Combined rock-magnetic and colorimetric stratigraphy for a 430 ka- covering loess-palaeosol sequence in the vicinity of Belgrade, Northern Serbia

Christian Laag[1,2], Ulrich Hambach[2,3], Christian Zeeden[4], Mladjen Jovanovic[5], Slobodan Marković[5]

Scope of study and setting

- Loess-palaeosol sequences (LPS) of the Carpathian Basin provide **high resolution records of Pleistocene climate change**
- The Zemun LPS located within the conurbation of Belgrade on the right banks of the Danube **covers in 24 meters 4 interglacial/glacial cycles** (marine oxygen isotope stage (MIS) 4-11)
- Based on the detection of **Palaeolithic stone tools** (Šarić et al., 2008) found on the Danube banks below the LPS the site was **placed under protection**
- We apply **environmental magnetic and colorimetric techniques for palaeoenvironmental reconstructions**
- Two tephra layers, tentatively assigned to prominent tephras widespread in the Carpathian Basin, provide additional stratigraphic information

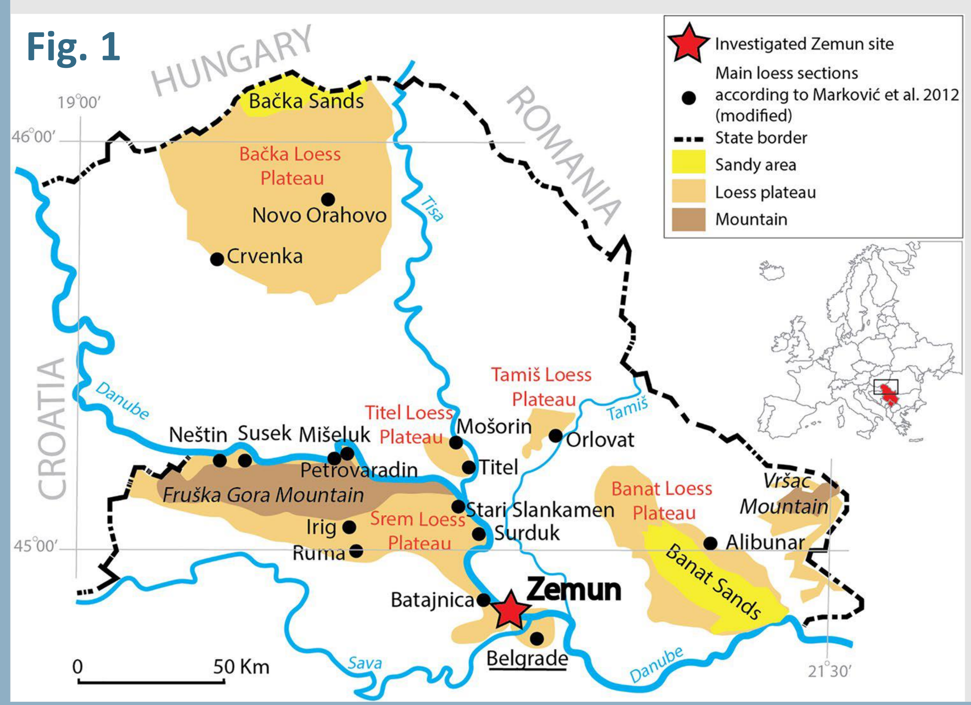
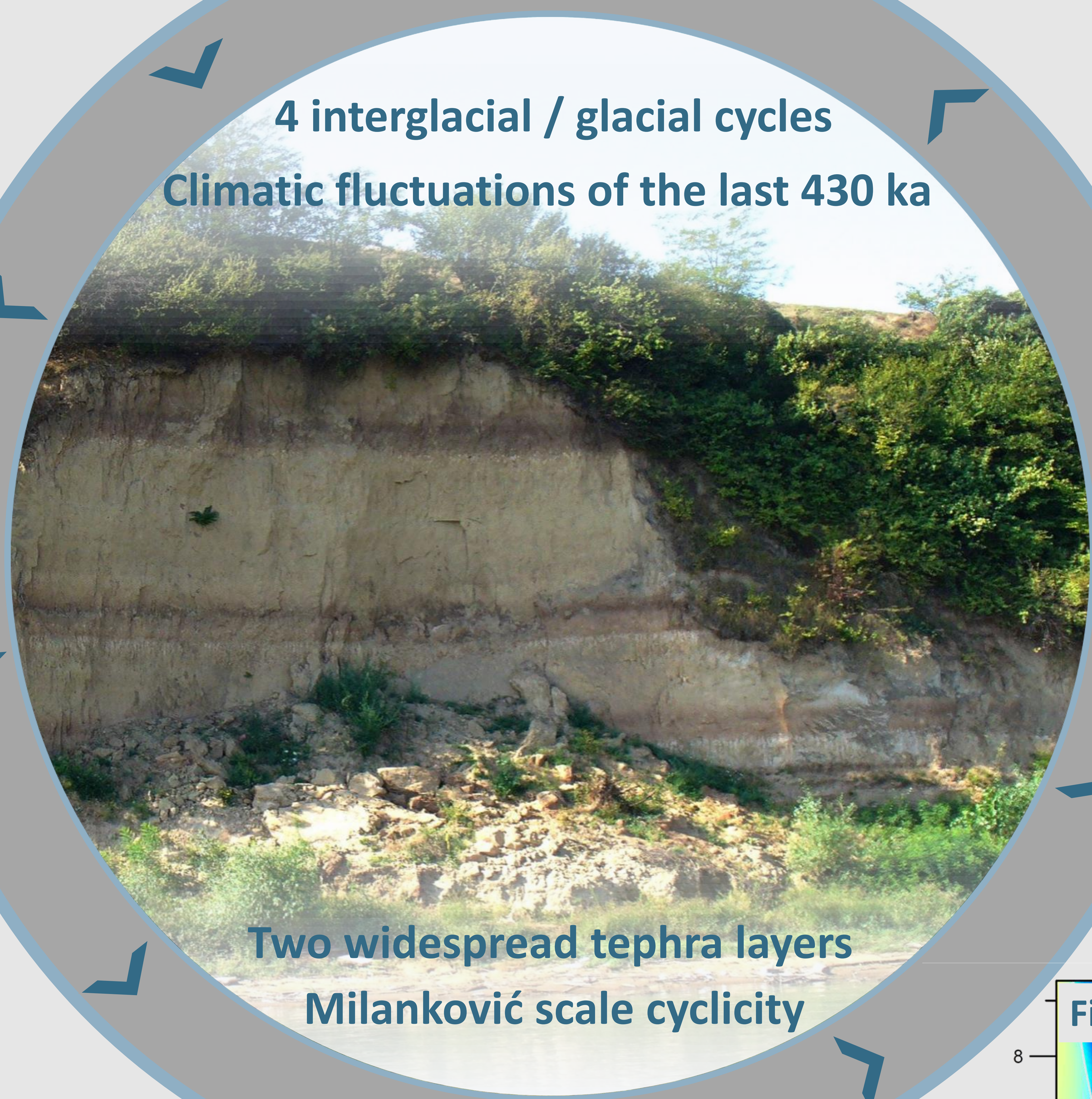


Fig. 1: Location of the investigated section Zemun in Northern Serbia. Loess plateaus and previously investigated sites are indicated (map adopted from Gavrilović et al., 2019).

Summary and conclusion

- The application of **environmental magnetic and colorimetric techniques** to a loess-palaeosol sequence from the southern Carpathian Basin reveal a **detailed palaeoenvironmental record of the last 4 interglacial/glacial cycles (MIS 4 to MIS 11)**
- An age model based on the LR04 stack (reflecting the global ice volume by benthic $\delta^{18}O$ ratios) and the Imbrie & Imbrie ice model provide **mass accumulation rates (MARs)** of aeolian dust **for the last 430 ka being during glacials 4 to 6 times higher as during interglacials**
- The obtained results witness **the quasi-continuous accumulation of mineral dust in the Carpathian Basin**, giving insights into climatic variations between glacial and interglacial environments ranging from MIS 4 to MIS 11



Implications for S2 (MIS 7) and S3 (MIS 9) palaeoclimatic records

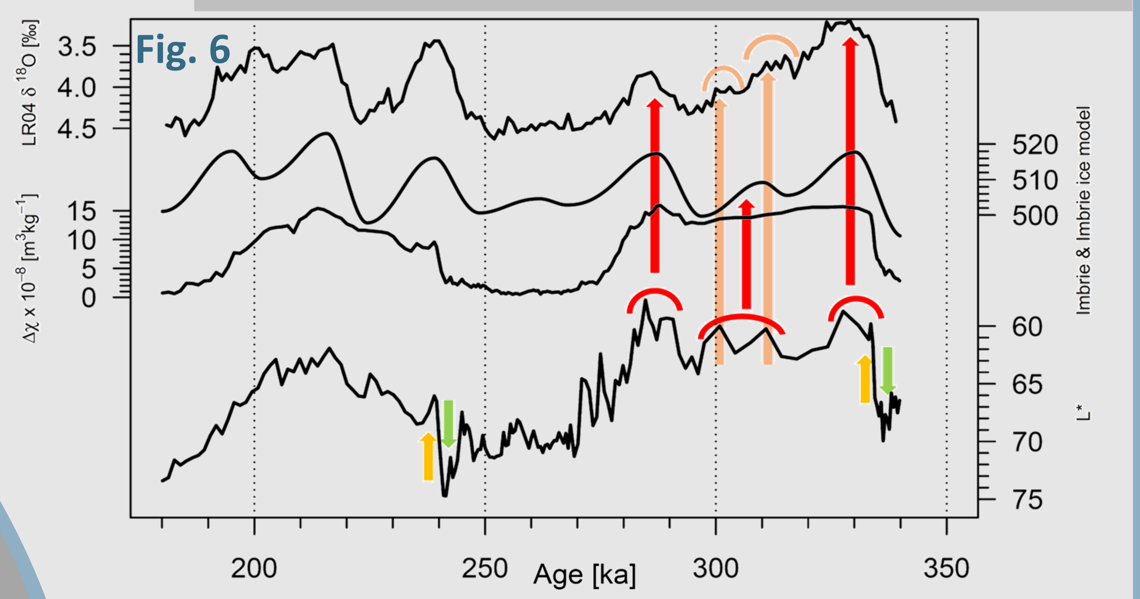


Fig. 6: The palaeoclimatic record based on luminance variations of the Zemun LPS is in excellent agreement with LR04 and Imbrie & Imbrie ice model (red and salmon-pink arrows), whereas $\Delta\chi$ shows almost no variability. Green arrows indicate distinct brighter units, identified as carbonate rich horizons. Orange arrows indicate a seemingly rapid increase of pedogenic intensity, appearing stratigraphically just above the carbonate horizons.

Multi-proxy screening and age model

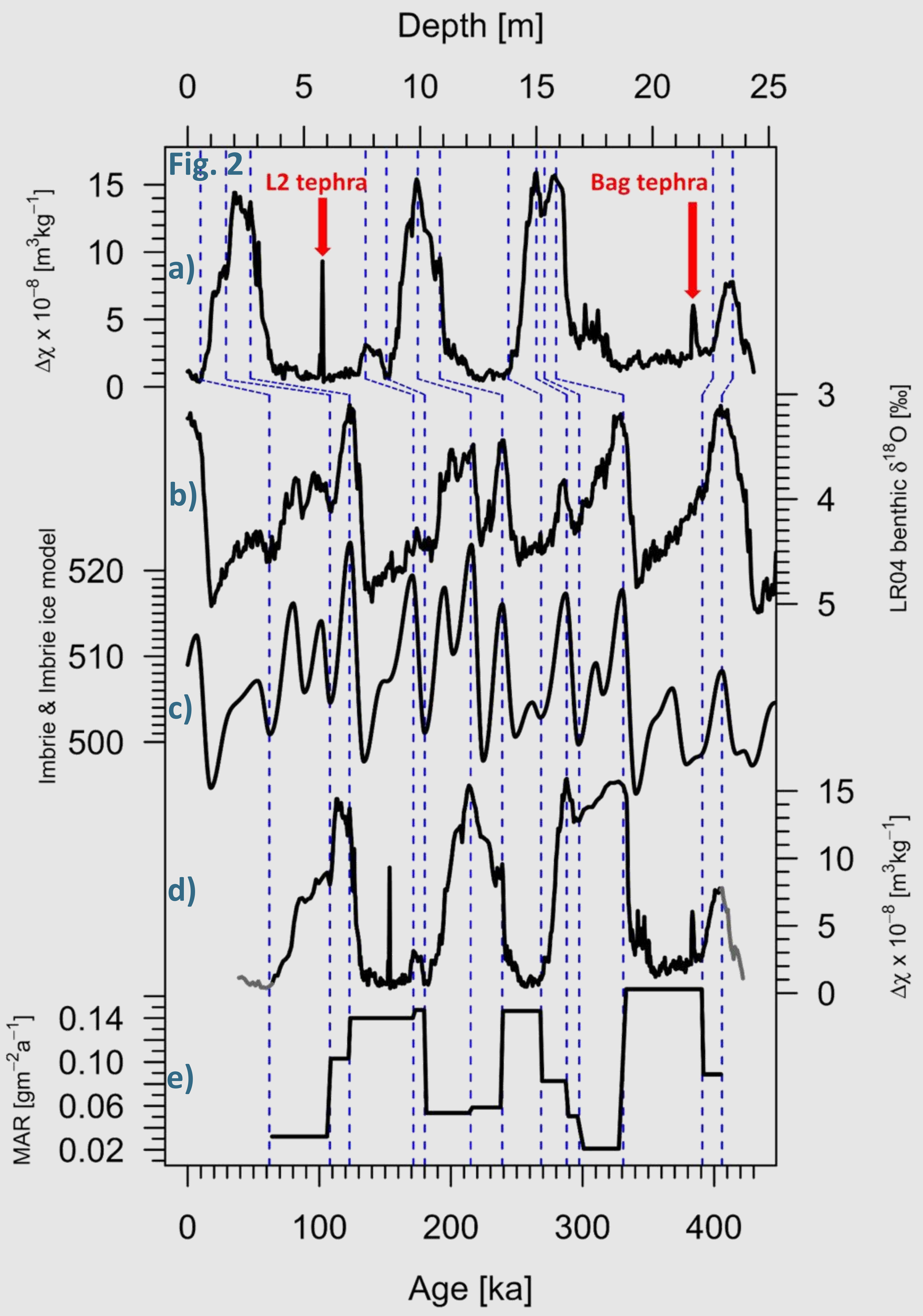


Fig. 2a: Downsection variation of $\Delta\chi$ reflecting pedogenic intensity and thus, fluctuations between interglacial and glacial climate. Observed tephra layers are assigned to the L2 tephra (Laag et al., 2018) and Bag tephra (Fu et al., 2019) and indicated by red arrows.
Fig. 2b: Time series of benthic $\delta^{18}O$ (LR04, Lisiecki & Raymo, 2005) covering the last 430 ka. Low values reflect interglacial conditions.
Fig. 2c: Global ice volume model of Imbrie & Imbrie (1980) for the last 430 ka. High values (arbitrary units) indicate low ice volume.
Fig. 2d: Tuned $\Delta\chi$ record as function of age. $\Delta\chi$ values were correlated to the LR04 stack and 13 tiepoints were selected to calculate ages for all samples with the R (R core team, 2020) package "astrochron" (Meyers, 2014) via linear interpolation. In a second step adjustments for local maxima in $\Delta\chi$ were carried out by correcting derived LR04 ages with maxima in the Imbrie and Imbrie ice model.
Fig. 2e: Calculated mass accumulation rates (MARs) of aeolian dust for the last 430 ka. Maximum MARs are detected in glacial times whereas during interglacials dust accumulation is 4 to 6 times lower.

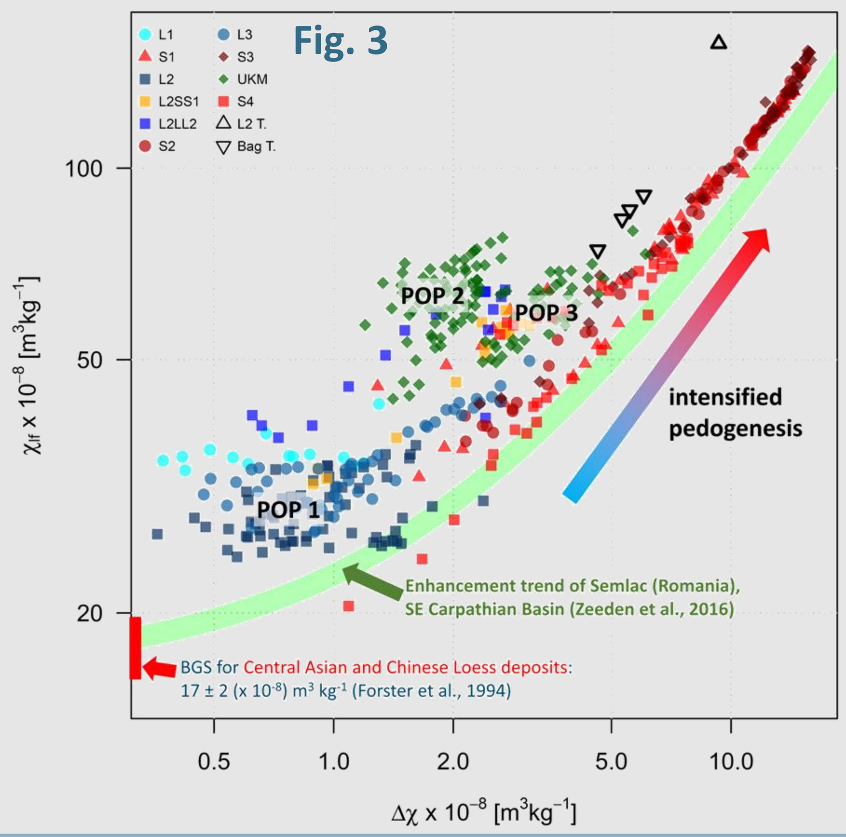
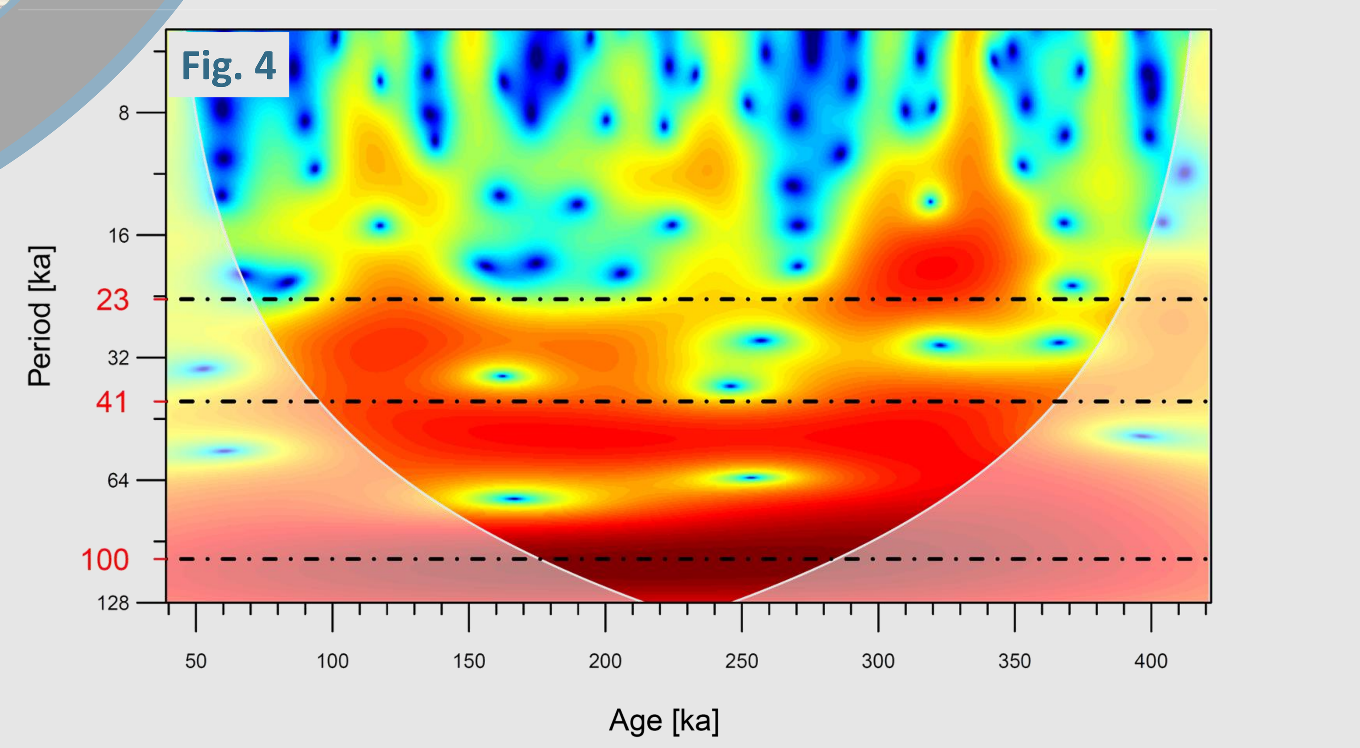


Fig. 3: Magnetic enhancement in the Zemun LPS. As reference, data from the Semlac LPS (Romania, green band, Zeeden et al., 2016 a & b) are given showing the exclusive dependence of χlf from $\Delta\chi$ and hence, pure and linear magnetic enhancement (Forster et al., 1994). Populations (POP) 1 to 3 indicate higher paramagnetic contributions. Samples from tephra layers show elevated χlf values compared to $\Delta\chi$ and are given as triangles. POP 2 and 3 mark samples from L4 which are characterised by paramagnetic and partly sandy limonitic horizons. UKM indicates material of unknown origin.

Time series and colorimetry

Fig. 4: Wavelet analysis (Grinsted, 2004) of $\Delta\chi$ time series reflecting quasi- continuous cyclicity at periods of about 23, 41 and 100 kyr. Hence, variations in $\Delta\chi$ reflect the strongest imprint of eccentricity, medium strength of obliquity and low signal strength of precession in the Zemun LPS.



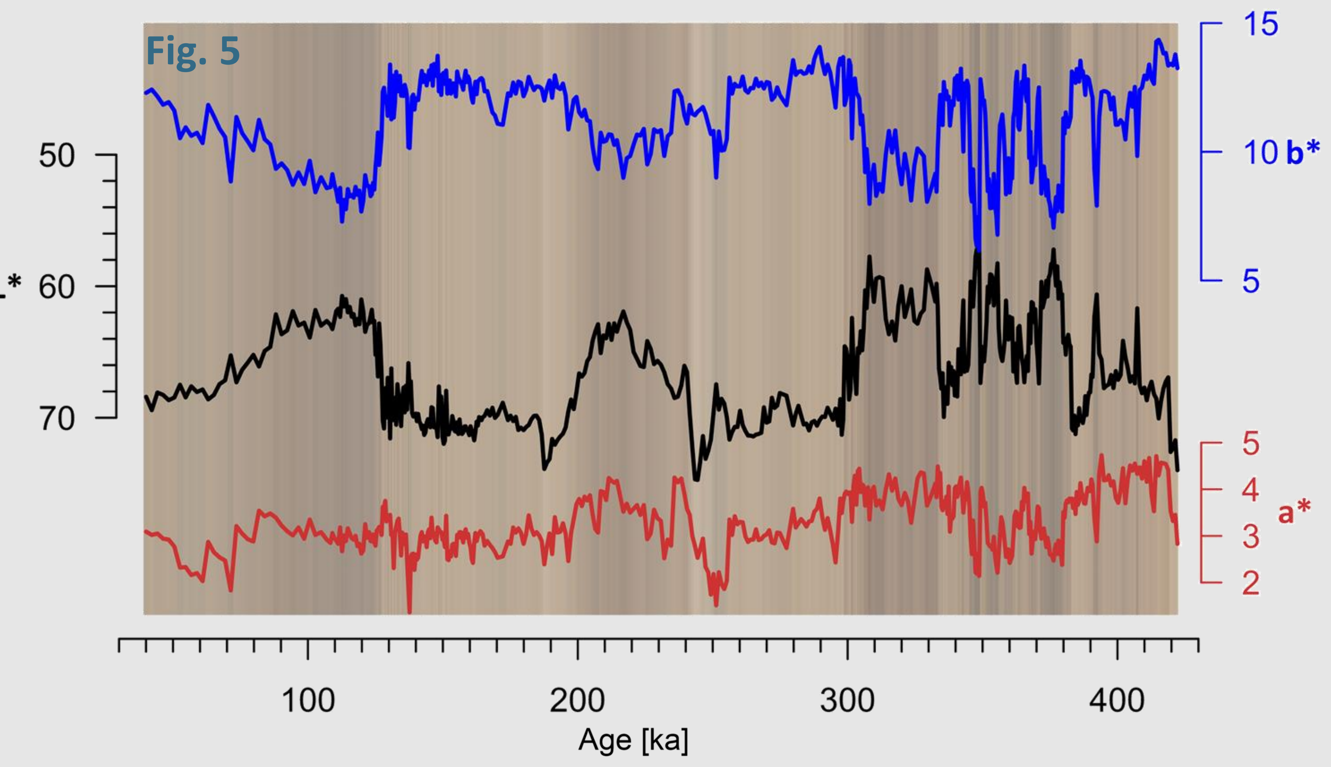


Fig. 5: Temporal variations of Lab-color-space-values transformed into RGB colours. L* and a* represent differences in pedogenic intensity of palaeosols; decreased luminance (L*) reflects increased weathering intensity and higher content of organic matter; a* goes along with climatically triggered iron oxide concentrations; b* displays the "yellowness" of the measured sample. The overall decrease in a* with time (sensitive for hematite) indicates a general cooling and aridisation trend since the early Middle Pleistocene (Buggle et al. 2013).

Methods

- Rock-magnetic and colorimetric measurements were performed at the laboratory for Palaeo- and Environmental Magnetism (PUM) at the University of Bayreuth (Germany).
- 490 bulk samples were analyzed for frequency dependent magnetic susceptibility with a Magnon VFSM kappa-bridge at low (χlf, 300 Hz) and high (χhf, 3000 Hz) frequency at a field of 320 A/m. Frequency dependence is calculated as $\Delta\chi = \chi lf - \chi hf$.
- Colorimetric reflectance values were measured with a Konica Minolta 700d photo-spectrometer. Colorimetric measurements provide values in the Lab colour-space (L*= Luminance, 0 = black, 100 = white; a* = negative green, positive red; b* = negative blue, positive yellow) and were transferred to the RGB colour-space for visualization using a modified R script after Zeeden et al. (2017).
- The age model was created using a correlation between the Lisiecki & Raymo (2005) LR04 stack, reflecting the global ice volume by benthic $\delta^{18}O$ ratios. The used tie points were adjusted for maxima in the Imbrie & Imbrie ice model (1980). All intercalated samples were given ages based on linear interpolation between the selected tiepoints.
- Mass accumulation rates (MARs) were calculated by averaging denisty of intervals between the used tie points. Exclusively aeolian deposition is assumed.

References

Buggle et al. (2013), Geology, 41 (7), pp. 771-774.
Forster et al. (2014), Geophys. J. Intern., 118, pp. 636-642.
Fu et al. (2019), XX INQUA, Chances and challenges in tephrochronology of loess: A case study of the Bag tephra in Serbia.
Gavrilović et al. (published online), PalZ
Grinsted et al. (2004), Nonlinear Proc. Geoph., 11 (5/6), pp. 561-566.
Imbrie & Imbrie (1980), Science, 207 (4434), pp. 943-953.
Laag et al. (2018), INQUA-INTAV https://www.doi.org/10.13140/RG.2.2.29686.96325.
Lisiecki & Raymo (2005), Paleoceanography, 20 (1), PA1003.
Meyers (2014), https://cran.r-project.org/package=astrochron.
R core team (2020), R: a Language and Environment for Statistical Computing.
Šarić (2009), Starinar, (58), pp. 9-27.
Zeeden et al. (2016a), Quat. Sci. Rev., 154, pp.130-142.
Zeeden et al. (2016b), PANGAEA, https://doi.org/10.1594/PANGAEA.859304
Zeeden et al. (2017), Quatern. Int., 429, Part B, pp. 100-107.

Affiliations

[1] **Université de Paris, Institut de Physique du Globe de Paris (IPGP), CNRS,** 1 rue Jussieu, 75005 Paris, France **(laag@ipgp.fr).**
[2] **Chair of Geomorphology, University of Bayreuth,** Universitätsstraße 30 Bayreuth, Germany.
[3] **BayCEER, Faculty of Biology, University of Bayreuth,** Universitätsstraße 30, Bayreuth, Germany.
[4] **Leibniz Institute for Applied Geophysics (LIAG),** Stilleweg 2, Hannover, Germany.
[5] **Chair of Physical Geography, Faculty of Sciences, University of Novi Sad,** Trg Dositeja Obradovića 3, 21000 Novi Sad, Serbia.

Acknowledgements: The authors want to thank the Zemun sampling team for intense and hard field work. **This study was awarded with the EGU Roland Schlich fund 2020.**