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The relationship between the loess stratigraphy in the Vojvodina region of northern Serbia and the Saalian and Rissian Stage glaciations – a review

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The regional loess stratigraphy in the Vojvodina region, in the southeastern Carpathian Basin has often been successfully correlated to global palaeoclimate. This is a quasi-continuous sedimentary record provide detailed environmental reconstruction during the last four glacial/interglacial cycles. In this study, we present a standardized loess stratigraphy and illustrate how it correlates with the marine oxygen isotope and Chinese loess stratigraphical records. We argue that the loess stratigraphy in Vojvodina region is an important link in the integration of European terrestrial stratigraphical schemes and the deep sea stratigraphical model. We highlight how the loess record can better illustrate terrestrial environmental change through multiple glacial cycles then other records, such as glacial records. The investigated loess record enables direct links to be made between the loess sediments and their glacial sources. This reveals evidence of glaciations during every glacial cycle of the Saalian Stage complex, equivalent to MIS 10, 8, and 6. Therefore, Serbian loess has the potential to provide a direct link between terrestrial glaciations and wider records of global climate change, which is an enigma for many other continental records. These loess records display a strong relationship with the intensity of European glaciations during different glacial cycles. Loess sedimentation rates are highest in the most intensive European glaciation of the Saalian complex (MIS 6) and much lower during the weaker “missing” glaciations equivalent to MIS 8 and 10. A key observation from the Vojvodina loess is the gradual increase in interglacial aridity through the late Middle Pleistocene. The explanation for the progressively increasing aridity in the investigated region at this time is still unclear. However, this trend is consistent with the idea of the Saalian complex as representing a 400 ka mega glacial cycle modulated by shorter classic 100 ka glacial cycles.

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The Pleistocene Epoch was characterised by the development of alternating widespread glaciations, within glacial cycles separated by interglacials, across the mid-northern latitudes. Regionally, Pleistocene glaciations varied spatially and temporally in magnitude (Batchelor *et al.* 2019). Despite significant advances in radiometric dating methods, stratigraphical interpretations for this time interval are still under debate (Head *et al.* 2008; Hughes *et al.* 2020).

The terrestrial Pleistocene stratigraphy across Europe is characterised by many different regional models, as well as numerous stratigraphical units. The main problem for this record is how to properly correlate the various European continental sedimentary records to the key, global, Quaternary climatic oscillations. Initial work on this matter began with Penck & Brückner (1909) and Soergel (1919). After the fundamental book of Köppen & Wegener (1924, including the important chapter of Milanković), Woldstedt (1929) and Zeuner (1938) tried to provide a proper chronology for the Quaternary Ice Age. On the shoulders of those giants, and applying novel isotopic methods on marine microfossils, Emiliani (in the 1950's) subdivided Quaternary deep-sea sediments based on quasi-periodic oscillations of cold and warm phases, and tried to correlate them to the glacial/interglacial cycles (Emiliani 1955; Emiliani & Geiss 1959; Emiliani & Shacketon 1974), as initially defined by Penck & Brückner (1909). Later, Kukla (1977) compared data from the central European loess and deep-sea sediments, opening up new approaches for land-sea stratigraphical correlations.

Currently, the terrestrial Pleistocene stratigraphy across Europe is characterised by many coexisting regional models, as well as numerous stratigraphical units (e.g. Gibbard & Van Kolfschoten 2005; Litt *et al.* 2007; Marković *et al.* 2008, 2015; Marks *et al.* 2018, 2019; Schaetzl *et al.* 2018). This complex web is a consequence of the environmental diversity of the region, caused by the intense fluctuations of the large northern European ice belt and the intensely glaciated Alps and other mountainous regions, surrounded by widespread lowlands. All of these areas have been open to the complex climatic influences and interplay of Polar, North Atlantic, Mediterranean and Continental air masses. The resultant, exceptional, Pleistocene stratigraphical diversity is a consequence of these natural dynamics. This inherent complexity has been explained via different schools of thought, developed in various European countries, as they undertook their own research and analyses. Thus, the international scientific community has been left with the significant task of fitting these numerous, regional, Pleistocene stratigraphical models into a more broadly-defined, European-scale, stratigraphical mosaic. Despite the rapid development of different methodological approaches during the last several decades, the reconciliation of the various regional stratigraphical models, obtained from surveys of different types of sediments, still represents a major research challenge.

The famous stratigrapher George Kukla (2005: p. 1573) posed the important question of how many glacials and how many interglacials were there in the last half million years. Kukla indicated that in the classic North European (Fennoscandian) stratigraphical system a postglacial (Flandrian) and two interglacials, the Eemian and the Holsteinian were recognised, separated by three glacials defined by three chronostratigraphical cold stages the Weichselian, Saalian and Elsterian Stages. This contrasts with evidence five interglacial/glacial cycles documented in continuous deep-sea (Bassinot*et al.* 1994; Lisiecki & Raymo 2005), lake sediments (Tzedakis *et al.* 2006), loess-soil sequences (Kukla 1987; Marković *et al.* 2015) and in the Antarctic ice cores (EPICA members 2004). Which stratigraphical subdivision is correct? Kukla raised new questions: is the classic stratigraphical system, pieced together from discontinuous sets of glacial moraines, river terraces and deposits of sea-level transgressions wrong? Or are the oceanic data and other continuous palaeoclimatic records misinterpreted? However, it turns out that both systems are essentially correct. The discrepancy is the result of the different understanding of basic Pleistocene climatostratigraphical units, the glacials (or cold stages) and the interglacials (or warm stages), and their interpretation in different geological records (cf. Gibbard & West 2000). This example illustrates the current unconformities between the various terrestrial and marine Pleistocene stratigraphical records.

Since at least the end of 19th century, the results of the continuing efforts in subdividing the geological and morphological remnants of continental ice sheets and alpine glaciations have been correlated across Europe. These models formed the initial backbone of the temporal subdivision of the Quaternary Ice Age (e.g. Penck & Brückner 1909). Unfortunately, this stratigraphical scheme is inherently characterised by unconformities and discontinuities, and represents a fragmentary record which create difficulties for comparisons to the more continuous ice-core, marine, and/or lacustrine stratigraphical records (Gibbard & West 2014; Gibbard & Hughes 2021). We argue that the loess stratigraphical record has the potential to alleviate some of these issues, as the loess-palaeosol sequences (LPS) of Europe (and China) represent some of the best-preserved terrestrial records of environmental change for the Pleistocene (Marković *et al.* 2015).

In this study, we present climatostratigraphical interpretations based on loess deposits preserved in the Vojvodina region of northern Serbia. These loess-palaeosol sequences represent one of the most complete and detailed European continental archives of Pleistocene climate and environment (Marković *et al.* 2015). A similar stratigraphical approach, provided by Vandenberghe (2000), compared the Chinese loess stratigraphy with the Northern European Pleistocene stratigraphical models. The main Middle Pleistocene loess sections in the Vojvodina region are on the Srem and Titel loess plateaux (Fig. 1). These areas lie between the Arctic, Atlantic, Continental and Mediterranean climatic zones, all of which have varied in intensity and expanded or contracted through time, and in so doing, reflect the timing and intensity of interglacial, glacial, interstadial, and stadial climates. In addition, loess in the Vojvodina region has been successfully correlated to various glacial, periglacial, fluvial and aeolian processes (Smalley *et al.* 2009).

The Alps are probably the most significant source of silt for this region, having been transported from the Alpine catchments by the Danube fluvial system, thereby facilitating the deposition of loess across a vast loess belt (Buggle *et al.* 2008; Újvári *et al.* 2008, 2012; Marković *et al.* 2015; Fenn *et al.* 2021; Fig. 1). Additional Middle Pleistocene dust sources were likely from glaciated catchments in the Dinaric Alps (Hughes *et al.* 2011; Adamson *et al.* 2014; Radaković *et al.* 2023) and the Carpathians (Urdea *et al.* 2022). Thus, the LPS in the Vojvodina region hold great potential as the basis for a climatostratigraphical model that is sensitive enough to adequately link the regional (i.e. Balkans and central Europe), North European, and Alpine classic stratigraphical subdivisions with the global marine isotope stratigraphy (Bassinot *et al.* 1994; Lisiecki & Raymo 2005), as well as with the general, glacial climatic cycles and super cycles defined by Kukla *et al.* (1961) and Kukla & Cilek (1996).

This paper aims to review the evidence for climate change recorded in the loess sequences of Serbia during the Saalian Stage complex (Marine Isotope Stage, MIS 10-6) and compare with the equivalent Rissian Stage glaciations of the Alps and other mountain areas of southern Europe. A further aim is to assess the degree to which the loess records can form the basis for regional chronostratigraphical frameworks to which glacial and other terrestrial records of Europe can be tied to aid regional terrestrial correlation with other records of global environmental change such as the marine isotope record.

Material and methods

Study area

Vojvodina is a lowland region in northern Serbia, located in the southeastern part of the Carpathian (Pannonian) Basin, and encompassing the confluences of the Danube, Sava and Tisa Rivers. More than 60% of this lowland area is covered with loess and loess-like sediments (Marković *et al.* 2008; Lehmkuhl *et al.* 2018; Fig.1). Its complex geomorphic evolution reduced what may have been a previously significantly larger distribution of loess to what is now six discontinuous loess plateaus, separated by the alluvial plains of the Danube, Tisa, Sava, Tamiš and Karaš Rivers (Marković *et al.* 2008). The investigated area is positioned in an important geographic location, i.e., close enough to the Atlantic Ocean to record its weak influence, but at the same time isolated inland by surrounding mountains and protected from intensive cold Arctic air masses. Currently, the Vojvodina region is one of the driest parts of the Carpathian Basin (Gavrilov *et al.* 2020). Because its palaeogeographical setting, the Middle and

Late Pleistocene LPS in the Vojvodina region are better preserved and more complete than those elsewhere, as indicated by other European loess-palaeosol records (Lehmkuhl *et al.* 2021). Furthermore, although cryogenic features are identified in many other European loess sites (Vandenberghe *et al.* 1998; Antoine *et al.* 2001; Rousseau *et al.* 2001; Jary 2009), no such features have been reported for the Vojvodina region, probable because of its continuously dry, continental climate (Hrnjak *et al.* 2014; Gavrilov *et al.* 2020). Thus, the 'temperate', warm and semi-arid, southeastern European loess province (Smalley *et al.* 2011; Lehmkuhl *et al.* 2021) is considered to be part of a transcontinental loess belt which is the most westerly extension of the Central Asian (e.g. Dodonov & Baizugina 1985; Machalett *et al.* 2008) and Chinese loess provinces (e.g. Kukla1987; Kukla & An 1989; Lu *et al.* 2022).

Correlation of magnetic records

Due to their good preservation, the LPS in the Vojvodina region represent one of the oldest and most complete European loess records (e.g. Marković *et al.* 2011, 2012a, 2015). Importantly, several characteristics of the LPS in the Vojvodina region allow for the use of magnetic data for stratigraphical correlation. Firstly, LPS in the Vojvodina region are quasi-continuous, at least on multi-millennial scale. Secondly, an additional advantage involves the relatively uniform (loess) stratigraphy of the region, with a relatively small number of stratigraphical sub-units, in comparison with other European loess provinces (Marković *et al.* 2008; Buggle *et al.* 2009). Finally, the similarities of the patterns in the normalized magnetostratigraphical records between the different loess sections in Vojvodina provide opportunities to relatively easily and accurately develop inter-profile correlations (Marković *et al.* 2018). In our study, we correlated the magnetic records from five of these loess sites: Titel loess plateau composite sequence (Marković *et al.* 2015), Zemun (Laag *et al.* 2021), Batajnica (Marković *et al.* 2009a), Stari Slankamen (Marković *et al.* 2011) and Ruma (Marković *et al.* 2006), as well as the records from Hungarian loess sites Sütto (Novothny *et al.* 2011) and Paks (Sartori *et al.* 1999), and the Ukrainian loess sequence Dolynske (Hlavatskyi & Bakhmutov 2021).

Sedimentation rates

Sedimentation rates were calculated as: loess (L) or palaeosol (S) unit thickness (in cm), obtained for the equivalent LPS stratigraphical units at these loess sections, divided by the length of the unit's formation (in ka), based on the direct correlation with the Marine Oxygen-Isotope Stages (MIS) chronology (Bassinot *et al.* 1994; Aitken 1997; Lisiecki & Raymo 2005).

Environmental reconstruction

Environmental reconstructions were performed according to land snail fauna within the loess layers L4 to L3 at the Titel loess plateau (Radaković *et al.* 2023). Detailed palaeopedological interpretations were also based on palaeosol stratigraphical units S4 to S2 from the Titel loess plateau, and from the Zemun, Batajnica, Stari Slankamen and Ruma sections (Marković *et al.* 2006, 2009a, 2012a, 2015; Laag *et al.* 2021).

A brief history of the loess stratigraphy interpretations in the Vojvodina region

Rivalled perhaps only by work in China, highly significant advances have been made regarding loess research in the Vojvodina region (e.g. Marković *et al.* 2015, 2016). For example, we note (i) the first description of European LPS (Marsigli 1726; Marković *et al.* 2009b), (ii) significant improvements in palaeopedological interpretations from fossil soils in LPS (Bronger 1976, 2003; Marković *et al.* 2004a, 2009b, 2023; Buggle *et al.* 2011), (iii) the successful application of amino-acid racemisation (AAR) geochronology in LPS, for the purposes of subdividing the glacial/interglacial cycles (Radaković *et al.* 2023; Marković *et al.* 2004b, 2005, 2006, 2007, 2008, 2021; Murray *et al.* 2014), (iv) the development of a Eurasian LPS transcontinental correlation (Marković *et al.* 2009a, 2011, 2012a, 2015; Liu *et al.* 2013; Basarin *et al.* 2014), and (v) the fundamental methodological developments in luminescence dating of LPS sediments and soils (Singhvi *et al.* 1989; Stevens *et al.* 2011; Murray *et al.* 2014; Perić *et al.* 2019, 2020, 2022; Avram *et al.* 2020).

An illustrative example of the progress of research on loess pedostratigraphy comes from the Vojvodina region (Table 1). The first pedostratigraphy of the LPS in the Vojvodina region was developed by Bronger (1976), based on a proposed set of dominant palaeopedological stratigraphical criteria defined at the 6th Congress of the International Union for Quaternary Research, held in 1961, in Warsaw, Poland (Smalley *et al.* 2010). In this interpretation, Fink (1962) postulated that the youngest Brown Forest Soil or Brown Forest Soil-Lessivé palaeosol, exposed within different loess exposures, was equivalent to the last (Riss/Würm or Eemian) interglacial, or ~MIS 5e. What was a conceptual pedostratigraphical opinion at that time has been shown to be correct for areas within the Western and Central European loess provinces (e.g. Rousseau 2001; Lehmkuhl *et al.* 2021). Bronger (1976) later developed the first uniform nomenclature for fossil soils in loess, based on work in the Middle Danube area. His nomenclature included the label F for individual fossil soil complexes. Each soil was assigned a numerical suffix (e.g., F1, F2, etc.), according to its stratigraphical position. However, this generalized pedostratigraphical model did not include the recent (Holocene), as well as the Pleistocene, environmental gradients. For example, the majority of the recent vegetation cover in the western and central European loess belt was steppe-like, having developed in the Middle Danube Basin (e.g. Marković *et al.* 2015). Many of the other (older) soils had developed under a forest cover.

The application of luminescence dating techniques and AAR relative geochronological methods have led to many subsequent chronostratigraphical revisions of the LPS interpretations for the region. Thermoluminescence dating by Singhvi *et al.* (1989) indicated that the fossil chernozems F2 and F3 were formed no earlier than MIS 5a and 5e. Bronger (2003) accepted this chronostratigraphical evidence and correlated palaeosols F5, F4, F3, and F2 with MIS 11 or MIS 9, MIS 7, MIS 5e or MIS 5a, respectively. Research by Marković *et al.* (2004a, b, 2005, 2006, 2007, 2008), based on the application of AAR geochronology, found that between palaeosols F3 and F2 there must have passed ample time for the duration of one glacial phase. The discovery that each palaeosol corresponds to an interglacial and each loess unit to glacial period led to the formation of a new, more accurate stratigraphical model (Marković *et al.* 2004a, b).

Our proposed loess stratigraphy for the Vojvodina region is designed to follow the Chinese loess stratigraphy (Kukla 1987, Kukla & An 1989). Therefore, we designate both L (loess) and S (fossil soil) stratigraphical units in the Vojvodina region, numbered in order of increasing age. Initially, this model used the prefix "SL" referring to a key loess section at Stari Slankamen (Marković *et al.* 2004a, b), or "V" for the Vojvodina region (Marković *et al.* 2008). Finally, we note that Marković *et al.* (2015) proposed the same stratigraphical model that Kukla (1987) introduced for the Chinese loess sequences (Fig. 2). This novel stratigraphical scheme allows for the standardisation of the (so far) highly regionally specific stratigraphies of European loess sections and offers a greater potential for correlation among the various Eurasian loess stratigraphical records (Marković *et al.* 2012a, 2015).

Recent studies using more advanced luminescence dating techniques continue to support this new pedostratigraphical model (Schmidt *et al.* 2010; Stevens *et al.* 2011; Murray *et al.* 2014; *Avram et al.* 2020; Perić *et al.* 2022). Specifically, these studies support the interpretation that palaeosols S4 (F5), S3 (F4), S2 (F3) and S1 (F2) in the Vojvodina region are stratigraphically equivalent to MIS 11, 9, 7 and 5, respectively (Marković *et al.* 2009b, 2011, 2015; Vandenberghe *et al.* 2014; Song *et al.* 2018; Fu *et al.* 2021). Fig. 3 illustrates this evolution of chronostratigraphical interpretations, based on the success of studies at the Stari Slankamen section, thereby providing an improved agreement between the luminescent ages and the assumed geological ages.

Magnetic stratigraphy

Variations in the magnetic susceptibility (MS) of the loess in the Vojvodina region are generally related to the abundance of magnetic minerals, and thus are a reflection of pedogenic processes, i.e., degree of soil development (Maher & Thompson 1992; Heller & Evans 1995; Namier *et al.* 2021). Ever since Heller & Liu (1984) promoted MS as a sensitive palaeoclimatic proxy, it has become the most commonly applied climatostratigraphical tool in global loess research. MS variations recorded in LPS reflect–surprisingly well–the pedostratigraphy (Heller & Liu 1984; Heller & Evans 1995; Evans & Heller 2001; Liu *et al.* 2013; Song *et al.* 2018; Zeeden *et al.* 2018). The enhancement of the magnetic signal due to pedogenesis appears to be valid for most parts of the semi-arid, Eurasian loess belt (Liu *et al.* 2013; Namier *et al.* 2021). Loess magnetic properties are therefore an efficient tool for inter-profile correlations, correlating well, even across long distances (Marković *et al.* 2012a, 2015, 2018).

Fig. 4 shows our proposed correlations between the magnetic records of the main loess sections in the Vojvodina region, specifically the composite profile of the Titel Loess plateau LPS (Marković *et al.* 2015), Zemun (Laag *et al.* 2021), Batajnica (Marković *et al.* 2009b), Stari Slankamen (Marković *et al.* 2003, 2011), and Ruma (Marković *et al.* 2006), as combined with the magnetic record of the Hungarian sections at Sütto (Novothny *et al.* 2011) and Paks (Sartori *et al.* 1999) and the Ukrainian loess site at Dolynske (Hlavatskyi & Bakhmutov 2021) as well as a broad-scale correlation with the synthetic MIS record (Lisiecki & Raymo *et al.* 2005). All these sections represent data from a plateau-like loess deposit, i.e., one that is predominantly controlled by climatic variations. We argue that then most reliable and palaeoclimatically meaningful correlations, using LPS data, derive from sections formed through dust deposition and subsequent pedogenesis on stable, plateau-like landforms (Sprafke & Obreht 2016; Marković *et al.* 2018). Erosion on these kinds of broad, loess plateaux is typically restricted to their steep edges/margins, preserving the entire loess depositional system in the centre (Porter & An 2005; Lukić *et al.* 2009; Bjelajac *et al.* 2016), with some exceptions (Stevens *et al.* 2007, 2018; Marković *et al.* 2011). Nonetheless, the lack of depositional gaps in any LPS must always be independently verified through careful field observations, multi-proxy datasets, and high-resolution numerical dating. The overall similarity and general agreement of the magnetic records among the different loess sections in the Vojvodina region provide for the opportunity to recognise such depositional hiatuses, such as at Stari Slankamen. Here, the MS record, as well as independently determined data on ages and aminostratigraphy (Marković *et al.* 2011; Murray *et al.* 2014) indicate a missing pedocomplex S2, as well as parts of loess layers L2 and L3. This missing part of the sequence is associated with an erosional unconformity represented by a distinct gravel stratum. Similarly, an unconformity within the L4 loess horizons of the Zemun loess sequence has been ascribed to an intercalated fluvial sedimentary sequence (Laag *et al.* 2021). Both of these stratigraphical anomalies are also visible within the exposure.

Recently, Namier *et al.* (2023) explored the possibilities for correlation of tephras among different loess sections through magnetic approaches, as well as the chronological implications of the tephras embedded in the Danube loess. Three tephra layers are indicated by the magnetic susceptibility spikes in loess units L5, L4, and L2 from the Serbian loess sections (Fig. 3). The rock magnetic results and mineral composition analysis support attribution of the Tephra-L5 to the same volcanic province as the Tephra-L4 from Alban Hills. Tephra-L5 possibly corresponds to the eruption of the Pozzolane Rosse phase at around 457 ka (MIS 12). Tephra-L4 is the stratigraphical equivalent to the Bag tephra, which was emplaced during MIS 10 (Namier *et al.* 2023) This relative tephrostratigraphical framework supports the chronostratigraphical model of Marković *et al.* (2011, 2015) and Song *et al.* (2018), in which the S4 palaeosol should correspond to MIS 11, instead of being incorporated into MIS 9 (Sümegi *et al.* 2018).

Alongside the widely used MS signal in correlation, future studies may also choose to examine the use of grain-size records as stratigraphical tools. An obvious reason is that the grain-size signal is preserved exactly at the sedimentary level where it is produced, but the MS signal is developed over time, being essentially the product of a weathering horizon, which means that it is affected by downward leaching in the soil and thus is an averaged signal over the soil thickness (as, for example, is also the case for soil colour). The consequence is that, in a sedimentary profile, the peaks of the grain size and MS may occur at slightly different depths (Vandenberghe 2012).

The problematic L2 and S2 stratigraphical units

The stratigraphical boundaries between the major LPS in the Vojvodina region are generally well defined. However, an exception occurs in the subdivision between the L2 and S2 stratigraphical units (Buggle *et al.* 2009; Marković *et al.* 2015) (Fig.2).

One of the most recognizable patterns in the MS record of the Danube loess belt (Buggle *et al.* 2009; Marković *et al.* 2015), through Tajikistan (Ding *et al.* 2002; Dodonov *et al.* 2006) to China (Sun *et al.* 2006; Hao *et al.* 2012), is associated with pedocomplex S2. This uppermost, weakly developed palaeosol subunit S2(S)S1 in the Vojvodina region has only minimal MS enhancement and is indicated by a darker grey background and the symbol “?” in Fig. 2. Buggle *et al.* (2009) proposed three possible solutions for the S2(S)S1 palaeosol subunit stratigraphical position dilemma. First, it may be correlated to the upper part of the slightly split, major S2 MS peak at the Louchuan loess section (Heslop *et al.* 2000), as well as at Lingtai/Zhaojiachuan (Sun *et al.* 2006). This correlation is, however, not supported by the work of Jordanova & Petersen (1999) and Panaiotu *et al.* (2001) and suffers from its weak pedogenic imprint and relative low MS signal in other, key Danubean loess sections (Jordanova & Petersen 1999; Panaiotu *et al.* 2001; Buggle e*t al*. 2009; Marković *et al.* 2009b, 2015). Second, it may be correlated to the “bend” in the top of the major S2 susceptibility peak at the Louchuan section (Heslop *et al.* 2000) and with a peak (LZb) in the MS record at Lingtai/Zhaojiachuan, which has an assumed age of 192 ka (Sun *et al.* 2006). Third, it may be correlated to the weak MS peak of the S2(S)S1 unit, at 167 ka in Lingtai/Zhaojiachuan (Sun *et al.* 2006). This last correlation is in agreement with the work of Jordanova & Petersen (1999) and Panaiotu *et al.* (2001). However, with an age of 167 ka, the weakly developed S2(S)S1 palaeosol would then be assigned to MIS 6 (Buggle *et al.* 2009), following Sun *et al.* (2006).

The rapid development of new luminescence methods, already applied to loess sections in the Vojvodina region (Perić *et al.* 2019, 2022; Avram *et al.* 2020), gives hope that this chronostratigraphical problem may soon be resolved.

Sedimentation rates

Fig. 5 shows the sedimentation rates for individual loess sections, as well as average values for each stratigraphical unit. Generally, the highest sedimentation rates (SR), especially of loess units associated with the LPS on the Titel loess plateau, have SRs that exceed 8 cm ka^{-1} (loess units L4 (the SR 14.1 cm ka^{-1}), L3 and L2). The SRs for the L4 loess unit at Titel loess plateau are significantly (2-6 times) higher than for the other sections. Therefore, we suggest that the high SR for L4 loess on the Titel loess plateau can be regarded as an outlier.

The basal, cambic-like palaeosol S4 has the lowest SR (3 cm ka^{-1}) of all the sites examined here. Contrary to the low average SR values in loess units L4 and L3 (~4 cm ka^{-1}), the average SR for palaeosol S3 is significantly higher (6.6 cm ka^{-1}). Because of their problematic stratigraphical status, units S2 (7.3 cm ka^{-1} and 5.5 cm ka^{-1}) and L2 (6.1 cm ka^{-1} and 3.9 cm ka^{-1}) have two calculated average SR values. The lowest SR rates occur during the MIS11, when the soil S4 developed. The LPS couplets L4/S3 and L3/S2 indicate average SRs of ~4 cm ka^{-1} and 6 cm ka^{-1}, respectively. Finally, the coldest glacial phase is associated with Penultimate Glacial Maximum, i.e., the Late Saalian Substage. As expected, this interval exhibits rapid dust deposition. If we assume that the weakly developed S2SS1 or L2SS1 palaeosol and the thin basal loess are part of the composite loess unit L2, then the SR assigned to MIS 6 is almost 8 cm ka^{-1}.

The data on the different SRs for the loess sections in the region are in accordance with global evidence on glaciation intensity during the various glacial cycles (Hughes *et al.* 2020). Lower SRs related to loess units L4 (with the exception of the Titel loess plateau) and L3 correspond with MIS 10 and 8, which were characterised by relatively limited glacier extent in northwestern Europe and North America (Hughes *et al.* 2011, 2020). This is in contrast to other, Middle Pleistocene glaciations in the Late Saalian Substage (~MIS 6), which may have had much larger extents and which are correlated to the higher SRs for loess unit L2. Alternatively, SRs for fossil pedocomplexes increase with time, as interglacial environments had transformed from forest, to forest-steppe, and finally, to fully steppe landscapes (Table 2).

Additionally, at some loess exposures in the Vojvodina region, such as at Ruma (Vandenberghe *et al.* 2014), loess deposition was nil during the interglacials, as was characteristic for interglacial loess in China. During these interglacials, soil formation was active and dominant, having taken place in the previously deposited loess with its relatively coarse grain size. These conditions may well be understood, given that all the possible source regions for silt uptake (on interfluves as well as the floodplains of the Danube) were vegetated (forest steppic or even temperate forests) in Europe. This situation contrasts with that in China, where large deserts were present during interglacials, as nowadays, facilitating at least some amount of silt deflation and loess deposition.

Environmental dynamics

During the formation of the Cambisol pedocomplex S4 (MIS 11) at sites on the Titel Loess Plateau, as well as on the Srem loess plateau (Zemun, Batajnica and Stari Slankamen), the study area was dominated by forest. However, MIS 11 is the last Pleistocene interglacial in which a climate favourable to forest occurred in this region (Table 2). Palaeoenvironmental reconstructions for the MIS 9 interglacial show that environmental conditions during this period had shifted towards increased aridity (Marković *et al.* 2012a, 2015). Thus, on the Titel loess plateau, and at the Batajnica, Zemun and Stari Slankamen sites, fossil soils with phaeozem morphologies indicate the presence of a forest-steppe vegetation cover at this time. This interpretation differs from that at the Ruma section (on the southern slopes of the Fruška Gora Mountain), which appears to have still supported forest at this time. Finally, during MIS 7, the palaeosol S2 has Chernozem morphologies at all the studied loess sections, indicating that it formed under grassland conditions (Table 2).

Most or all of the fossil pedocomplexes in the loess plateau deposits are intercalated with minimally-altered loess, such as layers L4, L3 and L2. On the Titel Loess Plateau, the loess is assumed to have been deposited under (more or less) dry, steppic conditions. The absence of cryoturbation features, as well as presence of numerous krotovinas (small mammal burrows) help to refine better the details of the steppic environments (Marković *et al.* 2008, 2012a, 2015).

As might be expected, evidence for a gradual increase in interglacial aridity during the late Middle Pleistocene in the Vojvodina region is not observed in the globally integrated marine (Lisiecki & Raymo 2005) and ice core records (EPICA community, 2004). This disparity suggests that regional climate variability was not coupled to global climate drivers. The explanation for the progressively increasing aridity in the southeastern Carpathian Basin (Marković *et al.* 2009b, 2011, 20012a, 2015; Buggle *et al.* 2013) and the Balkan region (Obreht *et al.* 2016) at this time is still unclear. However, this trend of gradually increasing interglacial aridity is typical of the glacial/interglacial cycle, or mega cycle, as defined by Kukla (1975, 2005). The evidence of long-term 400 ka glacial cycles was recognised by Rial (1999) who identified the role of eccentricity and its effects on precession as a driving mechanism. This was phenomenon was reiterated by Hughes and Gibbard (2018: p. 237) who suggested that 400 ka glacial cycles are modulated by the shorter classic 100 ka glacial cycles. Thus, mega glacial cycles may apply to not only the Saalian complex but other groups of glacial cycles too.

These statements are supported by the recent results of Ning *et al.* (2023). They found that the lithogenic susceptibility of Pleistocene LPS in the Chinese Loess Plateau, Central Asia, and Europe shows synchronous, long-term increases since ~0.6–0.5 Ma, suggestive of intensive glacial erosion and/or river incision in the surrounding mountains, which were dust sources. The dramatic increase in lithogenic susceptibility of Eurasian LPS provides new insights into the close relationships between global climate changes and dust source erosion.

The Saalian Stage supercycle

Long-term, Plio-Pleistocene climatic trends appear to indicate gradual cooling, suggested by the increasing amplitude of $\delta^{18}O$ values over time (Lisiecki & Raymo 2005). Some of the coldest glacial phases occurred during MIS 12, 6 and 2. These events correspond to loess units L5, L2, and L1 (more precisely L1LL1), as well as to the Elsterian, Saalian, and Weichselian Stage ice advances (Hughes *et al.* 2020). This synchronicity suggests a direct link between global climate changes, as recorded in the deep-sea sediments, and northern ice-sheet and Eurasian dust deposition dynamics (Kukla & Cilek 1996).

A similar stratigraphical approach, provided by Vandenberghe (2000) correlates palaeosols in the Chinese loess (S3 and S2) with MIS 9 and 7, as well as with the Landos and Hoogeveen-Belvédère warm phases of North-west European Pleistocene chronostratigraphical model, respectively.

Marković *et al.* (2015) subdivided the Danube LPS into six, higher order (litho- and pedo-) stratigraphical members, each generally coinciding with the “super-cycles” of Kukla (2005). Kukla (1995) had previously invoked “super-cycles” in order to bring the classical continental stages into correspondence with the marine isotope record. Each of these cycles comprises more than one glacial-interglacial cycle, beginning with an initial interglacial phase and finishing with the next the most substantial glacial period. Kukla (2005) compared the structure of these “super-cycles” with an enlarged individual glacial-interglacial cycle. Between “super-terminations”, a “super-cycle” includes an introductory interglacial (equivalent to an interglacial period), in this case, pedocomplex S4, the alternation of reduced climatic amplitude interglacials/glacials (representing early glacial conditions) - loess-palaeosol couplets L4/S3 and L3/S2 and finally, the coldest glacial phase of the "super-cycle" (full-glacial conditions), corresponding to loess unit L2. From this point of view, the 3rd LPS "super-cycle", as defined by Marković *et al.* (2015), can be regarded as an equivalent to the Saalian Stage "super cycle" of Kukla (2005).

The average duration of the Danube loess "super-cycles" is *c.* 250 ka (Basarin *et al.* 2014). Marković *et al.* (2012b) reported that spectral analyses of the orbitally tuned LPS record has its most prominent peak at 256 ka, followed by peak at 97 ka, indicating that climate dynamics in the Vojvodina region are dominated mainly by Earth's orbital eccentricity. In addition, a number of significant nonprimary spectral peaks also exist. Obliquital forcing is not represented over the studied time interval by a spectral peak of 41 ka, but peaks of 38 and 35 ka are observed. Orbital forcing at 24, 22, and 19 ka are consistent with precession parameters. We have no explanation for the prominent peak of 66 ka, although a weak 66 ka peak is also seen in Chinese loess record (Lu *et al.* 2004) (Fig. 6). Super cycles defined in this way can hardly be considered as climatostratigraphical units of a higher rank. Instead, they more likely represent the specific expression of palaeoclimate in the regional sedimentary records.

The Alpine Rissian Stage glaciations

Beginning long ago, the Alpine system was the most broadly applied stratigraphical model of intercontinental correlation for Pleistocene deposits (Penck & Brückner 1909).

This early system recognized the Würm(-ian), Riss(-ian) and Mindel(-an) glacials, and the intervening Riss/Würm and Mindel/Riss interglacials, based on type sections (for the glacials) of fluvial terraces in the northern Alpine foreland of southern Germany. The intervening interglacials were originally represented by the erosional steps between the terraces. During the interglacials, soils developed on the terrace treads. It was later shown, however, that the erosional intervals in the Alpine foreland occurred mostly during glacial intervals and that the terraces contain evidence of both glacial as well as interglacial climates (e.g. Kukla 2005). Thus, this early stratigraphical model, initially based on morphostratigraphical criteria, has since been partly modified and adapted to the astronomical insolation calendar developed by Milanković (1941).

Currently, the relationship between loess in the Vojvodina region and the Alpine glacial stratigraphical model is very general and functions only at the glacial and interglacial level. Even some prominent stratigraphical events such as the LGM are difficult to identify.

The Danube Basin includes a significant part of the Swiss Alps, as well as the Dinaric Alps, Carpathians and the Carpathian Basin. Fig. 7 represents a conceptual model illustrating the relationship between main types of deposit, as controlled by the intensity of erosion and sediment accumulation in that region. Due to the high intensity of erosion in the mountains, the region is only minimally characterized by sedimentary archives such as moraines, fluvioglacial deposits, and speleothems. Thus, one can only partially reconstruct the intensive Alpine geomorphological processes from the landforms and sediments there. We therefore argue that it is more insightful to reconstruct the dynamics of the Pleistocene Alpine glaciers from the thick, quasi-continuous sedimentary archives of the Carpathian Basin, e.g., the loess-palaeosol sequences and the various fluvial polycyclic sediments (e.g. Püspöki *et al.* 2021). Adequate deciphering of the relationship between the dynamics of the Pleistocene Alpine glaciers and loess-palaeosol sequences of the Carpathian Basin can provide this unique stratigraphical framework. Therefore, from an idealized point of view, we believe that the loess-palaeosol sequences represent the most complete and detailed record of the dynamics of Alpine and wider European glaciations, just as ocean floor sediments preserve the most detailed record of the changing global ice caps. In fact, given that the central European and Chinese loess sequences show good correlation (Fig.2), these palaeoclimate proxies are likely to represent the ebb and flow of the wider Eurasian glaciations, at a range of scales from the ice sheets to mountain glaciers. In short, the loess records of Europe and China are closely linked to the state of the global hydrological system, which is itself closely coupled with the extent of freshwater locked up in terrestrial ice. It is therefore logical that loess sequences and glaciations are closely linked, and the former offers an important indirect proxy for the extent and magnitude of glaciation during glacial cycles, at not just regional but also pan-continental scales. In this sense the loess records essential act as a parasequence (cf. Hughes *et al.* 2005) to which regional glacial (and other) records can be tied and compared with global records of environmental change, such as that of the marine isotopic record.

Conclusions

Despite the fact that solar forcing plays a major role in determining the intensity and duration of glacial and interglacial periods, the palaeosignature of these events–especially as determined from terrestrial sedimentary archives–remains problematic. The enigmatic expression of some of the so-called “missing glaciations” in continental deposits, formed during the last four glacial–interglacial cycles, appears to be associated with increased orbital eccentricity and precession (Hughes *et al.* 2020). Differences in this global climate forcing are preserved in diverse terrestrial sedimentary archives, but have none the less led to problems in stratigraphical correlation between marine, ice-core, and continental records of palaeoclimate.

The quasi-continuous LPS in the southeastern Carpathian Basin, which correlates well with the marine oxygen isotope record, offer great potential as palaeoclimate archives. We regard the loess stratigraphy of the Vojvodina region as the anchor for many of the other European, or even Eurasian, stratigraphical correlations. The geomorphological connection between the Alpine glaciers, which produced much of the sediment that eventually became loess, represents a unique opportunity for stratigraphical reconciliation of fragmentary (moraines), discontinuous (glaciofluvial and fluvial terraces, speleothem and lacustrine) and quasi-continuous LPS sedimentary records. In addition to solving these stratigraphical problems, we can also potentially provide links to the behaviour of glaciers in catchments draining into the Danube, especially from the Alps and other mountains areas such as the Dinaric Alps and Carpathians, via the grain-size composition of LPS, because the loess formed from

Danube River deposits. Using this approach, the Pleistocene chronostratigraphy can become the framework for many additional spatial and temporal reconstructions of the Pleistocene environmental mosaic in Europe.

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References

Adamson, K. R., Woodward, J. C. & Hughes, P. D. 2014: Glacial crushing of limestone and the production of carbonate-rich silts in a Pleistocene glaciofluvial system: a

597 potential source of loess in Southern Europe. *Geografiska Annaler: Series A, Physical Geography 96*, 339-356.

599 Aitken, M. J. 1997: Luminescence dating. *In* Richards, M. P. & Britton, K. (eds.): *Chronometric dating in archaeology*, 183-216. Springer, Boston.

601 Antoine, P., Rousseau, D. D., Zöller, L., Lang, A., Munaut, A. V., Hatté, C. & Fontugne, M. 2001: High-resolution record of the last interglacial–glacial cycle in the Nussloch loess–palaeosol sequences, Upper Rhine Area, Germany. *Quaternary International 76*, 211-229.

605 Avram, A., Constantin, D., Veres, D., Kelemen, S., Obreht, I., Hambach, U., Marković, S. B. & Timar-Gabor, A. 2020: Testing polymineral post-IR IRSL and quartz SAR-OSL protocols on Middle to Late Pleistocene loess at Batajnica, Serbia. *Boreas 49*, 615-633.

609 Batchelor, C. L., Margold, M., Krapp, M., Murton, D. K., Dalton, A. S., Gibbard, P. L., Stokes, C. R., Murton, J. B. & Manica, A. 2019: The configuration of Northern Hemisphere ice sheets through the Quaternary. *Nature communications 10*, 3713, https://doi.org/10.1038/s41467-019-11601-2.

613 Basarin, B., Buggle, B., Hambach, U., Marković, S. B., O'Hara-Dhand, K., Kovačević, A., Stevens, T., Guo, Z. T. & Lukić, T. 2014: Time-scale and astronical forcing of Serbian loess-paleosol sequeces. *Global and Planetary Change 122*, 89-106.

616 Bassinot, F. C., Labeyrie, L. D., Vincent, E., Quidelleur, X., Shackleton, N. J. & Lancelot, Y. 1994: The astronomical theory of climate and the age of the Brunhes-Matuyama magnetic reversal. *Earth and Planetary Science Letters 126,* 91-108.

Bjelajac, D., Mesaroš M., Schaetzl R. J., Pavić D., Micić T., Marković R. S., Gavrilov, M. B., Perić, Z. & Marković, S. B. 2016: Introducing the Loess Pyramid – an Unusual Landform in the Thick Loess Deposits of Vojvodina, Serbia. *Geographica Pannonica 20*, 1-7.

Bronger, A. 1976: *Zur quartären Klima- und Landschaftsentwicklung des Karpatenbeckens auf (palaeo-) pedologischer und bodengeographischer Grundlage*. Ph.D. thesis, Kiel University, 268 pp.

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*, 11-31.

Buggle, B., Glaser, B., Hambach, U., Gerasimenko, N. & Marković, S. B. 2011: An evaluation of geochemical weathering indices in loess–paleosol studies. *Quaternary International 240*, 12-21.

Buggle, B., Glaser, B., Zöller, L., Hambach, U., Marković, S., Glaser, I. & Gerasimenko, N. 2008: Geochemical characterization and origin of southeastern and eastern European loesses (Serbia, Romania, Ukraine). *Quaternary Science Reviews 27*, 1058-1075.

Buggle, B., Hambach, U., Glaser, B., Gerasimenko, N., Marković, S. B. Glaser, I. & Zöller, L. 2009: Magnetic susceptibility stratigraphy and spatial and temporal paleoclimatic trends in East European loess paleosol sequences. *Quaternary International 196*, 86-106.

Buggle, B., Hambach, U., Kehl, M., Marković, S. B., Zöller, L. & Glaser, B. 2013: The progressive evolution of a continental climate in SE-Central European lowlands

642 during the Middle Pleistocene recorded in loess paleosol sequences. *Geology 41*, 771-774.

644 Butrym, J. 1974: Profil lessowy Stari Slankamen - Čot Yugoslawia. *Annales Universitatis Mariae Curie-Sklodowska, Sec. B 26*, 113-133.

646 Butrym, J., Maruszczak, H. & Zeremski, M. 1991: Thermoluminescence stratigraphy on Danubian loess in Belgrade environs. *Annales Universitatis Mariae Curie-Sklodowska, Sec. B 46*, 53-64.

649 Ding, Z. L., Ranov, V., Yang, S. L., Finaev, A., Han, J. M., & Wang, G. A. 2002: The loess record in southern Tajikistan and correlation with Chinese loess. *Earth and Planetary Science Letters 200*, 387-400.

652 Dodonov, A. E. & Baizugina, L. L. 1985: Loess stratigraphy of Central Asia: palaeoclimatic and palaeoenvironmental aspects. *Quaternary Science Reviews 14*, 707-720.

655 Dodonov, A. E., Sadchikova, T. A., Sedov, S. N., Simakova, A. N. & Zhou, L. P. 2006: Multidisciplinary approach for paleoenvironmental reconstruction in loess-paleosol studies of the Darai Kalon section, Southern Tajikistan. *Quaternary International 152*, 48-58.

659 Emiliani, C. 1955: Pleistocene temperatures. *The Journal of Geology 63*, 538-578.

660 Emiliani, C. & Geiss, J. 1959: On glaciations and their causes. *Geologische Rundschau 46*, 576-601.

662 Emiliani, C. & Shackleton, N. J. 1974: The Brunhes epoch: isotopic paleotemperatures and geochronology. *Science 183*, 511-514.

EPICA community 2004: Eight glacial cycles from an Antarctic ice core. *Nature 429*, 623-628.

Evans, M. E. & Heller, F. 2001: Magnetism of loess/palaeosol sequences: recent developments. *Earth-Science Reviews 54*, 129-144.

Fenn, K., Thomas, D. S., Durcan, J. A., Millar, I. L., Veres, D., Piermattei, A. & Lane, C. S. 2021: A tale of two signals: Global and local influences on the Late Pleistocene loess sequences in Bulgarian Lower Danube. *Quaternary Science Reviews 274*, 107264, https://doi.org/10.1016/j.quascirev.2021.107264.

Fink, J. 1962: Die Gliederung des Jungpleistozäns in Österreich. *Mitteilungen der Geologischen Gesellschaft in Wien 54*, 1-25.

Fu, Y., Hao, Q., Peng, S., Marković, S. B., Gao, X., Han, L., Wu, X., Namier, N., Zhang, W., Gavrilov, M. B., Marković, R. S. & Guo, Z. 2021: Clay mineralogy of the Stari Slankamen (Serbia) loess-paleosol sequence during the last glacial cycle—Implications for dust provenance and interglacial climate. *Quaternary Science Reviews 263*, 106990, https://doi.org/10.1016/j.quascirev.2021.106990.

Gavrilov, M. B., Radaković, M. G., Sipos, G., Mezősi, G., Gavrilov, G., Lukić, T., Basarin, B., Benhye, B., Fiala, K., Kozák, P., Perić, Z. M., Govedarica, D., Song, Y. & Marković, S. B. 2020: Aridity in the central and southern Pannonian basin. *Atmosphere 11*, 1269, https://doi.org/10.3390/atmos11121269.

Geologische Bundesanstalt 2013: *Der Alpenraum zum Höhepunkt der letzten Eiszeit. Vienna (Geological Survey of Austria).* https://opac.geologie.ac.at/ais312/dokumente/Poster_Alpenraum%20Eiszeit_opt.pdf.

Gibbard, P. L. & Hughes, P. D. 2021: Terrestrial stratigraphical division in the Quaternary and its correlation. *Journal of the Geological Society 178*, pp.jgs2020-134, https://doi.org/10.1144/jgs2020-134.

Gibbard, P. L. & West, R. G. 2000: Quaternary chronostratigraphy: the nomenclature of terrestrial sequences. *Boreas 29*, 329-336.

Gibbard, P. & Van Kolfschoten, T. 2005: The Pleistocene and Holocene epochs. *A geologic time scale 2004*, 441-452.

Gibbard, P. L. & West R. G. 2014: The development of the stratigraphical division of the Quaternary as reflected in the activities of the Quaternary Research Association. *In* Catt, J. A. & Candy, I. (eds.): *History of the Quaternary Research Association*, 174-185. Quaternary Research Association, London.

Hao, Q., Wang, L., Oldfield, F., Peng, S., Qin, L., Song, Y., Xu, B., Qiao, Y, Bloemendal, J. & Guo, Z. 2012: Delayed build-up of Arctic ice sheets during 400,000-year minima in insolation variability. *Nature 490*, 393-396.

Head, M. J., Gibbard, P. & Salvador, A. 2008: The Quaternary: its character and definition. *Episodes Journal of International Geoscience 31*, 234-238.

Heller, F. & Evans, M. E. 1995: Loess magnetism*. Reviews of Geophysics 33*, 211-240.

Heller, F. & Liu, T.S. 1984: Magnetism of Chinese loess deposits. *Geophysical Journal International 77*, 125-141.

Heslop, D., Langereis, C. G., Dekkers, M. J. 2000: A new astronomical timescale for the loess deposits of Northern China. *Earth and Planetary Science Letters 184*, 125-139.

Hrnjak, I., Lukić, T., Gavrilov, M. B., Marković, S. B., Unkašević, M. & Tošić, I. 2014: Aridity in Vojvodina, Serbia. *Theoretical and Applied Climatology 115*, 323-332.

Hughes, P. D. & Gibbard, P. L. 2018: Global glacier dynamics during 100 ka Pleistocene glacial cycles. *Quaternary Research 90*, 222-243.

Hughes, P. D., Gibbard, P. L. & Woodward, J.C., 2005: Quaternary glacial records in mountain regions: a formal stratigraphical approach. *Episodes Journal of International Geoscience 28*, 85-92.

Hughes, P. D., Woodward, J. C., Van Calsteren, P. C. & Thomas, L. E. 2011: The glacial history of the Dinaric Alps, Montenegro. *Quaternary Science Reviews 30*, 3393-3412.

Hughes, P. D., Gibbard, P. L. & Ehlers, J. 2020: The “missing glaciations” of the Middle Pleistocene. *Quaternary Research 100*, 161-183.

Hlavatskyi, D. & Bakhmutov, V. 2021: Early–Middle Pleistocene magnetostratigraphic and rock magnetic records of the Dolynske Section (lower Danube, Ukraine) and their application to the correlation of loess–palaeosol sequences in eastern and south-eastern Europe. *Quaternary 4*, 1-43.

Jary, Z. 2009: Periglacial markers within the Late Pleistocene loess–palaeosol sequences in Poland and Western Ukraine. *Quaternary International 198*, 124-135.

Jordanova, D. & Petersen, N. 1999: Palaeoclimatic record from a loess-soil profile in northeastern Bulgaria—II. Correlation with global climatic events during the Pleistocene. *Geophysical Journal International 138*, 533-540.

Köppen, W. & Wegener, A. 1924: *Die Klimate der geologischen Vorzeit*. 255 pp. Gebrüder Bornträger, Berlin.

Kukla, G. J. 1975: Loess stratigraphy of central Europe. In Butzer, K. W. & Isaac, G. L. (eds.): *After the Australopithecines*, 99-187. Mouton, The Hague.

Kukla, G. J. 1977: Pleistocene land—sea correlations I. Europe. *Earth Science Reviews 13*, 307-374.

Kukla, G. 1987: Loess stratigraphy in central China. *Quaternary Science Reviews 6*, 191-219.

Kukla, G. 1995: Supercycles, superterminations and the classical Pleistocene subdivisions. *Terra Nostra 2*, p. 149.

Kukla, G. 2005: Saalian supercycle, Mindel/Riss interglacial and Milankovitch's dating. *Quaternary Science Reviews 24*, 1573-1583.

Kukla, G. & An, Z. 1989: Loess stratigraphy in central China. *Palaeogeography, Palaeoclimatology, Palaeoecology 72*, 203-225.

Kukla, G. & Cílek, V. 1996: Plio-Pleistocene megacycles: record of climate and tectonics. *Palaeogeography, Palaeoclimatology, Palaeoecology 120*, 171-194.

Kukla, J., Ložek, V. & Záruba, Q. 1961: Zur Stratigraphie der Lösse in der Tschechoslowakei. *Quartär–Internationales Jahrbuch zur Erforschung des Eiszeitalters und der Steinzeit 13*, 1-29.

Laag, C., Hambach, U., Zeeden, C., Lagroix, F., Guyodo, Y., Veres, D., Jovanović, M. & Marković, S. B. 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.

Lehmkuhl, F., Nett, J. J., Potter, S., Schulte, P., Sprafke, T., Jary, Z., Antoine, P., Wacha, L., Wolf, D., Zerboni, A., Hosek J., Marković, S. B., Obreht, I., Sumegi, P., Veres, D., Zeeden, C., Boemke, B., Schaubert, V., Viehweger, J. & Hambach, U. 2021: Loess landscapes of Europe - Mapping, geomorphology, and zonal differentiation. *Earth-Science Reviews 215*, 103769, https://doi.org/10.1016/j.earscirev.2020.103496.

Lehmkuhl, F., Bösken, J., Hošek, J., Sprafke, T., Marković, S. B., Obreht, I., Hambach, U., Sümegi, P., Thiemann, A., Steffens, S., Lindner, H., Veres, D. & Zeeden, C. 2018: Loess distribution and related Quaternary sediments in the Carpathian Basin. *Journal of Maps 14*, 661–670.

Lisiecki, L. E. & Raymo, M. E. 2005: A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records. *Paleoceanography 20,*1003, https://doi.org/10.1029/2004PA001071.

Litt, T., Behre, K. E., Meyer, K. D., Stephan, H. J., & Wansa, S. 2007: Stratigraphische Begriffe für das Quartär des norddeutschen Vereisungsgebietes. *E&G Quaternary Science Journal 56*, 7-65.

Liu, X., Liu, Z., Lü, B., Marković, S. B., Chen, J., Guo, H., Ma, M., Zhao, G. & Feng, H. 2013: The magnetic properties of Serbian loess and its environmental significance. *Chinese Science Bulletin 58*, 353-363.

Lu, H., Zhang, F. Q., Liu, X. & Duce, A. R. 2004: Periodicities of palaeoclimatic variations recorded by loess-paleosol sequences in China. *Quaternary Science Reviews 23*, 1891–1900.

Lu, H., Wang, X., Wang, Y., Zhang, X., Yi, S., Wang, X., Stevens, T., Kurbanov, R. & Marković, S. B. 2022: Chinese loess and the Asian monsoon: What we know and what remains unknown. *Quaternary International 620*, 85-97.

Lukić, T., Marković, S. B., Stevens, T., Vasiljević, D. A., Machalett, B., Milojković, N., Basarin, B. & Obreht, I. 2009: The loess “cave” near the village of Surduk-an unusual pseudokarst landform in the loess of Vojvodina, Serbia. *Acta Carsologica 38*, 227-235.

Machalett, B., Oches, E. A., Frechen, M., Zöller, L., Hambach, U., Mavlyanova, N. G., Marković, S. B. & Endlicher, W. 2008: Aeolian dust dynamics in Central Asia during the Pleistocene – driven by the long-term migration, seasonality and permanency of the Asiatic polar front. *Geophysics, Geochemistry and Geosystems 9*, Q08Q09, https://doi:10.1029/2007gc001938.

Maher, B. A. & Thompson, R. 1992: Paleoclimatic significance of the mineral magnetic record of the Chinese loess and paleosols. *Quaternary Research 37*, 155-170.

Marković, S. B., Smaelley, I. J., Zöller, L. & Antoine, P. 2009a: Loess in the Danube region and surrounding loess provinces: The Marsigli memorial volume. *Quaternary International 198*, 255-266.

Marković, S. B. Hambach, U., Catto, N., Jovanović, M., Buggle, B., Machalett, B., Zöller, L., Glaser, B. & Frechen, M. 2009b: The middle and late Pleistocene loess-paleosol sequences at Batajanica, Vojvodina, Serbia. *Quaternary International 198*, 255-266.

Marković, S. B., Oches, E. A., Perić, Z. M., Gaudenyi, T., Jovanović, M., Sipos, G., Perić, Z. M., Thiel, C., Buylaert, J. P., Stevan, S., McCoy, W. D., Radaković, M. G., Marković, R. S. & Gavrilov, M. B. 2021: 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 36*, 1436-1447.

Marković, S. B., Hambach, U., Stevens, T., Basarin, B., O'Hara-Dhand, K., Gavrilov, M. M., Gavrilov, M. B., Smalley, I. & Teofanov, N. 2012b: Relating the astronomical timescale to the loess–paleosol sequences in Vojvodina, Northern Serbia. *In* Berger, A. (ed.): *Climate change*, 65-78. Springer, Vienna.

Marković, S. B., Hambach, U., Stevens, T., Kukla, G. J., Heller, F., William D. McCoy, W. D., Oches, E.A., Buggle, B. & Zöller, L. 2011: The last million years recorded at the Stari Slankamen loess-palaeosol sequence: revised chronostratigraphy and long-term environmental trends. *Quaternary Science Reviews 30*, 1142-1154.

Marković, S. B., Heller, F., Kukla, G. J., Gaudenyi, T., Jovanović, M., & Miljković, L. 2003: Magnetostratigrafija lesnog profila Čot u Starom Slankamenu. *Zbornik radova Departmana za geografiju 32*, 20-28.

Marković, S. B., Stevens, T., Mason, J., Vandenberghe, J., Yang, S., Veres, D., Újvári, G., Timar-Gabor, A., Zeeden, C., Guo, Z., Hao, Q., Obreht, I., Hambach, U., Wu, H., Gavrilov, M. B., Rolf, C., Tomić, N. & Lehmkuhl, F. 2018: Loess correlations– Between myth and reality. *Palaeogeography, palaeoclimatology, palaeoecology 509*, 4-23.

818 Marković, S. B., Oches, E. A., Sümegi, P., Jovanović, M. & Gaudenyi, T. 2006: An introduction to the Middle and Upper Pleistocene loess-paleosol sequences at Ruma Brickyard (Vojvodina, Yugoslavia). *Quaternary International 149*, 80– 86.

821 Marković, S. B., Oches, E. A., McCoy, W. D., Frechen, M. & Gaudenyi, T. 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.

825 Marković, S. B., McCoy, W. D., Oches, E. A., Savić, S., Gaudenyi, T., Jovanović, M., Stevens, T., Walther, R., Ivanišević, P. & Galić, Z. 2005: Paleoclimate record in the Late Pleistocene loess-paleosol sequence at Petrovaradin Brickyard (Vojvodina, Serbia). *Geologica Carpathica 56*, 545– 552.

829 Marković, S. B., Bokhorst, M. P., Vandenberghe, J., McCoy, W. D., Oches, E. A., Hambach, U., Gaudenyi, T., Jovanović, M., Zöller, L., Stevens, T. & Machalett, B. 2008: Late Pleistocene loess-palaeosol sequences in the Vojvodina region, north Serbia. *Journal of Quaternary Science 23*, 73-84.

833 Marković, S. B., Fitzsimmons, K., Sprafke, T., Gavrilović, D., Smalley, I. J., Jović, V., Svirčev, Z., Gavrilov, M. B. & Bešlin, M. 2016: The history of Danube loess research. *Quaternary International 399*, 86-99.

836 Marković, S. B., Hambach, U, Jovanović, M., Stevens, T., O'Hara-Dhand, K., Basarin, B., Smalley, I. J., Buggle, B., Zech, M., Svirčev, Z., Milojković, N. & Zöller, L. 2012a: Loess in Vojvodina region (Northern Serbia): the missing link between European and Asian Pleistocene environments. *Netherlands Journal of Geosciences 91*, 173-188.

Marković, S. B., Kostić, N. & Oches, E. A. 2004a: Paleosols in the Ruma loess section. *Revista Mexicana de Ciencias Geológicas 21*, 79-87.

Marković, S. B., Stevens, T., Kukla, G. J., Hambach, U., Fitzsimmons, K. E., Gibbard, P., Buggle, B., Zech, M., Guo, Z., Hao, Q., Wu, H., O'Hara-Dhand, K., Smalley, I. J., Ujvari, G., Sümegi, P., Timar-Gabor, A., Veres, D., Sirocko, F., Vasiljević, Dj. A., Jary, Z., Svensson, A., Jović, V., Kovács, J., & Svirčev, Z. 2015: Danube loess stratigraphy—Towards a pan-European loess stratigraphic model. *Earth-Science Reviews 148*, 228-258.

Marković, S.B., Oches, E.A., Gaudenyi, T., Jovanović, M., Hambach, U., Zöller, L. & Sümegi, P. 2004b: Paleoclimate record in the Late Pleistocene loess-paleosol sequence at Miseluk (Vojvodina, Serbia). *Quaternaire 15*, 361– 368.

Marković, S. B., Vandenberghe, J., Perić, Z. M., Filyó, D., Bartyik, T., Radaković, M. G., Hao, Q., Marković, R. S., Lukić, T., Tomić, N., Gavrilov, M. B., Antić, A., Cvijanović, I. & Sipos, G. 2023: Local differentiation in the loess Deposition as a function of dust source: Key study Novo Orahovo loess paleosol sequence (Vojvodina, Serbia). *Quaternary 6*, 23, https://doi.org/10.3390/quat6010023.

Marković-Marjanović, J. 1970: Data concerning the stratigraphy and the fauna of the lower and middle Pleistocene of Yugoslavia. *Palaeogeography, Palaeoclimatology, Palaeoecology 8*, 153-163.

Marković-Marjanović, J. 1972: Rasprostranjenje i stratigrafija lesa u Juguslaviji. *Glasnik prirodnjačkog muzeja ser. A 27*, 93-107.

Marsigli, L. F. 1726: *Danubius Pannonico-Mysicus; observationibis geographicis, astronomicis, hydrographicis, et hysicis perlustratus*. Grosse, P., Alberts, Chr., de Hoodt, P., Herm. Uytwert and Franc Changuion, The Hague and Amsterdam.

Marks, L., Karabanov, A., Nitychoruk, J., Bahdasarau, M., Krzywicki, T., Majecka, A., Pochicka-Szwarc, K., Rychel, J., Woronko, B., Zbucki, L:, Hradunova, A., Hychanik, M., Mamchyk, S., Rylova, T., Nowacki, L. & Pielach, M. 2018: Revised limit of the Saalian ice sheet in central Europe. *Quaternary International 478*, 59-74.

Marks, L., Bińka, K., Woronko, B., Majecka, A. & Teodorski, A. 2019: Revision of the late Middle Pleistocene stratigraphy and palaeoclimate in Poland. *Quaternary International 534*, 5-17.

Milanković, M. 1941: Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitenproblem. *Section of Mathematics and Natural Sciences 132*, http://hdl.handle.net/123456789/702.

Murray, A. S., Schmidt, E. D., Stevens, T., Buylaert, J. P., Marković, S. B., Tsukamoto, S. & Frechen, M. 2014: Dating Middle Pleistocene loess from Stari Slankamen (Vojvodina, Serbia) — Limitations imposed by the saturation behaviour of an elevated temperature IRSL signal. *Catena 117*, 34-42.

Namier, N., Gao, X., Hao, Q., Marković, S. B., Fu, Y., Song, Y., Zhang, H. Wu, H., Deng, C. L., Gavrilov, M. B. & Guo, Z. 2021: Mineral magnetic properties of loess–paleosol couplets of northern Serbia over the last 1.0 Ma. *Quaternary Research 103*, 35-48.

Namier, N., Hao, Q. Z., Gao, X. B., Yu, F., Marković, S.B., Hambach, U., Veres, D., Mason, J. A., Song, Y., Deng, C., Gavrilov, M. B., Marković, R. & Guo, Z. T. 2023: Comprehensive magnetic analysis of the tephras in Middle-Late Pleistocene loess records of Serbia, and implications for tephra identification, correlation and loess chronology. *Quaternary Science Reviews 313*, 108202, https://doi.org/10.1016/j.quascirev.2023.108202.

Ning, W., Zan, J., Heller, F., Fang, X., Zhang, Y., Zhang, W., Kang, J. & Shen, M. 2023: Magnetic proxy of Eurasian loess revealing enhanced physical erosion since the mid-Pleistocene transition. *Geophysical Research Letters* 50, e2023GL104411, https://doi.org/10.1029/2023GL104411.

Novothny, Á., Frechen, M., Horváth, E., Wacha, L. & Rolf, C. 2011: Investigating the penultimate and last glacial cycles of the Süttő loess section (Hungary) using luminescence dating, high-resolution grain size, and magnetic susceptibility data. *Quaternary International 234*, 75-85.

Obreht, I., Zeeden, C., Hambach, U., Veres, D., Marković, S. B., Bösken, J., Svirčev, Z., Bačević, N., Gavrilov, M. B. & Lehmkuhl, F. 2016: Tracing the influence of Mediterranean climate on Southeastern Europe during the past 350,000 years. *Scientific Reports 6*, 36334, https://doi.org/10.1038/srep36334.

Panaiotu, C. G., Panaiotu, E. C., Grama, A. & Necula, C. 2001: Paleoclimatic record from a loess-paleosol profile in southeastern Romania. *Physics and Chemistry of the Earth, Part A: Solid Earth and Geodesy 26*, 893-898.

Penck, A. & Brückner, E. 1909: *Die Alpen im Eiszeitalter.* 1199 pp. Tauchnitz.

Perić, Z. M., Stevens, T., Obreht, I., Hambach, U., Lehmkuhl, F. & Marković, S. B. 2022: Detailed luminescence dating of dust mass accumulation rates over the last two glacial-interglacial cycles from the Irig loess-palaeosol sequence, Carpathian Basin. *Global and Planetary Change 215*, 103895, https://doi.org/10.1016/j.gloplacha.2022.103895.

Perić, Z., Lagerbäck Adolphi, E., Stevens, T., Újvári, G., Zeeden, C., Buylaert, J. P., Marković, S. B., Hambach, U., Fischer, P., Schmidt, C., Schulte, P., Huayu, L., Shuangwen, Y., Lehmkuhl, F., Obreht, I., Veres, D., Thiel, C., Frechen, M., Jain, M. & Gavrilov, M. B. 2019: Quartz OSL dating of late Quaternary Chinese and Serbian loess: A cross Eurasian comparison of dust mass accumulation rates. *Quaternary International 502*, 30–44.

Perić, Z. M., Marković, S. B., Sipos, G., Gavrilov, M. B., Thiel, C., Zeeden, C. & Murray, A. S. 2020: A post-IR IRSL chronology and dust mass accumulation rates of the Nosak loess-palaeosol sequence in north-eastern Serbia. *Boreas 49*, 841-857.

Porter, S. C. & An, Z. 2005: Episodic gullying and paleomonsoon cycles on the Chinese Loess Plateau. *Quaternary Research 64*, 234-241.

Püspöki, Z., Gibbard, P. L., Nádor, Á., Thamó-Bozsó, E., Sümegi, P., Fogarassy-Pummer, T., Tth-Makk, Á., Strecel, F., Krassay, Z., Kovács, P., Szöcs, T. & Fancsik, T. 2021: Fluvial magnetic susceptibility as a proxy for long-term variations of mountain permafrost development in the Alp-Carpathian region. *Boreas 50*, 806-825.

Radaković, M. G., Oches, E. A., Hughes, P. D., Marković, R. S., Hao, Q., Perić, Z. M., Gavrilović, B., Ludwig, P., Lukić, T., Gavrilov, M. B., Marković, S. B. 2023:

Reconstructed Malacothermometer July Paleotemperatures from the Last Nine Glacials over the South-Eastern Carpathian Basin (Serbia). *Atmosphere 14*, 791, https://doi.org/10.3390/atmos14050791.

Rial, J. A. 1999: Pacemaking the ice ages by frequency modulation of Earth's orbital eccentricity. *Science 285*, 564–568.

Rousseau, D. D. 2001: Loess biostratigraphy: new advances and approaches in mollusk studies. *Earth-Science Reviews 54*, 157-171.

Sartori, M., Heller, F., Forster, T., Borkovec, M., Hammann, J. & Vincent, E. 1999: Magnetic properties of loess grain size fractions from the section at Paks (Hungary). *Physics of the Earth and Planetary Interiors 116*, 53-64.

Schaetzl, R. J., Bettis, E. A., Crouvi, O., Fitzsimmons, K. E., Grimley, D. A., Hambach, U., Lehmkuhl, F., Marković, S. B., Mason, J. A., Owczarek, P., Roberts, H. M., Rousseau, D. D., Stevens, T., Vandenberghe, J., Zárate, M., Veres, D., Yang, S., Zech, M., Conroy, J. L., Dave, A.K., Faust, D., Hao, Q., Obreht, I., Prud'Homme, C., Smalley, I. J., Tripaldi, A., Zeeden, C. & Zech, R. 2018: Approaches and challenges to the study of loess - Introduction to the LoessFest Special Issue. *Quaternary Research 89*, 563-618.

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

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

Smalley, I. J., Markovic, S. B. & O'Hara-Dhand, K. 2010: The INQUA Loess Commission as a central European enterprise. *Central European Journal of Geosciences 2*, 3-8.

Smalley, I. J., O'Hara-Dhand, K., Wint, J., Machalett, B., Jary, Z. & Jefferson, I. 2009: Rivers and loess: the significance of long river transportation in the complex event-sequence approach to loess deposit formation. *Quaternary International 198*, 7-18.

Smalley, I. J., Marković, S. B. & Svirčev, Z. 2011: Loess is [almost totally formed by] the accumulation of dust. *Quaternary International 240*, 4-11.

Soergel, W. 1919: *Löße, Eiszeiten und paläolithische Kulturen*. 125-251. Jena.

Song, Y., Guo, Z., Marković, S., Hambach, U., Deng, C., Chang, L., Wu, J. & Hao, Q. 2018: Magnetic stratigraphy of the Danube loess: a composite Titel-Stari Slankamen loess section over the last one million years in Vojvodina, Serbia. *Journal of Asian Earth Sciences 155*, 68-80.

Sprafke, T. & Obreht, I. 2016: Loess: Rock, sediment or soil–What is missing for its definition? *Quaternary International 399*, 198-207.

Stevens, T., Buylaert, J. P., Thiel, C., Újvári, G., Yi, S., Murray, A. S., Frechen, M. & Lu, H. 2018: Ice-volume-forced erosion of the Chinese Loess Plateau global Quaternary stratotype site. *Nature communications 9*, 983, https://doi.org/10.1038/s41467-018-03329-2.

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

Stevens, T., Thomas, D. S., Armitage, S. J., Lunn, H. R. & Lu, H. 2007: Reinterpreting climate proxy records from late Quaternary Chinese loess: a detailed OSL investigation. *Earth-Science Reviews 80*, 111-136.

Sümegi, P., Gulyás, S., Molnár, D., Sümegi, B. P., Almond, P. C., Vandenberghe, J., Zlou, L., Pál-Molnár, E., Torocsik, T., Hao, Q., Smalley, I., Molnár, M. & Marsi,I. 2018: New chronology of the best developed loess/paleosol sequence of Hungary capturing the past 1.1 ma: Implications for correlation and proposed pan-Eurasian stratigraphic schemes. *Quaternary Science Reviews 191*, 144-166.

Sun, Y., Clemens, S. C., An, Z. & Yu, Z. 2006: Astronomical timescale and palaeoclimatic implication of stacked 3.6-Myr monsoon records from the Chinese Loess Plateau. *Quaternary Science Reviews 25*, 33-48.

Tzedakis, P. C., Hooghiemstra, H. & Pälike, H. 2006: The last 1.35 million years at Tenaghi Philippon: revised chronostratigraphy and long-term vegetation trends. *Quaternary Science Reviews 25*, 3416-3430.

Újvári, G., Varga, A. & Balogh-Brunstad, Z. 2008: Origin, weathering, and geochemical composition of loess in southwestern Hungary. *Quaternary Research 69*, 421-437.

Újvári, G., Varga, A., Ramos, F. C., Kovács, J., Németh, T. & Stevens, T. 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*, 83-96.

Urdea, P., Ardelean, F., Ardelean, M. & Onaca, A. 2022: The Romanian Carpathians: glacial landforms prior to the Last Glacial Maximum. *In* Palacios, D., Hughes, P. D., Garcia-Ruíz, J. M. & Andrés, N. (eds.): *European Glacial Landscapes: Maximum Extent of Glaciations*, 277-282. Elsevier, Amsterdam.

Vandenberghe, J. 2000: A global perspective of the European chronostratigraphy for the past 650 ka. *Quaternary Science Reviews 19*, 1701-1707.

Vandenberghe, J. 2012: Multi-proxy analysis: a reflection on essence and potential pitfalls. *Netherlands Journal of Geosciences 91*, 263-269.

Vandenberghe, J., Huijzer, B. S., Mücher, H. & Laan, W. 1998: Short climatic oscillations in a western European loess sequence (Kesselt, Belgium). *Journal of Quaternary Science 13*, 471-485.

Vandenberghe, J., Marković, S. B., Jovanović, M. & Hambach, U. 2014: Site-specific variability of loess and palaeosols (Ruma, Vojvodina, northern Serbia).*Quaternary International 334-335*, 86-93.

Woldstedt, P. 1929: *Das Eiszeitalter—Grundlinien einer Geologie des Diluviums*. 406 pp. 406. Ferdinand Enke, Stuttgart.

Zeeden, C., Hambach, U., Obreht, I., Hao, Q., Abels, H. A., Veres, D., Lehmkuhl, F., Gavrilov, M. & Marković, S. B. 2018: Patterns and timing of loess-paleosol transitions in Eurasia: constraints for paleoclimate studies. *Global and Planetary Change 162*, https://doi.org/10.1016/j.gloplacha.2017.12.021.

Zeuner, F. E. 1938: The chronology of the Pleistocene sea-levels. *Annals and Magazine of Natural History 1*, 389-405.

Figure captions:

Fig. 1. Location of the main, Middle Pleistocene loess sections in the Vojvodina region of Serbia. The distributions of loess, loess derivates, aeolian sand and alluvium follow Lehmkuhl *et al.* (2018).

Fig. 2. Relationships among the Mošorin and Stari Slankamen synthetic loess–palaeosol sequences (Marković *et al.* 2015) in the Vojvodina region and the Louchuan loess type section on the Chinese Loess Plateau (Hao *et al.* 2012). Dark grey zones labelled S represent well-developed fossil pedocomplexes, white zones labelled L represent typical loess units, and light grey zones (unlabelled) represent weakly developed palaeosols. The uncertain stratigraphical interval in the transition between L2 and S2 units is indicated with "?" Modified from Marković *et al.* (2015).

Fig. 3. A comparison of the Stari Slankamen loess-palaeosol sequence descriptions of 1. Marković-Marjanović (1970, 1972); 2. Butrym (1974); 3. Lithology according to Bronger (1976) with thermoluminescence ages after Singhvi *et al.* (1989); 4. Butrym *et al.* (1991); 5. Schmidt *et al.* (2010), interpretation presented here, with legend; 6. Lithology and stratigraphy after Marković *et al.* (2011), luminescence ages after Murray *et al.* (2014), interpretation presented here with legend; 7. The chronology of the Marine Isotope Stages taken from Aitken (1997).

Fig. 4. Graphical relationships between the simplified scheme of glacial-interglacial cycles defined by Kukla (1975), the north European stratigraphical scheme and the Marine Isotope Stages (Lisiecki & Raymo 2005), as they correlate to the normalized MS record of the combined Hungarian loess section at Sűtto (Novotheny *et al.* 2011) and Paks (Sartori *et al.* 1999), the Titel loess plateau (Marković *et al.* 2015, luminescence ages after Constantine *et al.* 2021), Zemun (Laag *et al.* 2021), Batajnica (Marković *et al.* 2009b, luminescence ages after Avram *et al.* 2020), and Stari Slankamen (Marković *et al.* 2003, 2011, luminescence ages after *Murray et al*. 2014). Also shown are the correlations to the loess sections at Ruma (Marković *et al.* 2006) and the Ukrainian Dolynske section (Hlavatsky & Bakhmutov 2021). Light grey backgrounds indicate correlations between fossil pedocomplexes S4, S3 and S2. Darker grey backgrounds illustrate the questionable intervals of the S2 and L2 units.

Fig. 5. Comparisons between the Marine Isotope Stratigraphy (Lisiecki & Raymo 2005) and the sedimentation rates (SRs) for individual loess sites. Also shown is the average SR for all sites together. Darker gray columns are related to the stratigraphically problematic L2 and S2 units.

Fig. 6. Spectral analysis results using the tuned MS time series record of the Mošorin and Stari Slankamen composite LPS for the past 1 Ma. The relative amplitudes of MS are shown as a function of period. The numbers above the peaks represent dominant cycles in ka unit. Modified from Marković *et al.* (2012b).

Fig. 7. A. Map of the upper and middle Danube Basin, where the black line represents the topographic profile shown in panel B. B. Topographic profile with a reconstruction of the Alpine glaciations during Last Glacial Maximum (LGM) (Geologische Bundesanstalt 2013) and a conceptual model of the relationship between the main types of deposits formed therein, as controlled by the intensity of erosion and accumulation in the Alps and Carpathian Basin.

Table titles:

Table 1. Retrospective of chronostratigraphic models proposed for the early Middle Pleistocene LPS in the Vojvodina region. Shaded cells temporally represent equivalent fossil pedocomplexes, based on different chronostratigraphic interpretations. MIS = Marine Isotope Stage.

Table 2. The relationships between stratigraphical units S4, L4, S3, L3, S2 and L2 at the Titel Loess Plateau (T), Zemun (Z), Batajnica (B), Stari Slankamen (S) and Ruma (R), and environmental conditions: forest (F), forest-steppe (FS), steppe (S), and loess steppe (LS) indicated by “x“.

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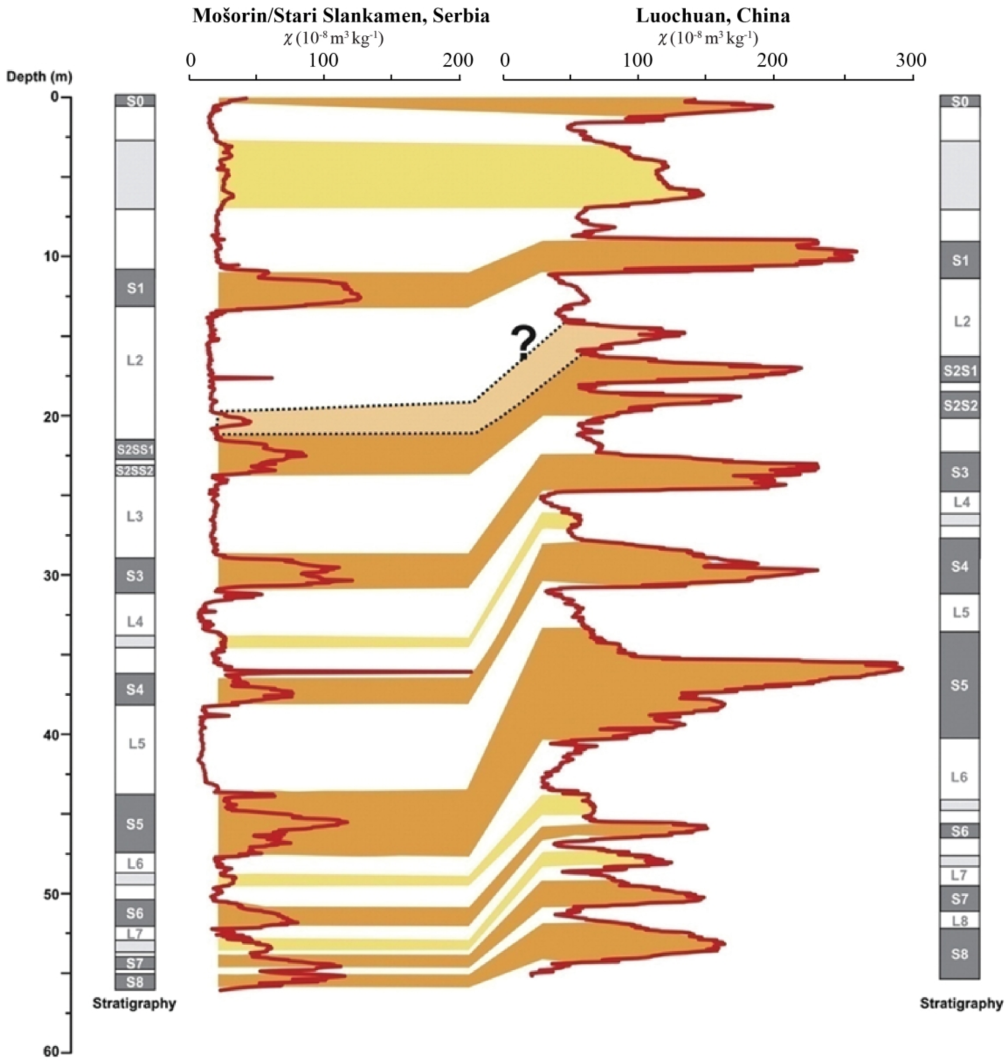

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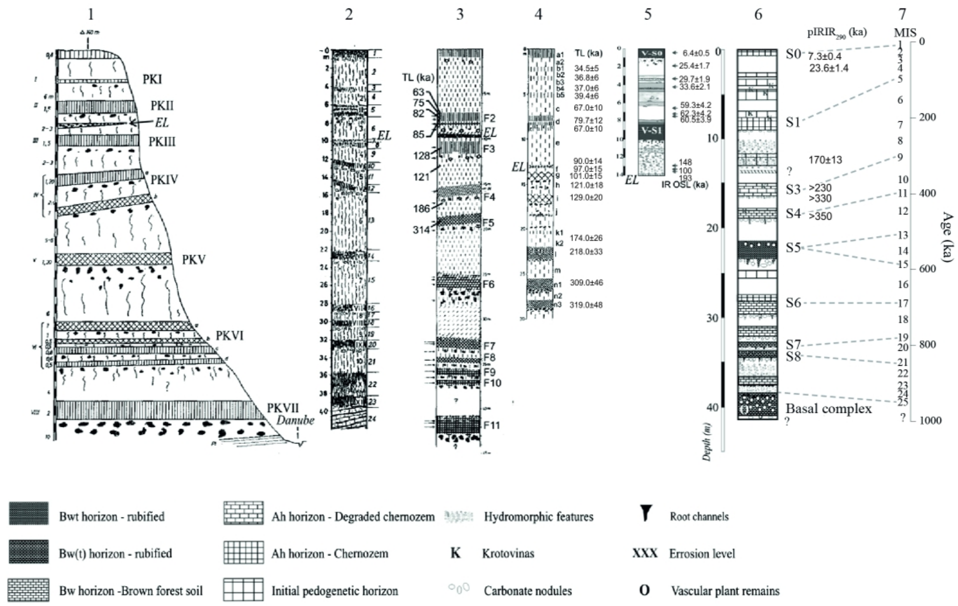

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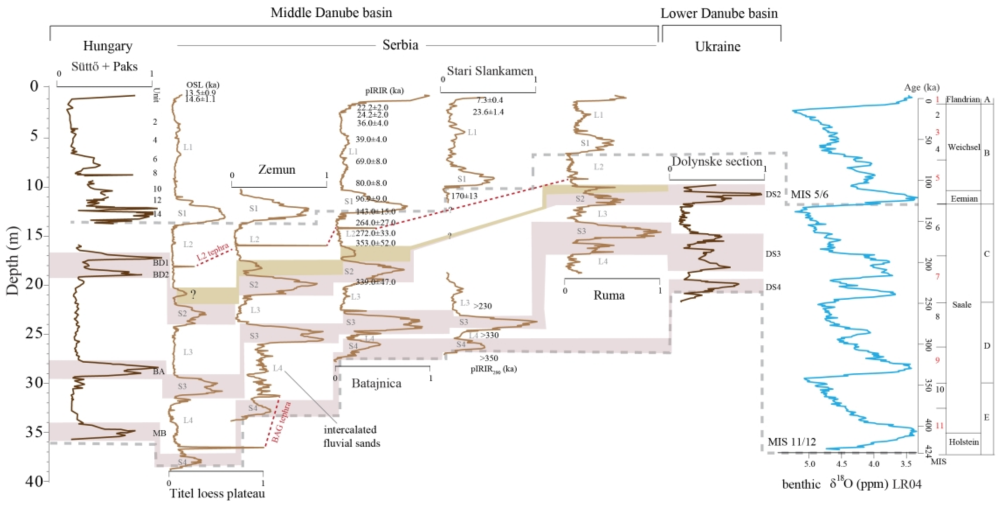

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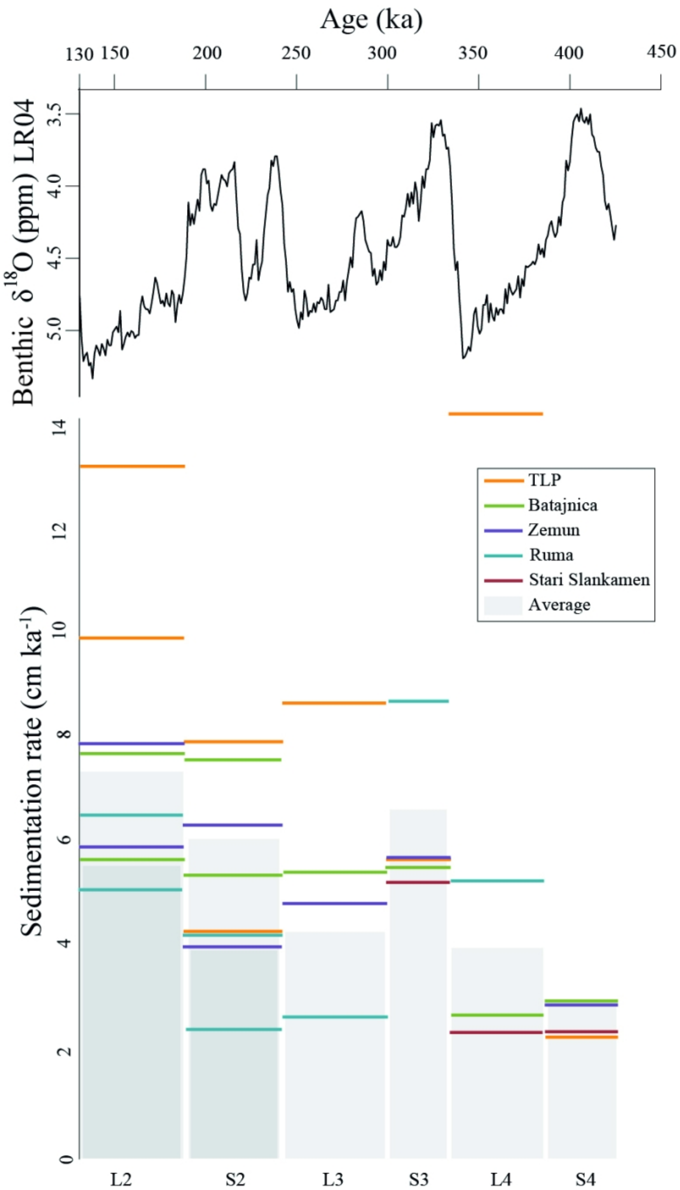

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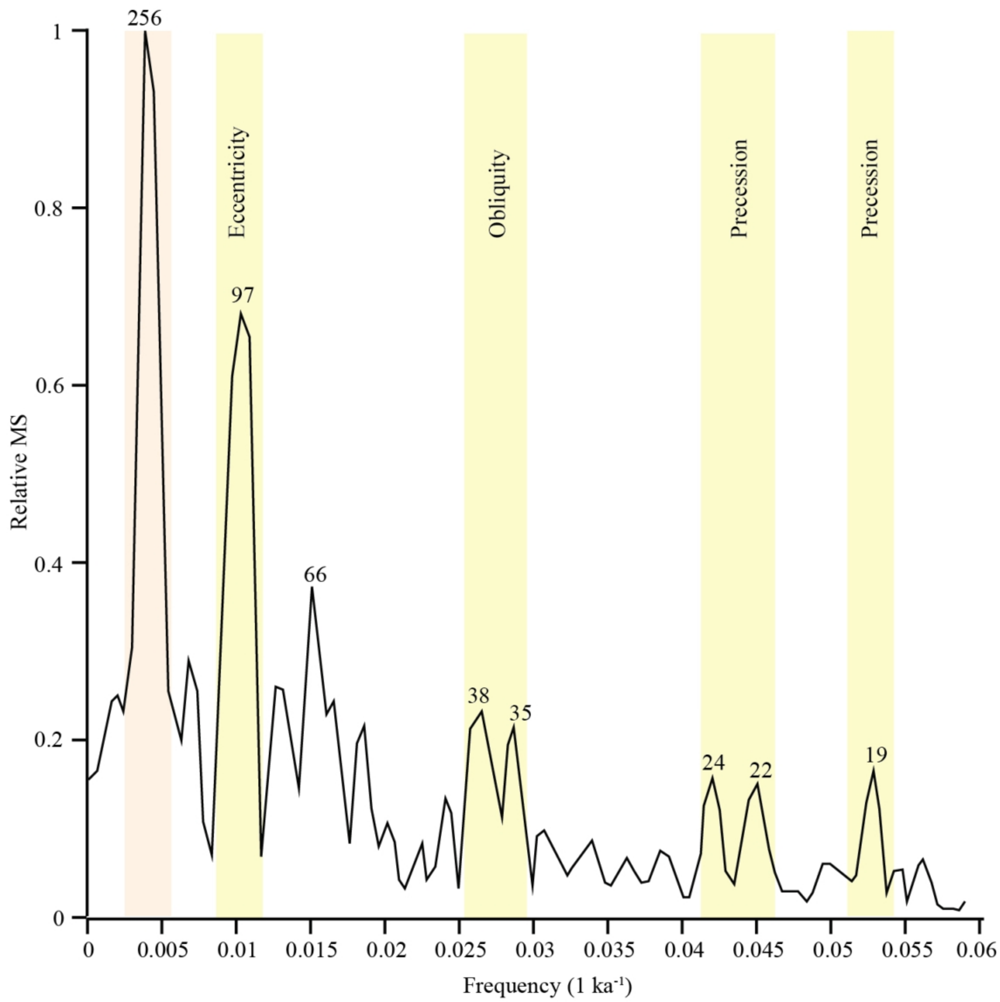

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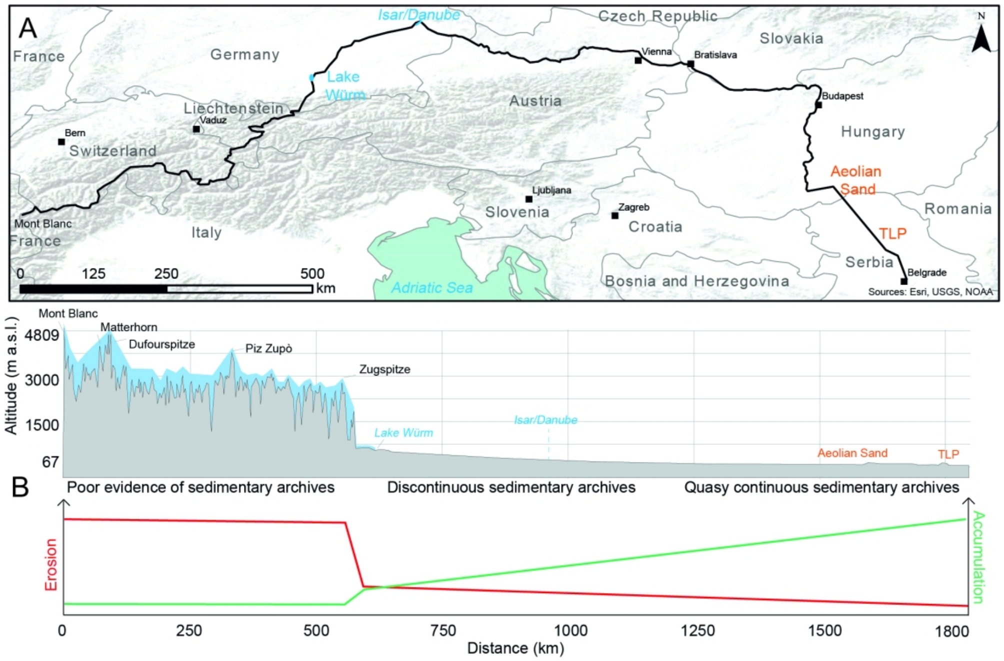

178x118mm (300 x 300 DPI)

Bronger (1976)		Singhvi *et al.* (1989)		Bronger (2003)		Marković *et al.* (2015)	
Palaeosol	Alpine subdivision	Palaeosol	MIS	Palaeosol	MIS	Palaeosol	MIS
F2	Würmian	F2	5a	F2	5a	S1	5
F3		F3	5e	F3	5e	S2	7
F4				F4	7	S3	9
F5	Rissian/Würmian			F5	9 or 11	S4	11

Site	S4					L4					S3					L3					S2					L2				
	T	Z	B	S	R	T	Z	B	S	R	T	Z	B	S	R	T	Z	B	S	R	T	Z	B	S	R	T	Z	B	S	R
F	x	x	x	x											x															
FS											x	x	x	x																
S																					x	x	x		x					
LS						x		x	x							x	x	x		x						x	x	x		x