DOI: https://doi.org/10.3986/ac.v53i2-3.14020

LETTER:

IUGS RECOGNITION OF THE RAČIŠKA PEČINA CAVE SECTION AS A GLOBAL GEOLOGICAL HERITAGE SITE

SEDIMENTNI PROFIL V RAČIŠKI PEČINI VPISAN V SEZNAM SVETOVNE GEOLOŠKE DEDIŠČINE MEDNARODNE ZVEZE GEOLOŠKIH ZNANOSTI (IUGS)

Nadja ZUPAN HAJNA[1]

1. INTRODUCTION

Račiška Pečina, a limestone cave in the Classical karst in southwestern Slovenia, which belongs to the External Dinarides (Slovenian Cave Register No. 935; 45°30'12.10"N; 14°09'00.83"E; 609 m a.s.l.), has received international recognition for its exceptional sedimentary section. The cave's sediments, which span 3.4 Ma, provide a continuous and detailed record of climate, environmental and paleomagnetic changes. This unique archive of the Earth's history has earned Račiška Pečina a place among the "Second 100 IUGS Geological Heritage Sites", an award announced by the International Union of Geological Sciences (IUGS) at the 37th International Geological Congress in Busan, South Korea. To explain, an IUGS Geological Heritage Site is a key place with extraordinary geological elements or processes of the highest scientific relevance, used as a global reference, and/or with a substantial contribution to the development of geological sciences through history (Lozano et al., 2024).

The scientific significance of the Račiška Pečina sedimentary section (i.e. RP section) is the result of more than two decades of interdisciplinary research led by the Karst Research Institute ZRC SAZU in Slovenia, mainly in cooperation with the Czech Academy of Sciences and the Polish Academy of Sciences. Through a combination of magnetostratigraphy, isotope studies and paleontological analyses, the researchers have created a comprehensive framework linking regional geology with global stratigraphic and paleoclimatic events (e.g. Horáček et al. 2007; Mihevc, 2003, 2007;

Moldovan et al., 2011; Pawlak et al., 2024; Pruner et al., 2010; Sierpień et al., 2021; Zupan Hajna et al., 2008, 2010, 2020, 2021). My thanks go to the researchers, institutions and international collaborators who made this achievement possible. This milestone once again underlines the importance of preserving and studying cave sites, which represent an exceptional geological heritage.

2. SIGNIFICANT RESULTS

The Račiška Pečina sedimentary section is today recognized as a globally significant archive of alternating speleothem layers (calcite flowstone) and clay or silt deposits, which were formed during periods of interrupted calcite deposition (hiatus). These hiatuses, related to changes in surface hydrology and climate, provide crucial insights into past geological and environmental conditions. Using advanced dating methods, including U-series, radiocarbon dating, paleomagnetic analyses and paleontologically based magnetostratigraphy, a robust chronology for the section has been established (Horáček et al., 2007; Zupan Hajna et al., 2021).

[1] ZRC SAZU, Karst research Institute, Titov trg 2, 6230 Postojna, Slovenia; e-mail: nadja.zupan-hajna@zrc- sazu.si

Prejeto/Received: 20. 11. 2024

One of the most remarkable discoveries is the Matuyama/Brunhes magnetic reversal, which was precisely dated to 777.7 ± 6 ka and recorded in a very detailed stratigraphic interval of 6 mm (Pawlak et al., 2024). The age model based on oxygen isotope stratigraphy locates the reversal in the middle of MIS 19 (between 777.9 and 777.2 ka), characterized by abrupt changes in stable isotopes ($\delta^{13}C$ and $\delta^{18}O$), trace element concentrations (e.g. Mg, Sr, Ba, Na, P, Si, Mn, Fe, Al, Cu, U, Pb, Ti) and calcite microstructure. These changes indicate significant temperature fluctuations and varying precipitation quantities. In particular, two maxima in the trace element concentrations at the beginning and end of the reversal indicate two periods of intense precipitation, which led to increased leaching of clay minerals into the cave. In addition, the shifts in stable isotopes reflect significant cooling and increased precipitation during the M/B transition, which occurred in the generally warm MIS 19. The section also records other important paleomagnetic events, including the Gauss/Matuyama reversal and the Olduvai subchron. The precise dating of the Matuyama/Brunhes reversal is consistent with estimates from other records, e.g. from the Mediterranean (Marino et al., 2015; Capraro et al., 2017; Toti & Bertini, 2018) and Osaka Bay (Kitaba et al., 2017). The reversal is estimated to have lasted around 1,000 years and represents an unstable, cooler phase with increased precipitation. These results raise interesting questions about the influence of the Earth's magnetic field on paleoenvironmental conditions and support the hypothesis that magnetic reversals can affect broader climate patterns. The accurate record and precise dating of the Matuyama/Brunhes boundary, correlated with stable isotope and faunal data, provide a detailed chronostratigraphic framework for the transition and establish Račiška Pečina as a key global terrestrial reference site.

The stable isotope analyses of the calcite layers ($\delta^{13}C$ and $\delta^{18}O$) provide isotope compositions that reveal long-term climate trends and provide a valuable record of past climate changes that correlate well with global oxygen isotope curves (Sierpień et al., 2021; Zupan Hajna et al., 2021). These data reveal transitions from the Pliocene to the Pleistocene as well as glacial and interglacial cycles during the Quaternary.

The RP section is also important for its paleontological discoveries. Various faunal remains were found in the cave sediments, including *Ursus* ex gr. *spelaeus*, dated to >72 ka, and fossil gastropods (*Zospeum* sp.), possibly the first troglobiontic snails, stratigraphical dated to around 2 Ma. These finds illustrate the ecological history and the dynamics of biodiversity in the region (Zupan Hajna et al., 2021). Notable discoveries include fragments of molars and incisors attributed to species such as *Clethrionomys* cf. *glareolus*, indicating a Late Early or Middle Pleistocene age, as well as *Apodemus* cf. *atavus* and *Pliomys* sp. characteristic of biozones MN17–Q1 (Horáček et al. 2007;

Zupan Hajna et al. 2021). These remains extracted from clay layers indicate different ecological conditions, including arboreal and steppe habitats. The combination of paleontological evidence and magnetostratigraphic data has signifcantly contributed to the chronological framework of the site and enriched our understanding of Pleistocene ecosystems and their evolution. In addition, radiocarbon-dated soot layers indicate the temporary presence of humans in the cave during the Holocene, adding an archaeological dimension to its significance (Zupan Hajna et al. 2021). Furthermore,

Figure 1: Diploma for the inclusion of Račiška Pečina in the IUGS Second 100 Geological Heritage Sites, awarded for its exceptional importance for the stratigraphic-sedimentary heritage.

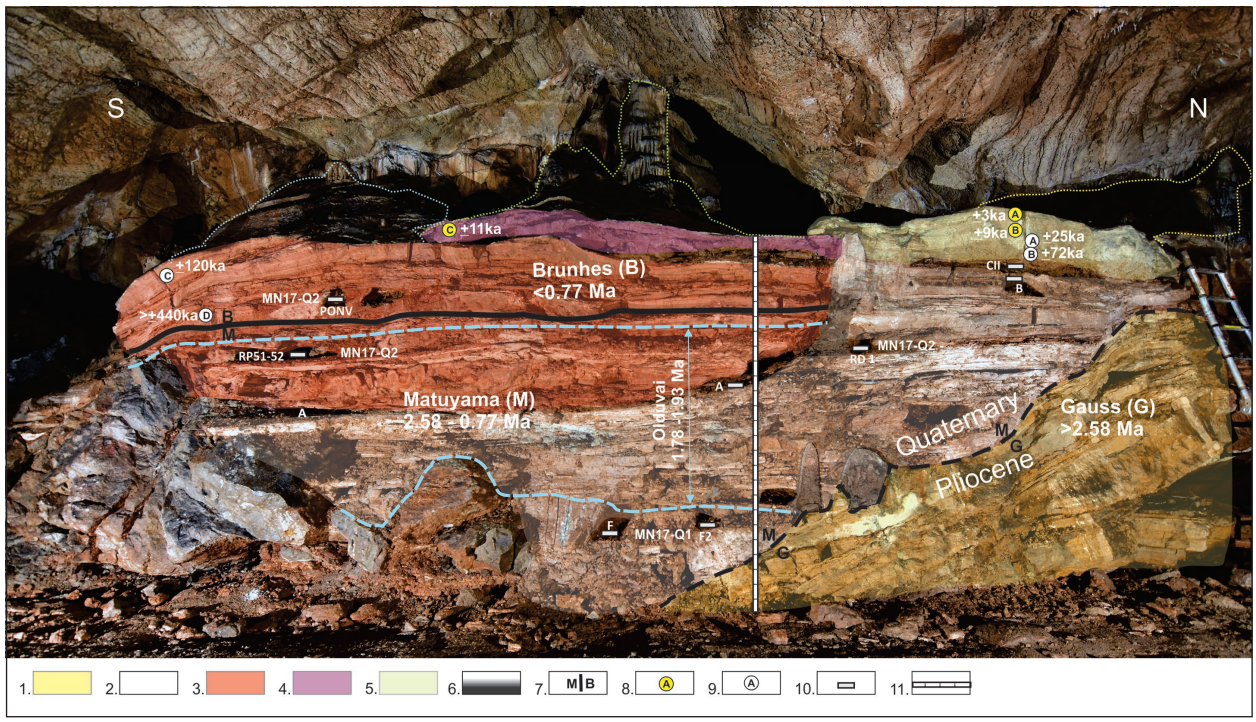

Figure 2: The RP section provides information on speleothem dome growth (in relation to the inflow source: 1-5), stalagmites (6), paleomagnetic reversals (7), dating results (8– ^{14}C, 9– U/Th), paleontology (10), and climate (a schematic log of stable isotopes– 11). Location of the M/B magnetic polarity reversal is marked with a black line. (According to Zupan Hajna et al., 2021).

the cave sediments provide insights about tectonic uplift and regional climate variability, show how local geological processes interact with global environmental changes.

3. CONCLUSIONS

The recognition of the Račiška Pečina by the IUGS highlights its exceptional global scientific importance. Its sedimentary profile, which has been carefully studied over decades, offers a rare opportunity to study important geological events such as the Matuyama/Brunhes magnetic reversal. Beyond its regional significance, Račiška Pečina serves as a crucial archive for understanding the intricate interplay between tectonic processes, climate dynamics and ecological changes over millions of years. Its inclusion on the IUGS Geological Heritage List underlines both its extraordinary scientific value and the need for its preservation. The cave is securely locked and protected, ensuring its availability for ongoing and future research.

Račiška Pečina is an example of the importance of interdisciplinary research and international cooperation to improve our understanding of the Earth's geological and environmental history. The well-preserved sedimentary record in the caves provides a rare opportunity to integrate regional geological findings into broader, global contexts, cementing their role as an important contribution to the study of Earth's dynamic systems and a crucial resource for ongoing and future research.

ACKNOWLEDGEMENTS

The results are mainly due to the cooperation with the Karst Research Institute of the Research Centre of the Slovenian Academy of Sciences and Arts in Postojna, the Institute of Geology of the Czech Academy of Science in Prague (MOBILITY PLUS project SAZU-24-04) with contributions from the Institute of Geological Sci-

ences of the Polish Academy of Sciences in Warsaw and the Department of Zoology of the Faculty of Sciences of Charles University in Prague. The author gratefully acknowledges the financial support of the research by the Slovenian Research and Innovation Agency(ARIS) under the frame of the national research programme Karst Research, No. P6-0119.

REFERENCES

Capraro, L., Ferretti, P., Macrì, P., Scarponi, D., Tateo, F., Fornaciari, E., Bellini, G., Dalan, G., 2017.
The Valle di Manche section (Calabria, southern Italy): a high resolution record of the early– middle Pleistocene transition (MIS 21–MIS 19) in the central Mediterranean. Quaternary Science Reviews, 165, 31–48. https://doi.org/10.1016/j.quascirev.2017.04.003

Horáček, I., Mihevc, A., Zupan Hajna, N., Pruner, P., Bosák, P., 2007. Fossil vertebrates and paleomagnetism update one of the earlier stages of cave evolution in the Classical Karst, Slovenia: Pliocene of Črnotiče II site and Račiška pečina. Acta Carsologica, 37 (3), 451–466. https://doi.org/10.3986/ac.v36i3.179

Kitaba, I., Hyodo, M., Nakagawa, Katoh, S., Dettman, D.L., Sato, H., 2017. Geological support for the Umbrella Effect as a link between geomagnetic field and climate. Scientific Reports, 7, 40682. https://doi.org/10.1038/srep40682.

Lozano, G., Carcavilla, L., Finney, S., Hilario, A., Vegas, J., Van Wyk de Vries, B., Zhang, J., 2024. The Second 100 IUGS Geological Heritage Sites. International Union of Geological Sciences, 300 p. https://iugs-geoheritage.org/publications-dl/IUGS-SECOND-100-SITES-WEB-BOOK.pdf

Marino, M., Bertini, A., Ciaranfi, N., Aiello, G., Barra, D., Gallicchio, S., Girone, A., La Perna, R., Lirer,
F., Maiorano, P., Petrosino, P., Toti, F., 2015. Paleoenvironmental and climatostratigraphic insights for marine isotope stage 19 (Pleistocene) at the Montalbano Jonico section, south Italy. Quaternary International, 383, 104–115. https://doi.org/10.1016/j.quaint.2015.01.043

Mihevc, A., 2003. Sledovi jamskega medveda v Račiški pečini. Naše jame, 45, 48–55.

Mihevc, A., 2007. The age of karst relief in West Slovenia. Acta Carsologica, 36(1), 35–44.

Moldovan, O., Mihevc, A., Miko, L., Constantin, S., Meleg, I., Petculescu, A., Bosák, P., 2011.
Invertebrate fossils from cave sediments: a new proxy for pre-Quaternary paleoenvironments. Biogeosciences, 8(7), 1825–1837. https://doi.org/10.5194/bg-8-1825-2011.

Pawlak, J., Hercman, H., Gąsiorowski, M., Pruner, P., Błaszczyk, M., Sierpień, P., Matoušková, Š., Kdýr,
Š., Schnabl, P., Zupan Hajna, N., Mihevc, A., Bosák, P., 2024. Matuyama/Brunhes magnetic reversal recorded in flowstone from the Račiška pečina Cave (Slovenia). Quaternary International, 686–687, 4-17. https://doi.org/10.1016/j.quaint.2023.05.002

Pruner, P., Zupan Hajna, N., Mihevc, A., Bosák, P., Venhodová, D., Schnabl, P., 2010. Paleomagnetic and rockmagnetic studies of cave deposits from Račiška pečina and Pečina v Borštu caves (Classical Karst, Slovenia). Studia Geophysica et Geodaetica, 54(1), 27–48. https://doi.org/10.1007/s11200-010-0002-1

Sierpień, P., Pawlak, J., Hercman, H., Pruner, P., Zupan Hajna, N., Mihevc, A., Bosák, P., 2021.
Flowstones from the Račiška pečina cave (SW Slovenia) record 3.2-ma-long history. Geochronometria, 48, 1–15. https://doi.org/10.2478/geochr-2021-0004

Toti, F., Bertini, A., 2018. Mediterranean pollen stratigraphy across the Early-Middle Pleistocene boundary. Alpine and Mediterranean Quaternary, 31, 199–203.

Zupan Hajna, N., Mihevc, A., Pruner, P., Bosák, P., 2008. Paleomagnetism and Magnetostratigraphy
of karst sediments in Slovenia. Carsologica, Založba ZRC, 266 p.

Zupan Hajna, N., Mihevc, A., Pruner, P., Bosák, P., 2010. Paleomagnetic research on karst sediments
in Slovenia. International Journal of Speleology, 39(2), 47–60. https://doi.org/10.5038/1827-
806X.39.2.1

Zupan Hajna, N., Bosák, P., Pruner, P., Mihevc, A., Hercman, H., Horáček, I., 2020. Karst sediments in Slovenia: Plio-Quaternary multi-proxy records. Quaternary International, 546, 4–19. https://doi.org/10.1016/j.quaint.2019.11.010

Zupan Hajna, N., Mihevc, A., Bosák, P., Pruner, P., Hercman, H., Horáček, I., Wagner, J., Čermák, J.,
Pawlak, J., Sierpień, P., Kdýr, Š., Juřičková, L., Švara, A., 2021. Pliocene to Holocene chronostratigraphy and paleoenvironmental records from cave sediments: Račiška pečina section (SW Slovenia). Quaternary International, 605–606, 5–24. https://doi.org/10.1016/j.quaint.2021.02.035.