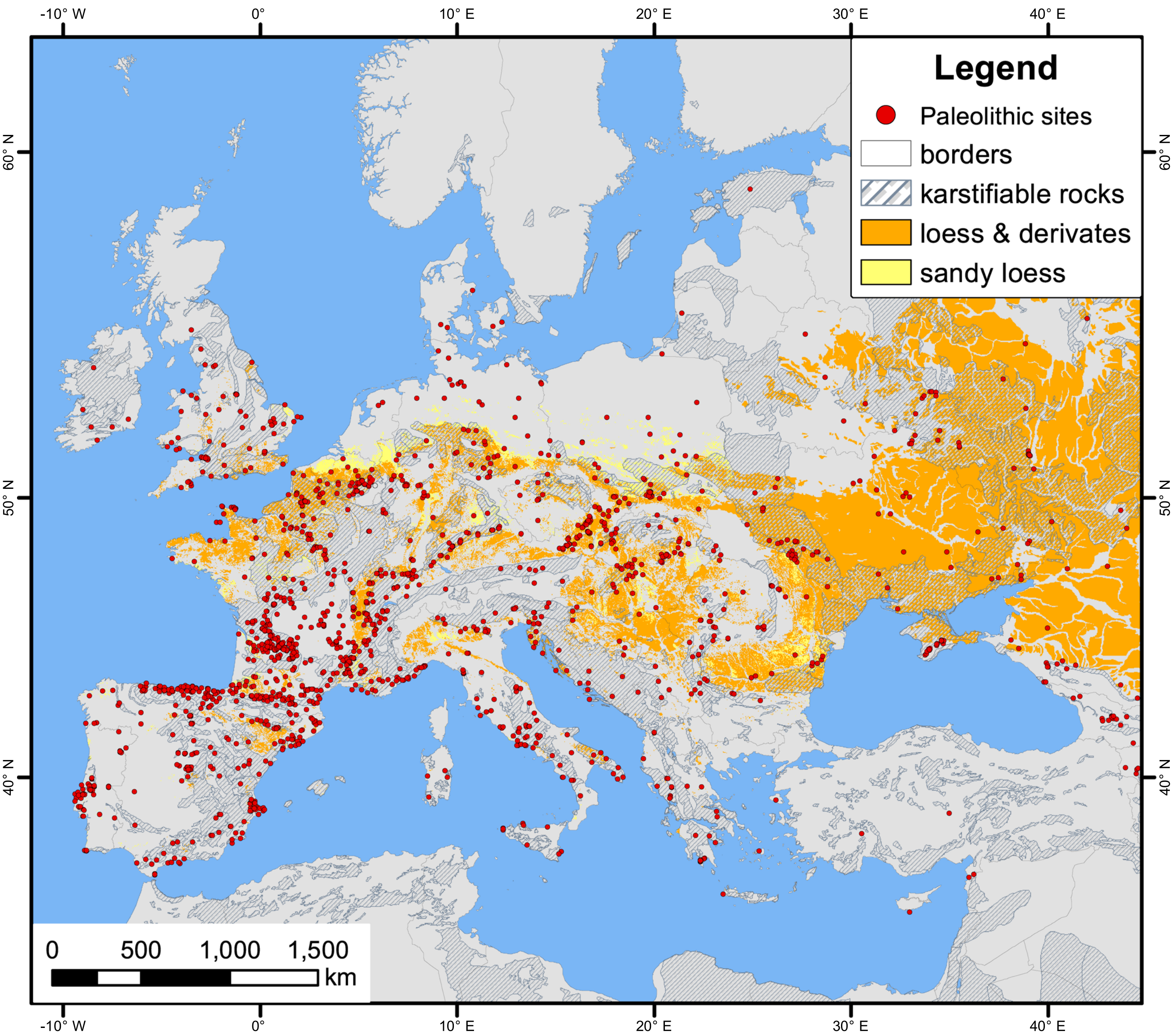

Figure 1. Distribution of European loess, loess derivates, sandy loess (using Bertran *et al.*, 2021; Lehmkuhl *et al.*, 2021) and karstifiable bedrock (from Chen *et al.*, 2017). Reliably dated pre-Holocene sites are derived from Vermeersch (2020). [Color figure can be viewed at wileyonlinelibrary.com].

common are luminescence dating, radiocarbon dating and magnetic stratigraphy, though their use is dictated by the age range under investigation and the availability of suitable material for dating. Due to their eolian origin, loess deposits are widely analyzed by luminescence dating, which determines the age of the accumulation of quartz and feldspar minerals after a bleaching event, usually the last sunlight exposure during eolian transport before deposition (e.g. Bösken *et al.*, 2017; Lomax *et al.*, 2019; Stevens *et al.*, 2020; Stone and Fenn, 2020; D'Amico *et al.*, 2021). Depending on the available grain size, single grain or single aliquot techniques are typically used. For very fine loess deposits that do not contain enough coarse material, single aliquot methods are exclusively applied where a layer of ~1 million grains between 4 and 11 µm is deposited on a single aliquot to be measured: this results in an average dose per aliquot. Coarser grains (>63 µm) can additionally be measured by the single grain technique, which determines a dose per grain for each of the 100 holes in the aliquot disc. The dose distribution of these data can be analyzed, such as for partial bleaching events (e.g. Reimann *et al.*, 2012). Additional to optically stimulated luminescence (OSL) dating, heated artifacts can also be dated by thermoluminescence methods, thereby providing a direct age of the heating event (Martini *et al.*, 2001). Note that this age does not reflect the age of sediment deposition and in general post-depositional processes can affect the age distribution. More recently, electron spin resonance (ESR) dating has been applied to Chinese loess deposits (e.g. Richter *et al.*, 2020), which works similar to luminescence dating, but measures the trapped electrons in certain paramagnetic centers by ESR spectrometry (Grün and Stringer, 1991).

While luminescence dating can readily be applied to loess deposits, age uncertainties are usually in the range of 5–10% (1σ); this is less precise than radiocarbon dating, which is frequently used for younger sediments <45 ka. This dating method is ideally applied to organic remains, such as bones or charcoal (e.g. Moine *et al.*, 2021). $CaCO_3$ from mollusk shells and earthworm calcite granules (ECGs) can also be suitable for dating though the tendency of some species to burrow and ingest old carbon may lead to erroneous results, underlining the need for multi-material applications (Bosq *et al.*, 2020). However, organic remains are not always preserved because of the high carbonate leaching potential in loess. When absent, bulk sediment samples can also be radiocarbon dated though often with less accuracy (e.g. Scheidt *et al.*, 2021). While luminescence dating determines the time since last sunlight or heat exposure, radiocarbon dating determines the time since the demise of the organism whose organic carbon is dated. For longer, particularly older sections, correlative dating via magnetic stratigraphy is often applied (e.g. Zeeden *et al.*, 2009; Scheidt *et al.*, 2021). Here, age control is given by 'wiggle-matching' fluctuations in rock- and paleomagnetic parameters to known master curves (Scheidt *et al.*, 2021). These parameters are often the magnetic susceptibility, which is elevated in paleosols, or the direction or paleointensity of the Earth's magnetic field. While it can be widely applied, it is difficult to accurately assess age uncertainty since it depends on the quality of the master curve, the wiggle matching method (e.g. Blaauw *et al.*, 2018) and the fact that the magnetic signal can be formed at a later time than loess deposition as magnetic minerals form during pedogenesis (see e.g. Maher, 1998; Ahmed and Maher, 2018). Additionally, tephras (volcanic ashes) and heavy minerals can be used as isochronous marker horizons to correlate non-adjacent profiles and deposits (Lowe, 2011; Davies *et al.*, 2015; Pirson *et al.*, 2018).

Still, dating sediments, artifacts or biological remains is seldom straightforward because discrepancies between various dating techniques often arise (Újvári *et al.*, 2014; Zeeden *et al.*, 2021). Comparisons between radiocarbon dating, luminescence dating and magnetic stratigraphy at a Romanian loess–paleosol sequence show that, at least at this site, radiocarbon dating is only reliable for the last 27–25 ka (Scheidt *et al.*, 2021), potentially related to a low organic carbon content and the probable admixture of younger organic carbon into samples (cf. Song *et al.*, 2015). Other studies investigating the saturation behavior of the quartz luminescence signal show that, at least for older samples, quartz is not a reliable dosimeter (Timar-Gabor *et al.*, 2012; Timar-Gabor and Wintle, 2013; Constantin *et al.*, 2014; Anechitei-Deacu *et al.*, 2018; Avram *et al.*, 2020). A particularly difficult example is presented by Groza *et al.* (2019) for the early Gravettian Krems-Wachtberg site (Austria), where the quartz extracts were heavily contaminated by other minerals, resulting in the rejection of half of the measured aliquots. Despite these challenges, several promising studies using, for instance, Bayesian modeling can help to overcome age inversions and reduce uncertainties (e.g. Schmidt *et al.*, 2021).

Inorganic proxy methods in loess

Because of its eolian genesis, loess can be a reliable marker for past atmospheric circulation to infer paleoclimate patterns using sedimentological, biological, geophysical and geochemical indicators (Rousseau and Hatté, 2021). Its potential for paleoclimatic reconstruction coupled with its widespread nature in the northern hemisphere is the main reason why loess deposits have been intensively investigated. While loess deposits are generally lower in resolution than layered or varved marine and limnic sediments, they provide an opportunity to investigate paleoclimatic and possible paleoanthropogenic archives in a wider spatiotemporal context. Moreover, loess proxy data can be correlated with better resolved records such as ice-cores, facilitating links to Greenland interstadials and past European soil development within loess sequences (Rousseau *et al.*, 2017). Finally, loess records are correlated across the entire Eurasian content, showing remarkable similarities (Haesaerts and Mestdagh, 2000; Bronger, 2003; Marković *et al.*, 2015, 2018a; Laag *et al.*, 2021), although some caution the use of simple correlations between records that might overlook notable differences in some time intervals (Zeeden *et al.*, 2020), or disregard causality or different delay times between proxies (Vandenberghe, 2012).

Loess records often have abundant environmental proxies embedded within them. When accompanying archeological materials, these can deliver high-resolution, local, conterminous paleoecological reconstructions that provide important context to anthropogenic subsistence. When archeological materials are not present however, they are often correlated with other regional records that document landscape change and occupation history over time (Romanis *et al.*, 2021) and space (Nerudová *et al.*, 2021). At a larger scale still, loess records have been used to inform diachronic changes in paleodemography and typotechnological trends born out primarily in the lithic record by providing an important record of broad-scale regional and temporal environmental change (Morgan *et al.*, 2011; Schmidt and Zimmermann, 2019) even if analytical units are still precarious (Reynolds, 2020).

Loess grain-sizes can provide information on paleoclimate (Újvári *et al.*, 2016). Loess grain-sizes are usually homogenous and well-sorted but distributions change during or after depositional events such as erosion, transport and soil formation. Variations in these distributions through time (i.e. depth) can infer information about climatic and environmental conditions. More recently, Schulte and Lehmkuhl (2018) presented a method indicative of the degree of chemical weathering in loess–paleosol sequences. However, grain-size is not only analyzed in pure sediment research, but often applied as a component of geoarcheological investigations (e.g. Chu *et al.*, 2018; Marković *et al.*, 2021b; Malinsky-Buller *et al.*, 2021). For instance, the importance of an in-depth understanding of the loess stratigraphy before any paleoenvironmental proxy interpretation has been emphasized for the Krems-Wachtberg site (Austria; Sprafke *et al.*, 2020) where grain-size analysis allowed a differentiation between eolian sediments and those reworked by slope processes. The study by Händel *et al.* (2021) further illustrates the synergies between archeology, field observations and granulometry and how they can refine site formation processes.

Inorganic geochemistry is applied to investigate the dust provenance area and the degree of weathering and soil formation. Although there are more suitable methods for provenance studies, such as zircon chronology (e.g. Újvári *et al.*, 2012; Ducea *et al.*, 2018), bulk geochemical analysis holds potential to distinguish different sediment sources and transport pathways (Pötter *et al.*, 2021b). To determine the degree of weathering, several indices are available that rely on the concept of mineral alteration whereby the selective removal of soluble and mobile elements is compared to a relative enrichment of immobile and non-soluble elements (Buggle *et al.*, 2011; Obreht *et al.*, 2019). This proxy method is frequently used in geoarcheological studies, mainly to provide the paleoenvironmental context of human occupation (e.g. Degryse and Alexander Bentley, 2017; Bösken *et al.*, 2019, 2018; Chu *et al.*, 2019).

Color measurements of loess or soil samples are also used to estimate paleoenvironmental change. While pure loess sediments are typically light yellow, red and black hues are related to pedological processes or humification (e.g. Sprafke *et al.*, 2020). Spectrophotometric measurements can be performed on sediment samples in the laboratory (Eckmeier *et al.*, 2010; Gocke *et al.*, 2014; Krauß *et al.*, 2016) or digital images can be analyzed to work non-destructively (Zeeden *et al.*, 2017). A further parameter used in loess research is the redness index (Barron and Torrent, 1986). Krauss *et al.* (2021) interpret the color together with further geochemical data as a weathering proxy at the Attenfeld loess–paleosol sequence. Color data can be also analyzed statistically, as, for example, done at the Malá nad Hronom loess–paleosol sequence (Slovak Republic). Here, a hierarchical cluster analysis was applied to characterize the entire reflectance spectrum and to classify various sediment groups (Szeberényi *et al.*, 2020).

The presented methods work usually best when applied in a multi-proxy approach. There are numerous examples in loess and geoarcheological studies. For instance, at the Bůhzdař site (Czech Republic) geochemical approaches [total organic carbon, X-ray fluorescence (XRF) elemental analyses, X-ray diffraction (XRD) mineralogy, ^{13}C and ^{18}O stable isotopes] are combined with grain-size distributions and OSL dating to assess the climatic conditions at the time of formation of the strata (Flašarová *et al.*, 2020). At the Upper Paleolithic site of Temereşti (Romania), post-depositional site formation processes were investigated by a multi-proxy approach using geographic information system (GIS), grain-size and geochemical analyses and geochronological methods (Chu *et al.*, 2019). Further early illustrative examples of multi-proxy analysis with geoarcheological context were undertaken at Maastricht-Belvedere (Van Kolfschoten and Roebroeks, 1985; Vandenberghe *et al.*, 1993).

Organic proxy methods in loess

Although organic carbon contents are usually low in pure loess deposits, both macro- and micro-vertebrate skeletal remains can be impressively well preserved in loess, such as mollusk shells (Bösken *et al.*, 2018; Moine *et al.*, 2021) or faunal bones that are used to understand the paleoenvironment and behavioral practices (Einwögerer *et al.*, 2006; Montalvo *et al.*, 2008; Markovič *et al.*, 2014; Wilczyński *et al.*, 2015). The underlying mechanisms of loess formation or loessification, sometimes regarded a pedogenetic or diagenetic process, is still incompletely understood, though it is suggested to involve trapping of eolian dust or silt, carbonate cementation and further secondary loessification processes such as pedogenesis, re-deposition or compaction (Sprafke and Obreht, 2016). These can rapidly affect bone diagenesis and, in some cases, erase mammalian skeletal remains completely (Machová *et al.*, 2020).

While other Quaternary paleoecological microfossils such as foraminifera, ostracods, radiolaria, diatoms and pollen are often not preserved in loess (Muhs, 2013), there are exceptions in reworked loess sediments in lacustrine and alluvial settings such as anomalous subaqueous loess facies (Kulesza *et al.*, 2020). The high carbonate content of loess deposits, however, is ideal for the preservation of terrestrial mollusks. Mollusks are sensitive to environmental changes and since modern analog assemblages are widely available, they represent a detailed paleoenvironmental proxy (e.g. Rousseau *et al.*, 2018; Sümegi *et al.*, 2021). These proxy data inform about summer temperatures and moisture conditions (e.g. using the malaco-thermometer method of Sümegi, 1989; Sümegi and Krolopp, 2002) and provide information about habitats, landscape types (dense or open) and vegetation types (boreal/deciduous forest, grassland, tundra, etc). Many studies deal with the paleoenvironmental reconstruction based on these land snails in loess (e.g. Rousseau, 2001; Sümegi and Krolopp, 2002; Marković *et al.*, 2007; Gerasimenko and Rousseau, 2008; Moine, 2008; Sümegi *et al.*, 2011; Zong *et al.*, 2020) by combining them with sedimentological, magnetic and geochronological data (see Marković *et al.*, 2021a). However, there has been discussion about its interpretation in the Carpathian Basin since some mollusk-based temperature reconstructions do not agree with stable carbon isotope-based ones (Obreht *et al.*, 2019, 2021; Sümegi *et al.*, 2021). Nevertheless, Ludwig *et al.* (2021) compared Last Glacial Maximum (LGM) temperature reconstructions based on the malacothermometer method with a high-resolution regional climate simulation and found close agreement for the Serbian Vojvodina region. Additionally, they showed different aridity gradients in the region in comparison to current climate conditions. Finally, some mollusk shells are well suited for radiocarbon dating (Újvári *et al.*, 2017, 2014; Molnár *et al.*, 2021). However, it is crucial to identify those taxa that do not (or only in low amounts) incorporate old carbonates (i.e. dead carbon), which are abundantly available in loess deposits (Újvári *et al.*, 2014).

Another biological proxy investigated in loess–paleosol sequences are ECGs that are common in western and central Europe, but rarer in the arid environments of Asia (Fenn and Prud'homme, 2020). ECGs are composed of rhombohedra calcite crystals produced by a biomineralization processes (Canti, 1998; Gago-Duport *et al.*, 2008; Fenn and Prud'homme, 2020). ECGs are linked to soil temperature and humidity and because they are produced mainly during the spring and autumn, they can be related to paleotemperature (Prud'homme *et al.*, 2016), paleoprecipitation (Prud'homme *et al.*, 2018) and seasonal climate fluctuations (Satchell, 1967; Fenn and Prud'homme, 2020) by their carbon and oxygen isotopic composition. They purportedly reflect conditions in the topsoil (Canti and Piearce, 2003) with limited mixing between different units, making ECGs a powerful paleoproxy that can also be radiocarbon dated (Moine *et al.*, 2017). A detailed and insightful example is given by Moine *et al.* (2021), which presents a first study combining high-resolution malacological data with radiocarbon-dated ECGs at the Upper Paleolithic site of Amiens-Renancourt 1 (Somme, France).

Most biological proxies present in loess–paleosol sequences are composed of calcite or aragonite and therefore can be used to analyze carbon and oxygen isotope compositions. $\delta^{13}C$ and $\delta^{18}O$ values of carbonate proxies can be indicators of vegetation type, precipitation and temperature (Fenn and Prud'homme, 2020). $\delta^{13}C$ is a useful proxy for inferring past photosynthetic pathways (C3 vs. C4 plants) and the degree of physiological water stress (Rousseau *et al.*, 2018; Obreht *et al.*, 2019). It can further be used for paleoprecipitation reconstruction (Hatté *et al.*, 2001; Hatté and Guiot, 2005; Kohn, 2010). The $\delta^{18}O$ values of inorganic calcite are influenced by the temperature during formation and the oxygen isotopic composition of water (Fenn and Prud'homme, 2020). In loess, oxygen isotopes are mainly measured on snails or secondary carbonates. $\delta^{18}O$ values of soil carbonates are generally driven by temperature, while $\delta^{13}C$ values are used to reconstruct the vegetation and environment during the Quaternary. However, temperature and precipitation can be difficult to quantify and disentangle. A new method holds potential by using clumped isotopes applied to terrestrial carbonates providing soil and air temperature estimates for the summer season (Újvári *et al.*, 2019). $\delta^{15}N$ is another stable isotope investigated in loess and is applied to soil biogeochemical cycles. Therefore, it has the potential to provide information on the relationship between precipitation and temperature, but more importantly about the openness or closedness of the N-cycle in the ecosystem (Obreht *et al.* 2019). While stable organic carbon and nitrogen isotopes can be used to interpret past vegetation patterns and ecosystem qualities, a careful pretreatment (decalcification method) is important to avoid misinterpretation of the data (Pötter *et al.*, 2021a).

Further micro-organic residues that are investigated in loess–paleosol sequences are n-alkanes and fossil glycerol dialkyl glycerol tetraethers (GDGTs). n-Alkanes are plant leaf wax biomarkers used for the reconstruction of the vegetation history as their signature differs in function based on the different vegetation types. GDGTs are membrane lipids produced by archaea and soil bacteria that can adjust their membrane permeability and fluidity to changing environmental conditions (e.g. pH and temperature), by changing their

Figure 2. Photo of the Late Pleistocene loess exposure of Vlașca in the Lower Danube Basin (Photo by Stephan Pötter, 2018).

molecular composition (Obreht *et al*., 2019). Based on modern data, n-alkanes nC27 and nC29 dominate in tree and shrub vegetation, whereas n-alkanes nC31 and nC33 were identified to predominate herbs and grasses (Zech *et al*., 2011a,b; Schäfer *et al*., 2016; Fenn and Prud'homme, 2020). After a regional calibration, this proxy is used to reconstruct past vegetation cover (e.g. relative proportion of grasses vs. trees; Bush and McInerney, 2013). However, post-sedimentary overprinting of organic matter in n-alkanes is possible in loess–paleosol sequences and needs to be accounted for (Gocke *et al*., 2011; Zech *et al*., 2011b; Fenn and Prud'homme, 2020). GDGTs can be used as a proxy for continental air temperatures and soil pH (Weijers *et al*., 2007). The ubiquitous occurrence of GDGTs in soils offers the potential to independently reconstruct continental paleotemperature from terrestrial deposits (Jia *et al*., 2013). However, the use in loess–paleosol sequences is cautioned by Zech *et al*. (2012) who found major disagreements with the available stratigraphic, pedological and geochemical data of three sequences. A new procedure for simultaneous extraction of n-alkanes and alkenones from GDGTs has been proposed by Auderset *et al*. (2020).

Gathering dust: new directions for Quaternary loess and the Paleolithic

Loess is a prime Pleistocene repository of Paleolithic artifacts that is intimately connected to past European sites and landscapes (see example of loess–paleosol sequence in Fig. 2). Widely distributed, loess has the potential to finely preserve Paleolithic sites, fauna and features in a variety of Pleistocene settings that can often be dated using an assortment of absolute and relative dating techniques. Advances in sedimentology and geochemistry have additionally improved the capacity to identify local and broad-scale spatiotemporal changes to the paleoenvironment that can contextualize how we interpret the archeological record and inform interpretations of how hominins adapted to and shaped these environments (Badino *et al*., 2020).

Still, current approaches are challenging as loess records are often discontinuous, lack high-resolution absolute chronology and are too generalized to meaningfully apply to the archeological record. Continued work is needed to establish direct links between paleoenvironments, site occupations and their contents, particularly where site features are not preserved. Loess formation processes and pedogenesis are still incompletely understood, complicating our understanding of their association with embedded cultural remains. The uneven spatiotemporal distribution of loess and embedded Paleolithic sites across Europe combined with the resolution of current dating techniques still limits our ability to make meaningful inferences of human behavior across Europe sometimes even at the broadest of scales (i.e. Marine Isotope Stages).

Nevertheless, current scholarship is increasingly demonstrating that detailed, multidisciplinary approaches can reveal regional and local shifts in hominin landscape use that provide new opportunities to understanding past adaptations to environmental change. Part of advancing the future of Paleolithic research in European loess therefore involves advancing the way we apply current geoarcheological methods and identifying ways in which new and existing methods can contribute to our understanding of past hominin behavior and link them to Paleolithic environments and landscapes. Archeological sites are unique datasets and often require tailored analyses to decode their post-depositional processes and significance.

Geospatial inventorization

An important part of continued Paleolithic research in loess involves identifying suitable loess areas at a variety of scales. Advances in digital geoarcheology that take advantage of air- and satellite-based remote sensing (Siart *et al*., 2018), soil mapping (Bertran *et al*., 2021) and GIS-based predictive modeling are such approaches (Blundell, 2020) that may contribute to our understanding of marginal zones of loess distribution which have hitherto received archeological little attention. In areas where loess mantles are thin, advances in shallow ground-based remote sensing techniques such as geomagnetics and ground-penetrating radar are uniquely positioned to identify new sites and map local Pleistocene landscapes (Urban *et al*., 2019; Barbieri *et al*., 2021). Such methods are seldom employed in European Pleistocene archeology, but the properties of loess make such thin exposures ideal for identifying distributions of past hearths, pits, stone and bone arrangements indicative of other site 'furniture'. These have the potential to help map diachronic landscape use and provide invaluable new examples of Pleistocene megasites and habitation structures to examine perceptions of space and place (Iakovleva *et al*., 2012; Maher and Conkey, 2019; Pryor *et al*., 2020).

Similarly, further field investigations at the European loess distribution periphery may yield deeper Pleistocene deposits that have otherwise been overlooked and might meaningfully contribute to interpretations of hominin demographics throughout the Paleolithic. Dolines, fissures, greda and other open-air sedimentary traps can provide important information from upland areas that have otherwise been eroded (Scott *et al*., 2019). Even if such investigations lead to meagre archeological results, they can still provide important comparative paleoenvironmental proxies and can meaningfully contribute to a more wholistic understanding of past hominin landscape use (Fitzsimmons *et al*., 2020). Here, understanding regional loess formation mechanisms is key (Assadi-Langroudi, 2019). By understanding the processes by which loess, particularly at the margins, is preserved, we can begin to decode the geomorphological processes underlying archeological site preservation and recovery and begin to decode how these influence interpretations of artifact distribution patterns and inferences on human habitat predilection; these aspects are already known to be biased (Blundell, 2016; Pope *et al*., 2016).

Reconstructing environmental processes by artifact condition and loess properties

As the most enduring part of the Paleolithic record, lithics embedded within loess profiles additionally have the potential to inform the loess interpretations and provide crosschecks against paleoenvironmental reconstructions. This should not be extended to using lithic types as chronological tie-points for loess sequences, which can lead to circular argumentation (Egberts *et al*., 2020). Rather, by regarding the embedded lithics as artificially inserted clasts within the sedimentological sequence, the suite of lithic taphonomic analyses that have been developed can be employed. Here, refits remain an important part of assessing lithic assemblage integrity in loess that can equally inform interpretations of sedimentary mixing (Villa, 1983; Van Kolfschoten and Roebroeks, 1985). Where available, sedimentary structures, artifact fabrics and size distributions are a principal method to understand the spatial distribution of artifact assemblages that can be used to identify subtle changes to site integrity (Lenoble *et al*., 2008; McPherron, 2018; Händel *et al*., 2021). How and when artifacts characteristically imbricate within eolian sediments because of post-depositional changes remains an area for future research (Borrazzo, 2016).

Artifact surface conditions can also contribute to understanding the post-depositional movement of lithic assemblages and help inform interpretations of pedogenesis and loess diagenesis (Vallin *et al*., 2001). Various geochemical weathering patterns (e.g. patinas) commonly found on flaked stone artifacts may eventually inform their syn- and post-depositional contexts and help to disentangle palimpsests in instances where loess deposition has been thin, deflated or disturbed (Glauberman and Thorson, 2012; Glauberman, 2016). At a microscopic scale, understanding lithic surface polishes may provide ways of deciphering initial modes and direction of loess deposition at discard and the intensity and variety of subaerial exposure to freeze–thaw cycles (Burroni *et al*., 2002; Chu *et al*., 2015; Bertran *et al*., 2017; Michel *et al*., 2019). Such studies might be best combined with the increasing archeometric improvements in tracewear and residue analysis to not only better understand the various *stigmata* that lithic assemblages in loess characteristically exhibit, but also how these may affect our interpretations of experimentally derived examples of lithic usewear and surficial chemical analysis (Kozowyk *et al*., 2020; Marreiros *et al*., 2020).

Linking loess to hominin social and cultural conditions

Beyond examining how loess studies and Paleolithic archeology can better inform the preservation and context of hominin sites, a main goal of future research is to incorporate wider advances from ecology and paleoanthropology to ascertain deeper questions into hominin evolution. In other words, how is loess connected to other aspects of hominin prehistory in more profound ways beyond its preservation qualities?

One way is through loess's connection to past evolving ecosystems. Throughout the Pleistocene, European loess has constituted a homogeneous, (semi-)contiguous mantle across the landmass characterized by high porosity and cation exchange capacity, leading to fertile, well-drained soils (e.g. Schaetzl and Thompson, 2015). At times, even when continent-wide environmental conditions were suboptimal, these fertile sediments sustained a relatively specific, highly productive steppic flora, establishing distinct biogeographic regions with ample megafauna to support substantial predator communities including early hominins (Blinnikov *et al*., 2011; Fitzsimmons *et al*., 2012; Guthrie, 2013, 1982). Particularly in south-eastern Europe, where climate was reliably milder, loess may have played a role in establishing biodiversity preservation zones, hominin refugia and coalescent communities that may have promoted hominin geneflow and been a catalyst for technological innovation (Marković *et al*., 2018b, 2021a). Here, the high degree of hominin hybridization and diversity of lithic technocomplexes during the Late Pleistocene may be a partial result (Svensson *et al*., 2021).

Loess may have impacted technosocial innovation in other ways as well. From at least the Upper Paleolithic, loess has also been used to make ceramic sculptures and may have facilitated increased forms and innovations in artistic expression among early hominins (Farbstein and Davies, 2017). Likewise, research at the Upper Paleolithic site of Sungir (Russia) has suggested that early hominin burials there reflect diverse social behaviors and that loess may have also played a role in the modes of mortuary practices (Trinkaus and Buzhilova, 2018). Further research in these areas may begin to show the complex and intertwined relationships that loess and past human behavior have in more direct ways.

In Eastern Europe, where loess is more ubiquitous and extensive, Paleolithic sites may also show how hominin biological and cultural adaptations are linked to loess landscapes. Internal nasal morphology of early *Homo sapiens* at Sungir and Mladeč (Czechia) demonstrate rapid physiological adaptations to the cold and dry climates indicative of the local loess environments (Stansfield *et al*., 2021). Similarly, the continuous tradition of Upper Paleolithic mammoth megastructures recovered within the Eastern European loess belt may uniquely illustrate how hominins adapted to loess steppes in the relative absence of caves and rockshelters (Demay *et al*., 2012; Marquer *et al*., 2012; Shipman, 2015). One avenue of ascertaining this connection may be in assessing the orientation of Paleolithic sites relative to wind direction (Lefort *et al*., 2019; Lefort *et al*., 2021).

Regardless of the direct connection of loess to human evolution and its overlap with other autocorrelated features of climate and landscape, loess and archeology are still commonly studied through a dichotomy of 'meaningful' culture and unmeaning nature (Lyons, 2019). We are just beginning to understand the extent to which lithic assemblages and loess connected beyond just their preservation material. Here a reassessment of loess and archeology's mutual goals is necessary with the aim to look beyond the descriptive analysis and correlation of sedimentary and archeological packages. In this regard, loess is uniquely suited to address larger-scale anthropological issues because of its ubiquity across the European landscape and its preservation of Paleolithic artifacts and features throughout the Pleistocene.

Cooperation and preservation

To date, transcontinental approaches to loess geoarcheology remain largely isolated, at least from a European perspective. While Europe has tended to dominate loess Paleolithic research, increasing scholarship from Asia is rapidly developing new methods and techniques of analysis to meet the challenges of exceptionally long sequences (Krajcarz *et al*., 2016b; Nian *et al*., 2016; Zhang *et al*., 2017; Zhu *et al*., 2018; Zhao *et al*., 2021). Likewise, in the Americas, Late Quaternary sites show complex responses of humans and fauna to paleoenvironmental change that can provide important cross-checks to human–environmental interactions derived in Europe (Graf and Goebel, 2017; Powers *et al*., 2017; Lanoë *et al*., 2020).

Finally, an area of intersecting interest between geosciences and the Paleolithic archeology must surely be the management and protection of finite loess archives (Vasiljević *et al*., 2011; Vujičić *et al*., 2018). Anthropogenic impact, including mining, agriculture and development, increasingly encroach on Europe's loess deposits and key Paleolithic loess sequences have already been erased, making the protection of their landscapes and archeological sites all the more urgent (Nykamp *et al*., 2017; Antoine, 2019; Bogucki *et al*., 2020). Geoconservationalists, archeologists and earth scientists alike have largely advocated for the establishment of protected areas in the forms of geoparks fueled by the active promotion of sustainable geotourism (Vasiljević *et al*., 2014; Jary *et al*., 2018). However, national structures vary across European borders and are commonly split between cultural heritage and environmental protection organizations, leading to disparate methods of identification, classification and preservation regimes. A main goal for geoheritage conservation of loess landscapes is therefore the stronger implementation of international initiatives and policies (Gordon, 2018).

Acknowledgements. We thank the many presenters, participants and organizational staff of the 'Loess and Archaeology Workshop' (Aachen; 28–29 November 2019) from which the papers in this special issue arose. We are indebted to Neil Roberts and the anonymous reviewers who provided timely constructive feedback to the authors in this special issue on their manuscripts. We further thank Pascal Bertran, Jef Vandenberghe and Ralf Vogelsang for reviewing the manuscript and providing valuable comments. We thank Frank Lehmkuhl and Jürgen Richter and the multitude of project members of the SFB806 who supported this work. All errors and misrepresentations are our own. Funding was provided by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Project No. 57444011 – SFB 806 and a Dutch Research Council grant (VI.C.191.O70) awarded to M. Soressi. Open Access funding enabled and organized by Projekt DEAL.

Abbreviations. ECGs, earthworm calcite granules; ESR, electron spin resonance; GDGTs, glycerol dialkyl glycerol tetraethers; OSL, optically stimulated luminescence; XRD, X-ray diffraction; XRF, X-ray fluorescence.

References

Ahmed IAM, Maher BA. 2018. Identification and paleoclimatic significance of magnetite nanoparticles in soils. *Proceedings of the National Academy of Sciences of the United States of America* **115**: 1736–1741.

Allsworth-Jones P, Borziac IA, Chetraru NA *et al*. 2018a. Brînzeni: a multidisciplinary study of an Upper Palaeolithic site in Moldova. *Proceedings of the Prehistoric Society* **84**: 41–76. https://doi.org/10.1017/ppr.2018.3

Allsworth-Jones P, Borziac IA, Chetraru NA *et al*. 2018b. The Middle Palaeolithic site of Buzdujeni in Moldova: establishing the archaeological and environmental record. *Journal of Paleolithic Archaeology* **1**: 139–177. https://doi.org/10.1007/s41982-018-0009-7

Anechitei-Deacu V, Timar-Gabor A, Constantin D *et al*. 2018. Assessing the maximum limit of SAR-OSL dating using quartz of different grain sizes. *Geochronometria* **45**: 146–159. https://doi.org/10.1515/geochr-2015-0092

Antoine P. 2019. Le quaternaire de la vallée de la Somme (terrasses fluviatiles, loess et paléosols): une contribution à l'inventaire national du patrimoine géologique. *Quaternaire* **30**: 257–270. https://doi.org/10.4000/quaternaire.12150

Antoine P, Coutard S, Bahain J *et al*. 2021. The last 750 ka in loess–palaeosol sequences from northern France: environmental background and dating of the Western European Palaeolithic. *Journal of Quaternary Science* **3281**. https://doi.org/10.1002/jqs.3281

Antoine P, Moncel M-H, Locht J-L *et al*. 2015. Dating the earliest human occupation of Western Europe: new evidence from the fluvial terrace system of the Somme basin (Northern France). *Quaternary International* **370**: 77–99. https://doi.org/10.1016/j.quaint.2014.08.012

Ashton N, Hosfield R. 2010. Mapping the human record in the British Early Palaeolithic: evidence from the Solent River system. *Journal of Quaternary Science* **25**: 737–753. https://doi.org/10.1002/jqs.1350

Assadi-Langroudi A. 2019. A conceptual model for loess in England: principles and applications. *Proceedings of the Geologists' Association* **130**: 115–125. https://doi.org/10.1016/j.pgeola.2018.12.003

Auderset A, Schmitt M, Martínez-García A. 2020. Simultaneous extraction and chromatographic separation of n-alkanes and alkenones from glycerol dialkyl glycerol tetraethers via selective accelerated solvent extraction. *Organic Geochemistry* **143**. https://doi.org/10.1016/j.orggeochem.2020.103979 [PubMed: 103979]

Avram A, Constantin D, Veres D *et al*. 2020. Testing polymineral post-IR IRSL and quartz SAR-OSL protocols on Middle to Late Pleistocene loess at Batajnica, Serbia. *Boreas* **49**: 615–633. https://doi.org/10.1111/bor.12442 [PubMed: 32999524]

Badino F, Pini R, Ravazzi C *et al*. 2020. An overview of Alpine and Mediterranean palaeogeography, terrestrial ecosystems and climate history during MIS 3 with focus on the Middle to Upper Palaeolithic transition. *Quaternary International* **551**: 7–28. https://doi.org/10.1016/j.quaint.2019.09.024

Barbieri A, Bachofer F, Schmaltz EM *et al*. 2021. Interpreting gaps: a geoarchaeological point of view on the Gravettian record of Ach and Lone valleys (Swabian Jura, SW Germany). *Journal of Archaeological Science* **127**. https://doi.org/10.1016/j.jas.2021.105335 [PubMed: 105335]

Barron V, Torrent J. 1986. Use of the Kubelka-Munk theory to study the influence of iron oxides on soil colour. *Journal of Soil Science* **37**: 499–510. https://doi.org/10.1111/j.1365-2389.1986.tb00382.x

Bertran P, Bordes J-G, Todisco D *et al*. 2017. Géoarchéologie et taphonomie des vestiges archéologiques: impacts des processus naturels sur les assemblages et méthodes d'analyse. In *Taphonomies. Ouvrage Du Groupement de Recherches 'taphonomie, Environnement et Archéologie', CNRS-INEE*, Brugal J-P (ed). Editions des Archives Contemporaines, 123–156.

Bertran P, Bosq M, Borderie Q *et al*. 2021. Revised map of European aeolian deposits derived from soil texture data. *Quaternary Science Reviews* **266**. https://doi.org/10.1016/j.quascirev.2021.107085 [PubMed: 107085]

Bertran P, Liard M, Sitzia L *et al*. 2016. A map of Pleistocene aeolian deposits in Western Europe, with special emphasis on France. *Journal of Quaternary Science* **31**: 844–856. https://doi.org/10.1002/jqs.2909

Blaauw M, Christen JA, Bennett KD *et al*. 2018. Double the dates and go for Bayes – impacts of model choice, dating density and quality on chronologies. *Quaternary Science Reviews* **188**: 58–66. https://doi.org/10.1016/j.quascirev.2018.03.032

Blinnikov MS, Gaglioti BV, Walker DA *et al*. 2011. Pleistocene graminoid-dominated ecosystems in the Arctic. *Quaternary Science Reviews* **30**: 2906–2929. https://doi.org/10.1016/j.quascirev.2011.07.002

Blundell L. 2016. Hominin activity on the Chalk uplands of southeast Britain: a geomorphological perspective on the archaeological record. *Lithics: the Journal of the Lithic Studies Society* **37**: 55–65.

Blundell L. 2020. *A critical evaluation of the Lower-Middle Palaeolithic archaeological record of the Chalk uplands of northwest Europe*. Doctoral thesis, University College London.

Bogucki A, Tomeniuk O, Sytnyk O *et al*. 2020. Main problems of the research on the Palaeolithic of Halych-Dnister region (Ukraine). *Open Geosciences* **12**: 791–803. https://doi.org/10.1515/geo-2020-0029

Bordes F. 1953. Levalloisien et moustérien. *Bulletin de la Société Préhistorique de France* **50**: 226–235. https://doi.org/10.3406/bspf.1953.3035

Bordes F. 1954. *Les limons quaternaires du Bassin de la Seine: stratigraphie et archéologie paléolithique*. Masson: Paris.

Borrazzo K. 2016. Lithic taphonomy in desert environments: contributions from Fuego-Patagonia (Southern South America). *Quaternary International* **422**: 19–28. https://doi.org/10.1016/j.quaint.2015.12.012

Bösken J, Klasen N, Zeeden C *et al*. 2017. New luminescence-based geochronology framing the last two glacial cycles at the southern limit of European Pleistocene loess in Stalać (Serbia). *Geochronometria* **44**: 150–161. https://doi.org/10.1515/geochr-2015-0062

Bösken J, Obreht I, Zeeden C *et al.* 2019. High-resolution paleoclimatic proxy data from the MIS3/2 transition recorded in northeastern Hungarian loess. *Quaternary International* **502**: 95–107. https://doi.org/10.1016/j.quaint.2017.12.008

Bösken J, Sümegi P, Zeeden C *et al.* 2018. Investigating the last glacial Gravettian site 'Ságvár Lyukas Hill' (Hungary) and its paleoenvironmental and geochronological context using a multi-proxy approach. *Palaeogeography, Palaeoclimatology, Palaeoecology* **509**: 77–90. https://doi.org/10.1016/j.palaeo.2017.08.010

Bosq M, Kreutzer S, Bertran P *et al.* 2020. Chronostratigraphy of two Late Pleistocene loess-palaeosol sequences in the Rhône Valley (southeast France). *Quaternary Science Reviews* **245**: 106473.

Bridgland DR, Howard AJ, White MJ *et al.* 2015. New insight into the Quaternary evolution of the River Trent, UK. *Proceedings of the Geologists' Association* **126**: 466–479. https://doi.org/10.1016/j.pgeola.2015.06.004

Bronger A. 2003. Correlation of loess–paleosol sequences in East and Central Asia with SE Central Europe: towards a continental Quaternary pedostratigraphy and paleoclimatic history. *Quaternary International* **106–107**: 11–31. https://doi.org/10.1016/S1040-6182(02)00159-3

Buggle B, Glaser B, Hambach U *et al.* 2011. An evaluation of geochemical weathering indices in loess–paleosol studies. *Quaternary International* **240**: 12–21. https://doi.org/10.1016/j.quaint.2010.07.019

Burroni D, Donahue RE, Pollard AM *et al.* 2002. The surface alteration features of flint artefacts as a record of environmental processes. *Journal of Archaeological Science* **29**: 1277–1287. https://doi.org/10.1006/jasc.2001.0771

Bush RT, McInerney FA. 2013. Leaf wax n-alkane distributions in and across modern plants: implications for paleoecology and chemotaxonomy. *Geochimica et Cosmochimica Acta* **117**: 161–179. https://doi.org/10.1016/j.gca.2013.04.016

Canti M. 1998. Origin of calcium carbonate granules found in buried soils and Quaternary deposits. *Boreas* **27**: 275–288. https://doi.org/10.1111/j.1502-3885.1998.tb01421.x

Canti MG, Piearce TG. 2003. Morphology and dynamics of calcium carbonate granules produced by different earthworm species: The 7th international symposium on earthworm ecology · Cardiff · Wales · 2002. *Pedobiologia* **47**: 511–521. https://doi.org/10.1078/0031-4056-00221

Canto M. 2015. *Geoarchaeology: Using Earth Sciences to Understand the Archaeological Record*. Historic England.

Chauhan PR, Bridgland DR, Moncel M-H *et al.* 2017. Fluvial deposits as an archive of early human activity: progress during the 20 years of the Fluvial Archives Group. *Quaternary Science Reviews* **166**: 114–149. https://doi.org/10.1016/j.quascirev.2017.03.016

Chen Z, Auler AS, Bakalowicz M *et al.* 2017. The World Karst Aquifer Mapping project: concept, mapping procedure and map of Europe. *Hydrogeology Journal* **25**: 771–785. https://doi.org/10.1007/s10040-016-1519-3

Chu W. 2018. The Danube Corridor Hypothesis and the Carpathian Basin: geological, environmental and archaeological approaches to characterizing Aurignacian dynamics. *Journal of World Prehistory* **31**: 117–178. https://doi.org/10.1007/s10963-018-9115-1

Chu W, Lengyel G, Zeeden C *et al.* 2018. Early Upper Paleolithic surface collections from loess-like sediments in the northern Carpathian Basin. *Quaternary International* **485**: 167–182. https://doi.org/10.1016/j.quaint.2017.05.017

Chu W, Pötter S, Doboș A *et al.* 2019. Geoarchaeology and geochronology of the Upper Palaeolithic site of Temerești Dealu Vinii, Banat, Romania: site formation processes and human activity of an open-air locality. *Quartar* **66**: 111–134. https://doi.org/10.7485/QU66_5

Chu W, Thompson C, Hosfield R. 2015. Micro-abrasion of flint artifacts by mobile sediments: a taphonomic approach. *Archaeological and Anthropological Sciences* **7**: 3–11. https://doi.org/10.1007/s12520-013-0157-0

Commont V. 1916. Les Hommes contemporains du Renne dans la vallée de la Somme. *Bulletin de la Société Préhistorique de France* **13**: 107–111. https://doi.org/10.3406/bspf.1916.7161

Constantin D, Begy R, Vasiliniuc S *et al.* 2014. High-resolution OSL dating of the Costinești section (Dobrogea, SE Romania) using fine and coarse quartz. *Quaternary International* **334–335**: 20–29. https://doi.org/10.1016/j.quaint.2013.06.016

Cordier S, Bridgland D, Benito G. 2015. Research on fluvial archives: from diversity to multidisciplinarity. *Quaternaire* **26**: 3–11. https://doi.org/10.4000/quaternaire.7119

Cremaschi M, Zerboni A, Nicosia C *et al.* 2015. Age, soil-forming processes, and archaeology of the loess deposits at the Apennine margin of the Po plain (northern Italy): new insights from the Ghiardo area. *Quaternary International* **376**: 173–188. https://doi.org/10.1016/j.quaint.2014.07.044

D'Amico ME, Casati E, Andreucci S *et al.* 2021. New dates of a Northern Italian loess deposit (Monte Orfano, Southern pre-Alps, Brescia). *Journal of Soils and Sediments* **21**: 832–841. https://doi.org/10.1007/s11368-020-02860-4

Davies W, White D, Lewis M *et al.* 2015. Evaluating the transitional mosaic: frameworks of change from Neanderthals to Homo sapiens in Eastern Europe. *Quaternary Science Reviews* **118**: 211–242. https://doi.org/10.1016/j.quascirev.2014.12.003

Davis RS, Holliday VT. 2017. Loessic Paleolithic, Tajikistan. In *Encyclopedia of Geoarchaeology*, Gilbert AS (ed). Springer Netherlands: Dordrecht; 492–494. https://doi.org/10.1007/978-1-4020-4409-0_110

de la Torre I. 2016. The origins of the Acheulean: past and present perspectives on a major transition in human evolution. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 371. https://doi.org/10.1098/rstb.2015.0245 [PubMed: 27298475]

Degryse P, Alexander Bentley R. 2017. Archeological geochemistry. In *Encyclopedia of Engineering Geology, Encyclopedia of Earth Sciences Series*, Bobrowsky P, Marker B (eds). Springer International Publishing: Cham. 1–11. https://doi.org/10.1007/978-3-319-39193-9_77-1

Delpiano D, Peresani M, Bertola S *et al.* 2019. Lashed by the wind: short-term middle Palaeolithic occupations within the loess-palaeosoil sequence at Monte Netto (Northern Italy). *Quaternary International* **502**: 137–147. https://doi.org/10.1016/j.quaint.2019.01.026

Demay L, Péan S, Patou-Mathis M. 2012. Mammoths used as food and building resources by Neanderthals: zooarchaeological study applied to layer 4, Molodova I (Ukraine). *Quaternary International* **276–277**: 212–226. https://doi.org/10.1016/j.quaint.2011.11.019

Ding H, Li Y, Yang Y *et al.* 2019. Origin and evolution of modern loess science −1824 to 1964. *Journal of Asian Earth Sciences* **170**: 45–55. https://doi.org/10.1016/j.jseaes.2018.10.024

Ducea MN, Giosan L, Carter A *et al.* 2018. U-Pb detrital zircon geochronology of the lower Danube and its tributaries: implications for the geology of the Carpathians. *Geochemistry, Geophysics, Geosystems* **19**: 3208–3223. https://doi.org/10.1029/2018GC007659

Eckmeier E, Egli M, Schmidt MWI *et al.* 2010. Preservation of fire-derived carbon compounds and sorptive stabilisation promote the accumulation of organic matter in black soils of the Southern Alps. *Geoderma* **159**: 147–155. https://doi.org/10.1016/j.geoderma.2010.07.006

Egberts E, Basell LS, Welham K *et al.* 2020. Pleistocene landscape evolution in the Avon valley, southern Britain: optical dating of terrace formation and Palaeolithic archaeology. *Proceedings of the Geologists' Association* **131**: 121–137. https://doi.org/10.1016/j.pgeola.2020.02.002

Einwögerer T, Friesinger H, Händel M *et al.* 2006. Upper Palaeolithic infant burials. *Nature* **444**: 285–285. https://doi.org/10.1038/444285a [PubMed: 17108949].

Farbstein R, Davies W. 2017. Palaeolithic ceramic technology: the artistic origins and impacts of a technological innovation. *Quaternary International* **441**: 3–11. https://doi.org/10.1016/j.quaint.2016.11.012

Fenn K, Prud'Homme C. 2020. *Dust Deposits: Loess, in: Reference Module in Earth Systems and Environmental Sciences*. Elsevier: Amsterdam.

Fewlass H, Talamo S, Kromer B *et al.* 2019. Direct radiocarbon dates of mid Upper Palaeolithic human remains from Dolní Věstonice II and Pavlov I. *Czech Republic. Journal of Archaeological Science: Reports* **27**: 102000. https://doi.org/10.1016/j.jasrep.2019.102000 [PubMed: 102000]

Fitzsimmons KE, Doboș A, Probst M *et al.* 2020. Thinking outside the box at open-air archeological contexts: examples from loess

landscapes in Southeast. *Romania. Frontiers in Earth Science* **8**. https://doi.org/10.3389/feart.2020.561207
Fitzsimmons KE, Marković SB, Hambach U. 2012. Pleistocene environmental dynamics recorded in the loess of the middle and lower Danube Basin. *Quaternary Science Reviews* **41**: 104–118. https://doi.org/10.1016/j.quascirev.2012.03.002
Flašarová K, Strouhalová B, Šefrna L *et al*. 2020. Multiproxy evidence of middle and Late Pleistocene environmental changes in the loess–paleosol sequence of Bůhzdař (Czech Republic). *Quaternary International* **552**: 4–14. https://doi.org/10.1016/j.quaint.2019.10.004
Fouache E. 2013. The geoarchaeological approach. In *Good Practice in Archaeological Diagnostics: Non-Invasive Survey of Complex Archaeological Sites, Natural Science in Archaeology*, Corsi C, Slapšak B, Vermeulen F (eds). Springer International Publishing: Cham; 245–252. https://doi.org/10.1007/978-3-319-01784-6_14
French C. 2015. *A Handbook of Geoarchaeological Approaches for Investigating Landscapes and Settlement Sites, Studying Scientific Archaeology*. Oxbow Books: Oxford.
Gago-Duport L, Briones M, Rodríguez J *et al*. 2008. Amorphous calcium carbonate biomineralization in the earthworm's calciferous gland: pathways to the formation of crystalline phases. *Journal of Structural Biology* **162**: 422–435. https://doi.org/10.1016/j.jsb.2008.02.007
Gerasimenko N, Rousseau D. 2008. Stratigraphy and paleoenvironments of the last Pleniglacial in the Kyiv loess region (Ukraine). *Quaternaire* **19**: 293–307. https://doi.org/10.4000/quaternaire.4592
Gilbert AS. 2016. *Encyclopedia of Geoarchaeology*. Springer: Berlin.
Glauberman P, Thorson R. 2012. Flint patina as an aspect of 'flaked stone taphonomy': a case study from the loess terrain of the Netherlands and Belgium. *Journal of Taphonomy* **10**: 21–43.
Glauberman PJ. 2016. Middle Palaeolithic land use in Dutch and Belgian Limburg: integrating data from surface sites. *Quaternary International* **411**: 198–215. https://doi.org/10.1016/j.quaint.2015.06.033
Gocke M, Hambach U, Eckmeier E *et al*. 2014. Introducing an improved multi-proxy approach for paleoenvironmental reconstruction of loess–paleosol archives applied on the Late Pleistocene Nußloch sequence (SW Germany). *Palaeogeography, Palaeoclimatology, Palaeoecology* **410**: 300–315. https://doi.org/10.1016/j.palaeo.2014.06.006
Gocke M, Pustovoytov K, Kühn P *et al*. 2011. Carbonate rhizoliths in loess and their implications for paleoenvironmental reconstruction revealed by isotopic composition: $\delta^{13}C$, ^{14}C. *Chemical Geology* **283**: 251–260. https://doi.org/10.1016/j.chemgeo.2011.01.022
Goldberg P, Macphail RI. 2009. *Practical and Theoretical Geoarchaeology*. John Wiley & Sons: Oxford.
Goldscheider N, Chen Z, Auler AS *et al*. 2020. Global distribution of carbonate rocks and karst water resources. *Hydrogeology Journal* **28**: 1661–1677. https://doi.org/10.1007/s10040-020-02139-5
Gordon JE. 2018. Geoheritage, geotourism and the cultural landscape: enhancing the visitor experience and promoting geoconservation. *Geosciences* **8**: 136. https://doi.org/10.3390/geosciences8040136
Graf KE, Goebel T. 2017. 3.3. The Paleolithic of eastern Beringia from western Alaska to Canadian Yukon. In *Human Colonization of the Arctic: the Interaction Between Early Migration and the Paleoenvironment*, Kotlyakov VM, Velichko AA, Vasil'ev SA (eds). Academic Press: Cambridge; 311–338. https://doi.org/10.1016/B978-0-12-813532-7.00016-4
Groza SM, Hambach U, Veres D *et al*. 2019. Optically stimulated luminescence ages for the Upper Palaeolithic site Krems-Wachtberg, Austria. *Quaternary Geochronology* **49**: 242–248. https://doi.org/10.1016/j.quageo.2018.04.005
Grün R, Stringer CB. 1991. Electron spin resonance dating and the evolution of modern humans. *Archaeometry* **33**: 153–199. https://doi.org/10.1111/j.1475-4754.1991.tb00696.x
Guthrie RD. 1982. Mammals of the mammoth steppe as paleoenvironmental indicators, *Paleoecology of Beringia*. Elsevier: Amsterdam; 307–326. https://doi.org/10.1016/B978-0-12-355860-2.50030-2
Guthrie RD. 2013. *Frozen Fauna of the Mammoth Steppe: the Story of Blue Babe*. University of Chicago Press: Chicago.
Haase D, Fink J, Haase G *et al*. 2007. Loess in Europe – its spatial distribution based on a European Loess Map, scale 1: 2,500,000. *Quaternary Science Reviews* **26**: 1301–1312. https://doi.org/10.1016/j.quascirev.2007.02.003
Haesaerts P, Mestdagh H. 2000. Pedosedimentary evolution of the last interglacial and early glacial sequence in the European loess belt from Belgium to central Russia. *Netherlands Journal of Geosciences* **79**: 313–324. https://doi.org/10.1017/S001677460002179X
Händel M, Simon U, Einwögerer T *et al*. 2009. Loess deposits and the conservation of the archaeological record – the Krems-Wachtberg example. *Quaternary International* **198**: 46–50. https://doi.org/10.1016/j.quaint.2008.07.005
Händel M, Thomas R, Sprafke T *et al*. 2021. Using archaeological data and sediment parameters to review the formation of the Gravettian layers at Krems-Wachtberg. *Journal of Quaternary Science* **3293**. https://doi.org/10.1002/jqs.3293
Hatté C, Antoine P, Fontugne M *et al*. 2001. $\delta^{13}C$ of loess organic matter as a potential proxy for paleoprecipitation. *Quaternary Research* **55**: 33–38. https://doi.org/10.1006/qres.2000.2191
Hatté C, Guiot J. 2005. Palaeoprecipitation reconstruction by inverse modelling using the isotopic signal of loess organic matter: application to the Nußloch loess sequence (Rhine Valley, Germany). *Climate Dynamics* **25**: 315–327. https://doi.org/10.1007/s00382-005-0034-3
Hijma MP, Cohen KM, Roebroeks W *et al*. 2012. Pleistocene Rhine–Thames landscapes: geological background for hominin occupation of the southern North Sea region. *Journal of Quaternary Science* **27**: 17–39. https://doi.org/10.1002/jqs.1549
Iakovleva L, Djindjian F. 2005. New data on Mammoth bone settlements of Eastern Europe in the light of the new excavations of the Gontsy site (Ukraine). *Quaternary International* **126–128**: 195–207. https://doi.org/10.1016/j.quaint.2004.04.023
Iakovleva L, Djindjian F, Maschenko EN *et al*. 2012. The late Upper Palaeolithic site of Gontsy (Ukraine): a reference for the reconstruction of the hunter–gatherer system based on a mammoth economy. *Quaternary International* **255**: 86–93. https://doi.org/10.1016/j.quaint.2011.10.004
Jary Z, Owczarek P, Ryzner K *et al*. 2018. Loess documentary sites and their potential for geotourism in Lower Silesia (Poland). *Open Geosciences* **10**: 647–660. https://doi.org/10.1515/geo-2018-0052
Jia G, Rao Z, Zhang J *et al*. 2013. Tetraether biomarker records from a loess–paleosol sequence in the western Chinese Loess Plateau. *Frontiers in Microbiology* **4**: 199. https://doi.org/10.3389/fmicb.2013.00199 [PubMed: 23898324]
Kohn MJ. 2010. Carbon isotope compositions of terrestrial C3 plants as indicators of (paleo)ecology and (paleo)climate. *Proceedings of the National Academy of Sciences of the United States of America* **107**: 19691–19695. https://doi.org/10.1073/pnas.1004933107] [PubMed: 21041671]
Kovács J, Újvári G, Varga G *et al*. 2020. Plio-Pleistocene dust traps on paleokarst surfaces: a case study from the Carpathian Basin. *Frontiers in Earth Science* **8**: 189.
Kozowyk PRB, van Gijn AL, Langejans GHJ. 2020. Understanding preservation and identification biases of ancient adhesives through experimentation. *Archaeological and Anthropological Sciences* **12**: 209. https://doi.org/10.1007/s12520-020-01179-y
Krajcarz MT, Cyrek K, Krajcarz M *et al*. 2016a. Loess in a cave: lithostratigraphic and correlative value of loess and loess-like layers in caves from the Kraków–Częstochowa Upland (Poland). *Quaternary International* **399**: 13–30. https://doi.org/10.1016/j.quaint.2015.08.069
Krajcarz MT, Kot M, Pavlenok K *et al*. 2016b. Middle Paleolithic sites of Katta Sai in western Tian Shan piedmont, Central Asiatic loess zone: geoarchaeological investigation of the site formation and the integrity of the lithic assemblages. *Quaternary International* **399**: 136–150. https://doi.org/10.1016/j.quaint.2015.07.051
Krauss L, Klasen N, Schulte P *et al*. 2021. New results concerning the pedo- and chronostratigraphy of the loess–palaeosol sequence Attenfeld (Bavaria, Germany) derived from a multi-methodological approach. *Journal of Quaternary Science* **3298**. https://doi.org/10.1002/jqs.3298
Krauß L, Zens J, Zeeden C *et al*. 2016. A multi-proxy analysis of two loess–paleosol sequences in the northern Harz foreland, Germany. *Palaeogeography, Palaeoclimatology, Palaeoecology* **461**: 401–417. https://doi.org/10.1016/j.palaeo.2016.09.001

Kulesza P, Łanczont M, Komar M. 2020. A biotic record of paleoenvironmental changes during the last interglacial-glacial cycle in a sub-Carpathian river valley; a case study of the Radymno loess section (SE Poland). *Quaternary International* **552**: 62–78. https://doi.org/10.1016/j.quaint.2019.12.007

Laag C, Hambach U, Zeeden C *et al.* 2021. A detailed paleoclimate proxy record for the Middle Danube Basin over the Last 430 kyr: a rock magnetic and colorimetric study of the Zemun loess-paleosol sequence. *Frontiers in Earth Science* **9**: 600086. https://doi.org/10.3389/feart.2021.600086 [PubMed: 600086]

Lanoë FB, Reuther JD, Holmes CE *et al.* 2020. Small mammals and paleovironmental context of the terminal Pleistocene and early Holocene human occupation of central Alaska. *Geoarchaeology* **35**: 164–176. https://doi.org/10.1002/gea.21768

Lefort J, Monnier J, Renouf J *et al.* 2021. Impact of katabatic winds on the environment of Neanderthals during the Middle Palaeolithic in westernmost Europe. *Journal of Quaternary Science* **3361**. https://doi.org/10.1002/jqs.3361

Lefort J-P, Monnier J-L, Danukalova G. 2019. Transport of Late Pleistocene loess particles by katabatic winds during the lowstands of the English Channel. *Journal of the Geological Society* **176**: 1169–1181. https://doi.org/10.1144/jgs2019-070

Lehmkuhl F, Nett JJ, Pötter S *et al.* 2021. Loess landscapes of Europe - mapping, geomorphology, and zonal differentiation. *Earth-Science Reviews* **215**: 103496. https://doi.org/10.1016/j.earscirev.2020.103496

Lenoble A, Bertran P, Lacrampe F. 2008. Solifluction-induced modifications of archaeological levels: simulation based on experimental data from a modern periglacial slope and application to French Palaeolithic sites. *Journal of Archaeological Science* **35**: 99–110. https://doi.org/10.1016/j.jas.2007.02.011

Lindner H, Lehmkuhl F, Zeeden C. 2017. Spatial loess distribution in the eastern Carpathian Basin: a novel approach based on geoscientific maps and data. *Journal of Maps* **13**: 173–181. https://doi.org/10.1080/17445647.2017.1279083

Lomax J, Fuchs M, Antoine P *et al.* 2019. A luminescence-based chronology for the Harletz loess sequence, Bulgaria. *Boreas* **48**: 179–194. https://doi.org/10.1111/bor.12348

Lowe DJ. 2011. Tephrochronology and its application: a review. *Quaternary Geochronology* **6**: 107–153. https://doi.org/10.1016/j.quageo.2010.08.003

Ludwig P, Gavrilov MB, Radaković MG *et al.* 2021. Malaco temperature reconstructions and numerical simulation of environmental conditions in the southeastern Carpathian Basin during the Last Glacial Maximum. *Journal of Quaternary Science* **3318**. https://doi.org/10.1002/jqs.3318

Lyons N. 2019. *Signs in the Dust: A Theory of Natural Culture and Cultural Nature*. Oxford University Press: Oxford.

Machová D, Mácová P, Mali G *et al.* 2020. Bone diagenesis in the loess deposits of Central. *Europe: the Celtic site of Radovesice in Bohemia. Archaeological and Anthropological Sciences* **12**: 257. https://doi.org/10.1007/s12520-020-01218-8

Madeyska T. 2002. Evidence of climatic variations in loess and cave Palaeolithic sites of southern Poland and western Ukraine. *Quaternary International* **91**: 65–73. https://doi.org/10.1016/S1040-6182(01)00103-3

Maher BA. 1998. Magnetic properties of modern soils and Quaternary loessic paleosols: paleoclimatic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology* **137**: 25–54. https://doi.org/10.1016/S0031-0182(97)00103-X

Maher LA, Conkey M. 2019. Homes for hunters? Exploring the concept of home at hunter-gatherer sites in Upper Paleolithic Europe and Epipaleolithic Southwest Asia. *Current Anthropology* **60**: 91–137. https://doi.org/10.1086/701523

Malinsky-Buller A, Glauberman P, Wilkinson K *et al.* 2021. Evidence for Middle Palaeolithic occupation and landscape change in central Armenia at the open-air site of Alapars-1. *Quaternary Research* **99**: 223–247. https://doi.org/10.1017/qua.2020.61

Marković SB, Fitzsimmons KE, Sprafke T *et al.* 2016. The history of Danube loess research. *Quaternary International* **399**: 86–99. https://doi.org/10.1016/j.quaint.2015.09.071

Markovič SB, Korač M, Mrđič N *et al.* 2014. Palaeoenvironment and geoconservation of mammoths from the Nosak loess–palaeosol sequence (Drmno, northeastern Serbia): initial results and perspectives. *Quaternary International* **334–335**: 30–39. https://doi.org/10.1016/j.quaint.2013.05.047

Marković SB, Oches EA, McCoy WD *et al.* 2007. Malacological and sedimentological evidence for 'warm' glacial climate from the Irig loess sequence, Vojvodina, Serbia. *Geochemistry, Geophysics, Geosystems* **8**: Q09008. https://doi.org/10.1029/2006GC001565

Marković SB, Oches EA, Perić ZM *et al.* 2021a. The Požarevac loess–paleosol sequence: a record of increased aridity in the south-eastern margin of the Carpathian Basin during the last 350 ka. *Journal of Quaternary Science* **3327**. https://doi.org/10.1002/jqs.3327

Marković SB, Stevens T, Kukla GJ *et al.* 2015. Danube loess stratigraphy – towards a pan-European loess stratigraphic model. *Earth-Science Reviews* **148**: 228–258. https://doi.org/10.1016/j.earscirev.2015.06.005

Marković SB, Stevens T, Mason J *et al.* 2018a. Loess correlations – between myth and reality. *Palaeogeography, Palaeoclimatology, Palaeoecology* **509**: 4–23. https://doi.org/10.1016/j.palaeo.2018.04.018

Marković SB, Sümegi P, Stevens T *et al.* 2018b. The Crvenka loess–paleosol sequence: a record of continuous grassland domination in the southern Carpathian Basin during the Late Pleistocene. *Palaeogeography, Palaeoclimatology, Palaeoecology* **509**: 33–46. https://doi.org/10.1016/j.palaeo.2018.03.019

Marković SB, Vandenberghe J, Stevens T *et al.* 2021b. Geomorphological evolution of the Petrovaradin Fortress Palaeolithic site (Novi Sad, Serbia). *Quaternary Research* **103**: 21–34. https://doi.org/10.1017/qua.2020.88

Marquer L, Lebreton V, Otto T *et al.* 2012. Charcoal scarcity in Epigravettian settlements with mammoth bone dwellings: the taphonomic evidence from Mezhyrich (Ukraine). *Journal of Archaeological Science* **39**: 109–120. https://doi.org/10.1016/j.jas.2011.09.008

Marreiros J, Calandra I, Gneisinger W *et al.* 2020. Rethinking use-wear analysis and experimentation as applied to the study of past hominin tool use. *Journal of Paleolithic Archaeology* **3**: 475–502. https://doi.org/10.1007/s41982-020-00058-1

Martini M, Sibilia E, Croci S *et al.* 2001. Thermoluminescence (TL) dating of burnt flints: problems, perspectives and some examples of application. *Journal of Cultural Heritage* **2**: 179–190. https://doi.org/10.1016/S1296-2074(01)01126-8

McPherron SP. 2018. Additional statistical and graphical methods for analyzing site formation processes using artifact orientations. *PLoS ONE* **13** e0190195. https://doi.org/10.1371/journal.pone.0190195 [PubMed: 29293573]

Michel M, Cnuts D, Rots V. 2019. Freezing in-sight: the effect of frost cycles on use-wear and residues on flint tools. *Archaeological and Anthropological Sciences* **11**: 5423–5443. https://doi.org/10.1007/s12520-019-00881-w

Moine O. 2008. West-European malacofauna from loess deposits of the Weichselian Upper Pleniglacial: compilation and preliminary analysis of the database. *Quaternaire* **19**: 11–29. https://doi.org/10.4000/quaternaire.1532

Moine O, Antoine P, Coutard S *et al.* 2021. Intra-interstadial environmental changes in Last Glacial loess revealed by molluscan assemblages from the Upper Palaeolithic site of Amiens-Renancourt 1 (Somme, France). *Journal of Quaternary Science* **3312**. https://doi.org/10.1002/jqs.3312

Moine O, Antoine P, Hatté C *et al.* 2017. The impact of Last Glacial climate variability in west-European loess revealed by radiocarbon dating of fossil earthworm granules. *Proceedings of the National Academy of Sciences of the United States of America* **114**: 6209–6214. https://doi.org/10.1073/pnas.1614751114 [PubMed: 28559353]

Molnár D, Sümegi P, Makó L *et al.* 2021. Palaeoecological background of the Upper Palaeolithic site of Ságvár, Hungary: radiocarbon-dated malacological and sedimentological studies on the Late Pleistocene environment. *Journal of Quaternary Science* **3306**. https://doi.org/10.1002/jqs.3306

Montalvo CI, Melchor RN, Visconti G *et al.* 2008. Vertebrate taphonomy in loess-palaeosol deposits: A case study from the Late Miocene of central Argentina. *Geobios* **41**: 133–143. https://doi.org/10.1016/j.geobios.2006.09.004

Morgan C, Barton L, Bettinger R *et al.* 2011. Glacial cycles and Palaeolithic adaptive variability on China's Western Loess Plateau. *Antiquity* **85**: 365–379. https://doi.org/10.1017/S0003598X00067818

Muhs DR. 2013. 11.9 loess and its geomorphic, stratigraphic, and paleoclimatic significance in the Quaternary, *Treatise on Geomorphology*. Elsevier: Amsterdam; 149–183. https://doi.org/10.1016/B978-0-12-374739-6.00302-X

Nerudová Z, Neruda P, Hamrozi P. 2021. Statistical and geographical modelling of Moravian (Czech Republic) Late Upper Palaeolithic occupation. *Quaternary International* **581–582**: 175–189. https://doi.org/10.1016/j.quaint.2020.07.003

Nian X, Li F, Chen F *et al.* 2016. Optically stimulated luminescence ages for human occupation during the penultimate glaciation in the western Loess Plateau of China. *Journal of Quaternary Science* **31**: e2917. https://doi.org/10.1002/jqs.2917

Nykamp M, Knitter D, Timár G *et al.* 2017. Estimation of wind-driven soil erosion of a loess-like sediment and its implications for the occurrence of archaeological surface and subsurface finds – an example from the environs of Cornești-Iarcuri, western Romania. *Journal of Archaeological Science: Reports* **12**: 601–612. https://doi.org/10.1016/j.jasrep.2017.03.030

Obreht I, Zeeden C, Hambach U *et al.* 2019. A critical reevaluation of palaeoclimate proxy records from loess in the Carpathian Basin. *Earth-Science Reviews* **190**: 498–520. https://doi.org/10.1016/j.earscirev.2019.01.020

Obreht I, Zeeden C, Hambach U *et al.* 2021. Reply to the discussion paper by P. Sümegi and S. Gulyás: some notes on the interpretation and reliability of malacological proxies in paleotemperature reconstructions from loess- comments to Obreht et al.'s "A critical reevaluation of paleoclimate proxy records from loess in the Carpathian Basin." Earth-Science Reviews **220**: 103737. https://doi.org/10.1016/j.earscirev.2021.103737

Pastre JF, Billard A, Debard E *et al.* 1996. A tephric horizon Mont-Dore provenance in the Plio-Pleistocene loessic sequence of Saint-Vallier (France). *Comptes Rendus de l'Acade´mie des Sciences de Paris* **323**: 607–614.

Pawlik A, Thissen J. 2017. Traceological analysis of 'unusual' wear traces on lithic artefacts from the Middle Palaeolithic site Inden-Altdorf and the functional context of the site. *Quaternary International* **427**: 104–127. https://doi.org/10.1016/j.quaint.2015.11.125

Peresani M, Cremaschi M, Ferraro F *et al.* 2008. Age of the final Middle Palaeolithic and Uluzzian levels at Fumane Cave, Northern Italy, using ^{14}C, ESR, ^{234}U/^{230}Th and thermoluminescence methods. *Journal of Archaeological Science* **35**: 2986–2996. https://doi.org/10.1016/J.JAS.2008.06.013

Pettitt P, White M. 2014. John Lubbock, caves, and the development of Middle and Upper Palaeolithic archaeology. *Notes and Records* **68**: 35–48. https://doi.org/10.1098/rsnr.2013.0050

Pirson S, Baele J-M, Balescu S *et al.* 2018. Green amphibole distribution as a stratigraphic tool in loess sequences from Belgium: a review. *Quaternary International* **485**: 183–198. https://doi.org/10.1016/j.quaint.2017.06.026

Pollard AM. 1999. Geoarchaeology: an introduction. *Geological Society, London, Special Publications* **165**: 7–14. https://doi.org/10.1144/GSL.SP.1999.165.01.01

Pope M, Blundell L, Scott B *et al.* 2016. Behaviour and process in the formation of the north European Acheulean record: towards a Unified Palaeolithic Landscape Approach. *Quaternary International* **411**: 85–94. https://doi.org/10.1016/j.quaint.2016.01.070

Pope M, Dinnis R, Milks A *et al.* 2013. A Middle Palaeolithic to Early Upper Palaeolithic succession from an open air site at Beedings, West Sussex. *Quaternary International* **316**: 14–26. https://doi.org/10.1016/j.quaint.2013.06.027

Pötter S, Schmitz A, Lücke A *et al.* 2021a. Middle to Late Pleistocene environments based on stable organic carbon and nitrogen isotopes of loess-palaeosol sequences from the Carpathian Basin. *Boreas* **50**: 184–204. https://doi.org/10.1111/bor.12470

Pötter S, Veres D, Baykal Y *et al.* 2021b. Disentangling sedimentary pathways for the Pleniglacial Lower Danube loess based on geochemical signatures. *Frontiers in Earth Science* **9**: 1–25. https://doi.org/10.3389/feart.2021.600010

Powers WR, Guthrie RD, Hoffecker JF. 2017. *Dry Creek: Archaeology and Paleoecology of a Late Pleistocene Alaskan Hunting Camp*. Texas A & M University Press: College Station.

Prud'homme C, Lécuyer C, Antoine P *et al.* 2018. δ^{13}C signal of earthworm calcite granules: A new proxy for palaeoprecipitation reconstructions during the Last Glacial in western Europe. *Quaternary Science Reviews* **179**: 158–166. https://doi.org/10.1016/j.quascirev.2017.11.017

Prud'homme C, Lécuyer C, Antoine P *et al.* 2016. Palaeotemperature reconstruction during the Last Glacial from δ^{18}O of earthworm calcite granules from Nussloch loess sequence, Germany. *Earth and Planetary Science Letters* **442**: 13–20. https://doi.org/10.1016/j.epsl.2016.02.045

Pryor AJE, Beresford-Jones DG, Dudin AE *et al.* 2020. The chronology and function of a new circular mammoth-bone structure at Kostenki 11. *Antiquity* **94**: 323–341. https://doi.org/10.15184/aqy.2020.7

Ranov V. 1995. The 'loessic palaeolithic' in South Tadjikistan, central Asia: its industries, chronology and correlation. *Quaternary Science Reviews* **14**: 731–745. https://doi.org/10.1016/0277-3791(95)00055-0

Ranov VA. 1989. Is the use of the term "loess Paleolithic" justifiable. The Quaternary Period. Paleontology and archeology. Yanshin, AL, *Kishinev*. 137–145.

Rapp GR, Hill CL. 2006. *Geoarchaeology: the Earth-Science Approach to Archaeological Interpretation*. Yale University Press: New Haven.

Reimann T, Thomsen KJ, Jain M *et al.* 2012. Single-grain dating of young sediments using the pIRIR signal from feldspar. *Quaternary Geochronology* **11**: 28–41. https://doi.org/10.1016/j.quageo.2012.04.016

Reynolds N. 2020. Threading the weft, testing the warp: population concepts and the European Upper Paleolithic chronocultural framework. In Culture History and Convergent Evolution: Can We Detect Populations in Prehistory? Groucutt HS (ed). Springer International Publishing, 187–212. https://doi.org/10.1007/978-3-030-46126-3_10

Richter M, Tsukamoto S, Long H. 2020. ESR dating of Chinese loess using the quartz Ti centre: A comparison with independent age control. *Quaternary International* **556**: 159–164. https://doi.org/10.1016/j.quaint.2019.04.003

Roebroeks W, Kolen J, Van Poecke M *et al.* 1997. "Site J": an early Weichselian (Middle Palaeolithic) flint scatter at Maastricht-Belvedere. *The Netherlands. Paléo* **9**: 143–172. https://doi.org/10.3406/pal.1997.1231

Roebroeks W, Speleers B. 2002. Last interglacial (Eemian) occupation of the north European plain and adjacent areas. *Publications du CERP* 31–39.

Romanis T, Sedov S, Lev S *et al.* 2021. Landscape change and occupation history in the Central Russian Upland from Upper Palaeolithic to medieval: paleopedological record from Zaraysk Kremlin. *CATENA* **196**: 104873. https://doi.org/10.1016/j.catena.2020.104873 [PubMed: 104873]

Rousseau D-D. 2001. Loess biostratigraphy: new advances and approaches in mollusk studies. *Earth-Science Reviews* **54**: 157–171. https://doi.org/10.1016/S0012-8252(01)00046-0

Rousseau D-D, Derbyshire E, Antoine P *et al.* 2018. European loess records, In *Reference Module in Earth Systems and Environmental Sciences*. Elsevier: Amsterdam.

Rousseau D-D, Hatté C. 2021. Ground-air interface: the loess sequences, markers of atmospheric circulation. In *Paleoclimatology, Frontiers in Earth Sciences*, Ramstein G, Landais A, Bouttes N, Sepulchre P, Govin A (eds). Springer International Publishing: Cham; 157–167. https://doi.org/10.1007/978-3-030-24982-3_13

Rousseau D-D, Svensson A, Bigler M *et al.* 2017. Eurasian contribution to the last glacial dust cycle: how are loess sequences built? *Climate of the Past* **13**: 1181–1197. https://doi.org/10.5194/cp-13-1181-2017

Sano K. 2012. Functional variability in the Magdalenian of north-western Europe: A lithic microwear analysis of the Gönnersdorf K-II assemblage. *Quaternary International* **272–273**: 264–274. https://doi.org/10.1016/j.quaint.2012.02.057

Satchell J. 1967. Lumbricidea. In Soil Biology, Burges A and Raw F (eds.). London: Academic Press, 259–322.

Schaetzl RJ, Thompson ML. 2015. *Soils: Genesis and Geomorphology*. 2nd edn. Cambridge University Press: New York.

Schäfer IK, Lanny V, Franke J *et al.* 2016. Leaf waxes in litter and topsoils along a European transect. *SOIL* **2**: 551–564. https://doi.org/10.5194/soil-2-551-2016

Schäfer J, Ranov VA, Sosin PM. 1998. The 'cultural evolution' of man and the chronostratigraphical background of changing environments in the loess palaeosoil sequences of Obi-Mazar and Khonako (Tajikstan). *Anthropologie (1962-)* **36**: 121–135.

Scheidt S, Berg S, Hambach U *et al.* 2021. Chronological assessment of the Balta Alba Kurgan loess-paleosol section (Romania) – a comparative study on different dating methods for a robust and precise age model. *Frontiers in Earth Science* **8**: 598448. https://doi.org/10.3389/feart.2020.598448 [PubMed: 598448]

Schmidt C, Zeeden C, Krauß L *et al.* 2021. A chronological and palaeoenvironmental re-evaluation of two loess-palaeosol records in the northern Harz foreland, Germany, based on innovative modelling tools. *Boreas* **50**: 746–763. https://doi.org/10.1111/bor.12510

Schmidt I, Zimmermann A. 2019. Population dynamics and socio-spatial organization of the Aurignacian: scalable quantitative demographic data for western and central Europe. *PLoS ONE* **14**: e0211562. https://doi.org/10.1371/journal.pone.0211562 [PubMed: 30759115]

Schulte P, Lehmkuhl F. 2018. The difference of two laser diffraction patterns as an indicator for post-depositional grain size reduction in loess–paleosol sequences. *Palaeogeography, Palaeoclimatology, Palaeoecology* **509**: 126–136. https://doi.org/10.1016/j.palaeo.2017.02.022

Scott B, Pope M, Ashton N et al. 2019. The Early Middle Palaeolithic of Britain and Jersey: reconnecting the Saalian occupations of the Channel Region. Préhistoire de l'Europe du Nord-Ouest: mobilités, climats et identités culturelles. Proceedings of the XXVIII e congrès préhistorique de France – Amiens, 30 mai-4 juin 2016. Paris: Institut national de recherches archéologiques préventives (INRAP), France, 215–227.

Shipman P. 2015. How do you kill 86 mammoths? taphonomic investigations of mammoth megasites. *Quaternary International* **359–360**: 38–46. https://doi.org/10.1016/j.quaint.2014.04.048

Siart C, Forbriger M, Bubenzer O (eds). 2018. *Digital Geoarchaeology: New Techniques for Interdisciplinary Human-Environmental Research, Natural Science in Archaeology*. Springer International Publishing: Cham.

Smalley I, Obreht I. 2018. The formation of loess ground by the process of loessification: a history of the concept. *Geologos* **24**: 163–170. https://doi.org/10.2478/logos-2018-0015

Sommé J, Tuffreau A. 1978. Historique des recherches sur le Quaternaire de la région du Nord de la France. *Bulletin de l'Association Française pour l'Étude du Quaternaire* **15**: 5–13. https://doi.org/10.3406/quate.1978.1330

Song Y, Lai Z, Li Y *et al.* 2015. Comparison between luminescence and radiocarbon dating of late Quaternary loess from the Ili Basin in Central Asia. *Quaternary Geochronology* **30**: 405–410. https://doi.org/10.1016/j.quageo.2015.01.012

Sprafke T, Obreht I. 2016. Loess: rock, sediment or soil – what is missing for its definition? *Quaternary International* **399**: 198–207. https://doi.org/10.1016/j.quaint.2015.03.033

Sprafke T, Schulte P, Meyer-Heintze S *et al.* 2020. Paleoenvironments from robust loess stratigraphy using high-resolution color and grain-size data of the last glacial Krems-Wachtberg record (NE Austria). *Quaternary Science Reviews* **248**: 106602. https://doi.org/10.1016/j.quascirev.2020.106602 [PubMed: 106602]

Stansfield E, Mitteroecker P, Vasilyev SY *et al.* 2021. Respiratory adaptation to climate in modern humans and Upper Palaeolithic individuals from Sungir and Mladeč. *Scientific Reports* **11**: 7997. https://doi.org/10.1038/s41598-021-86830-x [PubMed: 33846400]

Stevens T, Sechi D, Bradák B *et al.* 2020. Abrupt last glacial dust fall over southeast England associated with dynamics of the British–Irish ice sheet. *Quaternary Science Reviews* **250**: 106641. https://doi.org/10.1016/j.quascirev.2020.106641 [PubMed: 106641]

Stone A, Fenn K. 2020. Dating aeolian deposits. In *Reference Module in Earth Systems and Environmental Sciences*. Elsevier: Amsterdam.

Sümegi P. 1989. A Hajdúság felsőpleisztocén fejlődéstörénete finomrétegtani (őslénytani, üledékföldtani, geokémiai) vizsgálatok alapján (Upper Pleistocene geohistory of Hajdúság base on fine-stratigraphical (palaeontological, sedimentological, geochemical) investigation (Dr. Univ. Thesis). Kossuth University, Debrecen.

Sümegi P, Gulyás S, Molnár D *et al.* 2021. New chronology and extended paleoenvironmental data to the 1975 loess profile of Madaras brickyard, S Hungary. *Journal of Quaternary Science*

Sümegi P, Gulyás S, Persaits G *et al.* 2011. The loess–paleosol sequence of Basaharc (Hungary) revisited: mollusc-based paleoecological results for the Middle and Upper Pleistocene. *Quaternary International* **240**: 181–192. https://doi.org/10.1016/j.quaint.2011.05.005

Sümegi P, Krolopp E. 2002. Quatermalacological analyses for modeling of the Upper Weichselian palaeoenvironmental changes in the Carpathian Basin. *Quaternary International* **91**: 53–63. https://doi.org/10.1016/S1040-6182(01)00102-1

Svensson E, Günther T, Hoischen A *et al.* 2021. Genome of Peştera Muierii skull shows high diversity and low mutational load in pre-glacial Europe. *Current Biology* **31**: 2973–2983.e9. https://doi.org/10.1016/j.cub.2021.04.045 [PubMed: 34010592]

Szeberényi J, Kovács J, Bradák B *et al.* 2020. Experiencing new perspectives in the application of reflectance spectroscopy in loess research. *Quaternary International* **552**: 36–49. https://doi.org/10.1016/j.quaint.2019.09.035

Timar-Gabor A, Vasiliniuc Ș, Vandenberghe DAG *et al.* 2012. Investigations into the reliability of SAR-OSL equivalent doses obtained for quartz samples displaying dose response curves with more than one component. *Radiation Measurements* **47**: 740–745. https://doi.org/10.1016/j.radmeas.2011.12.001

Timar-Gabor A, Wintle AG. 2013. On natural and laboratory generated dose response curves for quartz of different grain sizes from Romanian loess. *Quaternary Geochronology* **18**: 34–40. https://doi.org/10.1016/j.quageo.2013.08.001

Trinkaus E, Buzhilova AP. 2018. Diversity and differential disposal of the dead at Sunghir. *Antiquity* **92**: 7–21. https://doi.org/10.15184/aqy.2017.223

Újvári G, Kele S, Bernasconi SM *et al.* 2019. Clumped isotope paleotemperatures from MIS 5 soil carbonates in southern Hungary. *Palaeogeography, Palaeoclimatology, Palaeoecology* **518**: 72–81. https://doi.org/10.1016/j.palaeo.2019.01.002

Újvári G, Kok JF, Varga G *et al.* 2016. The physics of wind-blown loess: implications for grain size proxy interpretations in Quaternary paleoclimate studies. *Earth-Science Reviews* **154**: 247–278. https://doi.org/10.1016/j.earscirev.2016.01.006

Újvári G, Molnár M, Novothny Á *et al.* 2014. AMS 14 C 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. https://doi.org/10.1016/j.quascirev.2014.06.009

Újvári G, Stevens T, Molnár M *et al.* 2017. Coupled European and Greenland last glacial dust activity driven by North Atlantic climate. *Proceedings of the National Academy of Sciences of the United States of America* **114**: E10632–E10638. https://doi.org/10.1073/pnas.1712651114 [PubMed: 29180406]

Újvári G, Varga A, Ramos FC *et al.* 2012. Evaluating the use of clay mineralogy, Sr–Nd isotopes and zircon U–Pb ages in tracking dust provenance: an example from loess of the Carpathian Basin. *Chemical Geology* **304–305**: 83–96. https://doi.org/10.1016/j.chemgeo.2012.02.007

Urban TM, Rasic JT, Alix C *et al.* 2019. Magnetic detection of archaeological hearths in Alaska: A tool for investigating the full span of human presence at the gateway to North America. *Quaternary Science Reviews* **211**: 73–92. https://doi.org/10.1016/j.quascirev.2019.03.018

Valde-Nowak P, Łanczont M. 2021. State-of-the-art overview of the Loess Palaeolithic of Poland. *Journal of Quaternary Science* **3356**. https://doi.org/10.1002/jqs.3356

Vallin L, Masson B, Caspar J-P. 2001. Taphonomy at Hermies, France: a Mousterian knapping site in a loessic context, *Journal of Field Archaeology* (**28**: 419–436. https://doi.org/10.1179/jfa.2001.28.3-4.419

Van Kolfschoten T, Roebroeks W. 1985. Maastricht-Belvédère: stratigraphy, palaeoenvironment and archaeology of the Middle and Late Pleistocene deposits. *Mededelingen van de Rijks Geologische Dienst* **39**: 1–121.

Vandenberghe J. 2012. Multi-proxy analysis: a reflection on essence and potential pitfalls. *Netherlands Journal of Geosciences - Geologie en Mijnbouw* **91**: 263–269. https://doi.org/10.1017/S0016774600001657

Vandenberghe J, Roebroeks W, Van, Kolfschoten T. 1993. Maastricht-Belvédère: stratigraphy, palaeoenvironment and archaeology of the Middle and Late Pleistocene deposits, Part II. *Mededelingen Rijks Geologische Dienst* **47**: 1–91.

Vasiljević DA, Marković SB, Hose TA *et al.* 2014. Loess–palaeosol sequences in China and Europe: common values and geoconservation issues. *CATENA* **117**: 108–118. https://doi.org/10.1016/j.catena.2013.06.005

Vasiljević DjA, Marković SB, Hose TA *et al.* 2011. The Introduction to Geoconservation of loess-palaeosol sequences in the Vojvodina region: significant geoheritage of Serbia. *Quaternary International* **240**: 108–116. https://doi.org/10.1016/j.quaint.2010.07.008

Vermeersch PM. 2020. Radiocarbon Palaeolithic Europe database: a regularly updated dataset of the radiometric data regarding the Palaeolithic of Europe, Siberia included. *Data in Brief* **31**: 105793. https://doi.org/10.1016/j.dib.2020.105793

Villa P. 1983. Terra amata and the Middle Pleistocene Archaeological Record of Southern France (University of California Publications in Anthropology). *Publications in Anthropology* **13**: 1–303.

Vujičić MD, Vasiljević DA, Hose TA *et al.* 2018. A multi-criteria decision analysis with special reference to loess and archaeological sites in Serbia (Could geosciences and archaeology cohabitate?). *Open Geosciences* **10**: 333–343. https://doi.org/10.1515/geo-2018-0026

Weijers JWH, Schouten S, van den Donker JC *et al.* 2007. Environmental controls on bacterial tetraether membrane lipid distribution in soils. *Geochimica et Cosmochimica Acta* **71**: 703–713. https://doi.org/10.1016/j.gca.2006.10.003

Wilczyński J, Wojtal P, Łanczont M *et al.* 2015. Loess, flints and bones: multidisciplinary research at Jaksice II Gravettian site (southern Poland). *Quaternary International* **359–360**: 114–130. https://doi.org/10.1016/j.quaint.2014.04.002

Wilczyński J, Žaár O, Nemergut A *et al.* 2020. The Upper Palaeolithic at Trenčianske Bohuslavice, Western Carpathians, Slovakia. *Journal of Field Archaeology* **45**: 270–292. https://doi.org/10.1080/00934690.2020.1733334

Zech M, Pedentchouk N, Buggle B *et al.* 2011a. Effect of leaf litter degradation and seasonality on D/H isotope ratios of n-alkane biomarkers. *Geochimica et Cosmochimica Acta* **75**: 4917–4928. https://doi.org/10.1016/j.gca.2011.06.006

Zech M, Zech R, Buggle B *et al.* 2011b. Novel methodological approaches in loess research – interrogating biomarkers and compound-specific stable isotopes. *Eiszeitalter & Gegenwart Quaternary Science Journal* **60**: 170–187. https://doi.org/10.3285/eg.60.1.12

Zech R, Gao L, Tarozo R *et al.* 2012. Branched glycerol dialkyl glycerol tetraethers in Pleistocene loess–paleosol sequences: three case studies. *Organic Geochemistry* **53**: 38–44. https://doi.org/10.1016/j.orggeochem.2012.09.005

Zeeden C, Hambach U, Klasen N *et al.* 2021. Sedimentology of a Late Quaternary lacustrine record from the south-eastern Carpathian Basin. *Journal of Quaternary Science* **3297**. https://doi.org/10.1002/jqs.3297

Zeeden C, Hambach U, Obreht I *et al.* 2018. Patterns and timing of loess–paleosol transitions in Eurasia: constraints for paleoclimate studies. *Global and Planetary Change* **162**: 1–7. https://doi.org/10.1016/j.gloplacha.2017.12.021

Zeeden C, Hambach U, Steguweit L *et al.* 2009. Using the relative intensity variation of the Earth's magnetic palaeofield as correlative dating technique: A case study from loess with Upper Palaeolithic cultural layers at Poiana Cireşului. *Romania. Quartär* **56**: 175–185.

Zeeden C, Krauß L, Kels H *et al.* 2017. Digital image analysis of outcropping sediments: comparison to photospectrometric data from Quaternary loess deposits at Şanoviţa (Romania) and Achenheim (France). *Quaternary International* **429**: 100–107. https://doi.org/10.1016/j.quaint.2016.02.047

Zeeden C, Obreht I, Veres D *et al.* 2020. Smoothed millennial-scale palaeoclimatic reference data as unconventional comparison targets: application to European loess records. *Scientific Reports* **10**: 5455. https://doi.org/10.1038/s41598-020-61528-8 [PubMed: 32214119]

Zeuner FE. 1956. Loess and palaeolithic chronology. *Proceedings of the Prehistoric Society* **21**: 51–64. https://doi.org/10.1017/S0079497X00017400

Zhang H, Lu H, Wang S *et al.* 2017. Consistent C3 plant habitat of hominins during 400–300 ka at the Longyadong Cave site (Luonan Basin, central China) revealed by stable carbon isotope analyses of loess deposits. *Journal of Human Evolution* **108**: 1–10. https://doi.org/10.1016/j.jhevol.2017.01.011 [PubMed: 28622923]

Zhao Y, Zhou J, Chen F *et al.* 2021. Lithic technological responses to environmental change during the penultimate glacial cycle (MIS 7–6) at the Yangshang site, western Chinese Loess Plateau. *Quaternary Research* **103**: 148–159. https://doi.org/10.1017/qua.2020.114

Zhu Z, Dennell R, Huang W *et al.* 2018. Hominin occupation of the Chinese Loess Plateau since about 2.1 million years ago. *Nature* **559**: 608–612. https://doi.org/10.1038/s41586-018-0299-4 [PubMed: 29995848]

Zong X, Dong J, Cheng P *et al.* 2020. Terrestrial mollusk records in the loess sequences from eastern Central Asia since the last deglaciation and their paleoenvironmental significance. *Palaeogeography, Palaeoclimatology, Palaeoecology* **556**: 109890. https://doi.org/10.1016/j.palaeo.2020.109890 [PubMed: 109890]