ABSTRACT BOOK

7th Regional Scientific Meeting on Quaternary Geology

November 14th – 15th 2024
Zagreb, Croatia

7th Regional Scientific Meeting on Quaternary Geology
November 14th – 15th 2024, Zagreb, Croatia

Karst research and the 100th anniversary of the birth of Mirko Malez

ABSTRACT BOOK

ZAGREB, 2024

COORGANIZERS:

Croatian national INQUA committee (NO INQUA Hr)

Institute for Quaternary Palaeontology and Geology, Croatian Academy of Sciences and Arts (ZPGK HAZU)

Slovenian national INQUA committee (SINQUA)

Slovenian Geological Society (SGD)

Publisher: Croatian Academy of Sciences and Arts

For the Publisher: F.C.A. Dario Vretenar, Secretary-General

Editors: Ankica Oros Sršen & Vibor Novak

Design and Layout: Vibor Novak

Scientific meeting title: Karst research and the 100th anniversary of the birth of Mirko Malez, 7th Regional Scientific Meeting on Quaternary Geology, November 14th – 15th 2024, Zagreb, Croatia

Publication: Abstract Book, 7th Regional Scientific Meeting on Quaternary Geology

KEYNOTE SPEAKERS:

SINIŠA RADOVIĆ, Institute for Quaternary Palaeontology and Geology, Croatian Academy of Sciences and Arts

NADJA ZUPAN HAJNA, Karst Research Institute, Scientific Research Centre, Slovenian Academy of Sciences and Arts

The meeting was organised with support from The Foundation of the Croatian Academy of Sciences and Arts

ISBN 978-953-347-593-6

ORGANIZING COMMITTEE:

ANKICA OROS SRŠEN, Croatian Academy of Sciences and Arts, Croatia
VIBOR NOVAK, Croatian Academy of Sciences and Arts, Croatia
PETRA JAMŠEK RUPNIK, Geological Survey of Slovenia, Slovenia
ASTRID ŠVARA, Slovenian Academy of Sciences and Arts, Slovenia
KATARINA BOTIĆ, Institute of Archaeology, Croatia
PETRA BAJO, Croatian Geological Survey, Croatia
NIKOLA VUKOSAVLJEVIĆ, University of Zagreb, Croatia
MAŠA SURIĆ, University of Zadar, Croatia
OZREN HASAN, Croatian Geological Survey, Croatia
JADRANKA MAUCH LENARDIĆ
DAMIR LACKOVIĆ, Croatian Natural History Museum, Croatia
ANDREJ STROJ, Croatian Geological Survey, Croatia
STANKO RUŽIČIĆ, University of Zagreb, Croatia

SCIENTIFIC COMMITTEE:

MLADEN JURAČIĆ, Croatian Academy of Sciences and Arts, Croatia
MILOŠ BAVEC, Geological Survey of Slovenia, Slovenia
NADJA ZUPAN HAJNA, Slovenian Academy of Sciences and Arts, Slovenia
GORAN DURN, University of Zagreb, Croatia
KRISTINA PIKELJ, University of Zagreb, Croatia
SANJA FAIVRE, University of Zagreb, Croatia
LARA WACHA, Croatian Geological Survey, Croatia
KRISTINA KRKLEC, University of Zagreb, Croatia
JADRANKA BAREŠIĆ, Ruđer Bošković Institute, Croatia
DAVORKA RADOVČIĆ, Croatian Natural History Museum, Croatia
IVOR KARAVANIĆ, University of Zagreb, Croatia
SLOBODAN MIKO, Croatian Geological Survey, Croatia
MARTA PAPPALARDO, University of Pisa, Italy
ALESSANDRO FONTANA, University of Padova, Italy
STEFANO FURLANI, University of Trieste, Italy

CONTENTS:

SESSIONS	
November 14th, 2024	
8:30 – 9:00	**Arrival and registration**
9:00 – 9:30	Opening ceremony
9:30 – 10:00	Siniša Radović: *The scientific work of Mirko Malez: contribution, controversies and legacy* (1st Keynote)
10:00 - 10:15	**Coffee break**
10:15 – 12:30	**1st Session (Chair: Nadja Zupan Hajna)**
10:15 – 11:00	Nadja Zupan Hajna: *Cave sediments as multi-proxy data: karst environments as important quaternary archives* (2nd Keynote)
11:00 – 11:15	Nina Lončar et al.: *Contributions of the Sealevel Project to speleothem based sea-level studies*
11:15 – 11:30	Maša Surić: *Quaternary speleothem records of anthropogenic origin in Croatia*
11:30 – 11:45	Iva Palatinuš et al.: *Late Holocene climate recontructions using stable isotope records of a stalagmite from Nova Grgosova Cave (Central Croatia)*
11:45 – 12:00	Neven Bočić et al.: *Geomorphological and geospeleological research in the Plitvice Lakes National Park*
12:00 – 12:15	Kristina Krklec et al.: *Local impacts on long-term denudation rates: case study from North Dalmatian Plain (Croatia)*
12:15 – 12:30	Marta Pappalardo et al.: *Climatic constraints to karst processes activity: evidence from the Balzi Rossi area, an Italian outstanding palaeolithic settlement complex*
12:30 – 14:00	**Lunch break**
14:00 – 15:45	**2nd Session (Chair: Davorka Radovčić)**
14:00 – 14:15	Alessandro Fontana & Giacomo Vinci: *The prehistoric mound of Udine (NE Italy) from the Bronze Age to the Legend of Attila*
14:15 – 14:30	Katarina Botić et al.: *A multi-proxy approach to the reconstruction of human-environment interaction in the 5th Millennium cal BC: case study site in the Danube River Valley (Northern Croatia)*
14:30 – 14:45	Mattia Azzalin et al.: *Environmental dynamics and settlements patterns in the coastal plain of NE Italy since Middle Holocene*
14:45 – 15:00	Nikola Vukosavljević et al.: *Reevaluating the stratigraphic integrity of Šandalja II Cave: a Paleolithic case study from the Adriatic (Istria, Croatia)*
15:00 – 15:15	Irena Debeljak: *Reconstructing life history events from cave bear teeth*
15:15 – 15:30	Eva Mencin Gale et al.: *Chronology of Pliocene-Pleistocene fluvial terraces in southeastern Slovenia (Krško and Velenje Basins)*
15:30 – 15:45	Koen Beerten et al.: *Palaeosoils in Late Glacial sandy terrains of the Pannonian Basin and adjacent areas*

15:45 – 16:00	**Coffee break**
16:00 – 17:45	**3rd Session (Chair: Kristina Pikelj)**
16:00 – 16:15	Veronica Chiarini et al.: *Documenting subglacial concretions in the Dolomites: ephemeral witnesses of past glaciers*
16:15 – 16:30	Dea Brunović et al.: *Drowned karst landforms in the Eastern Adriatic Sea*
16:30 – 16:45	Marin Mićunović & Sanja Faivre: *Evolution of pocket beaches according to their morphogenetic type (Island of Hvar, Central Adriatic)*
16:45 – 17:00	Nadia Dunato Pejnović et al.: *Kvarner area tidal notches*
17:00 – 17:15	Ozren Hasan et al.: *Resolving the Jadro and Cetina palaeoriver flow in the Eastern Adriatic coast during the Last Glacial Maximum*
17:15 – 17:30	Petra Hus et al.: *Micropaleontological and malacological proxies for Quaternary paleoenvironmental dynamics in the Krka River karst estuary*
17:30 – 17:45	Slobodan Miko et al.: *Late Holocene palaeoenvironmental impact of Osor (Cres Island, Croatia)*
17:45 – 18:30	**Poster session and drinks**
November 15th, 2024	
8:30 – 8:45	**Coffee**
8:45 – 10:00	**4th Session (Chair: Lara Wacha)**
8:45 – 9:00	Andrej Novak et al.: *The Ciprnik complex landslide: similarities and differences between main event and its reactivation*
9:00 – 9:15	Josipa Maslač Soldo et al.: *Geomorphological analysis of the Sveta Nedelja Fault in the Mt. Žumberak area (NW Croatia)*
9:15 – 9:30	Petra Jamšek Rupnik et al.: *Initial results from paleoseismological investigations of the Raša Fault in SW Slovenia*
9:30 – 9:45	Stanko Ružičić et al.: *Deciphering the pedo-sedimentary complex of Eastern Adriatic Coast: case study in Privlaka, Croatia*
9:45 – 10:30	**Closing and final discussion**
EXCURSION	
10:45 – 13:30	**Veternica Cave (with snack break)**
14:00 – 15:00	**Grgosova Cave**
15:30	**Lunch**
ca. 18:00	**Return to Zagreb**

November 14th, 2024	
17:45 – 18:30	**POSTERS**
Alessandro Fontana et al.	*The largest system of LGM continental dunes of the Italian peninsula: The Dunes of Belvedere – San Marco of Aquileia (NE Italy)*
Andrea Sironić et al.	*Fallen barrier at the National Park Plitvice Lakes*
Andrej Stroj et al.	*Veternica Cave speleogenesis based on speleomorphological and sedimentological research*
Ankica Oros Sršen	*Palaeoecology of the MIS 3 at the Eastern Adriatic Coast: evidence from the bird bone assemblage Marlera I (Southern Istria)*
Čedomir Benac et al.	*Geomorphological changes due to sea-level oscillations during Late Pleistocene in NE channel part of the Adriatic Sea*
Dragana Janeš et al.	*CroSpeleo database: a comprehensive system for mananging speleological data and valuable tool for preserving Croatia's speleological heritage*
Filip Šarc et al.	*Geochronological constraints on dedolomitization and geomorphological evolution of Mravljetovo Brezno v Gošarjevih Rupah Cave, Central Slovenia*
Filip Šegović et al.	*Coastal erosion of late Quaternary loess-paleosol pedosedimentary deposits at Pakoštane (Croatia), a marine and coastal vulnerability study*
Goran Gužvica et al.	*Vinica Cave – a paleontological and paleolitic site*
Ivana Maruščak & Dražen Japundžić	*Steppe mammoth in Glogovica channel, Slavonski Brod, Croatia*
Katarina Matan et al.	*Morphology and formation processes of pedogenic carbonates in Mediterranean soils: a case study from the North Dalmatian Plain, Croatia*
Laura Novak et al.	*Geochemical and sedimentological characteristics of the Morinje Bay (Middle Dalmatia): influences of natural and anthropogenic factors*
Lovro Suić et al.	*A new era for Croatian eastern Adriatic beaches: the shift from native to Lessepsian foraminiferal engineers*
Nina Trinajstić et al.	*Hidden Archive in Karst: Geochronological Evidence of Miocene Volcanic Activity in Quaternary Soils (Plitvice Lakes and Bosiljevo, Croatia)*
Petra Jamšek Rupnik et al.	*High-resolution lidar and UAV-based geomorphological study reveals quaternary surface displacements along the Raša Fault in SW Slovenia*
Sanja Faivre et al.	*High-resolution reconstruction of 4.5 ka relative sea-level changes and coseismic uplifts using algal rims and tidal notches from Dubrovnik epicentral area*
Tomislav Kurečić et al.	*Quaternary deposits of Rab Island as presented on the new geological map (1:50 000)*
Valentina Hajek-Tadesse et al.	*Can ostracods give a new light for a better understanding of a subterranean route in the karst between the different drainages; a case study from a Deep Cave Njemica (Biokovo Mt., Croatia)*
Vibor Novak & Borut Toškan	*Latest appearance of Cricetulus migratorius in the coastal Croatia*

THE SCIENTIFIC WORK OF MIRKO MALEZ: CONTRIBUTION, CONTROVERSIS AND LEGACY

Siniša Radović[1]

[1]Institute for Quaternary Palaeontology and Geology, Croatian Academy of Sciences and Arts, Croatia

Corresponding author: Siniša Radović (sradovic@hazu.hr)

The late Mirko Malez was one of the most prolific Croatian scientists and crucial for development of Croatian geology and palaeontology. Further, his contribution to the fields of speleology, palaeoanthropology, and archaeology cannot be overemphasized. In the year when we celebrate the 100th anniversary of his birth, we need to express our debt to his numerous achievements.

Mirko Malez was born on November 5, 1924, in Ivanec near Varaždin. Due to poverty and war, he went back to school as an adult and finished his high school education in 1948. In the same year, he enrolled in the study of geology at the Faculty of Science in Zagreb. He graduated in 1953, and later became assistant of Marijan Salopek at the Yugoslav Academy of Sciences and Arts (today the Croatian Academy of Sciences and Arts). He received his doctorate in 1963 with the dissertation „Stratigraphic and paleontological research of a diluvial site in Veternica cave (Medvednica Mt)“ [in Croatian]. In 1968 he became the head of the Geological-Palaeontological Collection and Karst Laboratory. Under him, this unit of the Academy grew into a research institute and changed its name to the Institute for Quaternary Palaeontology and Geology in 1974. He led the Institute until his retirement in 1990. He died on August 23 of the same year.

Malez was at that time one of the leading European Quaternary palaeontologists and geologists. His research covered several scientific topics: Quaternary geology, Tertiary and Quaternary vertebrates, palaeoanthropology, Palaeolithic archaeology and speleology. It was he who revitalized and further developed Quaternary vertebrate palaeontology and speleology, which, despite well-laid foundations in our region, somehow lost their scientific strength after the death of pioneering researchers Dragutin Gorjanović Kramberger and Josip Poljak. During his four decades of research, Malez conducted a large number of field research, in some cases even long-term systematic excavations of the sites. Among others, three sites stand out, as they have attracted his attention for years: Vindija, Veternica and Šandalja. He is also considered to be the founder of speleoarchaeology in Croatia.

After the world-famous Neandertal finds from Krapina, discovered at the turn of the 19th to 20th century, excavations by Malez at Vindija cave yielded the second collection of these prehistoric humans from the territory of Croatia. He recognized the importance of this site and thanks to his work, the Vindija Neandertals are now recognized on a global scale. Looking back at Malez's truly impressive scientific work, it can be said that the Vindija discoveries were a crown of his very prolific and impressive career, and represent his lifework. The Vindija Neandertals have contributed immensely to our knowledge of Neandertal genetics and even further to our understanding of how the Neandertal genes affect the genomic makeup of living populations.

Based on his scientific work, he was elected an associate member of the Yugoslav Academy (today HAZU) in 1968, and became a full member in 1979. In 1989, he was elected a corresponding member of the Austrian Academy of Sciences.

In addition to the aforementioned scientific contribution, Malez also left a deep mark on the formation of new generations of researchers and in the popularization of science. Having said that, it should be mentioned that his work was not flawless. However, this takes nothing from his achievements, and is a part of the scientific and personal maturation we all go through. Many Croatian and international scientists today base their research on the results of his work, often by analysing the same material or doing field work at the same sites, sometimes inspired by his ideas and discoveries. Science is constantly evolving and methods and research questions are changing, but these are often build on the previous work of pioneering prominent scientists, that Mirko Malez certainly is. Many of us, scientists of different fields, now continue in his footsteps. I dare to say that this is his true legacy.

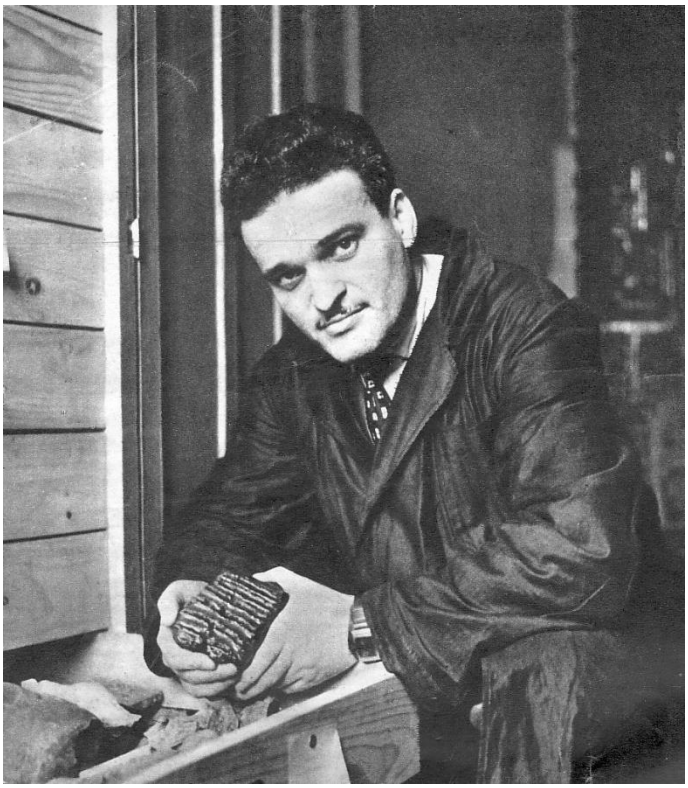

Figure 1: Mirko Malez, F.C.A.

REFERENCES

Garašić, M., 2011. Doprinosi akademika Mirka Maleza speleologiji u Hrvatskoj. Radovi Zavoda za znanstveni rad Varaždin, 22, 137-165.

Paunović, M., 1992. Život I djelo akademika Mirka Maleza, in: Majer, V. (Ed.), Mirko Malez, 1924-1990, Spomenica preminulim akademicima, sv. 66, Hrvatska akademija znanosti i umjetnosti, Zagreb, 12-18.

Smith, F. H., Karavanić, I., Janković, I., Mauch Lenardić, J., Radović, S., 2024. Vindija Cave: A Late Neandertal Site in Northern Croatia, FF Press, Zagreb.

Tomičić, Ž., 2011. Akademik Mirko Malez – pionir hrvatske speleoarheologije. Radovi Zavoda za znanstveni rad Varaždin, 22, 107-136.

CAVE SEDIMENTS AS MULTI-PROXY DATA: KARST ENVIRONMENTS AS IMPORTANT QUATERNARY ARCHIVES

Nadja Zupan Hajna[1]

[1]Karst Reserch Institute ZRC SAZU, Titov trg 2, 6230 Postojna

Corresponding author: Nadja Zupan Hajna (zupan@zrc-sazu.si)

Cave sediments provide a unique and valuable archive of past geological and environmental conditions, as they often represent the only terrestrial deposits from different phases of landscape evolution. These sediments are particularly well preserved in caves due to their protection from surface weathering and climate changes. Allogenic sediments transported into caves by sinking rivers capture changes in river catchments driven by tectonic or climatic forces. These deposits contain important information about sediment transport mechanics, the depositional processes, the sedimentary facies specific to cave environments, the origin of the clastic material, diagenetic processes, the paleoclimate and the timing of sedimentation. In addition, calcite speleothems formed under epiphreatic or vadose conditions are valuable for dating and studying past climatic and environmental changes through stable isotopes.

Cave sediments as part of a complex terrestrial depositional system challenge traditional stratigraphic principles. The law of superposition is often disrupted due to processes such as subsidence, reworking, burrowing and redeposition within the cave system. Sedimentation rates can be very different in vadose and phreatic karst, which further complicates chronological assessment due to frequent hiatuses and erosion phases.

In the karst areas of Slovenia, especially in the northwestern part of the Dinarides (SW Slovenia), we have studied multi-proxy records from Plio-Quaternary cave sediments. Our research integrates paleomagnetic and magnetostratigraphic data with U-series and radiocarbon dating, oxygen isotope stratigraphy, and paleontological and geomorphological analyses. These sediments, some of which are over 5 Ma, are found in near-surface and unroofed caves that have been exposed by karst denudation. The cave sediments provide crucial insights into speleogenesis, karst landscape evolution, tectonic regimes, catchment dynamics, and climate and environmental changes over time. The importance of cave sediments as comprehensive terrestrial archives for understanding the geological and environmental history of karst areas is well known from many recent studies.

CONTRIBUTIONS OF THE SEALEVEL PROJECT TO SPELEOTHEM BASED SEA-LEVEL STUDIES

Nina Lončar[1], Sanja Faivre[2] Blaž Miklavič[3], Bogdan Onac[4], Jadranka Barešić[5], Marko Baričević[6], Petra Kovač Konrad[7], Viktor Polyak[8], Yemane Asmerom[8]

[1]University of Zadar, Department of Geography, Trg kneza Višeslava 9, 23000 Zadar, Croatia
[2]University of Zagreb, Faculty of Science, Department of Geography, Marulićev trg 19/II, Zagreb, Croatia
[3]University of Guam, Water and Environmental Research Institute of the Western Pacific (WERI), UOG Station, 303 University Dr, Mangilao, 96913, Guam, USA
[4]University of South Florida, School of Geosciences, Stable Isotope Laboratory, 4202 East Fowler Avenue, NES 107, Tampa, Florida 33620, USA
[5]Ruđer Bošković Institute, Radiocarbon and Tritium Laboratory, Bijenička 54, 10000 Zagreb, Croatia
[6]Ericsson Nikola Tesla, Krapinska 45, 10000 Zagreb, Croatia
[7]Zagreb Speleological Union, Biankinijeva 3a, 10000 Zagreb, Croatia
[8]University of New Mexico, Earth & Planetary Sciences, Albuquerque, USA

Corresponding author: Nina Lončar (nloncar@unizd.hr)

Submerged and partially submerged brackish caves, ideal for speleothem-based paleoenvironmental studies, are abundant in Croatia (Surić et al., 2010; Lončar, 2021). As part of the SEALeveL project (HRZZ-IP-2019-04-9445), funded by the Croatian Science Foundation, speleological and cave-diving research in the eastern Adriatic (Kvarner, Zadar-Šibenik, and Dubrovnik coastal areas) was conducted. The primary goal was to find speleothems, particularly those with phreatic overgrowths (POS), for paleoclimate and sea-level reconstruction. Over 20 caves were explored, mostly submerged or partially submerged pits in stratified Cretaceous limestone. Systematic cave explorations led to speleothem sampling in Medvjeđa špilja on Lošinj Island, Kravljačica in Kornati archipelago and Šipun near Cavtat.

Research has made significant contributions, including the first documentation of Phreatic Overgrowth on Speleothems (POS) in the Adriatic, placing Croatia as the sixth global location contributing to POS-based sea-level research. Speleothem MLp-1 from Medveđa špilja revealed that ca. 2800 years ago, relative sea level was stable for about 300 years at a depth of approximately −1.28 ± 0.15 m below the current mean sea level (Lončar et al., 2024). U-Th dating of other submerged speleothem subsamples from Medvjeđa špilja (ML-12), Kravljačica pit (KRA-1) and Šipun cave (SIP-1 and SIP-2) revealed speleothems over 500,000 years old, providing insights into the long-term karst development and past environmental conditions of the Adriatic region. The continued deposition of speleothems in anchialine caves (Medvjeđa špilja and Šipun) after the last sea-level rise indicates that certain parts of these caves remained suitable for mineral growth despite partial submersion, reflecting complex hydrological conditions.

All collected samples have proven suitable for paleoclimate and sea-level studies, with ML-12, SIP-1 and KRA-1 among the oldest speleothems in Croatia. The presence of POS in the Adriatic suggests that this phenomenon may be more widespread than previously thought. These findings highlight the potential for further discoveries of POS in other coastal caves, particularly those located near paleo-shorelines. Along with mineralogical and stable

isotope analyses, these speleothems will refine paleoclimate records and improve the precision of relative sea-level change curves in the eastern Adriatic.

Acknowledgement

This research was supported by Croatian Science Foundation project HRZZ-IP-2019-04-9445 Relative sea-level change and climate change along the eastern Adriatic coast (Sea-LeveL).

REFERENCES

Lončar, N., 2021. Izotopni sastav siga i njegov značaj u rekonstrukciji paleookoliša Hrvatske. Acta geographica Croatica, 47/48 (1), 33-54. https://doi:10.21861/AGC.2021.47-48.03

Lončar, N., Faivre, S., Miklavič, B., Onac, B. P., Polyak, V. J., & Asmerom, Y. (2024). Characterization of phreatic overgrowths on speleothems precipitated in the northern Adriatic during a sea-level stillstand at ca. 2.8 ka. Quaternary Research 118, 88–99. https://doi.org/10.1017/qua.2023.65

Surić, M., Lončarić, R., Lončar, N., 2010: Submerged caves of Croatia: Distribution, classification and origin, Environmental Earth Sciences 61 (7), 1473–1480. https://doi.org/10.1007/s12665-010-0463-0

QUATERNARY SPELEOTHEM RECORDS OF ANTHROPOGENIC ORIGIN IN CROATIA

Maša Surić[1]

[1]Department of Geography, University of Zadar, F. Tuđmana 24 i, 23000, Zadar, Croatia

Corresponding author: Maša Surić (msuric@unizd.hr)

Speleothems are natural archives of environmental changes that can be recorded by various proxies – among other, by spelean calcite $\delta^{18}O$ and $\delta^{13}C$. As already confirmed regionally, their temporal variation corresponds to changes in precipitation amount and soil bioactivity, respectively (Surić et al., 2021a; 2021b; 2024). However, during the Late Quaternary, anthropogenic influence interferes with natural processes, thus sometimes the manmade changes masked the regional and global climate and environmental changes recorded elsewhere, making reconstruction impossible, but providing insight into the interaction of man and nature at the time.

In continental Croatia, stalagmites from Nova Grgosova Cave provided records of climate variability throughout the Holocene with the exception of short-term (centennial) changes from the last millennium which could not be resolved due to an apparent human intervention into the natural landscape. Namely, one of the largest European copper mines of that time in neighboring Ruda village (Vrkljan and Lebegner, 2008) was the reason for the massive deforestation in order to obtain arable land, timber for housing and supporting pillars in the mines and fuel for the ore smelting. Within isotopic record, it resulted with and increased $\delta^{13}C$ values (along with stable $\delta^{18}O$) which apparently altered the potential record of rapid climate changes such as those of the Medieval Warm Period or Little Ice Age (Surić et al., 2021a).

In littoral part of Croatia, Manita peć Cave on Velebit Mountain (570 m a.s.l.) and Modrič Cave in its foothill (32 m a.s.l.) share similar human-influenced environmental history (Rudzka et al., 2012; Surić et al., 2021b; 2024). Again, increased $\delta^{13}C$ values suggest occasional low soil bioactivity not only because of cold/dry conditions, but probably also due to the lack of vegetational cover. One of such episodes is overuse of the Velebit Mountain woodlands during the 16th-17th c. not only by high demand for timber by ruling Venetians, Otomans and Habsburgs, but also by growing local population and their needs for the firewood during the harsh Little Ice Age winters.

REFERENCES

Rudzka, D., McDermott, F., Surić, M. (2012): A late-Holocene climate record in stalagmites from Modrič Cave (Croatia). J. Quaternary Sci. 27, 585-596. https://doi.org/10.1002/jqs.2550.

Surić, M., Columbu, A., Lončarić, R., Bajo, P., Bočić, N., Lončar, N., Drysdale, R., Hellstrom, J. (2021a): Holocene hydroclimate changes in continental Croatia recorded in speleothem $\delta^{13}C$ and $\delta^{18}O$ from Nova Grgosova Cave. Holocene, 31 (9), 1401-1416. doi:10.1177/09596836211019120

Surić, M., Bajo, P., Lončarić, R., Lončar, N., Drysdale, R., Hellstrom, J., Hua, Q. (2021b): Speleothem records of the hydroclimate variability throughout the last glacial cycle from Manita peć Cave (Velebit Mountain, Croatia). Geosciences, 11 (8), 347, 21. doi:10.3390/geosciences11080347.

Surić, M., Bajo, P., Columbu, A., Lončarić, R., Lončar, N., Drysdale, R., Hellstrom, J. (2024): Reconstruction of environmental and hydroclimate changes in the Adriatic region over the last 367 kyr from Modrič Cave (Croatia) speleothems (in preparation)

Vrkljan D and Lebegner J (2008): Uređenje starog rudnika željeza u Rudama kraj Samobora (Renovating old iron mine in Rude near Samobor). *Mineral* 12(2): 22-24 (in Croatian)

LATE HOLOCENE CLIMATE RECONTRUCTIONS USING STABLE ISOTOPE RECORDS OF A STALAGMITE FROM NOVA GRGOSOVA CAVE (CENTRAL CROATIA)

Iva Palatinuš[1], Petra Bajo[1], Vlatko Brčić[1], Christoph Spötl[2], John Hellstrom[3], Hai Cheng[4], Philip Hopley[5]

[1]Croatian Geological Survey, Croatia
[2]Institute of Geology, University of Innsbruck, Austria
[3]School of Earth Sciences, University of Melbourne, Australia
[4]Institute of Global Environmental Change, Xi'an Jiaotong University, China
[5]Department of Earth and Planetary Sciences, Birkbeck, University of London, UK

Corresponding author: Iva Palatinuš (ipalatinus@hgi-cgs.hr)

Speleothems are cave formations that are increasingly used as reliable recorders of past environmental conditions, as they possess a range of climate-sensitive proxies (Johnson, 2021; McDermott, 2004). Their potential to provide high resolution chronologies has reinforced their role in palaeoclimate investigations during the past few decades. The most widely used speleothem proxies are the stable oxygen and carbon isotopes, which reflect both local environmental conditions as well as large-scale climate controls such as atmospheric circulation, moisture trajectories and solar forcing.

The climate of the Late Holocene was relatively stable in terms of environmental change, however, several warm and cold periods during the last two millennia can be distinguished, including the Dark Ages Cold Period, the Late Antique Little Ice Age, the Medieval Warm Period and the Little Ice Age.

Here, we present a high-resolution oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) stable isotope record obtained from an annually laminated Late Holocene stalagmite from Nova Grgosova cave in central Croatia. The age-depth model of the stalagmite is based on 15 U-Th ages, supported by a floating lamina-based chronology. The stalagmite grew continuously during the past ~1500 years until its collection in 2013. Distinct growth phases are evident, marked by significant changes in growth rate. The slowest growth rate (~ 0.01 mm yr^{-1}) occurred from ca. 1625 to 1830 CE, during the Little Ice Age, and from ca. 710 to 1060 CE, partially covering the Medieval Warm Period. From ca. 1060 CE to 1625 and ca. 535 to 710 CE the growth rate increased to ~0.1 mm yr^{-1}. The fastest growth rate (~0.2 mm yr^{-1}) was observed during the last ca. 185 years. Monitoring of this cave revealed that speleothems predominantly form during winter due to increased infiltration and enhanced dripwater degassing in a CO_2-depleted cave atmosphere (Bajo et al., 2024). Consequently, the calcite $\delta^{18}O$ serves as a proxy for cool-season precipitation.

Given the scarcity of precisely dated, high-resolution palaeoclimate records on Late Holocene climate variability, this study will not only contribute to the understanding of the local climate conditions in central Croatia, but also represents valuable information for further investigations of spatial and temporal coherence of the climate conditions over the past two millennia.

REFERENCES

Bajo, P., Briški, M., Benutić, A., Piplica, A., Brčić, V., Marciuš, B., Palatinuš, I., Stroj, A., 2024. Seasonality in cave dripwater and air properties – implications for speleothem palaeoclimatology, Nova Grgosova Cave (Croatia). Geologia Croatica, 77/3. https://doi.org/10.4154/gc.2024.16

Johnson, K.R., 2021. Tales from the underground: speleothem records of past hydroclimate. Elements, 17, 93–100. https://doi.org/10.2138/gselements.17.2.93

McDermott, F., 2004. Palaeo-climate reconstruction from stable isotope variations in speleothems: a review. Quaternary Science Reviews, 23, 901–918. https://doi.org/10.1016/j.quascirev.2003.06.021

GEOMORPHOLOGICAL AND GEOSPELEOLOGICAL RESEARCH IN THE PLITVICE LAKES NATIONAL PARK

Neven Bočić[1,2], Mladen Pahernik[2], Nenad Buzjak[1,2], Loris Redovniković[3]

[1]Department of Geography, Faculty of Science, University of Zagreb, Croatia
[2]Croatian Geomorphological Society, Croatia
[3]Institute of Applied Geodesy, Faculty of Geodesy, University of Zagreb, Croatia

Corresponding author: Neven Bočić (nbocic@geog.pmf.hrl)

The Plitvice Lakes National Park is a world-famous karst site that has been on the UNESCO World Heritage List since 1979. It covers an area of about 294 km^2. The basic phenomenon of the Park and its most famous element are the 16 lakes created by dividing the valley with tufa barriers over which the waterfalls tumble.

However, the area of the Park has an exceptional geomorphological diversity, in which surface and underground karst forms prevail. This lecture will present the results of research carried out as part of two projects: Geomorphological research of the Park and Geospeleological evaluation of the caves of the Park. The goals of these investigations were to carry out detailed geomorphological mapping and interpretation of relief morphogenesis and to carry out detailed geospeleological mapping and evaluation of selected caves.

In the first step, a general morphometric analysis based on a digital elevation model (DEM) of 5x5 m and 1x1 m was carried out. In a second step, geomorphological mapping was carried out. This was based on a DEM (0.5 x 0.5 m) created from Lidar scan data. The mapping was carried out by a combination of remote interpretation of the DEM and its derivatives and field mapping. Finally, a morphogenetic analysis and interpretation was carried out. Specific morphometric methods were used for the morphogenetic analysis (primarily dolines and drainage networks). In addition, 15 caves were selected for geospeleological research. Detailed mapping of geospeleological elements was carried out in these caves: structural elements, water bodies, macro- and mesomorphologic phenomena, speleogens, speleothems and cave sediments. The data obtained were used to interpret the speleogenesis and the assessment of the geodiversity of each of these caves.

Through the analysis of general morphometric parameters and the visualization of the landscape, the following maps and spatial data were obtained: elevation, slope, relative relief, slope orientation, slope curvature, hillshade, topographic position index, terrain ruggedness index, red relief image map, stream power index, topographic wetness index and others. As a result of the morphogenetic analysis, a structural-geomorphological map and a map of the spatial distribution of the exogenous morphogenetic relief types were created. Four morphogenetic relief types were identified: karst (34.4% of the area), fluviokarst (24.4%), fluviodenudational (31.8%) and accumulational relief (6.7%). The most common forms of karst relief are dolines. Thanks to the high-resolution DEM, exactly 18,879 dolines with a maximum density of 290.4 per km^2 were identified in the Park area. The highest densities were recorded in the areas built up from Cretaceous limestone. Special attention is also paid to map recent and relict tufa barriers and also to researching the morphogenesis of contact karst zones.

Geospeleological mapping was carried out in 15 caves with a total length of approx. 1200 m in order to determine the conditions of speleogenesis. In some channels the position of bedding planes played an important role, while

in others the position of fracture zones and faults was much more important. A large number of different speleogens were identified, some of which are very rare. The mapped speleogens form under different hydrological conditions. A great diversity of speleothems was also identified, with some rare forms occurring. The richness and variability of the clastic cave sediments were observed, the further study of which could provide detailed information on the speleogenesis and morphogenesis of this area.

The collected data indicate great dynamics in the development of the karst landscape and caves, as well as the great value of the geodiversity and geoheritage of the Plitvice Lakes National Park.

This research was financed by the Public Institution Plitvice Lakes National Park, which also provided us with a high-resolution DEM for use in the research. We especially thank them for that.

LOCAL IMPACTS ON LONG-TERM DENUDATION RATES: CASE STUDY FROM NORTH DALMATIAN PLAIN (CROATIA)

Kristina Krklec[1,2], Regis Braucher[3], Dražen Perica[4], David Domínguez-Villar[1]

[1]Department of Geology, Faculty of Sciences, University of Salamanca, Spain
[2]Department of Soil Science, Faculty of Agriculture, University of Zagreb, Croatia
[3]Aix-Marseille University, CNRS-IRD-Collège de France, UM 34 CEREGE, France
[4]Geography Department, University of Zadar, Croatia

Corresponding author: Kristina Krklec (krklec@usal.es)

Dissolution of carbonate rocks has been traditionally considered to be the main process governing carbonate rocks weathering (Dreybrodt, 1988). Consequently, processes such as physical and biological weathering, or impact of other factors have often been overlooked (Krklec et al., 2013, 2016, 2021). Thus, holistic approach is essential when studying evolution of karst landscapes.

We investigated long-term denudation rates in a location on the North Dalmatian Plain, a carbonate erosive surface located in the Dinaric karst region. Study site is composed of two different carbonate lithologies with distinct weathering styles, but without evident lithological impact on the local topography. Both lithologies were sampled for analyses of ^{36}Cl concentration (10 samples in total) and resulted in long-term denudation rates ranging from 14.7 to 22.8 m/Ma, with no statistical significance between samples from different lithologies. Since all samples were collected in a small area, having the same geomorphological context and climate features variable denudation rates are attributed to local differences in denudation.

Average denudation rate of the study site is 18.91 ± 0.81 m/Ma, allowing development of vertically dissected karst topography. However, the study site is characterised by levelled surface topography with bedrock residuals <0.5 m high and shallow soils, indicating differential denudation rates variable with time. We hypothesize that lichens and pedogenic carbonates have a significant role in modulating local differences in denudation rates. Where lichens have impact on differential denudation rate between residuals and the ground surface limiting the height of residuals and keeping the overall flat morphology of the planation, while precipitation of pedogenic carbonates in soils limits vertical progression of soil profile (Krklec et al., 2022).

ACKNOWLEDGEMENTS

This research is a part of the research project “Inter-comparison of karst denudation measurement methods” (KADEME) (IP-2018-01-7080) financed by Croatian Science Foundation.

REFERENCES

Dreybrodt, W., 1988. Processes in karst systems: physics, chemistry, and geology. Springer-Verlag, Berlin, New York.
Ford, D., Williams, P., 2007. Karst Hydrogeology and Geomorphology. John Wiley & Sons, Chichester.

Krklec, K., Braucher, R., Perica, D., Domínguez-Villar, D., 2022. Long-term denudation rate of karstic North Dalmatian Plain (Croatia) calculated from ^{36}Cl cosmogenic nuclides. Geomorphology 413, 108358. https://doi.org/10.1016/j.geomorph.2022.108358

Krklec, K., Domínguez-Villar, D., Carrasco, R.M., Pedraza, J., 2016. Current denudation rates over a dolostone karst from Central Spain: implications for the formation of unroofed caves. Geomorphology 264, 1–11. https://doi.org/10.1016/j.geomorph.2016.04.007

Krklec, K., Domínguez-Villar, D., Perica, D., 2021. Use of rock tablet method to measure rock weathering and landscape denudation. Earth Science Reviews 212, 103449. https://doi.org/10.1016/j.earscirev.2020.103449

Krklec, K., Marjanac, T., Perica, D., 2013. Analysis of "standard" (Lipica) limestone tablets and their weathering by carbonate staining and SEM imaging, a case study on the Vis Island, Croatia. Acta Carsologica 42/1, 135-142. https://doi.org/10.3986/ac.v42i1.636

CLIMATIC CONSTRAINTS TO KARST PROCESSES ACTIVITY: EVIDENCE FROM THE BALZI ROSSI AREA, AN ITALIAN OUTSTANDING PALAEOLITHIC SETTLEMENT COMPLEX

Marta Pappalardo[1], Eleonora Regattieri[2], Elena Rossoni-Notter[3], Olivier Notter[3], Abdelkader Moussous[3], Deirdre D. Ryan[1], Elisabetta Starnini[1], Matteo Vacchi[1], Alessio Rovere[4], Luca Forti[5], Andrea Pezzotta[5], Andrea Zerboni[5]

[1]Università di Pisa, Italy
[2]CNR-IGG, Pisa, Italy
[3]Musée d'Anthropologie Préhistorique de Monaco
[4]Università Ca'Foscari, Venice, Italy
[5]Università degli Studi di Milano, Italy

Corresponding author: Marta Pappalardo (marta.pappalardo@unipi.it)

Karst processes are active under very different climate conditions, being the presence of water the main constraint for their activity. In a specific environmental context where the amount of rainfall is close to the boundary of arid climate such as the Liguro-Provencal coastal area (Italian-French border), the occurrence of karst morphologies and/or deposits (clastic and speleothems) is the fingerprint of rainfall changes associated to major climate fluctuations. In such contexts, the products of spleogenesis, as well as other sedimentary products accumulated throughout the middle-late Pleistocene in cave environments or in near-cave locations and associated to caves development and evolution are preserved within a context of an archaeological site globally significant for Palaeolithic culture: the Balzi Rossi archaeological complex. Here, multiple cave and cliff-foot stratigraphic records provide a long-lasting combined record of environmental change and human settlement (Ryan et al., 2024).

Geomorphological investigations associated to a great number of chronological constraints performed under the umbrella of the SPHeritage Project, suggest alternated sedimentary phases dominated by speleothem formation and deposition of terrigenous sediments (particularly slope deposits) respectively.

This presentation will report on preliminary results of the research project aimed at combining the novel palaeoenvironmental dataset and archaeological evidence from the site. Its ultimate goal is to identify the timeframes when karst processes have been dominant and infer climate conditions associated to them.

Figure 1: Panoramic view of the Balzi Rossi archaeological complex.

REFERENCES

Ryan D.D., Starnini E., Serradimigni M., Rossoni-Notter E., Notter O., Zerboni A., Negrino F., Grimaldi S., Vacchi M., Ragaini L., Rovere A., Perego A., Muttoni G., Santaniello F., Moussous A., Pappalardo M., 2024. A geoarchaeological review of Balzi Rossi, Italy: a crossroad of Palaeolithic populations in the northwest Mediterranean. Quaternary Science Reviews 327, 108515. https://doi.org/10.1016/j.quascirev.2024.108515

THE PREHISTORIC MOUND OF UDINE (NE ITALY) FROM THE BRONZE AGE TO THE LEGEND OF ATTILA

Alessandro Fontana[1], Giacomo Vinci[1]

[1]Department of Geosciences, University of Padova, Italy.

Corresponding author: Alessandro Fontana (alessandro.fontana@unipd.it)

According to legend, the Hill of Udine in the Friuli Plain was built by Attila the Hun's soldiers, who constructed the mound for allowing their king to see the city of Aquileia burning after they had conquered it in 452 AD. The natural or artificial origin of the hill has been an issue that intrigued the scholars for centuries, but it was unsolved for long time because of the difficulty in obtaining stratigraphic data from the inner part of it (Fontana et al., 2023a). Between 2020 and 2022 five 40-m long stratigraphic cores were drilled, passing through the hill for its total thickness and allowing to investigate stratigraphy and chronology of it. An interdisciplinary research was carried out through geoarchaeological, paleobotanic and geochronological analyses (Fontana et al., 2023b). Moreover, the study analysed also the other available archaeological and geological information, collected in the last decades at the base and at the top of the hill. We also considered other hills and mounds in northern Italy and other European regions where folklore traditions relate their origin to Attila.

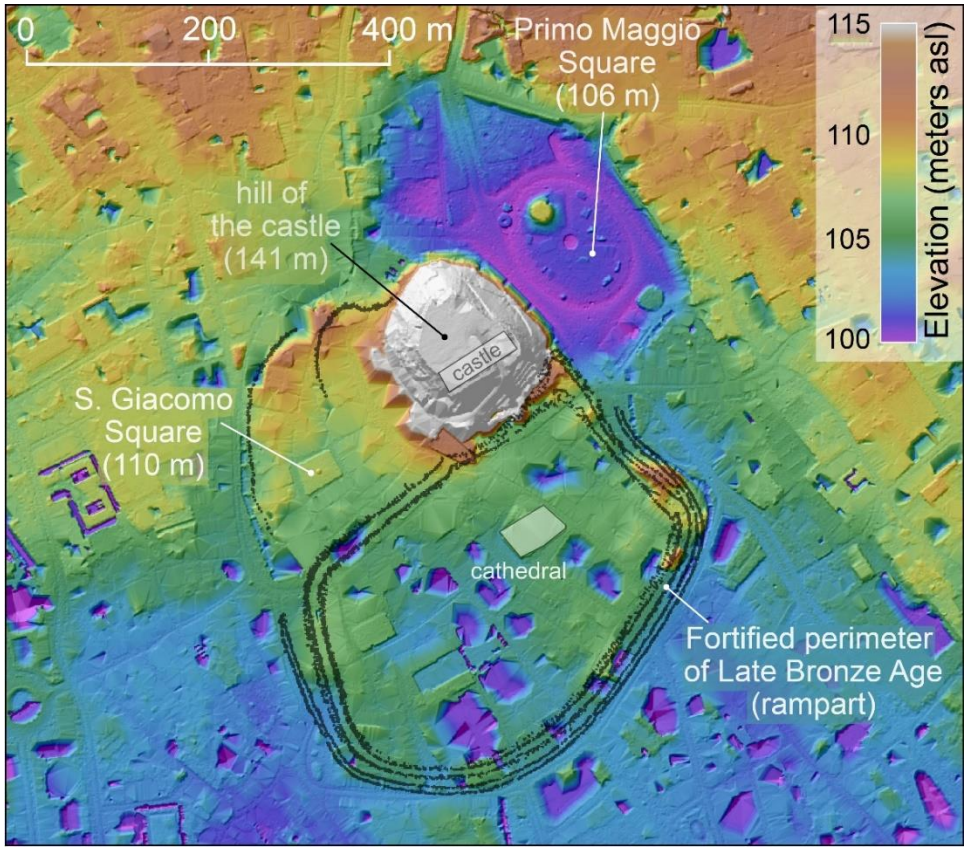

Figure 1: Digital Terrain Model of the centre of Udine with evidenced the Castle Hill and the wide depression of Primo Maggio Square, from where the large part of gravel and earth to build the mound was quarried.

Among the scientific community the most shared explanation about the origin of the hill used to reltate its existence to the tectonic activity occurred in the area during the Quaternary. In this view point, the core of the hill should consist of hard rock, probably of Neogene age. This hypothesis considered the importance of a natural relief that attracted the ancient people and, along the time raised and expanded the landform artificially. The new geoarchaeological data prove that the Hill of Udine is completely artificial and was built probably between the end of the Middle and the first part of the Recent Bronze Age (i.e. 1400-1300 BC), when the settlement of Udine experienced an important restructuration and reached 20 ha of extension. The period of construction of the first mound is framed by the radiocarbon dates available from the base of the mound and the archaeological remains found at the hilltop (Fontana et al. 2023a; 2023b). The detailed geomorphological study of the zone testifies that the large part of the material for erecting the mound was quarried from the area now occupied by Primo Maggio Square, where the original topography has been lowered up to 3-4 m below the natural pre-existing surface of the plain. Thus, the construction of the mound should be related to the excavation of a basin for creating a water reservoir. A shallow lake characterized the area of Piazza Maggio until the 18th century, when it was reclaimed and transformed in the city park.

The mound experienced some small modifications along the centuries but, apparently, it had already achieved the dimensions and the shape that still characterize it. In particular, it had a flat top surface already in the first phase, suggesting that it was used for some important activities as, probably, the presence of building related to territorial control and religious purposes. The base of the mound sealed the original surface of the alluvial plain, that was almost completely flat and only a small depression was likely existing in the western side of Primo Maggio square. The soil buried by the anthropogenic hill is comparable to the one occurring over the surface of the LGM fluvioglacial plain, but is characterized by the abundant presence of archaeological remains and clear traces of the human presence, as testified by occurrence of cereals and other paleobotanic remains related to anthropogenic activities. Anyhow, at the moment, the functions of the hill and the activities documented at the base and the top could be only hypothesized.

The new stratigraphic data allow to calculate the volume of gravels and earth that was used to build the mound, that are larger than 400,000 m^3 and likely range between 450,000 and 500,000 m^3 for the first phase. According to these data the Castle Hill of Udine is the largest mound in the European prehistory. This discovery reveals a new typology in earth construction of continental prehistory Age and reveals unprecedented capability in the Bronze Age people.

REFERENCES

Fontana, A., Vinci, G., Ronchi, L., Muscio, G., Visentini, P., Mocchiutti, A., Bassetti, M., Novellino, M.D., Badino, F., Musina, G., Bonomi, S., 2023a. “Che esso colle non dalla natura, ma alla mano degli uomini…” Storia degli studi geologici del colle di Udine dal Medioevo al 2020, in: Visentini P. (Ed.), Archeologia Urbana a Udine. Contributi per una rilettura dei dati provenienti dal colle del castello. Monografie Museo Friulano Storia Naturale 48, pp. 12–31.

Fontana, A., Vinci, G., Ronchi, L., Mocchiutti, A., Muscio, G., Visentini, P., Bassetti, M., Novellino, M.D., Badino, F., Musina, G., Bonomi, S., 2023b. The largest prehistoric mound in Europe is the Bronze-Age Hill of Udine (Italy) and legend linked its origin to Attila the Hun. *Scientific Reports*13, 8848. https://doi.org/10.1038/s41598-023-35175-8

A MULTI-PROXY APPROACH TO THE RECONSTRUCTION OF HUMAN-ENVIRONMENT INTERACTION IN THE 5TH MILLENNIUM CAL BC: CASE STUDY SITE IN THE DANUBE RIVER VALLEY (NORTHERN CROATIA)

Katarina Botić[1], Leszek Marks[2], Fabian Welc[3], Jerzy Nitychoruk[4], Anna Rogóż-Matyszczak[4], Marcin Szymanek[5], Monika Czajkowska[6], Izabela Cabała[5]

[1] Institute of Archaeology, Zagreb, Croatia
[2] Polish Geological Institute – National Research Institute, Warsaw, Poland
[3] Cardinal Stefan Wyszyński University, Institute of Archaeology, Warsaw, Poland
[4] Pope John Paul II University of Applied Sciences, Biała Podlaska, Poland
[5] University of Warsaw, Faculty of Geology, Warsaw, Poland
[6]Past Landscape Dynamics Laboratory, Institute of Geography and Spatial Organization, Polish Academy of Sciences

Corresponding author: Katarina Botić (kbotic@iarh.hr)

The formation of Neolithic tell settlements, a phenomenon that firstly occurred in the Neolithic period in the Middle East, in wetlands or near watercourses is documented in the published literature, but their extensive research is not often based on environmental study. Tell formation and development processes vary greatly between geographic regions and in time. Numerous Anatolian tells appeared in the Early Neolithic (7th millennium cal BC), indicating rapid settlement formation in the valleys on regularly flooded plains or near wetlands (Horejs 2019; Naumov 2020). Later, in the Southern Balkans (after 6650 cal BC; Krauß et al. 2018), the Northern Balkans and the Carpathian Basin (~5000 cal BC, at the end of the regional Middle and in the Late Neolithic; Link 2006) preference for wetlands and the vicinity of watercourses for their formation still persisted. The formation of these later tells was not the result of the establishment of the first pioneer settlements, as was the case in Anatolia, but was the choice of agricultural communities with a more developed social and economic structure (Naumov 2020). Geographic, climatic and hydrological conditions vary greatly in such large region, rendering results from Anatolia and the southern Balkans useless for the study of environmental conditions in the Northern Balkans or the Carpathian Basin, despite the presence of global climate events in these records (e.g. Gulyás, Sümegi 2011).

Our study provides an overview of the results from two sediment cores (BR1 and BR2) collected from the multi-layered tell archaeological site of Bršadin – Pašnjak pod selom, located on the former bank of the Vuka River, one of the Danube's tributaries in the north-eastern Croatia (Botić et al. 2024). Environmental history of the site was reconstructed using results from archaeological and sedimentary records. Based on multi-proxy data, seven zones (A–G) were distinguished in BR1/16 and five zones (A–E) in BR2/16 cores. Although it has been suggested that a waterlogged environment was deliberately selected for this type of settlement in the regional Late Neolithic, our results indicate dry and cool conditions prior and during the initial phase of the settlement formation (Phases 1 and 2, ~4900 cal BC). The abandonment of the settlement, possibly in the late 5th millennium cal BC, occurred most likely due to alternating dry and wet episodes (Phase 5), rather than a gradual increase in wet conditions, as suggested elsewhere in the region (Gulyás, Sümegi 2011). The existence of a large ditch around the settlement, not documented by archaeological research, can be indirectly confirmed by the results from the BR2/16 core and the analysis of aerial and satellite images. Despite the fact that a direct correlation between the two sediment

cores was not possible, connecting the results from the sediment archive with the archaeological context enabled the reconstruction of the site's environmental history.

REFERENCES

Botić, K., Marks, L., Welc, F., Nitychoruk, J., Rogóż-Matyszczak, A., Szymanek, M., Czajkowska, M., Cabała, I., 2024. Environmental change documented in the fluvial landscape: a case study of the Late Neolithic Bršadin–Pašnjak pod selom site (NE Croatia). Environmental Archaeology Special Issue: Multidisciplinary approaches to socio-environmental interactions in wetland landscapes, in press. https://doi.org/10.1080/14614103.2024.2408182

Gulyás, S., Sümegi, P., 2011. Farming and/or foraging? New environmental data to the life and economic transformation of Late Neolithic tell communities (Tisza Culture) in SE Hungary. Journal of Archaeological Science 38, 3323–3339. https://doi.org/10.1016/j.jas.2011.07.019

Horejs, B., 2019. Migrating and Creating Social Memories: On the Arrival and Adaptation of the Neolithic in Aegean Anatolia, in: Brami, M., Horejs, B. (Eds.), The Central/Western Anatolian Farming Frontier, Proceedings of the Neolithic Workshop held at 10th in Vienna, April 2016. Austrian Academy of Sciences Press, Vienna, pp. 159–179.

Krauß, R., Marinova, E., De Brue, H., Weninger, B., 2018. The rapid spread of early farming from the Aegean into the Balkans via the Sub-Mediterranean-Aegean Vegetation Zone. Quaternary International 496, 24–41. https://doi.org/10.1016/j.quaint.2017.01.019

Link, T., 2006. Das Ende der neolithischen Tellsiedlungen. Ein kulturgeschichtliches Phänomen des 5. Jahrtausends v. Chr. im Karpatenbecken. Universitätsforschungen zur Prähistorischen Archäologie 134, Verlag Dr. Rudolf Habelt GmbH, Bonn.

Naumov, G., 2020. Domestication of Tells: Settlements of the First Farmers in Pelagonia (Macedonia), in: Blanco-González, A., Kienlin, T.L. (Eds.), Current Approaches to Tells in the Prehistoric Old World, Oxbow Books, Oxford, pp. 111–124.

ENVIRONMENTAL DYNAMICS AND SETTLEMENTS PATTERNS IN THE COASTAL PLAIN OF NE-ITALY SINCE MIDDLE HOLOCENE

Mattia Azzalin[1], Alessandro Fontana[1], Giacomo Vinci[1], Timme Donders[2], Wouter Gerats[2]

[1]University of Padua, Italy
[2]Utrecht University, Netherlands

Corresponding author: Mattia Azzalin (mattia.azzalin@phd.unipd.it)

Besides the Lagoon of Venice, the other tidal and brackish environments characterizing the NW Adriatic Sea experienced an evolution of over 8000 years that strongly imprinted the available resources of the coastal plain and partly constrained the activities and habits of ancient population (Fontana & Ronchi, 2021). We analyzed some key areas where some important paleo-ecological archives are available and the archaeological presence is documented since the Neolithic (Fontana, 2006). In particular, we focused on the area around Concordia Sagittaria and Aquileia (*Figure 1*), that became important Roman cities, but where large settlements already existed since late Prehistory (Fontana et al., 2017).

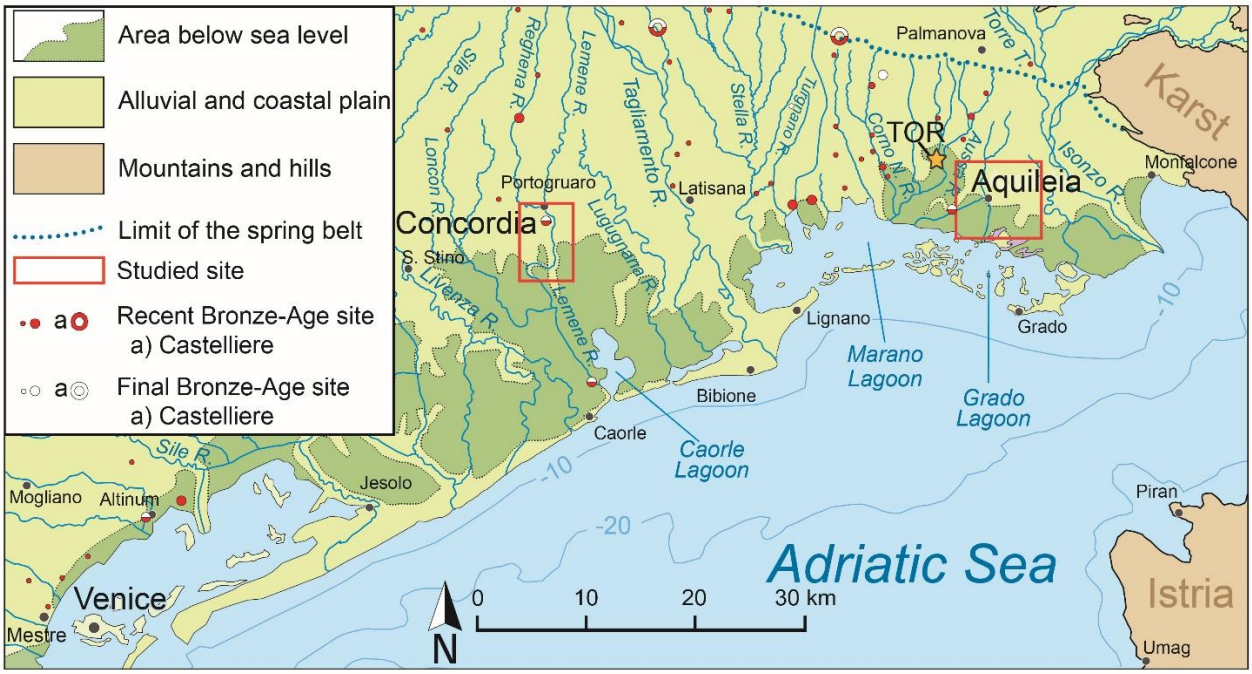

Figure 1: Location of key areas for geomorphological and paleo-ecological studies (modified after Fontana et al., 2017).

This research is based on a multidisciplinary approach that implies the interpretation and integration of LiDAR-derived DEMs, remote-sensed images and paleoenvironmental reconstructions obtained through detailed paleobotanic and micropaleontological analyses. In particular, the stratigraphic architecture of the coastal plain has been reconstructed through the use of over 5000 boreholes produced in the last 20 years by the collaboration

between the universities of Padova and Utrecht, during student fieldworks and specific research projects (Ronchi et al., 2021).

Near Concordia Sagittaria a large incised fluvial valley was formed by Tagliamento River during Late Glacial, separated by scarps of over 10 m from the rest of the plain and with a width up to 1500 m. Since around 8500 years BCE the marine transgression transformed this depressed landform to an estuary extending the brackish environments for over 15 km landward (Ronchi et al., 2021). This peculiar setting catalyzed the prehistoric settlements over the edges of this valley (Fontana, 2006) and, at the same time, the fluvial incision represents a unique ecological archive with an almost continuous sedimentation until historic time, that allows detailed paleo-environmental reconstructions (Favaretto & Sostizzo, 2006).

Recent geological surveys documented the existence of other incised fluvial valleys near the city of Aquileia (Fontana et al. 2024; Vanzani et al., 2024) and this opens new perspectives for archaeological and paleo-environmental studies in this area, that corresponds to the northernmost extension of lagoon environments in the Mediterranean. Investigations through mechanical and manual boreholes in this sector indicate that a number of brackish swamps formed since around 5000 years BCE. The detection and mapping of these features through LiDAR-derived DEMs and aerial photographs coupled with the interpretation of data obtained through archaeological investigations (Fontana et al., 2017) as well as detailed pollen analysis allow to reconstruct the evolution of the ancient human impact on the natural environment, suggesting that it became tangible well before the Roman Period. Between Middle and Recent Bronze Age, a dense pattern of settlements developed also in the coastal plain, with many synchronous sites along the lagoon fringe. New pollen data from stratigraphic core in Torviscosa (TOR), near Aquileia, demonstrate that significant wood clearance already occurred during the Middle Bronze Age also in the distal plain.

REFERENCES

Favaretto, S., Sostizzo, I., 2006. Vegetazione e ambienti del passato nell'area di Concordia Sagittaria (VE). Quaderni del Dottorato, Università di Padova, Dipartimento di Geografia, 1, pp. 57-70.

Fontana, A., 2006. Evoluzione geomorfologica della bassa pianura friulana: e sue relazioni con le dinamiche insediative antiche: Ed. del Museo Friulano di Storia Naturale, 287 p.

Fontana, A., Ronchi, L., 2021. Paesaggi sommersi in Alto Adriatico Dalla pianura glaciale al futuro innalzamento marino: Dalla pianura glaciale al futuro innalzamento marino. Studi e ricerche. doi:10.30687/978-88-6969-480-6/001.

Fontana, A., Vanzani, F., Bagalini, M., Chiarini, V., 2024. La bassa pianura del sistema Isonzo-Torre, in: Fontana A. (Ed.) La pianura del Friuli Venezia Giulia. Geomorfologia e Geologia del Quaternario. Regione Friuli Venezia Giulia, pp. 183-198.

Fontana, A., Vinci, G., Tasca, G., Mozzi, P., Vacchi, M., Bivi, G., Salvador, S., Rossato, S., Antonioli, F., Asioli, A., Bresolin, M., Di Mario, F., Hajdas, I., 2017. Lagoonal settlements and relative sea level during Bronze Age in Northern Adriatic: Geoarchaeological evidence and paleogeographic constraints. Quaternary International, v. 439, pp. 17–36.

Ronchi, L., Fontana, A., Cohen, K.M., Stouthamer, E., 2021. Late Quaternary landscape evolution of the buried incised valley of Concordia Sagittaria (Tagliamento River, NE Italy): A reconstruction of incision and transgression. Geomorphology, v. 373, p. 107509.

Vanzani, F., Fontana, A., Ronchi, L., Boaga, J., Chiarini, V., Hajdas, I., 2024. The Dunes of Belvedere–San Marco of Aquileia: Integrating High-Resolution Digital Terrain Models and Multispectral Images with Ground-Penetrating Radar Survey to Map the Largest System of Continental Dunes of Northern Italy. Remote Sensing, 16, 765. https://doi.org/10.3390/rs16050765.

REEVALUATING THE STRATIGRAPHIC INTEGRITY OF ŠANDALJA II CAVE: A PALAEOLITHIC CASE STUDY FROM THE ADRIATIC (ISTRIA, CROATIA)

Nikola Vukosavljević[1], Marc Vander Linden[2], Siniša Radović[3], Ivor Karavanić[1], Aitor Ruiz-Redondo[4]

[1]University of Zagreb Faculty of Humanities and Social Sciences, Department of Archaeology, Croatia
[2]Bournemouth University, Institute for the Modelling of Socio-Environmental Transitions (IMSET), United Kingdom
[3]Institute for Quaternary Paleontology and Geology in Zagreb, Croatian Academy of Sciences and Arts (HAZU), Croatia
[4]University of Zaragoza, Institute for Research in Environmental Sciences of Aragon (IUCA), Spain

Corresponding author: Nikola Vukosavljević (nvukosav@ffzg.unizg.hr)

Šandalja II has been a key site for decades in defining and studying the Eastern Adriatic Upper Palaeolithic and its associated techno-complexes. This is due to its extensive material record and the alleged presence of rare techno-complexes in the region, such as the Aurignacian and Early Epigravettian. In this paper, we present two new series of C14-AMS dates (from layers H, E, C/d, and A/d) recently published (Ruiz-Redondo et al., 2023) to evaluate the validity of Šandalja II archaeological sequence, along with previously obtained radiocarbon dates, both AMS and conventional. The results clearly demonstrate the unreliability of the stratigraphy defined during the site's excavation due to the poor excavation methodology. A straightforward chronometric deconstruction shows that the assemblages from Šandalja II can no longer be used to illustrate the diachronic evolution within the Aurignacian and Epigravettian of the Eastern Adriatic. This necessitates a re-evaluation of features defined for the Adriatic Upper Palaeolithic based on the assemblages from Šandalja II. Consequently, Šandalja II joins a growing list of so-called reference sites that should no longer be considered "referential".

REFERENCES

Ruiz-Redondo, A., Vander Linden ,M., Radović, S., Karavanić, I., Vukosavljević, N., 2024. A cautionary tale from the Adriatic Palaeolithic: reassessing the stratigraphic reliability of Šandalja II cave (Istria, Croatia). Comptes Rendus Palevol 23 (15), 197–210. https://doi.org/10.5852/cr-palevol2024v23a15

RECONSTRUCTING LIFE HISTORY EVENTS FROM CAVE BEAR TEETH

Irena Debeljak

Ivan Rakovec Institute of Palaeontology, ZRC SAZU, Ljubljana, Slovenia

Corresponding author: Irena Debeljak (irena.debeljak@zrc-sazu.si)

Dental tissues – enamel, dentin and cementum – are considered to be an 'archive of life' (e.g. Cerrito et al., 2020) and can serve as an important source of information about extant and extinct mammalian species (e.g. Hillson, 2005). Unlike bone tissue, dental tissues do not undergo continuous remodeling once formed. Major life events can thus remain recorded in incremental structures in teeth (e.g. Klevezal, 1996). Dental cementum is of special importance in this regard, as it is deposited on the surface of tooth roots throughout life, until death. Counting cementum annuli has long been used as the most reliable and objective method for determining individual age in present-day bears (e.g. Rausch, 1961; Mundy & Fuller, 1964; Hensel & Sorensen, 1980). Furthermore, some studies on female black and polar bears have shown that past reproductive events can usually be inferred from the width of individual cementum annuli (Coy & Garshelis, 1992; Medill, 2008; Medill et al., 2010).

By using various sample preparation techniques, individual age of cave bears can be relatively easily determined based on cementum increments, and often even season at death (Debeljak, 1996; 2000). In cave bear, cementum analyses provided key data on mortality patterns, senescence, longevity, and seasonality (e.g. Debeljak, 2002; 2004; 2007; 2011). Furthermore, research is currently underway to investigate the possibility of reconstructing reproductive histories from cementum increments. Data on the age when females first reared cubs, the average interval between litters and other reproductive parameters could significantly improve our understanding of the species' vulnerability, and serve as another source of information in environmental studies. Normal growth patterns (e.g. Debeljak, 2011) as well as disturbances caused by pathological processes can be observed in dentin. Based on knowledge about ontogenetic development of cave bear teeth (Debeljak 1997; 2002), it is sometimes possible to determine at what age exactly a certain stressful event, like severe dental trauma for example, occurred. Also this kind of information can give as some clue about health and behavioral specifics of the cave bear.

REFERENCES

Cerrito, P., Bailey, S.E., Hu B., Bromage, T.G., 2020. Parturitions, menopause and other physiological stressors are recorded in dental cementum microstructure. Scientific Reports 10/1: 5381. https://doi.org/10.1038/s41598-020-62177-7

Coy, P.L., Garshelis, D.L., 1992. Reconstructing reproductive histories of black bears from the incremental layering in dental cementum. Can. J. Zool. 70/11, 2150-2160. https://doi.org/10.1139/z92-290

Debeljak, I., 1996. A simple preparation technique of cave bear teeth for age determination by cementum increments. Rev. Paléobiol. 15/1, 105-108.

Debeljak, I., 1997. Ontogenetic development of dentition in the cave bear. Geologija 39, 13-77. https://doi.org/10.5474/geologija.1996.001

Debeljak, I., 2000. Dental cementum in the cave bear; comparison of different preparation techniques. Geol. zbornik 15, 53-66.

Debeljak, I., 2002. Fossil population structure of the cave bear from Divje babe I site, Slovenia: Preliminary results. Abh. zur Karst- und Höhlenkunde 34, 41-48.

Debeljak, I., 2004. Fossil Population Structure of the Cave Bear from Potočka zijalka (Slovenia). Mitt. Komm. Quartärforsch. Österr. Akad. Wiss. 13, 173-182.

Debeljak, I., 2007. Fossil population structure and mortality of the cave bear from the Mokrica cave (North Slovenia). Acta Carsologica 36/3, 475-484. https://doi.org/10.3986/ac.v36i3.181

Debeljak, I., 2011. Determination of Individual Age and Season at Death in Cave Bear from Ajdovska jama near Krško (Slovenia). Mitt. Komm. Quartärforsch. Österr. Akad. Wiss. 20, 51–63.

Hensel, R.J., Sorenson, F.E., Jr., 1980. Age determination of live polar bears. Bears - Their Biology and Management 4, 93-100. https://doi.org/10.2307/3872849

Hillson, S., 2005. Teeth. Cambridge Manuals in Archaeology, 2nd edition, Cambridge University Press, pp. 1-388. https://doi.org/10.1017/CBO9780511614477

Klevezal, G.A., 1996. Recording Structures of Mammals. Determination of Age and Reconstruction of Life History. A. A. Balkema, Rotterdam, pp. 1-274.

Medill, S.A., 2008. Reconstructing life histories using cementum: Information recorded in premolars of polar bears (*Ursus maritimus*). University of Alberta Library, pp. 1-132. https://dx.doi.org/10.7939/r3-zkc7-5e98 https://era.library.ualberta.ca/items/501a828e-d820-40db-b911-35fdb76f9153

Medill, S., Derocher, A.E., Stirling, I., Lunn, N., 2010. Reconstructing the reproductive history of female polar bears using cementum patterns of premolar teeth. Polar Biol. 33, 115–124. http://dx.doi.org/10.1007/s00300-009-0689-z

Mundy, K.R.D., Fuller, W.A., 1964. Age determination in the grizzly bear. J. Wildl. Manage. 28/4, 863-866. https://doi.org/10.2307/3798810

Rausch, R.L., 1961. Notes on the black bear (*Ursus americanus* Pallas) in Alaska, with particular reference to dentition and growth. Z. Saugetierk. 26/2, 77-107.

Tochigi, K., Tamatani, H., Kozakai, C., Inagaki, A., Naganuma, T., Myojo, H., Yamazaki, K., Koike, S., 2018. Reproductive Histories of Asian Black Bears Can be Determined by Cementum Annuli Width Mammal Study 43/4, 261-268. https://doi.org/10.3106/ms2018-0016

CHRONOLOGY OF PLIOCENE-PLEISTOCENE FLUVIAL TERRACES IN SOUTH-EASTERN SLOVENIA (KRŠKO AND VELENJE BASINS)

Eva Mencin Gale[1], Petra Jamšek Rupnik[1], Jure Atanackov[1], Miloš Bavec[1], Michael Logan Cline[2], Stephanie Neuhuber[3], Sandra M. Braumann[3], Alexander Wieser[4], Oscar Marchart[4], Marcus Christl[5], Christof Vockenhuber[5], Naki Akçar[6]

[1]Geological Survey of Slovenia, Department for Regional geology, Ljubljana, Slovenia
[2] U.S. Bureau of Reclamation, Seismology and Geomorphology Group, USA
[3]University of Natural Resources and Life Sciences, Department of Civil Engineering and Natural Hazards, Institute of Applied Geology, Vienna, Austria
[4]University of Vienna, Faculty of Physics, Isotope Physics, Vienna, Austria
[5]ETH Zurich, Laboratory of Ion Beam Physics, Zurich, Switzerland
[6]University of Bern, Institute of Geological Sciences, Bern, Switzerland

Corresponding author: Eva Mencin Gale (eva.mencin-gale@geo-zs.si))

Landscape evolution during the Pliocene and Quaternary was strongly influenced by abrupt changes in climate and tectonic activity. These changes were strongest in the highly dynamic European Alps and their foreland, where the deposition and remobilization of Pliocene-Quaternary terrestrial deposits caused by climatic and tectonic changes took place. In the south-eastern Alpine foreland (Slovenia) Pliocene-Quaternary fluvial sediments were deposited in several intramontane basins: the Slovenj Gradec, Nazarje, Celje, Drava-Ptuj, Velenje, and Krško basins. Fluvial deposits in these basins are preserved in terrace systems, with the oldest Pliocene-Early Pleistocene terraces located at the highest landscape position and the youngest, Holocene terraces occupying the lowest landscape positions, close to the recent floodplain. Investigating the erosional and deposition history of the basin sediments provides critical insights to the Pliocene-Quaternary landscape evolution and requires a holistic approach that considers morphology, composition, chronology, and climatic and tectonic factors. Age dating has been so far conducted only in the Krško and Velenje Basins, employing several techniques: radiocarbon dating, luminescence dating, and cosmogenic radionuclide dating. In the Krško Basin, an extensive geochronology is available. The highest (oldest) terrace group was dated to range from 1.2-2.9 Ma and 500-700 ka, the middle terrace group ranges from 95 ka-152 ka, and the lowest (youngest) terrace group ranges from 13 k to 20 ka. The span of ages for the highest terrace group indicates the need to further distinguish the Pliocene-Middle Pleistocene units in this basin. In the Velenje Basin, a single age for the highest terrace group, which is consistent with the age of the highest terrace group in the Krško Basin, returned an age of approximately 2.7 Ma. The main objective of this study is to continue developing the geochronology for the basins to improve morphostratigraphic models, enable inter-basin correlation and to constrain erosion and incision rates across the region. Results will ultimately inform our understanding of landscape evolution in the south-eastern Alpine foreland.

PALAEOSOILS IN LATE GLACIAL SANDY TERRAINS OF THE PANNONIAN BASIN AND ADJACENT AREAS

Koen Beerten[1], Lidija Galović[2], Petar Stejić[3], Stjepan Husnjak[4], Jasmina Martinčević Lazar[1], Rodoljub Gajić[3], Stanko Ružičić[5], Ajka Pjanić[1], Mihajlo Pandurov[3]

[1]Belgian Nuclear Research Centre, Engineered and Geosystems Analysis, 2400 Mol, Belgium
[2]Croatian Geological Survey, 10000 Zagreb, Croatia
[3]Geological Survey of Serbia, 11000 Belgrade, Serbia
[4]University of Zagreb, Faculty of Agriculture, 10000 Zagreb, Croatia
[5]University of Zagreb, Faculty of Mining Geology and Petroleum Engineering, 10000 Zagreb, Croatia

Corresponding author: Koen Beerten (kbeerten@sckcen.be)

The stepwise climatic amelioration that accompanied the transition from the Last Glacial pleniglacial to the Holocene interglacial has left significant imprints in the geological record. Amongst these are palaeosoils that developed during the Late Glacial (LG), during episodes of landscape stability, roughly between 15 ka and 11.7 ka. Unlike their equivalents in simultaneously deposited loess sediment, palaeosoils in sandy terrains have received much less attention in terms of regional and supra-regional correlations. Nevertheless, comparing the timing and nature of LG soil formation across European sites would allow us to picture the spatio-temporal climatic evolution from a different perspective. Apart from the loess belt, and mainly north of it, the European Sand Belt (ESB) can be seen as an enormous archive in this context since it mainly consists of outcropping Late Pleistocene (and Holocene) sand sheets and dunes, stretching from northwestern France to the Ukraine and beyond. In addition, outside the ESB, and mostly to the south of it, many local archives in sandy terrains show similar (but not equal?) pedogenetic developments during the LG as those observed in the ESB. Such inland sandy terrains are known from, e.g., Spain, southwestern France, southern Czech Republic, Hungary, Croatia and Serbia. Sandy terrains from the latter three are predominantly situated in the Pannonian Basin, and may therefore be a good starting point to set up correlations towards the north, in the direction of the ESB.

In this presentation, we will first show typical examples of Late Glacial palaeosoils from northern Croatia and eastern Serbia, and discuss their properties and context (episodes of landscape stability during Late Glacial dune development), as well as their estimated time of formation. Next, these findings will be confronted with published information from Late Glacial palaeosoils in sandy terrains in the north of the Pannonian Basin, i.e., in Hungary. Finally, several similarities and differences between LG palaeosoils in the ESB and the Pannonian Basin will be highlighted. It will become clear that unlocking the LG palaeosoil archive at a supra-regional scale will significantly increase its potential to reconstruct patterns of palaeoenvironmental change during the Pleistocene-Holocene transition.

DOCUMENTING SUBGLACIAL CONCRETIONS IN THE DOLOMITES: EPHEMERAL WITNESSES OF PAST GLACIERS

Veronica Chiarini[1], Nereo Preto[1], Simone Bizzi[1], Stefano Castelli[1], Livio Ronchi[1], Alessandro Fontana[1]

[1]Dipartimento di Geoscienze, Università di Padova, via Giovanni Gradenigo 6, 35131 Padova, Italy

Corresponding author: Veronica Chiarini (veronica.chiarini@unipd.it)

Global warming is causing rapid continental glacier retreat worldwide. The Alpine area appears to be one of the most affected regions with an annual glacier mass loss of about 1.2 kg/m^2 between 1997 and 2017 (*Copernicus Climate Change Service(C3S)/WGMS*). This rapid retreat is exposing surfaces which were previously covered by a thick icecap revealing new morphologies and deposits. Where carbonate bedrocks are present, at the ice-rock interface carbonate deposits can precipitate. Known as "subglacial carbonate concretions" they were first noticed and described in the early '70s in the Canadian Rocky Mountains (Ford et al., 1970). They appear as crusts deposited on the lee side of obstacles and their formation has been related to melting and re-gelation processes of thin films of water at the base of glaciers (Ford et al., 1970; Hallet 1976; Hallet, 1979; Frisia and Borsato 1994; Nq and Hallett, 2002). Their potential as paleoenvironmental proxies is not clear since their isotopic signals ($\delta^{13}C$ and $\delta^{18}O$) can be affected by strong kinetic fractionation (Hanshaw and Hallet, 1976; Lemmens et al., 1982; Lipar et al., 2020). However, Lipar et al. (2020) dated back to the Younger Dryas and the LGM some subglacial concretions from the Triglav Glacier (Slovenia), showing their potential in providing information about glaciers development during the current interglacial phase. Indeed, once exposed to weathering, these subglacial deposits soon disappear: Frisia and Borsato (1994) estimated a maximum duration of subglacial concretions of about 50 years in the "Dolomiti del Brenta" area. This suggests that subglacial carbonate deposits, when found, indicate the absence of an icecap for a maximum of about 50 years. If we consider the widespread presence of carbonate bedrock in the central and eastern part of the Italian Alps and the massive glacier retreat this region is experiencing, it comes out that new subglacial concretions are being exposing fast. But they will not last for long. It is thus important to document and study them before they will be destroyed by weathering and erosion processes.

We here present the documentation and morphological description of subglacial carbonate deposits from three mountain groups in the Dolomites: Marmolada, Antelao, and Tuckett.

Photogrammetric surveys were carried out in 2020 and 2021 on subglacial deposits identified both at the flanks (Antelao and Tuckett sites) and at the front (Antelao and Marmolada) of the glaciers. Some samples were collected for geochemical analyses and petrographic investigation.

3D models of the investigated sites were realised using the Structure for Motion (SfM) technique with the Agisoft MetaShape software. This low-cost method allowed us to easily obtain data from which it is possible to produce models with a sub-millimetric resolution, thus highlighting the potential of this easily accessible method to document these types of concretions. Subglacial deposits were described according to their morphological features and a tentative classification was proposed.

REFERENCES

Frisia, S., Borsato, A., 1994. Composizione, precipitazione e dissoluzione di carbonati subglaciali nelle Dolomiti di Brenta. Museo tridentino di scienze naturali.

Ford, D., Fuller, P., Drake, J, 1970. Calcite Precipitates at the Soles of Temperate Glaciers. Nature 226, 441–442.

Hallet, B., 1976. Deposits formed by subglacial precipitation of $CaCO_3$. Geological Society of America Bulletin, 87(7), 1003-1015.

Hallet, B., 1979. Subglacial regelation water film. Journal of Glaciology, 23(89), 321-334.

Hanshaw, B. B., & Hallet, B., 1978. Oxygen isotope composition of subglacially precipitated calcite: possible paleoclimatic implications. Science, 200(4347), 1267-1270.

Lemmens, M., Lorrain, R., & Haren, J., 1982. Isotopic composition of ice and subglacially precipitated calcite in an alpine area. Zeitschrift für Gletscherkunde und Glazialgeologie, 18(2), 151-159.

Lipar, M., Martín-Pérez, A., Tičar, J., Pavšek, M., Gabrovec, M., Hrvatin, M., Komac, B., Zorn, M., Zupan Hajna, N., Zhao J.-X., Drysdale, R.N., Ferk, M., 2021. Subglacial carbonate deposits as a potential proxy for a glacier's former presence. The Cryosphere, 15(1), 17-30.

Ng, F., & Hallet, B., 2002. Patterning mechanisms in subglacial carbonate dissolution and deposition. Journal of Glaciology, 48(162), 386-400.

DROWNED KARST LANDFORMS IN THE EASTERN ADRIATIC SEA

Dea Brunović[1], Slobodan Miko[1], Ozren Hasan[1], Nikolina Ilijanić[1], Natalia Smrkulj[1], Filip Šegović[1]

[1]Croatian Geological Survey, Sachsova 2, 10000 Zagreb, Croatia

Corresponding author: dea.brunovic@hgi-cgs.hr

The present-day eastern Adriatic coast was formed during the Late Pleistocene and Holocene transgression when pre-existing karstified relief was submerged. Thus, many karst landforms in the eastern Adriatic are hidden below the present sea surface. Our study enabled the recognition of drowned karst topography by application of acoustic geophysical methods, such as sub-bottom profiler and multibeam echosounder. Acoustic methods are a powerful tool for the identification of morphologies currently present on the seafloor and those in the shallow subsurface. Sediment cores provided additional palaeoenvironmental context and ground-truthing of the acoustic data. The main objective of the study was to document, classify and map submerged karst features in the eastern Adriatic Sea. Our findings suggest that vast areas of the eastern Adriatic are karstified with complex and diverse landform morphologies. Submerged karst springs, tufa barriers, karst dolines, karst poljes and river valleys were recognized in the acquired data. They are present at depths between 5 and 98 m below the sea level. However, these karst features were part of the land during the Quaternary periods of lower sea levels. The correlation of the submerged landforms with their on-land modern analogs is important for their identification, interpretation and understanding of mechanisms necessary for their formation and development. Our study demonstrated that the eastern Adriatic offers great potential for geomorphic investigation of the submerged karst landforms, which is currently lacking in the available literature. Furthermore, the obtained data will improve our understanding of the Quaternary palaeoenvironmental evolution of coastal karst settings influenced by significant climate and sea-level changes.

This work was supported by the Croatian Science Foundation projects LoLADRIA (HRZZ-IP-2013-11-9419) and QMAD (HRZZ IP-04-2019-8505) and the internal research project RIM funded by the National Recovery and Resilience Plan 2021–2026 of the European Union – NextGenerationEU, and monitored by the Ministry of Science and Education of the Republic of Croatia.

EVOLUTION OF POCKET BEACHES ACCORDING TO THEIR MORPHOGENETIC TYPE (ISLAND OF HVAR, CENTRAL ADRIATIC)

Marin Mićunović[1], Sanja Faivre[1]

[1]University of Zagreb, Faculty of Science, Department of Geography

Corresponding author: Marin Mićunović (mmicunov@geog.pmf.hr)

Coastal areas are dynamic geomorphological systems that are constantly influenced by both natural and anthropogenic factors. Beaches, as important coastal landforms, represent a considerable portion of the world's coastlines and face various challenges such as erosion due to the sea level rise induced by current climate change, and various socio-economic pressures. Approximately 24% of the world's beaches are already affected by erosion (Luiendijk et al., 2018). This trend is also evident along the Eastern Adriatic coast (Pikelj and Juračić, 2013), particularly on the island of Hvar (Mićunović and Faivre, 2024). This study specifically investigates the evolution of 47 pocket beaches on the island of Hvar over the past 200 years, with a particular focus on their morphogenesis.

This research utilized a combination of fieldwork and remote sensing methods. Fieldwork was conducted multiple times between 2020 and 2023, during which data on the morphogenesis and morphometric characteristics of the beaches were collected and analyzed. Archival sources, including the Franciscan cadastre from 1834, historical photographs from the 1900s to the 1980s, and aerial imagery from the 1950s, were used to track changes over time. More recent data was obtained using a DJI Phantom 4 Pro UAV, with ground control points collected using a Trimble DA2 GNSS. All collected data were processed and analyzed using Agisoft Metashape and ArcGIS Pro software. The sediment size was measured directly in the field and using ImageJ software. The comparison of archival and modern data allowed for precise tracking of changes in beach area and shoreline position over the past 200 years.

The morphogenesis of beaches on the island of Hvar is influenced by the interaction of various geomorphological processes and the lithology. There are three primary types of beaches on the island. The majority (85.1%) are formed in alluvial fans at the mouths of drainage basins, creating a distinct geomorphological system. Beaches under the cliff account for 8.5% of the total and are typically found in Eocene flysch or Quaternary breccia. Beaches formed in aeolian deposits have the smallest share, comprising just 6.4%.

The results showed that the pocket beaches on the island of Hvar have undergone significant changes over the past 200 years. On average, all beaches lost 44.1% of their area, while shorelines retreated inland by an average of 5.5 meters. The most substantial changes were observed in beaches formed in aeolian deposits, which experienced an average area loss of ~67%. For example, Mina Beach lost 73% of its area and, due to significant erosion, was nourished in the second half of 2021 (Fig.1.). Cliff-formed beaches exhibited more stable evolution due to a continuous supply of sediment, largely from slope processes, while beaches formed in alluvial fan material eroded by an average of ~46%. Anthropogenic activities, such as infrastructure construction, have further accelerated erosion by disrupting sediment input from drainage basins. Changes in land cover, including the reduction of agricultural activity, have also reduced sediment input, intensifying beach erosion.

The evolution of pocket beaches on the island of Hvar over the past 200 years shows significant differences depending on their genesis and sediment size. Beaches with finer sediments are more susceptible to rapid erosion, while beaches formed below the cliffs are more stable due to the continuous supply of sediment. Anthropogenic activities, including infrastructure development and the abandonment of agriculture, have negatively impacted natural processes, further accelerating erosion.

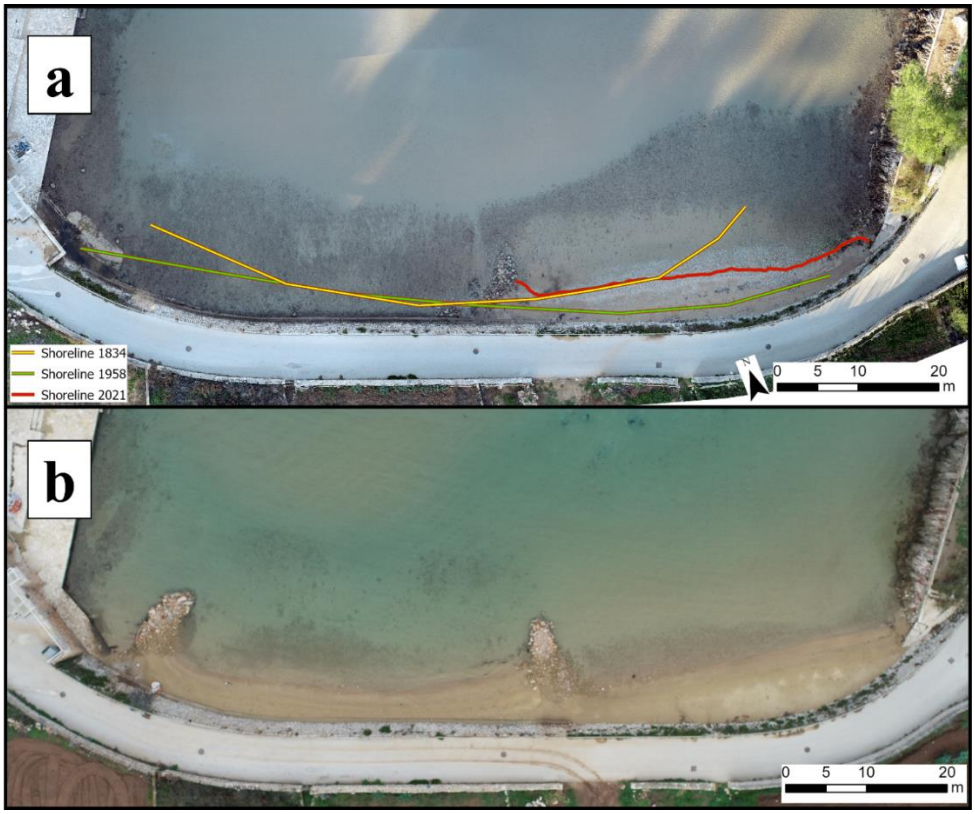

Figure 1: (a) Changes in the shoreline position of Mina beach from 1834 to 2021; (b) Nourished beach (second half of 2021)

ACKNOWLEDGMENTS

This research was done with the support of the Croatian Science Foundation (HRZZ-IP-2019-04-9445) SEALeveL (Relative sea level change and climate change along the eastern Adriatic coast).

REFERENCES

Luijendijk, A., Hagenaars, G., Ranasinghe, R., Baart, F., Donchyts, G., Aarninkhof, S., 2018. The state of the world's beaches. Sci. Rep. 8 (1), 1–11.

Mićunović, M., Faivre, S., 2024. Evolution of Hvar island pocket beaches during the last 200 years (eastern Adriatic coast, Croatia). Geomorphology, 447, 109023.

Pikelj, K., Juračić, M., 2013. Eastern Adriatic Coast (EAC): geomorphology and coastal vulnerability of a karstic coast. Journal of coastal research, 29(4), 944-957.

TIDAL NOTCHES IN THE KVARNER AREA (CROATIA)

Nadia Dunato Pejnović[1], Čedomir Benac[2], Kristina Pikelj[3]

[1]Natural History Museum Rijeka, Lorenzov prolaz 1, Rijeka, Croatia
[2]University of Rijeka, R. Matejčić 3, 51000 Rijeka, Hrvatska
[3]University of Zagreb, Faculty of Science, Geology Department, Horvatovac 102a, Zagreb, Croatia

Corresponding author: Nadia Dunato Pejnović (nadia@prirodoslovni.com)

Tidal notches are distinctive erosional features that develop on relatively sheltered carbonate rocky coastlines with low tidal ranges. Their presence above or below present sea level makes them valuable geomorphological indicators of local sea-level changes. The inward depth of a tidal notch profile provides insights into the duration of relative sea level stability, while its morphology reveals the speed of emergence or submergence (whether slow or rapid). In the Kvarner area, a semi-enclosed channel of the Adriatic Sea, tidal notches are located deeper than 0.5 m below the present mean sea level (Benac et al., 2004; Benac et al, 2008). Currently, a comprehensive survey of the coasts of the Krk, Prvić, Plavnik, Grgur and Cres islands in the Kvarner area (Fig. 1) was conducted. Notch geometry elements were examined following methodologies given by (Benac et al., 2004, Pirazzoli, 1986), using biological mean sea level as a reference value based on biological zonation in the intertidal zone. Tidal notches cannot be directly dated due to post-submergence bioerosion that eradicates datable biological remains. However, they systematically indicate relative sea level changes.

The focus of this work is the geometry of the tidal notch profiles. Morphological analyses and curve analyses were performed on individual profiles, as well as a statistical analysis of all profiles to identify patterns and trends that were not evident from individual analyses, and to obtain average values of the geometric elements of the notches. The impact of lithology on the development of the notch profile shapes wasl assessed. A fetch model will be developed to determine the extent of the influence of site exposure on the geometry of the notch geometry, all with the purpose to better understand relative sea-level changes and recent tectonic regional processes in the Kvarner area.

A total of thirty locations were surveyed, and detailed analysis and measurements were conducted on forty tidal notch profiles. During ongoing research, a previously undescribed third profile type with two inflection points has been observed. The lower part of this profile type indicates an initial phase of gradual sea level rise. The uplift of the erosional base also contributed to the elongation of the tidal notch profiles. Subsequently, rapid submergence occurred within the tidal range, resulting in shaping the upper part of the tidal notch and eventual complete flooding. The variations in notch profiles may be attributed to recent tectonic movements in the Kvarner area and exposure to wave action. Further fieldwork, along with morphological and curvature analyses, is necessary to gain a deeper understanding of these processes. To estimate the relative stability of sea level during the development of tidal notches, a bioerosion rate of 0.1 mm/year was adopted (Furlani et al., 2009). This suggests that the formation of the average depth of measured tidal notch profiles, 74.5 cm, would require a period of relatively stable sea level lasting 7,450 years.

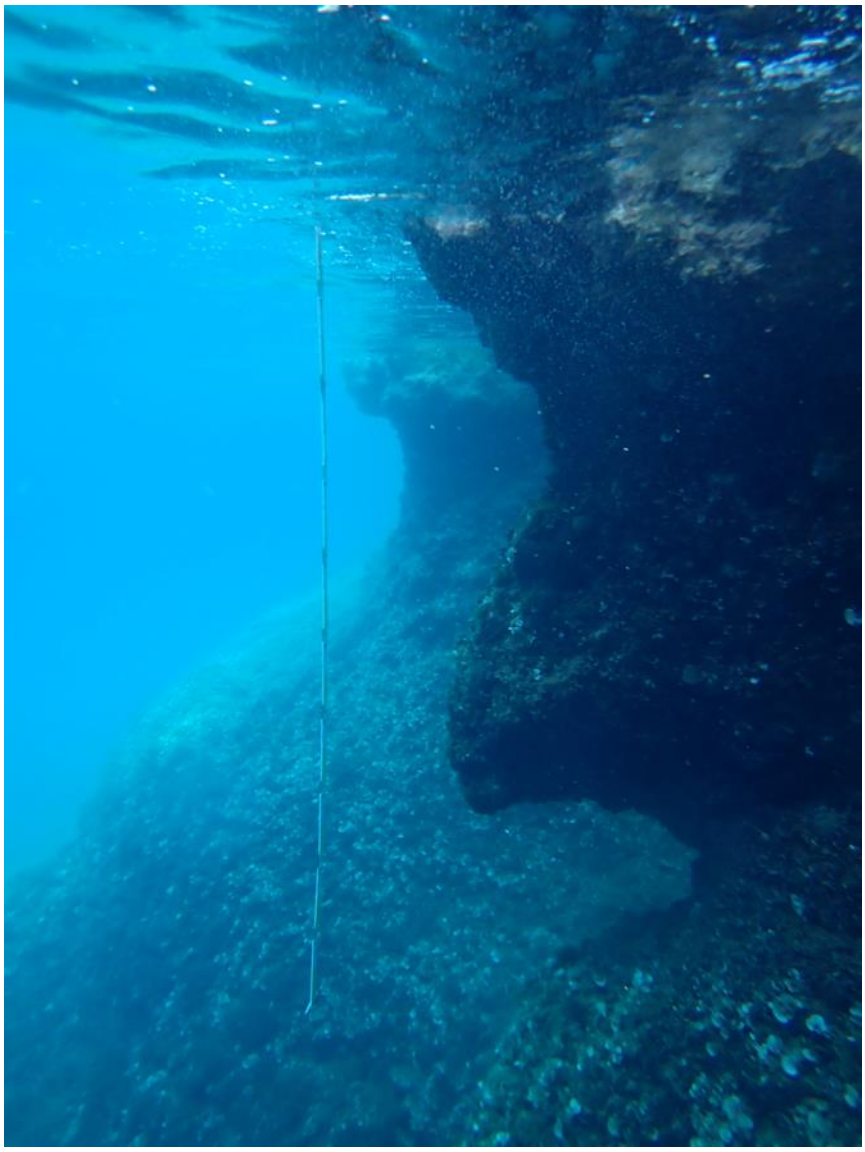

Figure 1: Submerged tidal notch, Propovedna cove, Cres Island.

REFERENCES

Benac, Č., Juračić, M., Blašković, I., 2008. Tidal notches in Vinodol Channel and Bakar Bay, NE Adriatic Sea: Indicators of recent tectonics. Marine Geology 248/3–4, 151–160.

Benac, Č., Juračić, M., Bakran-Petricioli, T., 2004. Submerged tidal notches in the Rijeka Bay NE Adriatic Sea: indicators of relative sea-level change and of recent tectonic movements. Marine Geology, 212, 21–33.

Pirazzoli, P.A., 1986. Marine notches. In: van de Plassche, O. (Ed.), Sea-level Research: A Manual for the Collection and Evaluation of Data. Geo Books, Norwich, 361–400.

Furlani, S., Cucchi, F., Forti, F., Rossi, A., 2009. Comparison between coastal and inland Karst limestone lowering rates in the northeastern Adriatic Region (Italy and Croatia). Geomorphology. 104. 73-81. 10.1016/j.geomorph.2008.05.015.

RESOLVING THE JADRO AND CETINA PALAEORIVER FLOW IN THE EASTERN ADRIATIC COAST DURING THE LAST GLACIAL MAXIMUM

Ozren Hasan[1], Dea Brunović[1], Slobodan Miko[1], Filip Šegović[1], Nikolina Ilijanić[1], Natalia Smrkulj[1], Ivan Razum[2], Martina Šparica Miko[1]

[1]Croatian Geological Survey, Croatia
[2]Croatian Natural History Museum, Croatia

Corresponding author: Ozren Hasan (ohasan@hgi-cgs.hr)

The submerged landscapes formed along the eastern Adriatic coast during the Late Quaternary glacial and interglacial cycles remain insufficiently explored. During the Last Glacial Maximum (LGM), which occurred between approximately 30 000 and 19 000 years Before Present, numerous karst rivers incised their channels or valleys into the now submerged part of the eastern Adriatic shelf (Juračić and Prohić, 1991). This occurred due to the sea level being positioned at a depth of between -120 and -134 meters below the present level, which allowed for a large part of the shallow continental shelf to be exposed to subaerial conditions (Lambeck et al., 2014; Maselli and Trincardi, 2013). However, the currently available studies (e.g. Fritz and Bahun, 1997; Crmarić et al., 1998, Pikelj, 2010; Sikora et al., 2014) do not indicate the flow path, subsurface morphology, or sediment infill of the submerged fluvial systems. Furthermore, the position of the LGM palaeocoastline, the chronological framework of the palaeoenvironmental evolution, and the marine flooding of the area remain unresolved.

This study aims to define submerged Quaternary landscapes surrounding two karst rivers in central Dalmatia – Jadro and Cetina, with a particular focus on the precise recognition of the submerged fluvial channels. The aim is to ascertain whether and where the rivers entered the Mid-Adriatic Deep (MAD) during the LGM. To achieve these objectives, we employ state-of-the-art instruments and methodologies, including a sub-bottom profiler (SBP), a multibeam echosounder (MBES), and GIS analyses, which will be complemented by sediment core analyses. The findings of this study will enhance our understanding of Quaternary sea-level dynamics and sea-level-related landscape changes in the study area, which are pivotal for estimating future climate, sea-level variability, and the response of coastal systems to such changes. A collection of more than 700 km of SBP and MBES data is used to interpret the processes that lead to the formation of submerged fluvial and lacustrine environments that were shaped during and after the LGM. An evolution of the well-defined fluvial channel can be tracked for the Jadro River from its present-day river mouth, through the Kaštela Bay and Split channel towards the MAD. Cetina River flow also displays a well-defined incised channel and an indication of the formation of a lacustrine environment between the islands of Brač and Hvar.

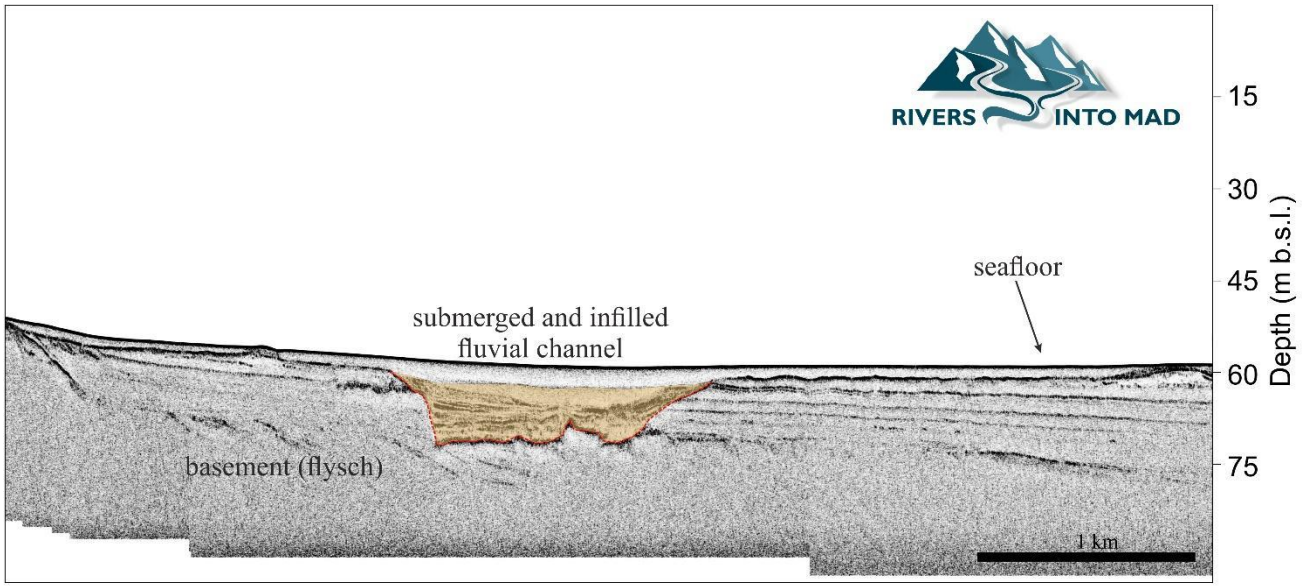

Figure 1: An example of Jadro River submerged fluvial channel sub-bottom profile located at the Split channel.

Presented research was conducted in the scope of the internal research project „Rivers Into MAD - Resolving the Jadro and Cetina palaeoriver landscapes during the Last Glacial Maximum" at the Croatian Geological Survey, funded by the National Recovery and Resilience Plan 2021–2026 of the European Union – NextGenerationEU, and monitored by the Ministry of Science and Education of the Republic of Croatia. The presented research was also supported by the Croatian Science Foundation project "QMAD" (HRZZ IP-04-2019-8505).

REFERENCES

Crmarić, R., Bogner, D., & Juračić, M., 1998. Holocenski sedimenti i sedimentacija u Kaštelanskom zaljevu. In M. Hodžić (Ed.), Znanstveno-stručni kulturološki skup, Kaštela, Zbornik radova, pp. 178-182.

Fritz, F., Bahun, S., 1997. The morphogenesis of submarine springs in the Bay of Kastela, Croatia. Geol. Croat. 50, pp. 105–110. https://doi.org/10.4154/GC.1997.10

Juračić, M. and Prohić, E., 1991. Mineralogy, sources of particles and sedimentation in the Krka River estuary (Croatia). Geološki Vjesn. 44, pp. 195–200.

Lambeck, K., Rouby, H., Purcell, A., Sun, Y., Sambridge, M., 2014. Sea level and global ice volumes from the Last Glacial Maximum to the Holocene. Proc. Natl. Acad. Sci. U. S. A. 111, pp. 15296–15303. https://doi.org/10.1073/pnas.1411762111

Maselli, V., Trincardi, F., 2013. Large-scale single incised valley from a small catchment basin on the western Adriatic margin (central Mediterranean Sea). Glob. Planet. Change 100, pp. 245–262. https://doi.org/10.1016/j.gloplacha.2012.10.008

Pikelj, K., 2010. Sastav i porjeklo sedimenata dna istočne strane Jadranskog mora. Sveučilište u Zagrebu, pp. 1-239.

Sikora, M., Mihanović, H., Vilibić, I., 2014. Paleo-coastline of the Central Eastern Adriatic Sea, and Paleo-Channels of the Cetina and Neretva rivers during the last glacial maximum. Acta Adriat. 55, pp. 3–18.

MICROPALEONTOLOGICAL AND MALACOLOGICAL PROXIES FOR QUATERNARY PALEOENVIRONMENTAL DYNAMICS IN THE KRKA RIVER KARST ESTUARY

Petra Hus[1], Dea Brunović[1], Natalia Smrkulj[1], Ozren Hasan[1], Nikolina Ilijanić[1], Slobodan Miko[1]

[1]Croatian Geological Survey, Department for Mineral Resources and Marine Geology, Sachsova 2, 10000, Zagreb, Croatia

Corresponding author: Petra Hus (phus@hgi-cgs.hr)

Benthic faunal and protozoan communities are abundant in marginal marine environments such as estuaries. Based on their ecological preferences, we can determine the conditions at the seafloor during a given period.

The combined analysis of malacological and foraminiferal data in karst estuaries, which are globally unique and distinctive, offers valuable insights into Quaternary palaeoenvironments and sea-level changes.

In Croatia large karst areas are now submerged due to deglaciation and sea-level rise since the Last Glacial Maximum (LGM). This research centres on the Krka River karst estuary, a salt-wedge oligotrophic estuary. We present findings from two sediment cores, PROK-1 and PROK-3, which were drilled in Prokljan Lake and further analysed (grain size, carbon-to-nitrogen ratio, radiocarbon dating) with a focus on the paleontological analysis of benthic foraminifera, gastropods, and bivalves. The flooding of the estuary occurred in several phases, each characterized by distinct assemblages. These phases are present in both cores, except for the predominantly freshwater phase that occurred during the Early Holocene, which was recognized only in the basal part of the PROK-3 core, where foraminifera species *Ammonia tepida* is present in very low numbers. Also, during this phase, freshwater gastropods were found, as well as the hypoxic bivalve species like *Lucinella divaricata*, further confirming an organic-rich environment. Following the freshwater phase, there is a transitional phase with the formation of an enclosed marine pond and pluvial conditions from the Early to Middle Holocene, where the foraminiferal assemblages become more diverse. *A. tepida* specimens still dominate during this phase, while *Haynesina germanica* specimens become more abundant. The malacological community confirms these phases through the presence of mixed freshwater and marine species. Finally, the development of a marine setting and halocline stabilization during the Middle Holocene is represented by a diverse marine community with *H. germanica* and *Elphidium translucens* as the dominant foraminiferal species, along with typical infralittoral and intertidal molluscs like *Acanthocardia paucicostata* and *Kurtiella bidentata*. Compared to PROK-3, the PROK-1 coring area was flooded a few thousand years later, corresponding to the Middle to Late Holocene period. This difference in flooding occurred due to the existence of the tufa barriers, which protected the estuary and inland areas from being completely drowned. With benthic foraminifera and molluscs, we can observe assemblage changes over very short periods, track sea-level rise, and reconstruct past environmental conditions throughout the Holocene.

The presented data are part of the Croatian Science Foundation project ''Sediments between source and sink during a Late Quaternary eustatic cycle: The Krka and the Mid Adriatic Deep System-QMAD''.

LATE HOLOCENE PALAEOENVIRONMENTAL IMPACT OF OSOR (CRES ISLAND, CROATIA)

Slobodan Miko[1], Dea Brunović[1], Ozren Hasan[1], Valentina Hajek Tadesse[1], Petra Hus[1], Nives Doneus[2], Nikolina Ilijanić[1], Filip Šegović[1], Ivan Razum[3], Michael Doneus[4], Martina Šparica Miko[1], Koraljka Bakrač[1]

[1]Croatian Geological Survey, Zagreb, Croatia
[2] Vienna Institute for Archaeological Science, University of Vienna, Vienna, Austria
[3] Croatian Natural History Museum, Zagreb, Croatia
[4] Department of Prehistoric and Historical Archaeology, University of Vienna, Vienna, Austria

Corresponding author: Slobodan Miko (smiko@hgi-cgs.hr)

Cres and Lošinj islands are divided by the 10 m wide Osor Channel, which is widely accepted to be artificial and already in use during Roman times. Through the implementation of multidisciplinary research methodologies, we mapped and reconstructed the seafloor and coastal geomorphology surrounding the town of Osor, Croatia, which was greatly affected by human activities during the Late Holocene. This research was conducted as part of the ongoing project "Osor beyond the myth" (2023.-2026.) in cooperation with the University of Vienna, Austria. The project focuses on reconstructing the landscape context of the Iron and Roman Age Osor and its role as a maritime trading centre in the past. A landscape-based approach includes geology, archaeological remote sensing (ALS/ALB) and terrestrial (GPR, magnetics) and marine geophysical prospection, with the aim of combining underwater and terrestrial research.

Osor's Mediterranean setting presents a multifaceted research environment that encompasses interconnected land and sea elements (Doneus et al., 2017). Osor is located on a small, almost circular land bridge between the islands of Cres and Lošinj. A shallow coastal plain with submerged karst dolines (Brunović et al., 2019) and a deeper marine environment with a complex paleoenvironmental history (Brunović et al., 2020) exist in the south. Cres and Lošinj are separated by the 2.6 metre deep Osor Channel, which is widely believed to be artificial and in use since Roman times, although this theory has not been scientifically proven to date (Doneus et al., 2017, Draganits et al. 2019). The northern steep side of Osor is characterized by a shoreface that abruptly forms a flat seafloor at a depth of 40-45 m extending towards the Istrian peninsula. The terrestrial landscape is characterized by Mesozoic karstified carbonate rocks with thin soil cover, whereas Quaternary marine sediments can reach a thickness of more than several tens of meters. Analysis of coastal marine sedimentary records can be used to assess the impact of human intervention on the environment over time. High-resolution land and bathymetric maps were produced by merging airborne laser scanning (ALS/ALB) and high-resolution multibeam sonar data, and sub-bottom profiling. They allowed a holistic interpretation of the geomorphology of Osor and its surroundings. Sediments deposited during the mid-and late Holocene were used to disentangle the natural and anthropogenic imprints in the sedimentary record. The dated cores from the northern side of Osor were analysed using a multiproxy approach, including mineralogical, grain size, microX-ray fluorescence scanning analysis, organic and inorganic carbon analysis, ostracods, foraminifera, and palynofacies analyses. The dated sediment core OSOR-2M (cored close to the northern side of the channel at a depth of 35 m) spans last 6000 years. The abrupt environmental

change recorded in the core based on geochemistry, sedimentation rates, and organic carbon contents predated 369–47 cal BC. There was a change in organic carbon content from 0.4 % (3672 - 3364 cal BC) to 6.7% (270 - 584 cal AD). The taxonomic composition of ostracod assemblages is typical of normal and shallow marine environments. The presence of *Leptocythere* spp. in this interval is indicative of a brackish water environment or a lagoon with submerged macrophytes. These findings are valuable in the sense that they could indicate the possible transport and re-sedimentation of material from the shallow (lagoonal) southern part of the manmade channel and its accumulation on the northern shoreface. Moreover, shifts in foraminiferal assemblages could indicate similar, small, but detectable contributions from sediment from the shallow southern coastal plain. The amount of transported sediment material is not significant, but contributions of species not typical of natural environmental conditions may indicate the timing of the Osor channel construction. The shallow southern side of the channel is unsuitable for detecting these changes because of dredging activities and the lack of stratification of cultural layers (Doneus et al., 2017). The transport of sediment declined during the Middle Ages, which could be attributed to a general population decrease. The analysis of coastal marine sedimentary records from two contrasting marine environments connected by human intervention (construction of a channel), in combination with geomorphological analysis, may aid in a better understanding of the environmental changes caused by the inhabitants of Osor spanning several thousands of years.

REFERENCES

Brunović, D., Miko, S., Hasan, O., Papatheodorou, G., Ilijanić, N., Miserocchi, S., Correggiari, A., Geraga, M., 2020. Late Pleistocene and Holocene paleoenvironmental reconstruction of a drowned karst isolation basin (Lošinj Channel, NE Adriatic Sea). Palaeogeogr. Palaeoclimatol. Palaeoecol. 544, 109587. https://doi.org/10.1016/j.palaeo.2020.109587

Brunović, D., Miko, S., Ilijanić, N., Peh, Z., Hasan, O., Kolar, T., Šparica Miko, M., Razum, I., 2019. Holocene foraminiferal and geochemical records in the coastal karst dolines of Cres Island, Croatia. Geol. Croat. 72, 19–42. https://doi.org/10.4154/gc.2019.02

Doneus, N., Doneus, M., Ettinger Starčić, Z. 2017. The ancient city of Osor, northern Adriatic, in integrated archaeological prospection. Hortus Artium Medievalium, 23, 2; 761-775. https://doi.org/10.1484/J.HAM.5.113761

Draganits, E., Gier, E., Doneus, N., Doneus, M., 2019. Geoarchaeological evaluation of the Roman topography and accessibility by sea of ancient Osor (Cres Island, Croatia). Austrian Journal of Earth Sciences, Volume 112 (1) 1-19. https://doi.org/10.17738/ajes.2019.0001

THE CIPRNIK COMPLEX LANDSLIDE: SIMILARITIES AND DIFFERENCES BETWEEN MAIN EVENT AND ITS REACTIVATION

Andrej Novak[1], Marko Vrabec[2], Andrej Šmuc[2]

[1]Geological Survey of Slovenia, Slovenia
[2]University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Geology, Slovenia

Corresponding author: Andrej Novak (andrej.novak@geo-zs.si)

Mass movements are important processes that shape alpine relief and represent a threat to infrastructure and human activity. In this study we present a more than two-decade long activity and evolution of the Ciprnik complex landslide located in the Planica valley, NW Slovenia (Figure 1). The initial Ciprnik landslide is characterised by three stages of movement: a translational landslide, debris flow, and hyperconcentrated flow event. It occurred on 19th of November 2000, facilitated by the local geological structure (bedding paralleling the slope and pervasive fracturing of the bedrock), lithology (alternation of thin beds of carbonates and fine-grained clastics), and high precipitation (Šmuc et al., 2015). Long-lasting record-breaking rainfall saturated thin and fractured clastic layers, which lead to a translational landslide. This transformed into a debris flow that travelled to the bottom of the valley. Deposition of the debris flow showed fining down of the transported material with coarser clasts being deposited in the upper zone of deposition and finer grains in the lower zones. In the most distal parts debris flow transformed into a hyperconcetrated flow with only fine-grained sediment being deposited. A transport of between 50.000 and 80.000 m^3 of material was estimated (Komac & Zorn, 2007). On the night from 24th to 25th of October 2023 large parts of the Ciprnik complex landslide were reactivated with very similar transport and triggering mechanisms. In this study we analysed surface changes of the area affected by Ciprnik complex landslide following the 2000 event. The analysis was done based on aerial photographic surveying (surveys in 2006, 2011, 2015, 2017 and 2020) performed by the Surveying and Mapping Authority of Slovenia (GURS, 2024) for the period between 2006 and 2020. Digital elevation models (DEMs) were produced from uncorrected aerial imagery with structure-from-motion (SfM) photogrammetric reconstruction using Agisoft Metashape software. Surface and volumetric changes were determined based on calculating the Difference of DEM (DoD) with an accuracy of 0.5 m. From 2020 onwards the area of the Ciprnik landslide was closely monitored using fieldwork observations and annual Unmanned Aerial Vehicle (UAV) photogrammetric surveys. UAV imagery was used to produce orthophotos and DEMs with SfM photogrammetry with a resolution of 0.1 m to detect surface and volumetric changes. Fourteen samples were collected along the transport-depositional area of the 2023 event, and granulometric analysis was performed using standard sieve pans and a Fritch Analysette 22–28 particle sizer. Meteorological data from the Slovenian Environment Agency (ARSO, 2023) was analysed to interpret the triggering precipitation conditions. The results show that since the initial event in 2000 the area of the complex landslide remained unstable. Between 2006 and 2011 more than 20.000 m^3 of material was eroded. Subsequently (2011-2015, 2015-2017 and 2017-2020) the amount of erosion and deposition was less extensive, with maximum of 10.000 m^3 of eroded and deposited material between 2017-2020. UAV-derived data show, that minimal erosion (482 m^3) and deposition (797.1 m^3) occurred between 2020 and 2021. The reactivation event in October 2023 measured approximately 26.000 m^3. The event had the same transport and depositional characteristics as the event in 2000. It started as a 16.000 m^3 large translational landslide, later transforming into a debris flow, which travelled towards

the valley floor, creating additional erosion and deposition on the steep slopes. The debris flow formed an up to one-meter-tall fan at the valley bottom, where all coarse-grained material composed of muddy gravels, cobbles and boulders was deposited. Only sand and mud travelled further down the valley and were deposited in up to few 10s of centimetres thick, muddy layers. The granulometric analysis shows that in the uppermost depositional area the material was composed of muddy sandy gravel with approximately 75% of gravel, 15% of sand and 10% of mud. Further down the percentages changed, with only 40% of gravel, 45% of sand and 15% of mud fraction. The very distal samples taken in the muddy layers are composed of sandy silt, containing approximately 40% sand, 50% silt and 10% clay. The initial landslide was triggered by an intense 12-hour precipitation event with a five-year return period amounting to 104,2 mm. Following the event in October additional rainfalls occurred, with the most intense one having 96.8 mm in 24 hours. These rainfalls subsequently eroded and deposited in total 5706.9 m^3 and 3774.9 m^3 of material respectively. This study shows, that the area of the Ciprnik complex landslide did not remain stable after the main event in 2000. Each year a few hundred to a few thousand cubic metres of sediment were eroded by rainfalls with minor slidings, slumps and erosion of baren and unconsolidated sediment. Both events in years 2000 and 2023 had the same transport and depositional evolution: translational landslide to debris flow to hyperconcentrated flow events. In both events the sediment was fined along the transport-depositional path. The events differ in the triggering precipitation mechanism. While the event in 2000 was triggered by long-duration low-intensity rainfall, the 2023 event was triggered by short-duration high-intensity rainfall. The case study of the complex Ciprnik landslide demonstrates that identical mass-movement events with the same effects on landscape, environment and infrastructure can reoccur years after the initial event and with different triggering mechanisms.

Figure 1: Area affected by the Ciprnik complex landslide in November 2000 (solid blue line) and area affected by the reactivation in October 2023 (dashed violet line).

REFERENCES

ARSO. (2023). Arhiv meritev. http://www.meteo.si/met/sl/archive/

GURS. (2024). Geodetska uprava Republike Slovenije, Ortofotoposnetki. https://www.e-prostor.gov.si/podrocja/drzavni-topografski-sistem/daljinsko-zaznavanje/?acitem=1292-1293

Komac, B., & Zorn, M. (2007). Pobočni procesi in človek (D. Perko & D. Kladnik, Eds.). Geografski inštitiut Antona Melika ZRC SAZU.

Šmuc, A., Janecka, K., Lempa, M., & Kaczka, R. J. (2015). The Spatio-Temporal Dynamics of the Ciprnik Complex Landslide, Tamar Valley, Julian Alps, Slovenia. Studia Geomorphologica Carpatho-Balcanica, 49(1), 35–54. https://doi.org/10.1515/sgcb-2015-0008

GEOMORPHOLOGICAL ANALYSIS OF THE SVETA NEDELJA FAULT IN THE MT. ŽUMBERAK AREA (NW CROATIA)

Josipa Maslač Soldo[1], Petra Jamšek Rupnik[2], Bojan Matoš[3], Branko Kordić[1]

[1]Croatian Geological Survey (HGI-CGS), Department of Geology, Croatia
[2]Geological Survey of Slovenia (GeoZS), Ljubljana, Slovenia
[3]University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Department of Geology and Geological Engineering, Croatia

Corresponding author: Josipa Maslač Soldo (jmaslac@hgi-cgs.hr)

Northwest Croatia is a seismically active region with dense population and several active fault systems that are yet to be characterized in terms of their activity. It occupies a junction of major tectonic units: the Eastern Alps to the north, the Internal Dinarides to the west, and the eastern Tisza mega block, encompassing the Pannonian Basin System (Tomljenović & Csontos, 2001, Schmid et al., 2020). The complex Cenozoic tectonics are related to the slow convergence (between 3 and 4.5 mm/year) of the Adriatic microplate and the Eurasian plate (Vlahović et al., 2005; Grenerczy et al., 2005, Weber et al., 2010) initiated by the obduction of ophiolites on the eastern margin of the Adriatic microplate. Throughout the Oligocene–Miocene, the Adriatic microplate shifts northward, while the European plate retreated eastward, resulting in the lateral extrusion of Eastern Alps and Tisza-Dacia tectonic blocks (Ustaszewski et al., 2008). These pivotal tectonic events served as the main cause of current structural emplacement, which has undergone various changes in tectonic regimes during the evolution of Pannonian Basin System (Pavelić & Kovačić, 2018; Schmid et al., 2020). The Pliocene-Quaternary compressional/transpressional tectonic phase in the Croatian part of the Pannonian Basin has been confirmed by structural analyses, geodetic measurements, and instrumental seismicity records (e.g., earthquake focal mechanisms). These data, along with historical seismic events, highlight the Pliocene-Quaternary activity of faults such as the North Medvednica Fault (NMF) and the Petrinja-Pokupsko Fault (PPF). At the same time, the NE-SW striking Sveta Nedelja Fault (SNF) that appears to be a continuation of the NMF west of Zagreb, is located perpendicular to the PPF and requires further investigation to understand its kinematics, timing of activity and seismogenic potential.

The SNF is positioned along the southern mountain front of Mt. Žumberak, marking a boundary between karst plateaus to the north and the Karlovac Basin to the south. The fault separates older Triassic-Cretaceous carbonate and ophiolite formations in the north from the Miocene basin deposits in the south. Geomorphological analysis of the SNF reveals that the northern part of the SNF has been uplifted and tilted, especially in the central section where along the strike appears transpressive pop-up structure. Constructed swath profiles perpendicular to fault strike show a steep north-facing gradient in this central part, which gradually decreases toward the east and west. The uplifted structure suggests sinistral oblique-slip fault kinematics, which is most pronounced in the Plešivica area, a key feature of the SNF (Fig 1). In contrast, the western section of the fault exhibits more subtle morphological changes, with strike-slip faulting juxtaposing Triassic-Cretaceous rocks against Miocene deposits, leading to more gradual transitions in topography.

The geomorphological data also suggest that the SNF has played a significant role in shaping the local fluvial drainage patterns. Analysis of the Konščica sub-basin, which crosses the fault, reveals a series of vertical steps, i.e., knickpoints in the crests and convex stream profiles, both indicative of Quaternary fault activity. Reconstruction of the second-order drainage crossing the fault can be achieved by 160 to 2800 m of back-slip along the fault, realigning some of the wind-gaps and streams on both sides. These geomorphological features suggest that faulting has affected the landscape on both long-term and short-term scales. While the uplifted and tilted karst plateaus north of the SNF reflect long-term tectonic processes, the more recent Quaternary activity has shaped the drainage patterns and created distinct geomorphological features such as the vertical steps in crests and deflected streams.

Preliminary geomorphological results indicate that the SNF has been active during the Pliocene-Quaternary, contributing to the neotectonic evolution of the Žumberak topography. The sinistral-oblique transpressional character of the fault agrees with earthquake focal mechanisms in the area. Future research will focus on quantifying deformation rates along the SNF and further exploring its relationships with neighbouring fault systems, such as the PPF and the NMF. In the next steps, shallow geophysical and paleoseismological methods will be applied to better assess the timing and extent of recent fault activity. This study contributes to understanding the SNF kinematics and identifying its seismogenic potential. This is particularly important due to the very recent 2020 Zagreb and Petrinja earthquakes (Baize et al. 2020) that have highlighted the need for a more comprehensive seismic hazard assessment, which is crucial for mitigating future seismic risks in the region.

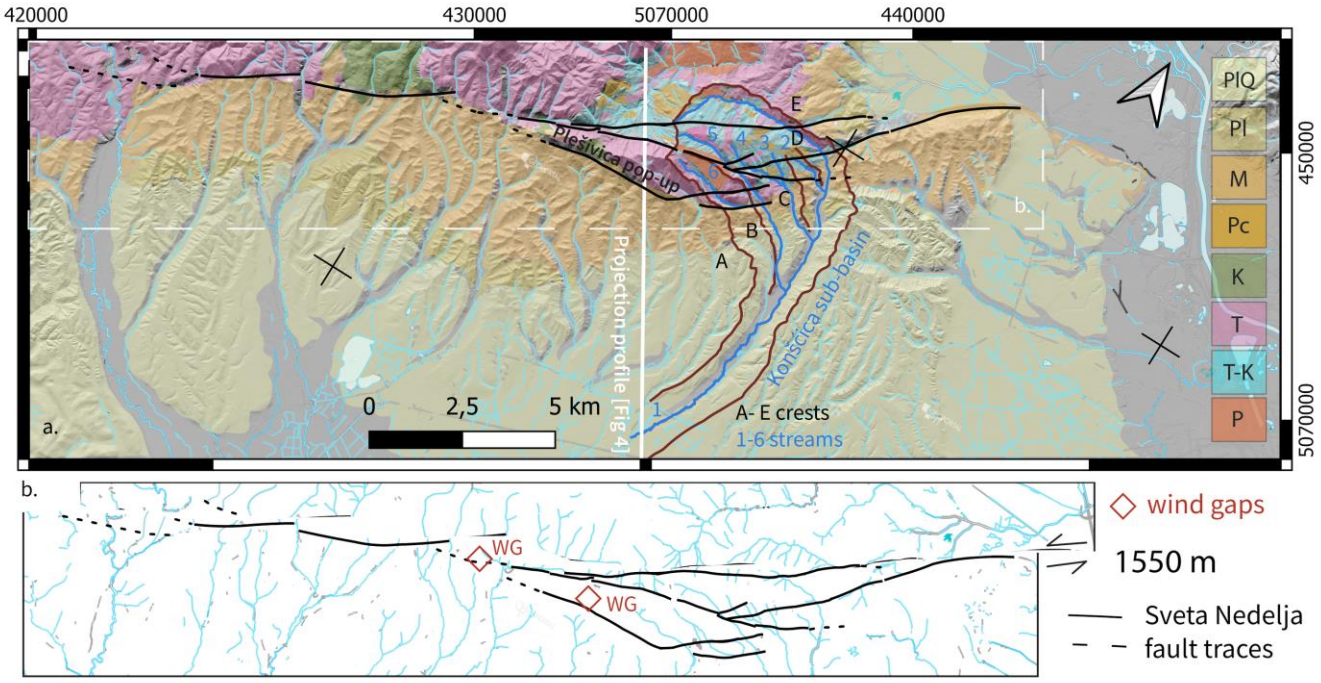

Figure 1: a.) Geological map (adapted from Šikić et al. 1978, Pleničar et al., 1976, Benček et al. 2014), with active traces of the Sveta Nedelja Fault. Within the central area, particular focus is given to Konščica sub-basin, including its tributaries (1-6) and crests (A-E). b.) Reconstructed back-slip of the second-order drainage network on the Sveta Nedelja Fault.

REFERENCES

Baize, S., Amoroso, S., Belić, N., Benedetti, L., Boncio, P., Budić, M., ... & Ricci, T. (2022). Environmental effects and seismogenic source characterization of the December 2020 earthquake sequence near Petrinja, Croatia. Geophysical Journal International, 230(2), 1394-1418.

Benček, Đ., Bukovac, J., Magaš, N. & Šimunić, A. (2014): Basic Geological Map of Croatia 1:100000, Sheet Karlovac. Croatian Geological Survey, Zagreb.

Grenerczy, G., Sella, G., Stein, S. & Kenyeres, A. (2005): Tectonic implications of the GPS velocity field in the northern Adriatic region. Geophysical Research Letters, 32 (L16311), doi:10.1029/2005GL022947.

Pavelić, D., & Kovačić, M. (2018). Sedimentology and stratigraphy of the Neogene rift-type North Croatian Basin (Pannonian Basin System, Croatia): A review. Marine and petroleum geology, 91, 455-469.

Pleničar, M., Premru, U. & Herak, M. (1976). Basic Geological Mapo f Yugoslavia 1:100000, Sheet Novo Mesto L33-79, Federal Geological Institute Beograd, Belgrade.

Schmid, S.M., Fügenschuh, B., Kounov, A., Maţenco, L., Nievergelt, P., … & van Hinsbergen, D.J.J. (2020). Tectonic units of the Alpine collision zone between Eastern Alps and western Turkey. Gondwana Research, 7, 308-374.

Šikić, K., Basch, O. & Šimunić, A. (1978): Basic Geological Mapo f Yugoslavia 1:100000, Sheet Zagreb L33-80, Federal Geological Institute Beograd, Belgrade.

Tomljenović, B., & Csontos, L. (2001). Neogene–Quaternary structures in the border zone between Alps, Dinarides and Pannonian Basin (Hrvatsko zagorje and Karlovac basins, Croatia). International Journal of Earth Sciences, 90, 560-578.

Ustaszewski, K., Schmid, S. M., Fügenschuh, B., Tischler, M., Kissling, E., & Spakman, W. (2008). A map-view restoration of the Alpine-Carpathian-Dinaridic system for the Early Miocene. Swiss journal of Geosciences, 101, 273-294.

Vlahović, I., Tišljar, J., Velić, & I. Matičec, D. (2005): Evolution of the Adriatic Carbonate Platform: Paleogeography, main events and depositional dynamics. Palaeogeography, Palaeoclimatology, Palaeoecology, 220, 333–360.

Weber, J., Vrabec, M., Pavlovčič-Prešeren, P., Dixon, T., Jiang, Y., & Stopar, B. (2010). GPS-derived motion of the Adriatic microplate from Istria Peninsula and Po Plain sites, and geodynamic implications. Tectonophysics, 483(3-4), 214-222.

INITIAL RESULTS FROM PALEOSEISMOLOGICAL INVESTIGATIONS OF THE RAŠA FAULT IN SW SLOVENIA

Petra Jamšek Rupnik[1], Eva Mencin Gale[1], Aleša Uršič Arko[1], Lovro Rupar[1], Jernej Jež[1], Ana Novak[1], Josipa Maslač[2], Andrej Anžel[1], Jure Atanackov[1]

[1]Geological Survey of Slovenia, Dimičeva ul. 14, 1000 Ljubljana, Slovenia
[2]Croatian Geological Survey, Ul. Milana Sachsa 2, 10000 Zagreb, Croatia

Corresponding author: Petra Jamšek Rupnik (petra.jamsek@geo-zs.si)

The dextral strike-slip Raša Fault, a major fault of the Dinaric Fault System in SW Slovenia (Figure 1A), has been the subject of extensive studies to understand its structure, activity and seismogenic potential (Moulin et al., 2016; Vičič et al., 2019; Atanackov et al., 2021; Zupančič et al., 2024). This contribution presents the first results of our paleoseismological investigation, which follows tectonic-geomorphological analysis, structural-geological mapping, and geophysical studies between the villages of Branik and Košana (Jež et al., 2022; Jamšek Rupnik et al., 2023). These foundational studies have identified several key sites for targeted paleoseismological excavations. So far, we have investigated one trench at the Petrovci site and are planning another one in the Raša Valley for late summer 2024.

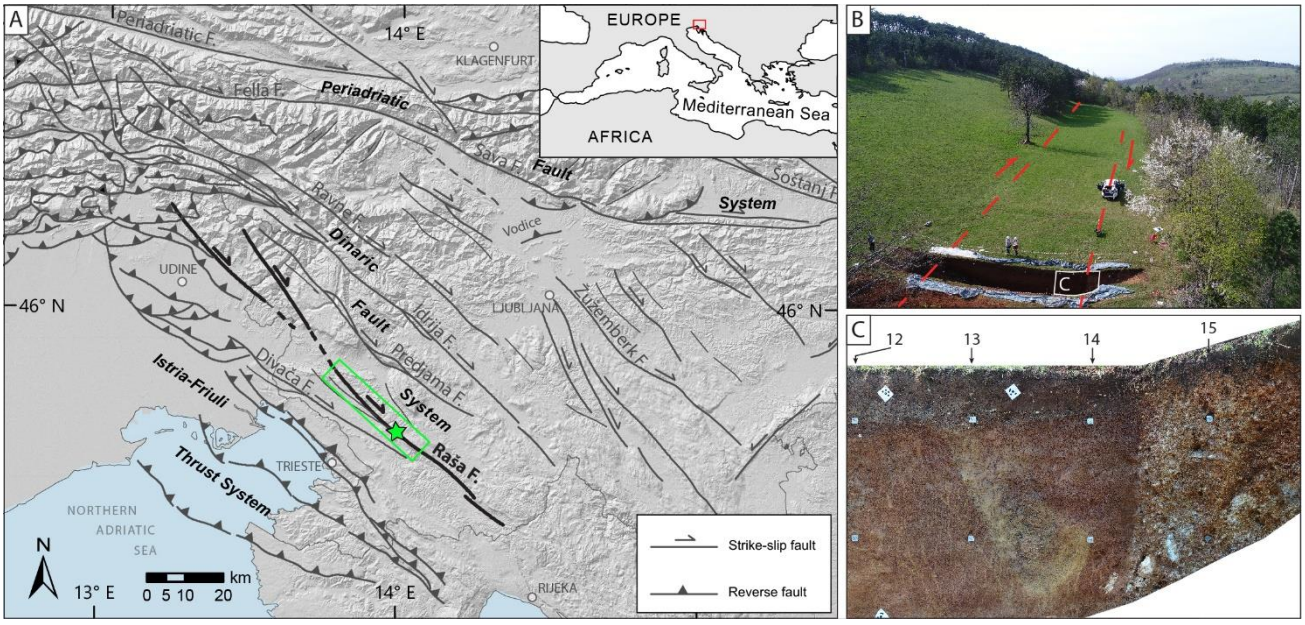

Figure 1: A – Dinaric Fault System in Slovenia with the highlighted Raša Fault (green rectangle for investigated section) and paleoseismological trench site Petrovci (green star). B – Trench Petrovci crossing a narrow and linear sedimentary basin extending along the slope-cutting fault, view towards NW. C – Part of the W wall of the trench with a fault zone, the numbers mark a meter dimension.

The trench at Petrovci was dug perpendicularly to an approximately 20 m wide linear sedimentary basin that extends along the fault dissecting the slopes (Figure 1B). An uphill facing fault scarp provided a sedimentary trap at this site. The 19 meters long and up to 2.4 meters deep trench exposed weathered limestone bedrock on both sides of the trench, with distinct fault zones characterized by shattered rock and visible faults. The overlying deposits comprised a layer of diamict above the bedrock and then several units of mud, silt, and silty sand. The depositional environment, shaped by fault movement and local geomorphological processes, reflects a combination of in situ weathering, aeolian transport and slope outwash. The trench revealed several fault planes and cracks within the sedimentary succession (Figure 1C), with apparent vertical displacements ranging from 13 cm to 180 cm. These faults, oriented NW-SE and steeply dipping, exhibit both vertical and strike-slip movements, in agreement with the Raša Fault kinematics. Our reconstruction of sedimentary and deformation events suggests at least six paleoseismic events, with the youngest four events well constrained by deformed and sealing units. Older events are less certain and likely missing due to the incomplete stratigraphic record.

Upcoming radiocarbon dating results will help constrain the timing of these events, and additional excavations are planned to better constrain the paleoseismic history of the Raša Fault. This research will improve our understanding of the seismic behaviour of this fault and contribute to a better assessment of the seismic hazard in the region.

ACKNOWLEDGMENTS

The paleoseismological study of the Raša Fault is carried out within the framework of the Dynamic Earth (P1-0419) and Regional Geology (P1-0011) program groups funded by the Slovenian Research and Innovation Agency (ARIS). This study would not have been possible without the previous structural, geomorphological, and geophysical investigations funded by the Slovenian Environment Agency (ARSO, 2021-2024). L. Rupar acknowledges the funding by ARIS in the frame of the young researchers programme. J. Maslač participated in the study as part of the Mobility project of the Croatian Science Foundation (HRZZ). We would like to thank Blaž Milanič, Anže Markelj, Maša Mušič, Petra Škrap (Geological survey of Slovenia), Nejc Novak Zakeršnik and Nika Pišek Szillich (students from the Department of Geology of the Faculty of Natural Sciences and Engineering, University of Ljubljana) for their help in preparing the trench.

REFERENCES

Atanackov, J., Jamšek Rupnik, P., Jež, J., Celarc, B., Novak, M., Milanič, B., Markelj, A., Bavec, M., Kastelic, V., 2021. Database of Active Faults in Slovenia: Compiling a New Active Fault Database at the Junction Between the Alps, the Dinarides and the Pannonian Basin Tectonic Domains. Frontiers in Earth Science 9, doi:10.3389/feart.2021.604388.

Jamšek Rupnik, P., Rupar, L., Gostinčar, P., Placencia Gomez, R.E., Atanackov, J., Zajc, M., Jež, J., 2023, Tektonsko-geomorfološke in geofizikalne raziskave Raškega preloma med Branikom in Košano. Ljubljana, Geological survey of Slovenia, 107 p.

Jež, J., Jamšek Rupnik, P., Atanackov, J., Novak, A., Milanič, B., Novak, M., Markelj, A., Ivančič, K., Slapnik, L., Valand, N., 2022. Strukturno-geološke raziskave Raškega preloma med Senadolami in Kobdiljem. Ljubljana, Geological survey of Slovenia, 52 p.

Moulin, A., Benedetti, L., Rizza, M., Jamšek Rupnik, P., Gosar, A., Bourlès, D., Keddadouche, K., Aumaître, G., Arnold, M., Guillou, V., Ritz, J.F., 2016. The Dinaric fault system: Large-scale structure, rates of slip, and Plio-Pleistocene evolution

of the transpressive northeastern boundary of the Adria microplate. Tectonics 35, 10, 2258–2292, doi:10.1002/2016TC004188.

Vičič, B., Aoudia, A., Javed, F., Foroutan, M., Costa, G., 2019. Geometry and mechanics of the active fault system in western Slovenia. Geophysical Journal International, doi:10.1093/gji/ggz118.

Zupančič, P., Šket Motnikar, B., Carafa, M.M.C., Jamšek Rupnik, P., Živčić, M., Kastelic, V., Rajh, G., Čarman, M., Atanackov, J., Gosar, A., 2024. Seismogenic depth and seismic coupling estimation in the transition zone between Alps, Dinarides and Pannonian Basin for the new Slovenian seismic hazard model: Natural Hazards and Earth System Sciences 24, 2, 651–672, doi:10.5194/nhess-24-651-2024.

DECIPHERING THE PEDO-SEDIMENTARY COMPLEX OF EASTERN ADRIATIC COAST: A CASE STUDY IN PRIVLAKA, CROATIA

Stanko Ružičić[1], Lidija Galović[2], Koen Beerten[3], Nina Hećej[2], Jasmina Martinčević Lazar[2], Rodoljub Gajić[4], Stjepan Husnjak[5], Mihajlo Pandurov[4], Petar Stejić[4], Rosa Maria Poch[6], Ajka Pjanić[2]

[1]University of Zagreb Faculty of Mining, Geology and Petroleum Engineering, Croatia
[2]Croatian Geological Survey, Zagreb, Croatia
[3]Belgian Nuclear Research Centre SCK CEN, Mol, Belgium
[4]Geological Survey of Serbia, Belgrade, Serbia
[5]University of Zagreb Faculty of Agriculture, Croatia
[6]Universitat de Lleida, Departament de Química, Física i Ciències Ambientals i del Sòl, Catalonia, Spain

Corresponding author: Stanko Ružičić (stanko.ruzicic@rgn.unizg.hr)

This study provides the first results of the Quaternary eight-meter-thick pedo-sedimentary complex developed in Privlaka, Croatia to understand the succession of paleosols and sediments, the deposition mechanism and the source of the material. This pedo-sedimentary profile (8 meters) is divided into four main units (Figure 1): a reddish paleosol and three sediment packages (sands with gravels) each indicating a different pedo-sedimentological context. Each distinctive horizon was sampled for sedimentological, physico-chemical, mineralogical and petrographical analyses to conduct a high-resolution investigation. In addition, optically stimulated luminescence (OSL) dating is used to assess the sediment's age. Grain size analysis revealed that the paleosols are rich in fine-grained components, predominantly silt. The quartz grains exhibit an angular to subangular morphology typical for (glacio-)fluvial transport, suggesting that the sand-gravel body is formed by sediment transport and deposition by water. The upper part of investigated profile has dominantly carbonate grains such as carbonate concretions (ryzoconcretions) and nodules. The $CaCO_3$ content (calcites) generally decreases from the upper to the lower part of the investigated profile. All analysed samples had an alkaline reaction. Organic matter is higher in the paleosol part of the profile due to soil pedogenetic development. The proportion of the light mineral fraction (LMF) in almost all samples is roughly 98 %, with quartz as the dominant component, followed by lithic particles (5 – 15 %) and feldspars (3 - 7 %). Volcanic glass is accessory (<3 %). Such high content of quartz, suggesting that these sediments have undergone more redeposition of quartz than in loess of the northern Adriatic Island of Susak . The increase in weathered quartz grains with increasing depth could indicate that the proportion of fluvial sediments has increased compared to the aeolian sediments. The distribution of weight share for heavy mineral fraction (HMF) is uniform across the profile and ranges from 1.1 to 2.5 %. Among the HMF, opaque grains predominate. Along with opaque grains that cannot be determined (30 - 57 %), goethite grains make up a significant proportion (12 – 33 %). The most abundant transparent heavy minerals are resistant grains like dominant garnet (27 – 51 %), followed by zircon (9 – 24 %) and rutile (6 – 21 %). The predominant minerals in the paleosols are calcite and quartz. The samples also contain feldspars, goethite and some phyllosilicates. Two types of calcites are distinguished in the paleosol and (glacio-)fluvial sediments: primary calcite, which was formed by the process of physical weathering of carbonate rocks from the hinterland, and secondary, i.e., authigenic calcite, which was precipitated as a cement in carbonate concretions and rhyzoconcretions during pedogenesis. Petrographic analyses confirmed the presence of chromite, serpentinite and serpentinized olivine basalt, indicating the area of

origin within ultramafic rocks, which could be the Dinaric ophiolitic zone in the hinterland. The carbonate grains are polygenetic in origin and consist of equal parts of highly spherical upper Cretaceous rudist limestones, Eocene nummulitic limestones and low spherical pedogenic carbonate concretions, indicating local transport. The apparent OSL ages of the (glacio-)fluvial sediment overlying the paleosol would range between ca. 230 ka and 130 ka for the lowermost sample, and ca. 190 ka and 105 ka for the uppermost sample. According to the OSL dating results, the (glacio-)fluvial materials were deposited during the earliest part of OIS5 or OIS6, while the paleosol can most likely not be younger than OIS5 and might even have an age that corresponds with OIS7. This research is funded by the Croatian Science Foundation under the project ACCENT (IP-2020-02-3274).

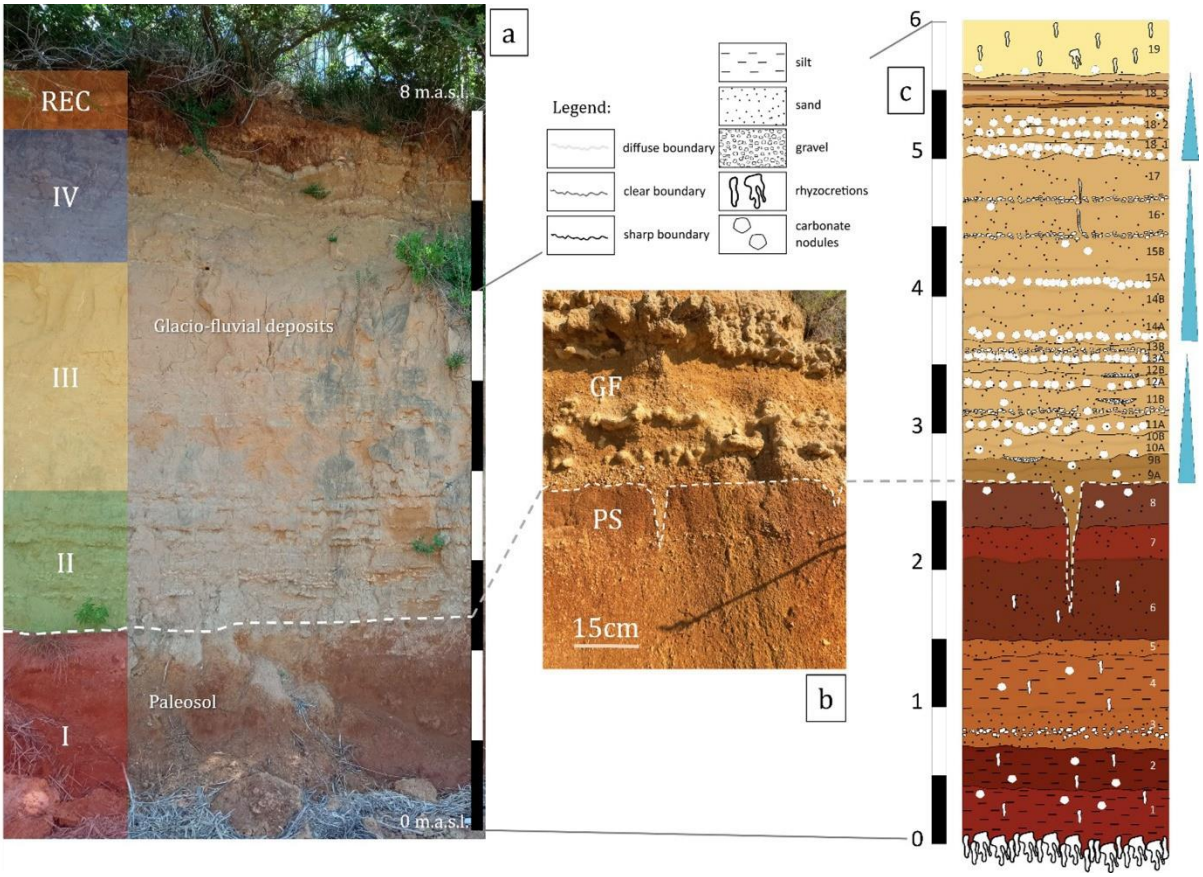

Figure 1: The pedo-sedimentary complex of Privlaka, profile a) units of the pedo-sedimentary complex; b) paleosol(s) (PS)/(glacio-)fluvial (GF) erosion boundary with distinctive features; c) detailed graphical log of the profile PN1-5 with marked horizons/layers.

MODELLING THE HOLOCENE MARINE TRANSGRESSION IN THE GULF OF TRIESTE

Ana Novak

Geological Survey of Slovenia, Slovenia

Corresponding author: Ana Novak (ana.novak@geo-zs.si)

The global transgression following the Last Glacial Maximum greatly impacted vast areas of previously subaerially exposed continental shelves. In the northern Adriatic Sea the generally northwestward-directed transgression is well recorded in the seabed sedimentary record (Correggiari et al., 1996; Moscon et al., 2015; Ronchi et al., 2019, 2018; Storms et al., 2008; Trincardi et al., 2011; Zecchin et al., 2015). While it is clear from sedimentary data that the sea started entering the Gulf of Trieste in the Early Holocene (Covelli et al., 2006; Ogorelec et al., 1981; Trincardi et al., 2011; Zecchin et al., 2024) the spatio-temporal dynamics of the transgression are more ambiguous. This contribution presents an attempt to model the sea-land extent in the Gulf of Trieste during the Early Holocene in order to better understand the transgressive flooding of the area.

Several phases of the transgression were modelled on a topographic dataset from Trobec et al. (2018) which, especially in the southern part of the Gulf, corresponds to the pre-transgressional topography of the area. The elevation model was flooded with the "Simulate Water Level Rise/Flooding" tool in the Global Mapper GIS software at water levels between 30-25 m, 23 m, and 20 m below present-day sea level. Higher sea-levels during storms and high tides were accounted for with an added increase of 1 m to the predetermined water-levels. The resulting polygons of the flooded areas were exported in the shapefile format. The sea-land extent at the higher water levels was chronologically constrained to the sea-level curve of Kaniewski et al. (2021).

The modelling results show that the sea started to enter the Gulf of Trieste after it rose above -29 m a.s.l. This is supported by the so-far published sea-level index point from the gulf, which are all shallower than -29 m (Vacchi et al., 2016 and references within). After the sea level reached this threshold approximately half of the area of the present-day Gulf of Trieste was abruptly flooded. In this early phase the predominant transgression direction was towards the northeast. After the deepest parts of the basin were flooded the spatial advance of the transgression slowed down and the main transgression direction oriented towards the northwest.

The transgression direction in the gulf in the initial phase is perpendicular to the direction in the northern Adriatic. This is attributed to the paleotopography which resulted from the LGM activity of the Torre and Soča (Isonzo) megafan systems (Fontana et al., 2014; Ronchi et al., 2023). The higher portions of the fans acted as a topographical barrier for the advancing coastline. When the water level was high enough to overstep the boundary, flooding of the Gulf of Trieste was abrupt and extensive. The predominant northeast flooding direction resulted from the topographic gradient as it was perpendicular to the longitudinal direction of the Soča/Isonzo megafan (Fontana et al., 2014; Ronchi et al., 2023). The pre-existing topography probably also played an important role in the exceptionally preserved fluvial sequences in the gulf (Novak et al., 2020; Ronchi et al., 2023; Trobec et al., 2017) as the topographical highs probably dissipated wave energy and reduced their erosive action. This study was published in Novak (in press).

REFERENCES

Correggiari, A., Field, M.E., Trincardi, F., 1996. Late Quaternary transgressive large dunes on the sediment-starved Adriatic shelf. Geological Society, London, Special Publications 117, 155–169. https://doi.org/10.1144/gsl.sp.1996.117.01.09

Covelli, S., Fontolan, G., Faganeli, J., Ogrinc, N., 2006. Anthropogenic markers in the Holocene stratigraphic sequence of the Gulf of Trieste (northern Adriatic Sea). Marine Geology 230, 29–51. https://doi.org/10.1016/j.margeo.2006.03.013

Fontana, A., Mozzi, P., Marchetti, M., 2014. Alluvial fans and megafans along the southern side of the Alps. Sedimentary Geology 301, 150–171. https://doi.org/10.1016/j.sedgeo.2013.09.003

Kaniewski, D., Marriner, N., Cheddadi, R., Morhange, C., Vacchi, M., Rovere, A., Faivre, S., Otto, T., Luce, F., Carre, M.-B., Benčić, G., Van Campo, E., 2021. Coastal submersions in the north-eastern Adriatic during the last 5200 years. Global and Planetary Change 204, 103570. https://doi.org/10.1016/j.gloplacha.2021.103570

Moscon, G., Correggiari, A., Stefani, C., Fontana, A., Remia, A., 2015. Very-high resolution analysis of a transgressive deposit in the Northern Adriatic Sea (Italy). Alpine and Mediterranean Quaternary 28, 121–129.

Novak, A., in press. Paleocoastline modelling – What a difference a few meters of sediment make? Quaternary International. https://doi.org/10.1016/j.quaint.2024.07.005

Novak, A., Šmuc, A., Poglajen, S., Vrabec, M., 2020. Linking the high-resolution acoustic and sedimentary facies of a transgressed Late Quaternary alluvial plain (Gulf of Trieste, northern Adriatic). Marine Geology 419, 106061. https://doi.org/10.1016/j.margeo.2019.106061

Ogorelec, B., Mišič, M., Šercelj, A., Cimerman, F., Faganeli, J., Stegnar, P., 1981. Sediment sečoveljske soline. Geologija 24, 180–216.

Ronchi, L., Fontana, A., Correggiari, A., Asioli, A., 2018b. Late Quaternary incised and infilled landforms in the shelf of the northern Adriatic Sea (Italy). Marine Geology 405, 47–67. https://doi.org/10.1016/j.margeo.2018.08.004

Ronchi, L., Fontana, A., Correggiari, A., Remia, A., 2019. Anatomy of a transgressive tidal inlet reconstructed through high-resolution seismic profiling. Geomorphology 343, 65–80. https://doi.org/10.1016/j.geomorph.2019.06.026

Ronchi, L., Fontana, A., Novak, A., Correggiari, A., Poglajen, S., 2023. Late-Quaternary Evolution of the Semi-Confined Alluvial Megafan of Isonzo River (Northern Adriatic): Where the Fluvial System of the Southern Alps Meets the Karst. Geosciences 13, 135. https://doi.org/10.3390/geosciences13050135

Storms, J.E.A., Weltje, G.J., Terra, G.J., Cattaneo, A., Trincardi, F., 2008. Coastal dynamics under conditions of rapid sea-level rise: Late Pleistocene to Early Holocene evolution of barrier–lagoon systems on the northern Adriatic shelf (Italy). Quaternary Science Reviews 27, 1107–1123. https://doi.org/10.1016/j.quascirev.2008.02.009

Trincardi, F., Argnani, A., Correggiari, A., Foglini, F., Rovere, M., Angeletti, L., Asioli, A., Campiani, E., Cattaneo, A., Gallerani, A., Piva, A., Remia, A., Ridente, D., Taviani, M., 2011a. Note illustrative della Carta Geologica dei mari italiani alla scala 1:250.000 foglio NL 33-7 Venezia 151–151.

Trobec, A., Busetti, M., Zgur, F., Baradello, L., Babich, A., Cova, A., Gordini, E., Romeo, R., Tomini, I., Poglajen, S., Diviacco, P., Vrabec, M., 2018. Thickness of marine Holocene sediment in the Gulf of Trieste (northern Adriatic Sea). Earth System Science Data 10, 1077–1092. https://doi.org/10.5194/essd-10-1077-2018

Trobec, A., Šmuc, A., Poglajen, S., Vrabec, M., 2017. Submerged and buried Pleistocene river channels in the Gulf of Trieste (Northern Adriatic Sea): Geomorphic, stratigraphic and tectonic inferences. Geomorphology 286, 110–120. https://doi.org/10.1016/j.geomorph.2017.03.012

Vacchi, M., Marriner, N., Morhange, C., Spada, G., Fontana, A., Rovere, A., 2016. Multiproxy assessment of Holocene relative sea-level changes in the western Mediterranean: Sea-level variability and improvements in the definition of the isostatic signal. Earth-Science Reviews 155, 172–197. https://doi.org/10.1016/j.earscirev.2016.02.002

Zecchin, M., Caffau, M., Busetti, M., Masoli, C.A., Baradello, L., Civile, D., Dal Cin, M., Petronio, L., Romeo, R., Zampa, L.S., Lenaz, D., Lucchi, R.G., Caburlotto, A., 2024. Late Quaternary transgressions and regressions in the Trieste Gulf (north-eastern Adriatic Sea). Quat Int 695, 1–17. https://doi.org/10.1016/j.quaint.2024.03.001

Zecchin, M., Gordini, E., Ramella, R., 2015. Recognition of a drowned delta in the northern Adriatic Sea, Italy: Stratigraphic characteristics and its significance in the frame of the early Holocene sea-level rise. The Holocene 25, 1027–1038. https://doi.org/10.1177/0959683615575358

ABRUPT CLIMATE CHANGES ARCHIVED IN PALAEOSOLS INTERCALATED IN LOESS

Lidija Galović[1], Stjepan Husnjak[2], Rosa Maria Poch[3], Petar Stejić[4], Rodoljub Gajić[4], Ajka Pjanić[1], Mihajlo Pandurov[4], Koen Beerten[5], Jasmina Martinčević Lazar[1], Stanko Ružičić[6]

[1]Croatian Geological Survey, Croatia
[2]Faculty of Agriculture, Croatia
[3]University of Lleida, Catalonia, Spain
[4]Geological Survey of Serbia, Serbia
[5]Belgian Nuclear Research Centre SCK CEN, Belgium
[6]Faculty of Mining, Geology and Petroleum Engineering, Croatia

Corresponding author: Lidija Galović (lgalovic@hgi-cgs.hr)

The specific geological, pedological, geomorphological and climatic diversity of Croatia enables us to study in high resolution the parallel development of abrupt climate change (CC) during the Late Pleistocene and Holocene. Four investigated locations are only 300 km apart: loess/palaeosol sequences and dunes in the Pannonian area (continental climate) on the one hand, and fluvioglacial sediments and karst lacustrine sediments in the Dinaric area (Mediterranean climate) on the other hand. This abstract will present the investigation on the example of the loess/palaeosol section Zmajevac.

The applied methods were: radiocarbon (^{14}C) and infrared luminescence dating (IRSL), standard sedimentological, mineralogical, paleontological, pedological and micromorphological analyses.

Warm periods (interstadials) are archived in geological successions as palaeosols. The ages of these palaeosols and overlying sediments indicate hiatuses in sedimentary succession. Since the upper parts of soil profiles are missing, it can be concluded that the ends of warm periods were characterised by strong soil erosion during the investigated period (last 120 ka). Such events are preserved in each investigated location with different recent and palaeoclimate conditions.

The bulk mineralogy is dominated by quartz, followed by plagioclase and mica in similar amounts, except in profile ZN3, where muscovite can reach up to 33 %. Carbonates are found in varying percentages in the form of calcite and dolomite. In addition, potassium feldspars, phyllosilicates, amphiboles, and, in some horizons, pyroxenes are also present. This mineralogical assemblage was found in previous investigations in the area.

Sedimentation of the parent material of the youngest soil (ZN REC) corresponds with Heinrich Event 1 (16.6 ka BP), based on ^{14}C analyses of shells. Heinrich Event 1 is followed by the Bølling–Allerød (BA) interstadial period, roughly between 14.7 and 12.9 ka BP. The ZN REC soil could be a palaeoclimatological archive of the BA, similar to what is preserved in the Đurđevac dune sands. If the ZN REC soil had remained unburied on the surface during the Holocene, the degree of pedological development would have been much higher. Thus, following the conclusions, Holocene synpedological aeolian sedimentation could occur, slowing down soil formation. Palaeosols often form through the interaction of slow deposition and climatic influences as indicated by studies of modern pedogenesis during active loess deposition. On the other hand, ZN REC is situated on the loess plateau close to the cliff, which is subject to strong wind erosion. Thus, the possibility cannot be excluded that all the material that

could have been sedimented after Heinrich Event 1 has been eroded, and that the loess deposited during Heinrich Event 1 is now exposed to pedogenesis and climatologically represents recent pedogenesis. The degree of pedogenetic development on the investigated micro-location is lower than usual in this area due to synpedogenetic erosion, the supply of fresh material, and the micro-location of the investigated profile.

This work has been fully supported by Croatian Science Foundation under the project ACCENT [3274].

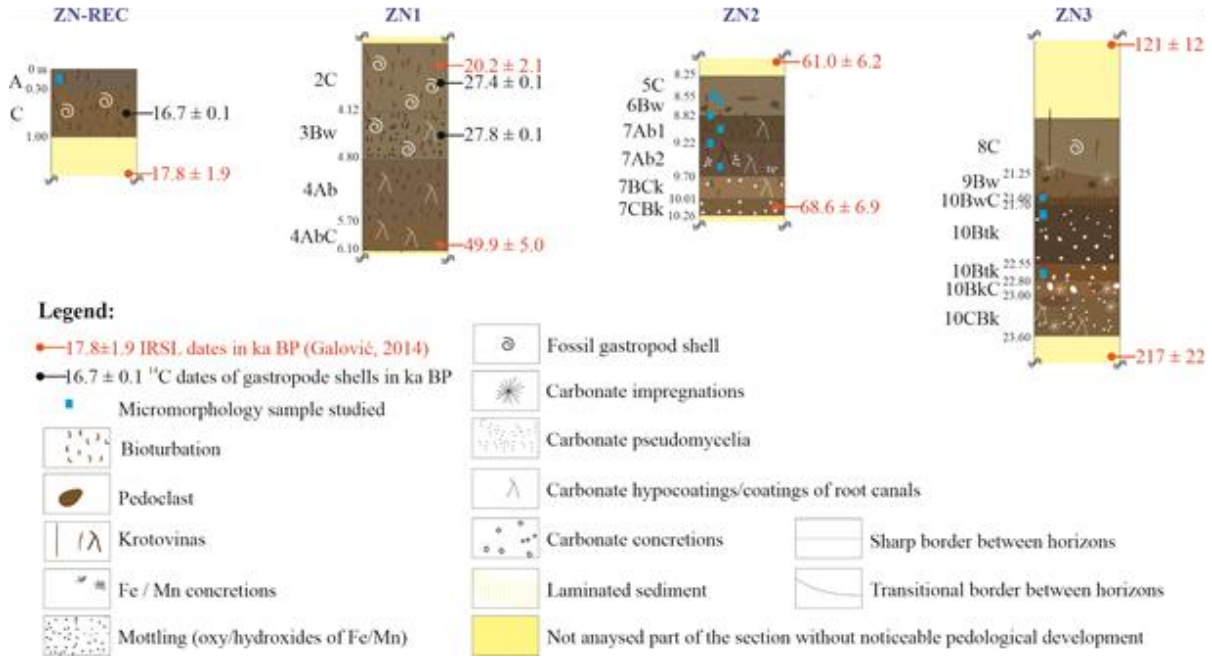

Figure 1: Zmajevac pedosedimentary sequence, composed of a recent soil (ZN-REC) and three palaeosols (ZN1, ZN2, ZN3) separated by unaltered loess. Depths (m) referred to the surface are indicated between the denomination of the genetic horizons.

REFERENCES

Eger, A., Almond, P.C., Condron, L.M., 2012. Upbuilding pedogenesis under active loess deposition in a super-humid, temperate climate — quantification of deposition rates, soil chemistry and pedogenic thresholds. Geoderma 189–190, 491–501. https://doi.org/10.1016/j.geoderma.2012.06.019

Galović, L., Frechen, M., Halamić, J., Durn, G., Romić, M., 2009. Loess chronostratigraphy in Eastern Croatia – A luminescence dating approach. Quaternary International 198/1-2, 85-97. https://doi.org/10.4154/GC.2013.18

Galović L., Beerten K., Hećej N., Posilović H. 2023a. Đurđevac Sands and the intraformational paleosoils (Podravina, N Croatia) are newly dated to Late Pleistocene/Holocene. Geologica Carpathica 74, 181-194. https://doi.org/10.31577/GeolCarp.2023.07

Galović, L., Husnjak, S., Šorša, A., Martinčević Lazar, J. 2023b. Evidence and mineralogical and physico-chemical properties of chernozem and chernozem-like soils in Croatia. Geologia Croatica 76/3, 113-129. https://doi.org/10.4154/gc.2023.08

Galović, L., Šorša, A., Peh, Z., 2024. Modelling the paleopedological development of loess/palaeosol sections using discriminant function analysis of compositional geoscience data, case study in Eastern Croatia. Journal of Geochemical Exploration 262, 107473 https://doi.org/10.1016/j.gexplo.2024.107473

Poch, R.M., Galović, L., Husnjak, S., Martinčević Lazar, J., Hećej, N., Ružičić, S., Pjanić, A., Álvarez, D., Beerten, K., Gajić, R., Stejić, P., Pandurov, M., 2024. Soil formation and environmental reconstruction of a loess-paleosol sequence in Zmajevac, Croatia. Catena 247, 108507. https://doi.org/10.1016/j.catena.2024.108507

FALLEN BARRIER AT THE NATIONAL PARK PLITVICE LAKES

Andreja Sironić[1], Jadranka Barešić[1], Damir Borković[1], Kazimir Miculinić[2], Andrijana Brozinčević[2]

[1]1Ruđer Bošković Institute, Bijenička cesta 54, 10000 Zagreb, Croatia
[2] National Park Pltitvice Lakes, Scientific and professional center "Dr. Ivo Pevalek", 53231 Plitvička Jezera, Croatia.

Jadranka Barešić (jbaresic@irb.hr)

The Plitvice Lakes consist of 16 cascaded lakes separated by tufa barriers. In 1949 were declared a national park and in 1979 were included in the UNESCO World Heritage List. High-water event in early spring of 2018 caused breakage one of tufa barrier. The autumn / winter period in 2017 / 2018 was characterized with relatively high precipitation (rain and snow, 384 mm in September 2017 and 333 mm in February 2018), and low winter temperatures (average temperature for February -2.7°C) (CMHS 2024). It has to be emphasized that Plitvice Lakes are „used to“ cold winters with high snowfall and low temperatures as the climate is classified as Cfb type (temperate humid climate without dry season with warm summer, Peel et al. 2007) and lately even as Dfb type (cold, no dry season with warm summer, Beck et al. 2018). Additionally, Plitvice were exposed to even lower temperatures and higher amount in precipitation in the past, so it was quite shocking for Nation Park authorities to discover a barrier cracking which caused a drainage of small lake formed above the barrier.

During the field work, a wooden plank was discovered 2 m below the fallen barrier and four tufa samples were taken (S1 – 0.5 m above plank, S2 at 0 m, and S3 and S4 0.5 m below the plank). Obtained radiocarbon age of plank was 1699 – 1959 cal AD, and organic residue of S1 1989 – 1996 cal AD. Organic residues of samples S3 and S4 were dated to 1431 – 1449 cal AD and 1320 – 1425 cal AD. The δ13C values of dated samples S1, S3 and S4 were -29.3‰, -29.8‰ and -31.2‰, respectively indicating negligible hard-water effect, so the radiocarbon ages gave good chronology of tufa growth. Sample S2 with δ13C of -35.3‰ indicates aquatic origin of the sample and therefore the hard-water effect which gave older age (1448 – 1455 cal AD).

Results indicate that destroying of this tufa barrier was inevitably since its growth was initiated by the wooden plank probably introduced to a waterfall as an improvised bridge. Tufa barrier grew up to two meters in a very short period of approximately 60 years. As such, barrier was unstable and unconsolidated. From the period when the Plitvice Lakes were declared as a national park up to 2018, the barrier was regarded the same as all other naturally formed barriers. Therefore, a serious concern was expressed for the future of the lakes when high-water event destroyed the barrier. However, the radiocarbon analyses revealed that the barrier growth was induced by a human activity (not a usual scenario) and hopefully this kind of event will not be seen in the near future.

REFERENCES

Beck HE, Zimmermann NE, McVicar TR, Vergopolan N, Berg A, Wood EF. 2018. Data Descriptor: Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific data 5:180214. DOI: 10.1038/sdata.2018.214.

CMHS. Croatian Meteorological and Hydrological Service. 2024

Peel MC, Finlyanson BL, McMahon TA. 2007. Updated world map of the Köppen-Geiger climate classification. Hydrol. Earth System Science 11:1633–44.

VETERNICA CAVE SPELEOGENESIS BASED ON SPELEOMORPHOLOGICAL AND SEDIMENTOLOGICAL RESEARCH

Andrej Stroj[1], Damir Lacković[2], Ira D. Sasowsky[3], Petra Bajo[1], Bosiljka Glumac[4]

[1]Croatian Geological Survey, Sachsova 2, 10000 Zagreb, Croatia
[2]Croatian Natural History Museum, Deželićeva 30, 10000 Zagreb, Croatia
[3]Department of Geosciences, The University of Akron, Akron, OH 44325-4101, USA
[4]Department of Geosciences, Smith College, Northampton, Massachusetts 01063, USA

Corresponding author: Andrej Stroj (astroj@hgi-cgs.hr)

With more than seven kilometers of passages, Veternica Cave is the longest known cave in Croatia outside the Dinaric Karst area. In addition to its speleological and tourist appeal, its well-preserved cave sediments offer valuable insights into the geological history of both the cave and its broader surroundings. By combining speleomorphological mapping, paleomagnetic analyses of stream (clastic) sediments, and U-Th dating of speleothems, chronological data have been reconstructed, detailing the development of Veternica Cave over the past 600,000+ years. Several speleogenetic phases were identified, reflecting alternations between long periods of stability and shorter tectonically active phases in the wider region. During the periods of active tectonic uplift in Medvednica and the consequent lowering of the erosion base level, the cave's channel morphology adapted rapidly, with the groundwater level dropping by 6 meters per 10,000 years—a rate comparable to that observed in other caves located in similarly tectonically active areas.

PALAEOECOLOGY OF THE MIS 3 AT THE EASTERN ADRIATIC COAST: EVIDENCE FROM THE BIRD BONE ASSEMBLAGE MARLERA I (SOUTHERN ISTRIA)

Ankica Oros Sršen

Institute for Quaternary Palaeontology and Geology, Croatian Academy of Sciences and Arts, Ante Kovačića 5, 10 000 Zagreb

Corresponding author: Ankica Oros Sršen (aos@hazu.hr)

The Eastern Adriatic Coast is known for its Late Pleistocene cave sites. However, most of the sites are of Pleniglacial to Late Glacial and younger in age (MIS 2 – 1; Mauch Lenardić et al., 2018, Oros Sršen et al., 2014). Here we present a rich MIS 3 avifaunal assemblage from the southern Istrian peninsula that enables us to fill the gap in the palaeoecological reconstruction of this very dynamic time period. Marlera is a limestone quarry at 30 m.a.s.l, 15 km southeast from the town of Pula in Southern Istria. There are at least two cavities in the quarry filled with reddish sediment and the Late Pleistocene faunal remains, Marlera I and II. However, only Marlera I was excavated and analysed in detail (Brajković et al., 2005, 2006, 2010). Stratigraphy of Marlera I is still unclear since there were no visible sedimentary units, therefore deposits were dug in 20 cm spits. ^{14}C AMS dating reveals the Late Pleistocene age, around 45,000 cal yr BP (Brajković et al., 2005). Faunal assemblage is diverse and includes: amphibians, reptiles, birds and mammals.

Here we present a NISP (number of identified specimens) of 100 bird bones that were collected until 2010 and have been analysed or re-analysed, since part of the remains (until 2006) was preliminarily determined by V. Malez (Brajković et al., 2005, 2006). A total of seven orders comprising 12 families, 13 genera, and 11 species (16 if confere species are counted) were identified in Marlera I (Oros Sršen, 2015). Different representatives of the following orders have been determined: Anseriformes, Falconiformes, Galliformes, Gruiformes, Charadriiformes, Coraciiformes and Passeriformes (Figure 1). According to avifaunal remains, the excavated sediments can be vertically divided into two distinct units. Unit I refers to the uppermost part of the section (from the surface to the -410 cm) dominated by bird species that prefer open and dry habitats, while Unit II encompasses lower deposits (from -410 cm to -510 cm) with bird species that prefer aquatic habitats.

Almost all identified taxa from the Marlera assemblage are characteristic of a temperate climate and can be found in Istria today or in the last two hundred years (Kralj, 1997; Lukač, 2007). The majority of the identified species belong to the breeding birds, which are presumed to be residents or summer visitors on the eastern Adriatic coast during the Late Pleistocene. Only the rock ptarmigan (*Lagopus muta*) is not present in Croatia today, and it is found relatively distant from its present day habitat in the Alps. The presence of this species could indicate stadial conditions during the accumulation of the Assemblage I. Other taxa from this assemblage indicate an open grassland, steppe environment with trees sporadically present. Assemblage II is characterised by taxa adapted to the similar habitats and temperate climate, with the addition of aquatic taxa. Most probably these two assemblages indicate (one or more) stadial and interstadial changes that occurred during MIS 3 and/or MIS 4. The overall avifaunal composition suggests open grassland habitats with patches of trees and fresh water bodies on

and around the southernmost tip of the present-day Istrian peninsula, which was part of the Great Adriatic Plain during MIS 3. This implies productive environments suitable for different bird species.

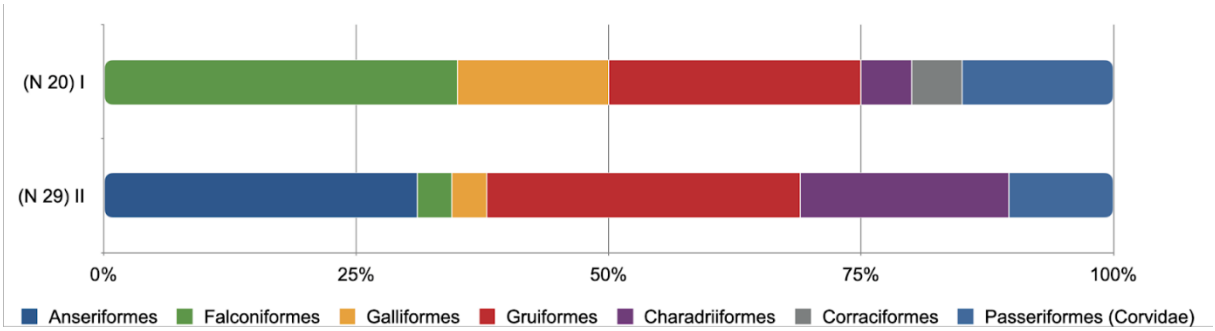

Figure 1: Relative taxonomic abundances of orders in Assemblage I and II at Marlera I.

ACKNOWLEDGES

The research was funded by the Ministry of Science, Education and Sport of the Republic of Croatia through the project 101-2690680-2270 “Correlation of Palaeolithic, Mesolithic and Neolithic of continental and coastal Croatia” led by Dr. Dejana Brajković.

REFERENCES

Brajković, D., Malez, V., Mauch Lenardić, J., Karavanić, I. and Miculinić, K. 2005. Rezultati dosadašnjeg istraživanja novog pleistocenskog lokaliteta na Marleri u južnoj Istri, in: Velić, I., Vlahović, I. & Biondić, R. (Eds.): Knjiga sažetaka / Abstract Book, 3. Hrvatski geološki kongres / Third Croatian Geological Congress, Opatija 29.9.–1.10.2005., Hrvatsko geološko društvo, Hrvatski geološki institut, Prirodoslovno-matematički fakultet, Rudarsko-geološko-naftni fakultet, INA-Industrija nafte d.d., Zagreb, pp. 17–18.

Brajković, D., Mauch Lenardić, J., Brajković, D., Miracle, P.T. and Radović, S. 2006. Recent analyses of the Upper Pleistocene mammal fauna and flora of the Istrian peninsula (Croatia), in: Fonda, G., Melis, R. & Romano, R. (Eds.): Riassunti / Abstracts, Giornate di Paleontologia 2006, Trieste 8-11 giugno 2006, Società Paleontologica Italiana, pp. 13–14.

Brajković, D., Mauch Lenardić, J., Pavičić, Lj., Radović, S. and Oros Sršen, A. 2010. New results of investigations of Pleistocene locality Marlera I (southern Istria, Croatia), in: Horvat, M. (Ed.): Knjiga sažetaka / Abstracts book, 4. Hrvatski geološki kongres s međunarodnim sudjelovanjem / 4. Croatian Geological Congress with international participation, Šibenik 14.–15.10.2010., Zagreb, pp. 23–26.

Kralj, J. 1997. Ornitofauna Hrvatske tijekom posljednjih dvjesto godina. Larus, 46, 1–112.

Lukač, G. 2007. Popis ptica Hrvatske. Natura Croatica, 7/3, pp. 1–160.

Mauch Lenardić, J., Oros Sršen A., Radović, S., 2018. Quaternary fauna of the Eastern Adriatic (Croatia) with the special review on the Late Pleistocene sites, Quaternary International 494, 131 – 151. https://doi.org/10.1016/j.quaint.2017.11.028

Oros Sršen, A., Brajković, D., Radović, S., Mauch Lenardić, J., Miracle, P.T., 2014. The Avifauna of southern Istria (Croatia) during the Late Pleistocene: implications for the Palaeoecology and biodiversity of the Northern Adriatic Region. Int. J. Osteoarchaeol. 24 (3), 289-299. https://doi.org/10.1002/oa.2364.

Oros Sršen, A., 2015. Palaeoecological and taphonomic aspects of Avifauna from the Eastern Adriatic coast during the Late Pleistocene and Holocene. Unpublished PhD Thesis, University of Zagreb, Zagreb, pp. 1-207.

GEOMORPHOLOGICAL CHANGES DUE TO SEA-LEVEL OSCILLATIONS DURING LATE PLEISTOCENE IN NE CHANNEL PART OF THE ADRIATIC SEA

Čedomir Benac [1], Neven Bočić[2], Mladen Juračić[3]

[1]University of Rijeka, Faculty of Civil Engineering, Rijeka, Croatia
[2]University of Zagreb, Faculty of Science, Department of Geography, Zagreb, Croatia
[3]Croatian Academy of Sciences and Arts, Zagreb, Croatia

Corresponding author: Neven Bočić (nbocic@geog.pmf.hr)

Sea level oscillations caused pronounced morphological changes in the north-eastern channel part of the Adriatic Sea during the Late Pleistocene (130 - 10 ka B.P. or from MIS 5. to MIS 2). The sea level began to fall and oscillated between 20 m and 50 m below the present mean sea level (MSL) (from 110 to 75 ka B.P.) and between 50 m and 80 m below MSL (from 70 to 30 ka B.P.). The marine area became significantly smaller and the transition from marine to terrestrial or lacustrine environments occurred in many depressions such as Rijeka Bay, the Vinodol-Velebit Channel, and the Kvarnerić basin (Benac and Juračić, 1998). The distribution and granulometric composition of sediments on the seabed in this area is a consequence of sea level oscillations during the Late Pleistocene and Holocene (Juračić et al., 1999)

The deeper Kvarnerić basin remained a marine environment during this period. The deep straits or paleo-canyons between paleo-basins in the Kvarner area have significantly influenced marine transgression and regression. At the mouth of the Rječina River on the northern coast of Rijeka Bay the river cut its riverbed into bedrock more than 60 meters below the present sea level. The deepest ponor-like depression on the bottom of the Vrana Lake on Cres Island is located 61 m below MSL mean sea level. Paleo riverbeds were cut into bedrock more than 40 m below the present sea level at the mouths of the Dubračina and Novaljska Ričina rivers on the north-eastern coast of the Vinodol Channel (Benac and Juračić, 1998). The deepest known entrance of a submerged cave in the Kvarner area is 48 m below mean sea level (Benac et al., 2008).

The global fall of the sea level during the Last Glacial Maximum (LGM) (30 - 20 ka B.P.) when the sea level dropped to a depth of -100 to -120 m caused additional shrinking of marine area in the northern Adriatic Sea and the Kvarnerić basin. The erosional disconformities, visible on the echosounder cross-sections in some parts of the Kvarner area are strong evidence of the terrestrial environment during the LGM (Benac et al., 2022). The Kvarenrić basin became the largest paleo-polje in the Dinarides with an approximate area of 880 km^2 (Figure 1). Paleolakes were preserved in the adjacent Velebit Channel and the depressions of Rijeka Bay and the Lošinj Channel. The maximum depth of karstification was recognised as 70 m below recent MSL in the wide Kvarner area. These data correspond to paleo marine terraces, which are a reliable indicator of sea-level stagnation.

The valley of the Zrmanja paleo-river can be traced along the Velebit Channel at a distance of approximately 140 km from the present river mouth. However, there is not enough data on whether this ancient river during the LGM flowed on the surface to the Po paleo-river through straits between Ilovik and Premuda islands or Škarda and Ist islands. Another plausible possibility is that this paleo-river was a sinking river with ponors in the border of the paleo-polje (Figure 1). Since the end of the LGM, the sea level rose very rapidly during the period between

19 and 7 ka B.P and the sea flooded the Kvarnerić basin, and after that the Vinodol-Velebit channel and Rijeka Bay.

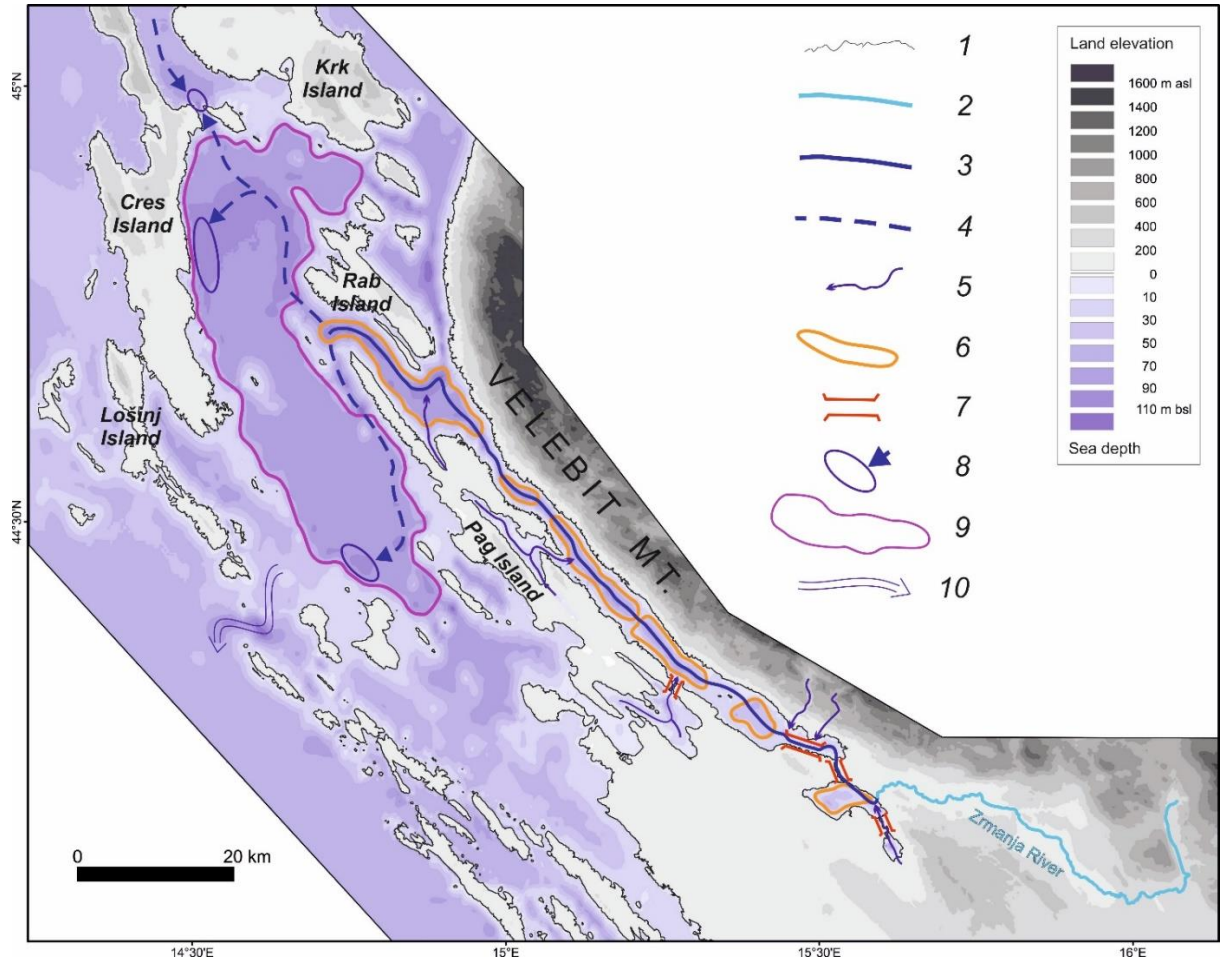

Figure 1: 1-recent shoreline, 2-recent Zrmanja riverbed, 3- the Zrmanja paleoriver valley, 4-possible continuations of the Zrmanja paleo-river, 5-main tributaries, 6-presumed flood plains, 7-submerged canyon, 8-assumed ponor zones, 9-contours of Kvarnerić paleo-polje, 10-possible surface connections of the polje and neighboring lower terrains (According to: Benac et al., 2023)

REFERENCES

Benac, Č., Juračić, M., 1998. Geomorphological indicators of the sea level changes during Upper Pleistocene (Wuerm) and Holocene in the Kvarner region. Acta Geographica Croatica 33, pp. 27-45.

Benac, Č., Gržančić, Ž., Šišić, S., Ružić, I., 2008. Submerged Karst Phenomena in the Kvarner Area. In: Marjanac, T. (Ed.) Proceedings of 5th International ProGEO Symposium on Conservation of the Geological Heritage, pp. 12-13.

Benac, Č., Bočić, N., Juračić, M., 2022. Geomorphologic changes of the Velebit Channel during Late Pleistocene and Holocene (NE Adriatic). Geografia Fisica e Dinamica Quaternaria, 45, pp. 41-54.

Benac, Č., Bočić, N., Ružić, I., Juračić, M., 2023. Kvarnerić polje and Zrmanja paleoriver during Last Glacial Maximum. In: Fio Firi, K. (Ed.) 7th Croatian Geological Congress, Abstract Book, pp. 20-21.

Juračić, M., Benac, Č., Crmarić, R., 1999. Seabeded and surface sediments map of the Kvarner Bay, Adriatic Sea, Croatia. Geologica Croatica 52, pp. 131-140.

CROSPELEO DATABASE: A COMPREHENSIVE SYSTEM FOR MANANGING SPELEOLOGICAL DATA AND VALUABLE TOOL FOR PRESERVING CROATIA'S SPELEOLOGICAL HERITAGE

Dragana Janeš[1], Luka Katušić[1], Gabrijela Božić[1]

[1]Ministry of Environmental Protection and Green Transition, Institute for Environment and Nature Protection, Radnička cesta 80/7, Zagreb

Corresponding author: Dragana Janeš (dragana.janes@mzozt.hr)

The importance of karst is already well known. It provides drinking water to people all over the world, offers habitat for rare and endangered species, karst caves and pits provides wide range of information about geological and human history. In Croatia more than 50 % of mainland is made up of karst relief, which belongs to the largest karst area in Europe - the Dinarides. The Dinaric karst represents a type locality (*locus typicus*) for all karst areas in the world, with unique and invaluable geodiversity. Specificity of the karst are the underground forms - caves and pits of which about 10.000 have been discovered in Croatia, and every year speleologists discover and explore new ones. We have 16th deepest cave in the world - "Jamski sustav Lukina jama – Trojama" and 60th longest cave system in the world – "Jamski sustav Crnopac" (*Internet source:* Cave Exploring). Due to the exceptional wealth of cave species, Croatia, as part of the Dinarides, is an important global center of cave fauna diversity. To date, about 700 species and subspecies of real cave animals have been recorded, which makes up about 10% of the total world diversity of cave fauna. Most of them are Croatian endemic. Consequently, one of the activities of the Strategy and action plan for nature protection of the Republic of Croatia for the period 2017 to 2025 (OG 72/17) is to collect, update, and verify existing data on speleological objects and to carry out the inventory of speleological objects in cooperation with speleological associations. According to the Nature Protection Act (OG 80/13, 15/18, 14/19, 127/19), speleological objects are of special interest to the Republic of Croatia and enjoy its special protection.

With the aim of preserving this uniqueness of the Croatian karst, in 2015, the Croatian Environment and Nature Agency (today the Institute for Environment and Nature Protection, within the Ministry of Environmental Protection and Green Transition), in cooperation with speleological associations and institutions engaged in speleological activities within the Republic of Croatia, established the Cadastre of Speleological Objects of the Republic of Croatia as part of the Nature Protection Information System (*https://crospeleo.mingor.hr/*). The Cadastre of Speleological Objects of the Republic of Croatia is part of the Nature Protection Information System and is jointly established by the Institute for Environment and Nature Protection of the Ministry of Environmental Protection and Green Transition, along with the participants in the Cadastre — speleological associations and institutions engaged in speleological activities within the Republic of Croatia. The primary goal of the Cadastre is to consolidate and harmonize data on speleological objects and to enable access to it. Participants collect, update, and verify the data, entering it into the Cadastre along with accompanying photo documentation, drawings, and other archives, while the Institute coordinates data collection, provides additional technical validation, and offers all the necessary IT infrastructure and support. Each year, at least one new data entry cycle is held. During 2021, in the 10th cycle, data for a total of 721 speleological objects were entered. In the 11th cycle, during 2022, data

entry for the Cadastre of Speleological Objects of the Republic of Croatia was completed through the new platform CroSpeleo data where a total of 457 speleological objects were entered. This year, the 12th cycle was opened with a total of 434 new speleological objects entered.

The long-term cooperation with speleo associations will continue, and the data entry will be continuous to ensure sufficient data for use by all Cadastre participants, organisations within the nature protection sector and state and public institutions dealing with the protection and rescue of people and their property. Data of reduced scope and spatial precision are available to the public within the web portal of the Nature Protection Information System – Bioportal (*https://bioportal.hr/gis/*).

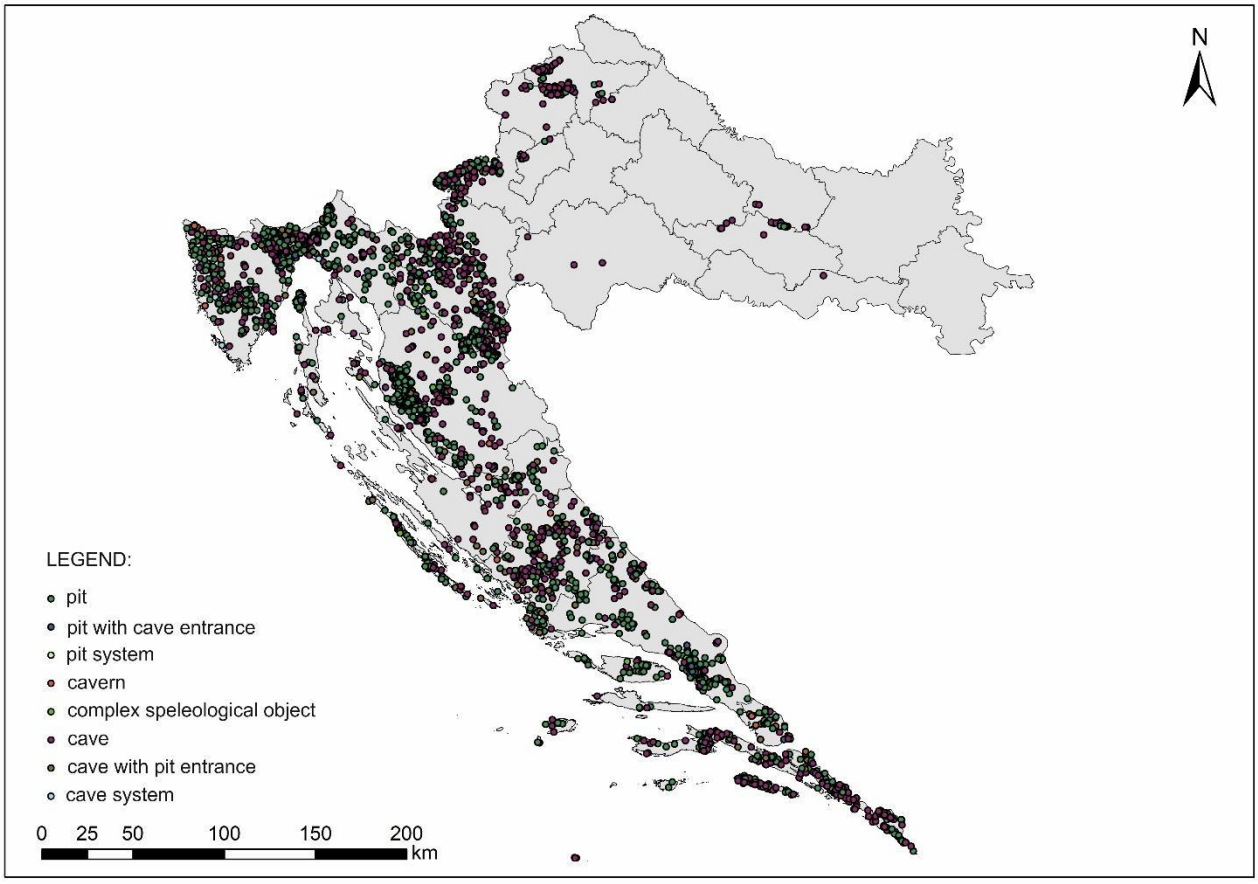

Figure 1: Overview of speleological objects at the level of the Republic of Croatia that have been entered into the CroSpeleo database.

REFERENCES

https://cave-exploring.com/
https://crospeleo.mingor.hr/
https://bioportal.hr/gis/

GEOCHRONOLOGICAL CONSTRAINTS ON DEDOLOMITIZATION AND GEOMORPHOLOGICAL EVOLUTION OF MRAVLJETOVO BREZNO V GOŠARJEVIH RUPAH CAVE, CENTRAL SLOVENIA

Filip Šarc[1], Bojan Otoničar[1], Andrzej Tyc[2], Krzysztof Gaidzik[2]

[1] Karst Research Institute ZRC SAZU, Titov trg 2, Postojna, Slovenia
[2] Institute of Earth Sciences, University of Silesia in Katowice, Będzińska 60, 41-200 Sosnowiec, Poland

Corresponding author: Filip Šarc (filip.sarc@zrc-sazu.si)

This study offers comprehensive research of the processes related to dedolomitization and the geomorphological evolution of the Mravljetovo Brezno v Gošarjevih Rupah cave in central Slovenia (Otoničar et al. 2016). The cave is developed in Middle Triassic dolostones, which are part of a broader Permian–Triassic succession characterized by a heterogeneous lithological composition of both carbonate and non-carbonate rocks. The region's complex lithology, combined with tectonic activity, has resulted in intricate surface and subsurface geomorphological features.

One of the most important results is the identification of dedolomitization products within the cave, which provide insights into diagenetic processes, hydrological changes, and geomorphological evolution. Dedolomitization, a potential early phase of speleogenesis, likely occurred under phreatic conditions driven by interaction of dolostone host-rock with Ca-rich meteoric waters (according to Evamy 1967).

In terms of hydrological evolution and speleogenesis, the cave system experienced significant changes, likely due to tectonic uplift, resulting in the erosion of pre-existing cave structures under epiphreatic and vadose conditions, followed by the deposition of siliciclastic materials. In the latter stages, vadose shafts developed, accompanied by sparse speleothem deposition, all of which have since been affected by ongoing condensation corrosion, leading to secondary mineral crust formations on the cave walls (Fig. 1).

A multi-proxy approach was used to integrate field-based geological and geomorphological mapping with laboratory analyses which allowed detailed reconstruction of relationships between geomorphological and diagenetic processes within the cave system.

New data obtained through geochronological methods add a significant temporal dimension to this framework. Coarse grained calcite crystals associated with dedolomitization products were dated using the U/Th method, yielding an age of 380 ka with an uncertainty of 120 ka. In contrast, the siliciclastic sediments that entered the cave in a latter stage were dated using optically stimulated luminescence (OSL) at 87 ka.

These new dates not only refine the temporal context of cave development but also clarify the sequence of hydrological and geomorphological changes. The dedolomitization occurred early in the cave's history in phreatic conditions, while the later deposition of siliciclastic materials reflects subsequent erosional and depositional dynamics in epiphreatic or vadose conditions. Together, all the data provide a comprehensive understanding of the cave system's evolution and its connection to the broader geomorphological history of the region.

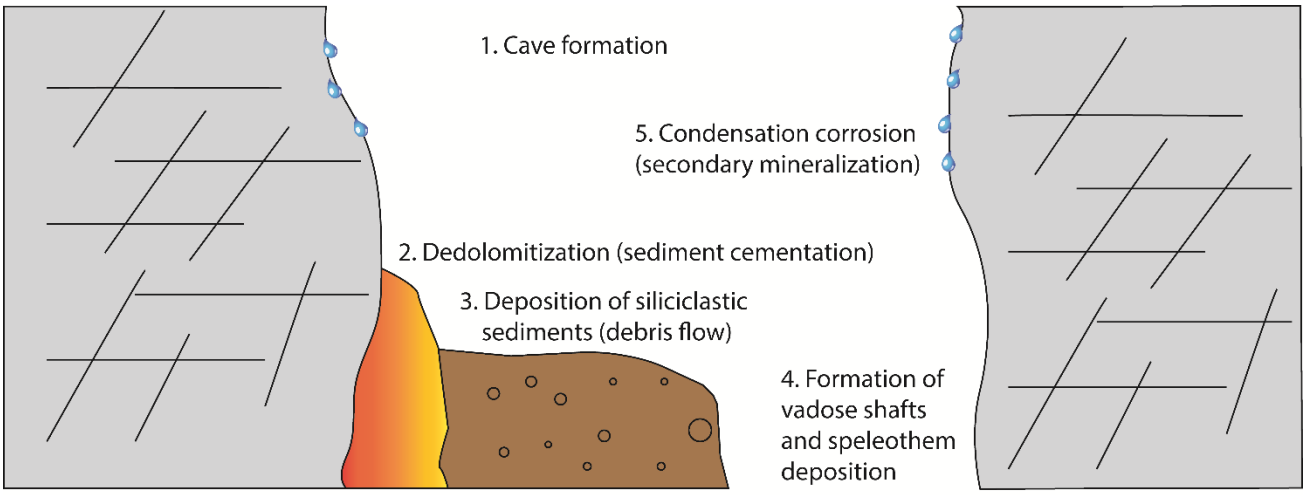

Figure 1: The conceptual model of the main speleogenetic phases of the cave Mravljetovo brezno v Gošarjevih rupah

REFERENCES

Otoničar, B., Dublyansky, Y., Osborne, R. A. L., Tyc, A., Philipp, S. (2016). Cave inception in dedolomite (a case study from Central Slovenia). National Cave and Karst Research Institute, Proceedings of DeepKarst 2016, p.p. 189-198.

Evamy, B. D. (1967). Dedolomitization and the development of rhombohedral pores in limestones. *Journal of Sedimentary Research*, *37*(4), p.p. 1204-1215.

COASTAL EROSION OF LATE QUATERNARY LOESS-PALEOSOL PEDOSEDIMENTARY DEPOSITS AT PAKOŠTANE (CROATIA), A MARINE AND COASTAL VULNERABILITY STUDY

Filip Šegović[1], Ozren Hasan[1], Dea Brunović[1], Nikolina Ilijanić[1], Ivan Razum[2] Slobodan Miko[1], Vlatko Gulam[1], Tihomir Frangen[1]

[1]Croatian Geological Survey, Sachsova 2, 10000 Zagreb Croatia
[2] Croatian Natural History Museum, Demetrova 2, 10000 Zagreb, Croatia

Corresponding author: Filip Šegović (fsegovic@hgi-cgs.hr)

The Geological Service for Europe (GSEU) is a collaborative initiative funded by the EU Horizon program to create a unified geological data and information service across Europe. The initiative, among others, focuses on standardizing and integrating data related to marine and coastal vulnerabilities. One of the focus areas of the study is the eastern Adriatic coast, known for its unique karstic geomorphology with steep, rocky coastlines and fragmented beaches. This region is particularly susceptible to chemical weathering from marine influences and physical changes driven by wave action, with pressures from urbanization and tourism further exacerbating these risks. The sensitivity of these karst environments highlights the need for careful management and protection to prevent significant environmental damage that could have lasting effects on the ecosystem and local communities. A case study of the Pakoštane area in Croatia investigates the loess plateau, resting on carbonate rocks, which is subject to significant erosion. Our study exemplifies the challenges faced by many European coastal regions, where the interplay of natural and human factors requires sophisticated, multidisciplinary approaches to ensure long-term stability and sustainability.

The so-called Pakoštane Loess Plateau on the Eastern Adriatic coast of Croatia has been studied since the 1970s. It is exposed on the steep vertical profiles on the coast and extends for 1 km eastward from the town Pakoštane in central Dalmatia, Croatia. The Quaternary sediment succession on the plateau, which developed over limestone bedrock, consists of red and brown paleosols, sand, conglomerate, loess, and topsoil, providing valuable evidence of past climate change. The latest dating using the OSL (optically stimulated luminescence) technique revealed an age of 71.2 ± 5.9 ky BP (marine isotope stages (MIS) 4) for the oldest loess layers and 203 ± 18 ky BP (MIS 7.2) for the deposits above red paleosol. Loess and paleosol contain both, detrital dust and pedogenically produced material, with magnetic susceptibility increase in paleosol layers and a gradual decrease in clay content upwards, suggesting a shift to a drier, colder climate.

A comprehensive three-year monitoring program is planned to determine the vulnerability of the Pakoštane loess plateau. So far, the first geophysical surveys with multibeam bathymetry (MBES) and subbottom profiling (SBP) have been carried out, as well as Unmanned Aerial Vehicle (UAV) bathymetry of the shallow part of the sea (so-called white ribbon). Geodetic surveys were also completed, and coastal monitoring devices were installed. These include laser imaging, detection, and ranging (LiDAR) and UAV photogrammetry surveys to closely monitor erosion and coastal stability. The main goal is to predict future coastal vulnerability and assess potential hazards, particularly for the growing town of Pakoštane.

VINICA CAVE – A PALEONTOLOGICAL AND PALEOLITIC SITE

Goran Gužvica[1], Biserka Radanović-Gužvica[2], Lidija Šver[3]

[1]Oikon Ltd. Institute of Applied Ecology, Croatia
[2]Croatian Natural History Museum, Croatia
[3]Association for Research, Photographing and Conservation of Croatian Natural Heritage - Bioterra, Croatia

Corresponding author: Goran Gužvica (gguzvica@oikon.hr)

Vinica cave is located in northwestern Croatia, in the eastern part of Ravna gora near the village of Vinica Breg in the Varaždin region (46.326143 N, 16.127785 E). The cave entrance is located at 250 meters above sea level. The cave is morphologically simple and initially consisted of a 6-meter-long channel, approximately 60 cm in height and 100 cm in width, ending in a small, round hall measuring 4.5 meters in diameter. The cave was formed in lithothamnium limestone (Novosel and Gužvica, 1997, Gužvica et al., 2000).

Excavations of the cave were carried out from 1997 to 2003 under the scientific project "Research of Fossil and Recent Large Carnivores in Croatia". The stratigraphic sequence of the cave includes four distinct layers. *Layer a* - loose humus with organic remains and small limestone rubble, dark brown in color, ranging from 3 to 20 cm thick. *Layer b* - dense clay sediment, yellow-brown in color, 23 to 156 cm thick. There are occasional lenses with fine pebbles, and even more rarely some larger lithothamnium limestone blocks. In the lower part of this layer there are frequent lenses with fine pebbles hence the layer was divided into two horizons (b1 and b2). *Layer c* - sandy-clay sediment with a lot of rubble, reddish-brown in color, 30 to 72 cm thick. *Layer d* - sandy-clay sediment with very little rubble, brownish-red in color, 42 to 57 cm thick. The macroscopic features and the results of the granulometric analysis of the Vinica cave deposits carried out according to the method adapted for cave sediments (Osole, 1959) show that in layers b1, b2 and d there are no products of mechanical weathering, while in layer c there are many products of mechanical weathering as a result of intense crushing of the cave ceiling and lateral rocks due to freezing, indicating a cold and wet climate.

During the systematic excavations of the Vinica cave, 28 quadrants of the pre-cave area and 48 quadrants within the cave were covered. A total of 6156 finds were collected, of which 5645 were osteological and odontological remains from Holocene and Pleistocene fauna, while 511 lithic finds indicating the presence of Paleolithic culture (Vukosavljević et al., 2022). The highest concentration of finds was in quadrants F5 (672), F4 (447), and E3 (433), located near the cave entrance. Western pre-cave quadrants (E2, F2, G2) also yielded significant numbers of finds (215–303), and a moderate number of finds was noted in inner cave quadrants (G11, H11, G10) near the round hall.

The taxonomic determination of the collected osteological and odontological material revealed the presence of 15 species from the class of mammals (Mammalia), mainly from the order of carnivores (Carnivora): cave bear (*Ursus spelaeus*), wolf (*Canis lupus*), european dhole (*Cuon alpinus europaeus*), leopard (*Panthera pardus*), cave hyena (*Crocuta spelaea*), wild cat *(Felis silvestris*), fox (*Vulpes vulpes*) and badger (*Meles meles*). Less common species belong to the group Artiodactyla (deer (*Cervus elaphus*), elk (*Alces* sp.), bovide (*Bos* sp.) and wild boar (*Sus scrofa*)), Rodentia (squirrel (*Sciurus vulgaris*)), Lagomorpha (european hare (*Lepus europaeus*)) and Insectivora

(european mole (*Talpa europaea*)). The remains of fauna from the classes Aves, Amphibia and Gastropoda can also be found in the Vinica cave.

A morphometric and morphogenetic analysis of cave bear premolars and molars was carried out on a total of 33 teeth, and the results show that the analysed sample belongs to a typical and highly evolved form of the cave bear (Gottstein et al., 2000).

Lithic artefacts were found in layers c and d, the age of which was determined by 14C AMS dating. The sample from layer d yielded an indefinite age older than 50,300 years BP while calibrated age for the sample from layer c is 36–34.5 ka BP. Quartz is the predominant raw material in both layers followed by various cherts. Among the small number of tools, scrapers are the most common. Mousterian lithic assemblages from both c and d layers suggest that Vinica cave was used as short term Neandertal camp during the Middle Paleolithic (Vukosavljević et al., 2022).

Figure 1: Vinica cave entrance

REFERENCES

Gottstein Ž, Malez S, Gužvica G. (2000) Morphometric and morphogenetic analyses of the teeth of cave bear (*Ursus spelaeus*) from Vinica cave. Proceedings of the 7th Congress of Croatian Biologists; 2000 Sep 24-29; Hvar, Croatia. Zagreb: Hrvatsko biološko društvo.

Gužvica G, Radanović-Gužvica B, Huber Đ. (2000) Prvi rezultati istraživanja špilje Vinice - novog paleontološkog i paleolitičkog nalazišta. U: Vlahović I, Biondi, R, Ur. 2. Hrvatski geološki kongres: Zbornik radova 2. Hrvatskog geološkog kongresa; 2000 May 17-20; Cavtat-Dubrovnik, Hrvatska. Zagreb: Institut za geološka istraživanja; p. 193-7.

Novosel D, Gužvica G. (1997): Paleontološka istraživanja špilje Vinice, Speleozin, 5/7, 40, Karlovac.

Osole, F. (1959): Analiza pleistocenskih jamskih sedimentov. Geologija - Razprave in poročila, knj. 5, 123-128, Ljubljana.

Vukosavljević N, Gužvica G, Radanović-Gužvica B, Kurtanjek D, Karavanić I. (2022) Mousterian lithic assemblage from Vinica cave (Hrvatsko zagorje, Croatia) – new insights into regional Middle Paleolithic technological behavior // Arheološki vestnik, 73 (2022), 7-28 doi:10.3986/AV.73.01

STEPPE MAMMOTH (*MAMMUTHUS TROGONTHERII*) IN GLOGOVICA CHANNEL, SLAVONSKI BROD, CROATIA

Ivana Maruščak[1], Dražen Japundžić[2]

[1]Muzej Brodskog Posavlja, Starčevićeva 40, Slavonski Brod
[2]Hrvatski prirodoslovni muzej, Demetrova 1, Zagreb

Corresponding author: Ivana Maruščak (ivana.maruscak@muzejbp.hr)

In the summer of 1957, a skull with mammoth tusks was found in the Glogovica channel in Slavonski Brod. At the end of the 1960s academician Mirko Malez, a paleontologist from the Institute for Paleontology and Quaternary Geology of the Croatian Academy of Sciences and Arts (then Geological-Paleontological Collection and Karst Laboratory JAZU) came to the Brod Posavlje Museum and determined the exceptional value of the fossil find. Through a detailed examination of the skull, he determined that it was well preserved and that there was no damage that would indicate that it had been deposited or carried by water currents, so the rest of the skeleton should be located in the immediate vicinity. He proposed a detailed field survey of the site.

In 1973 academician Mirko Malez and M.Sc. Darko Rukavina, a geologist and paleontologist, opened a research probe in the side of the channel at a depth of eight meters using the block method with profiling and test drilling on an area of 18 m². Stratigraphic profiles were recorded and sediment samples were taken for various analyzes (granulometric, sedimentological, palynological, determining the ratio of fluorine and phosphorus, radiocarbon dating, etc.). In the layer of bluish clay in which the skull was found, a fragment of a missing tusk, a rib fragment of a fossil rhinoceros and a forearm of a smaller animal were found, but the rest of the mammoth skeleton was not found. Many Pleistocene gastropods were found: *Viviparus, Monachoides, Limnaea, Succinella, Helix, Pisidium*, which are related to aquatic environments; *Melanopsis* and *Planorbis* indicate the nearness of water flow; *Chondrula tridens* indicates a moderate arid climate, typical for interglacial and steppe and forest-steppe environments. Remains of charred wood and traces of pollen were also found, which was determined by analysis to belong to willow, alder and poplar species. Analysis of the recorded profiles showed that the skull was lying on the edge of a former swamp with a sloping bank and that it probably slipped away from the rest of the skeleton due to gravity. Therefore, there is a possibility that the rest of the skeleton is dislocated horizontally on a larger surface in the same layer.

The skull from Glogovica was measured and described in 1994 by Ph.D. Jadranka Mauch Lenardić, paleontologist of the Croatian Academy of Sciences and Arts. According to the data available at the time of similar findings from Europe and based on a comparison with morphometric measurements of the skull from Gelsenkirchen, the finding from Glogovica was identified as the steppe mammoth *Mammuthus trogontherii* (POHLIG, 1885). The steppe mammoth is a transitional species between the southern mammoth and the woolly mammoth, so there are significant variations in the measurements of the teeth parameters, which are the main distinguishing criteria for determining the species in elephants. The shape of the tooth crown in this species varies from short and widened to narrow and elongated, depending on whether it is an older and more primitive form that is phylogenetically closer to the southern mammoth, or a younger form closer to the woolly mammoth. Until recently, steppe mammoths were associated exclusively with the Middle Pleistocene period and placed in the time frame of

780,000 - 200,000 years, so the steppe mammoth from Glogovica was originally placed in the Middle Pleistocene. During the last restoration of the skull, which was carried out in 2021, a sample of the enamel of the left M3 molar was taken to determine the age of the finding. Age determination was carried out using U-Th Dating at the Instytut Nauk Geologicznych, Warszawa. According to the results, the skull from Glogovica is 96.1 + 4.8 /- 4.5 thousand years old, which stratigraphically belongs to the Late Pleistocene and MIS 5, the last warm interglacial before the end of the last Ice Age.

Figure 1: The scull of a steppe mammoth from Glogovica channel; sampling for U/Th analysis.

Previously, all mammoth finds stratigraphically belonging to the Late Pleistocene were automatically attributed to woolly mammoths. Through recent research and detailed morphometric measurements of teeth parameters on findings from the beginning of the Late Pleistocene, it was concluded that we can no longer discuss the primitive forms of woolly mammoths, but that between the typical Middle Pleistocene species *Mammuthus trogontherii* and the Late Pleistocene *Mammuthus primigenius*, there is a transitional species of steppe mammoth, *Mammuthus intermedius*, which inhabited steppe environments throughout Eurasia during the interglacials of the late Middle Pleistocene and early Late Pleistocene.

REFERENCES

Banak, A. et al, 2020. Pleistocene Climate change in central Europe. In book: Pleistocene Archaeology - Migration, Technology and Adaptation. IntechOpen, London, pp. 28-39.

Foronova, I.V., 2014. *Mammuthus intermedius* (*Proboscidea, Elephantidae*) from the late Middle Pleistocene of the southern Western and central Siberia, Russia: the problem of intermediate elements in the mammmoth lineage. Russian J. Theriol. 13 (2), pp. 71-82.

Lenardić, J., 1994. Description and Morphometric Analysis of the *Mammuthus armeniacus* (FALCONER, 1857) skull from Slavonski Brod (Croatia). Geologia croatica, 47/2, pp. 157-166.

Malez, M., 1978. Paleontološka i kvartargeološka istraživanja u 1973. godini. Ljetopis JAZU, 78(1973-1974), pp. 559-572.

MORPHOLOGY AND FORMATION PROCESSES OF PEDOGENIC CARBONATES IN MEDITERRANEAN SOILS: A CASE STUDY FROM THE NORTH DALMATIAN PLAIN, CROATIA

Katarina Matan[1], Aleksandra Bensa[1], David Domínguez-Villar[2], Kristina Krklec[1,2]

[1]University of Zagreb Faculty of Agriculture, Svetošimunska cesta 25, 10 000 Zagreb
[2]University of Salamanca, Plaza de los Caídos s/n, 37008 Salamanca, Spain

Corresponding author: Katarina Matan (kmatan@agr.hr)

Pedogenic carbonates (PC) are secondary carbonate deposits that form within soils, particularly in arid and semiarid regions. They form through the complex processes of the dissolution and reprecipitation of geological, biological, or pre-existing pedogenic carbonates in the soil (Zamanian et al., 2016). Their formation is influenced by a combination of climatic factors, soil chemical and physical properties, biological activity, and water movement within the soil. Pedogenic carbonates play a key role in global carbon sequestration, as they are capable of trapping carbon in inorganic forms over long timescales (Egli et al., 2021). Additionally, their presence can significantly affect soil physical properties, such as soil structure, porosity, and hydraulic conductivity, as well as influence nutrient availability and the soil's overall fertility (Castellini et al., 2019; Panagos et al., 2014). Their diverse morphology, distribution, and isotopic composition are valuable proxies for reconstructing past environmental and climatic conditions, making them essential for paleoenvironmental and paleoclimatic research (D.V. Fernández et al., 2022).

We studied the distribution, morphology, and formation processes of pedogenic carbonates from the Calcocambisol soil profile developed over Eocene foraminiferal limestones located on the North Dalmatian plain, Croatia. A 0.95 m deep soil profile was studied at 5 cm resolution and included analyses of soil properties (texture, soil moisture content, pH, carbonate content) and analyses of PC particles (classification, morphometry, and microscopy analyses). The results showed an absence of carbonate particles within the upper 20 cm of the soil profile, with a noticeable increase in both size and abundance below this depth (>23 cm), consistent with the observed properties of the soil profile. Soil texture varies through the profile - from silty clay in topsoil to clay loam at the bottom of the profile. The topsoil exhibits intense biological activity, resulting in higher concentrations of soil organic carbon, a lower pH, and the consequent full dissolution of carbonate particles. As biological activity decreases with depth, there is a corresponding decrease in soil organic carbon content and consequently, an increase in pH values, indicating the neutralization of the acidic environment through carbonate dissolution. This shift creates favourable conditions for the precipitation of pedogenic carbonates within the deeper layers of the soil profile.

Pedogenic carbonates present in the studied soil profile can be classified as pedogenic nodules, with sharp outer boundaries and bulbous protrusions. SEM analyses revealed pitted and hummocky surfaces, along with microrunnels, and dissolution pits, highlighting the ongoing processes of carbonate dissolution and precipitation within the soil. Nodule size increases with depth, reaching up to 60.4 mm in deeper horizons. Additionally, studied nodules primarily exhibit replacive growth, where calcite precipitates around particles from the surrounding soil, preserving the original structure as it is replaced. Less commonly, displacive growth is observed, where the nodule

pushes aside host sediment, forming flat edges. The internal structure of the nodules, composed of micrite, microsparite, and sparite, shows no single nucleation center, suggesting episodic growth likely driven by seasonal variations in soil moisture content and CO_2 levels. In the upper 20 cm of the profile, higher biological activity and a decrease in organic carbon content create an acidic environment that favors carbonate dissolution, resulting in the absence of nodules, consistent with the "perdescendum" model of pedogenic carbonate formation. In the deeper horizons, soil properties such as texture and moisture facilitate the in situ dissolution and reprecipitation of carbonates, aligning with the "in situ" model.

ACKNOWLEDGEMENTS

This work is part of the research project ”Inter-comparison of karst denudation measuring methods” (KADEME, IP-2018-01-7080) and “Young Researchers’ Career Development Project-Training New Doctoral Students” (DOK-2021-02-1788) financed by Croatian Science Foundation.

REFERENCES

Castellini, M., Stellacci, A. M., Tomaiuolo, M., Barca, E., 2019. Spatial variability of soil physical and hydraulic properties in a durum wheat field: An assessment by the BEST-procedure. Water, 11 (10), 1434. https://doi.org/10.3390/w11071434

Egli, M., Bösiger, M., Lamorski, K., Sławiński, C., Plötze, M., Wiesenberg, G.L.B., Tikhomirov, D., Musso, A., Hsu, S.-Y., Raimondi, S., 2021. Pedogenesis and carbon sequestration in transformed agricultural soils of Sicily. Geoderma, 402, 115355. https://doi.org/10.1016/j.geoderma.2021.115355

Fernández V. D., Solleiro Rebolledo E., Sedov S., Pustovoitov, K., 2022. Provenance, and environment context of pedogenic carbonates formation from MIS 3 to MIS 1 in the Teotihuacan Valley, Mexico. Quaternary International, 618. https://doi.org/10.1016/j.quaint.2021.03.019

Panagos, P., Meusburger, K., Ballabio, C., Borrelli, P., Alewell, C. 2014., Soil erodibility in Europe: A high-resolution dataset based on LUCAS. Science of the Total Environment, 479–480, 189–200. https://doi.org/10.1016/j.scitotenv.2014.02.010

Zamanian, K., Pustovoytov, K., Kuzyakov, Y., 2016. Pedogenic carbonates: Forms and formation processes. Earth-Science Reviews, 157, 1-17. https://doi.org/10.1016/j.earscirev.2016.03.003

GEOCHEMICAL AND SEDIMENTOLOGICAL CHARACTERISTICS OF THE MORINJE BAY (MIDDLE DALMATIA): INFLUENCES OF NATURAL AND ANTHROPOGENIC FACTORS

Laura Novak[1], Igor Felja[1], Željka Fiket[2]

[1]Department of Geology, Faculty of Science, University of Zagreb, Horvatovac 102a, 10000 Zagreb, Croatia
[2]Ruđer Bošković Institute, Division for Marine and Environmental Research, Bijenička cesta 54, 10000 Zagreb, Croatia

Corresponding author: Laura Novak (novak.laura1998@gmail.com)

Morinje Bay is a coastal lagoon situated in Central Dalmatia and it is part of the Natura 2000 ecological network, protected under EU directives for habitat and bird conservation. Despite its ecological importance, Morinje Bay is facing severe environmental challenges. In the northern section of the bay, there is an accumulation of disposed medical waste, while construction debris—including broken bricks, tiles, rubble, glass, and plastic sheets—is dispersed along the shoreline. The Mučići salt marsh is heavily contaminated with discarded car tires, and the surface of the marsh water is visibly impacted by oil films and foam. Bay is also impacted by agricultural activity, including olive cultivation and viticulture. The study aims to determine the sources and range of potential contamination and how it may spread within the bay, considering sedimentological characteristics and local geology.

The geology of the broader area mainly consists of Upper Cretaceous and Paleogene deposits, occasionally covered with Quaternary sediments. Paleogene layers include Eocene foraminiferal limestones and clastic deposits (sandstones and marls), whereas Quaternary sediments consist of dominantly gravel, sand and mud. The Morinje Bay was shaped after the last glaciation, with sea level rise during Holocene initiating transgression into the Morinje Bay.

This study investigates sediment and soil samples collected from 26 locations around the Morinje Bay in order to understand the impact of natural processes and human activity on the Bay area. This research uses geochemical and sedimentological methods to analyze the bay's sediments and soils, assessing particle size distribution, carbonate content, organic matter content, pH levels and the presence of metals and metalloids. Particle size distribution was determined using laser granulometry and it is shown that in both, sediments and soils, sand is the dominant fraction, with clay being least represented. All samples are classified (Folk, 1954) mainly as sandy muds but also as sandy silts, silty sands or muddy sands. Samples are poorly sorted and show bimodal/polymodal particle size distribution curve suggesting multiple sources of deposited sediments, which aligns with previous research (Mihelčić et al., 2006). Levels of pH are indicating highly alkaline environment. Carbonate content is in positive correlation with particle size as samples with highest carbonate content, also exhibit the largest sand fractions. These elevated carbonate-sand fractions (up to 80 %) are likely a result of the weathering of surrounding carbonate rocks, consistent with the locations where the samples were collected, as the substrate consists of foraminiferal limestones, as well as contributions from marine organism shells. In contrast, samples that are dominated by silt and clay fractions have carbonate content around 50% or lower. This indicates that the sediment also contains siliciclastic material derived from the weathering of nearby flysch deposits and Eocene sandstones, as well as sediment deposition from intermittent torrential flows. One of the key findings is the high concentration of heavy metals (As, Cd, Cu, Pb, Sb, Sn, Zn) in specific areas, particularly near illegal waste disposal sites where

lead and zinc levels exceed background values, with concentrations up to 40 times higher than the geochemical baseline for the region. Concentrations of copper in some soil samples are up to 20 times higher than regional averages, indicating significant contamination from agricultural activities (fungicide usage). Previous studies of the Morinje Bay area concluded that erosion of waste ash does not significantly contribute to metal concentrations at distances greater than 50 m from the shore (Miko et al., 2007), however the observed trend of increased trace element concentrations in the area suggests that pollution may have spread to some extent over the last few decades.

REFERENCES

Folk, R. L. The distinction between grain size and mineral composition in sedimentary rock nomenclature. Journal of Geology, 62, pp. 344–359 (1954).

Mihelčić, G., Lojen, S., Dolenec, T., Kniewald, G. Trace Metals Conservation in Morinje Bay Sediment: Historical Record of Anthropogenic Imissions into a Shallow Adriatic Bay. Croatica Chemica Acta 79, pp. 161–167 (2006).

Miko, S., Koch, G., Mesić, S. et al. Influence of land use in small karst watersheds on the chemical status of peloid sediments on the eastern Adriatic coast. J Soils Sediments 7, 303–312 (2007). https://doi.org/10.1065/jss2007.10.254

A NEW ERA FOR CROATIAN EASTERN ADRIATIC BEACHES: THE SHIFT FROM NATIVE TO LESSEPSIAN FORAMINIFERAL ENGINEERS

Lovro Suić[1], Antonela Ban[1], Igor Felja[1], Vlasta Ćosović[1]

[1]Department of Geology, Faculty of Science, University of Zagreb, Horvatovac 102b, Zagreb, Croatia

Corresponding author: Lovro Suić (lovro.suic@student.pmf.hr)

Eastern Adriatic sandy beaches (Croatia) predominantly consist of carbonates, greatly derived skeletal fragments of marine organisms, among which foraminifera as calcifiers are the most important contributors.

To assess foraminifera's influence on these sands, seven sediment samples were collected from three bays on the Pag Island in July 2023, at depths ranging from 10 cm to 8 m. Snorkeling and diving were used to obtain app. 50 ml of loose sediment from the topmost layer which was then stored in 120 to 180 ml plastic containers. Foraminiferal tests were isolated from the finer fractions (< 0.5 mm) after wet sieving. They were stained with Rose Bengal solution (2 g/L in 95 % ethanol) for two weeks, washed, dried and five samples with sufficient foraminifera tests were analyzed. The samples were characterized by foraminiferal assemblages consisting of average 60 to 88 % of porcelaneous forms of the order Miliolida, whereas hyaline forms of the order Rotaliida account for 11.8 to 36.5%. A total of forty-six species were identified, plus seventeen unclassified taxa.

Epiphytic foraminifera are the most abundant and diverse group in these assemblages. *Peneroplis* species, a Rhodophyta bearing larger benthic foraminifera, are particularly prevalent, with *P. planatus* and *P. pertusus* comprising 6 - 32.3 % and 13.7 - 41.6 % of the total, respectively. The following species were the most abundant in the descending order: *Elphidium crispum* (in all samples, in proportions ranging from 10 to 23 %) > *Quinqueloculina lamarckiana* (in two samples, in high abundance ranging from 14.9 to 53 %) > *Ammonia neobeccarii* (19 % in one sample) > *Massilina secans* (in one sample, 8.7 %). Rose Bengal staining revealed predominantly empty tests in sediments. These tests were generally well-preserved, with minimal breakage (less than 5 %), bioerosional traces, or a dull texture. Their uniform size suggests wave transport via seagrass, macroalgae or post-mortem by bedload.

However, the foraminiferal composition is alarming. In 2018, epiphytic rotaliids dominated sandy sediments collected in Lokunja Bay (Pag Island), representing 92 – 97 % of the total assemblage (Ban et al., 2019). Miliolids and peneroplids were present in lower proportions, with miliolids reaching up to 8 % and peneroplids only 0.3%. However, in recent samples, the invasive genus *Peneroplis* has outcompeted native species. Their wide distribution is favored by 1) warmer waters. Winter temperature must exceed 18^0 C in their 1- 25 m habitats, which is necessary for all endosymbiont forms (Langer and Hottinger, 2000). This temperature range is likely near the optimal range of 23 ± 1^0 C or even higher (Faber, 1991; Kenigsberg et al., 2022); 2) coarse carbonate sands and, 3) low nutrient levels. Only miliolids (*s.str.*) show significant abundance. Native epiphytic species (*Asterigerina mammila*, *Ammonia parkinsoniana, Rosalina s*pp. *Cibicides* spp., Ćosović et al., 2011) have been displaced, leading to decreased species diversity and impacting the seabed morphology and functioning of the shallow-water ecosystem.

Rising air and seawater temperatures in recent years have driven a shift in foraminiferal assemblages from native, rotaliid-dominated to Lessepsian, *Peneroplis* dominated.

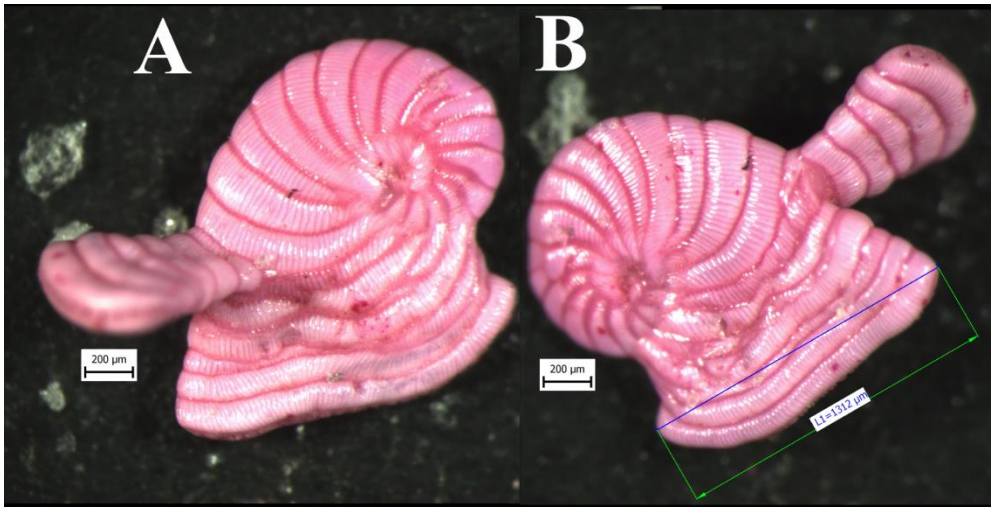

Figure 1: *Peneroplis planatus* test (from Stara Povljana Bay) exhibits abnormal morphology, including doubled test and irregularly added chambers. The microphotograph was taken by an Olympus SZX7 stereomicroscope with an Olympus U-TV1XC camera.

REFERENCES

Ban, A., Pugliese, N., Felja, I., Ćosović, V., 2019. Taxonomy and distribution of foraminifera and ostracods in an intertidal zone of Lokunja salt marsh (Pag is.). In: Horvat, M., Matoš, B., Wacha, L. (eds.), Abstract book of the 6th Croatian Geological Congress, Croatian Geological Survey, Zagreb, pp. 20.

Ćosović, V., Zavodnik, D., Borčić, A., Vidović, J., Deak, S., Moro, A., 2011. A checklist of Foraminifera of Eastern Shelf of the Adriatic Sea. Zootaxa 3035, 1-56.

Faber, W. W., 1991. Distribution and Substrate Preference of *Peneroplis planatus* and *P. arietinus* from the Halophila Meadow near Wadi Taba, Eilat, Israel. Journal of Foraminiferal Research 21 (2), 18-22.

Kenigsberg, C., Titelboim, D., Ashckenazi-Polivoda, S., Herut, B., Kucera, M., Zukerman, Y., Hyamas-Kaphzan, O., Almogi-Labin, A., Abramovich, s. (2022). The combined effects of rising temperatures and salinity may halt the future proliferation of symbiont-bearing foraminifera as ecosystem engineers. Science of the Total Environment, https://doi.org/10.1016/j.scitotenv.2021.150581.

Langer, M.R., Hottinger, L., 2000. Biogeography of Selected larger Benthic Foraminifera. Micropaleontology 46, 105-126.

HIDDEN ARCHIVE IN KARST: GEOCHRONOLOGICAL EVIDENCE OF MIOCENE VOLCANIC ACTIVITY IN QUATERNARY DEPOSITS (PLITVICE LAKES AND BOSILJEVO, CROATIA)

Nina Trinajstić[1], Vlatko Brčić[1], István Dunkl[2], Tomislav Kurečić[1], Lara Wacha[1], Filip Šarc[3], Sanja Šuica[4], Mihovil Brlek[1], Duje Kukoč[1], Marko Budić[1], Sanja Šuica[4], Hilmar von Eynatten[2]

[1]Department of Geology, Croatian Geological Survey, Croatia
[2] Department of Sedimentology and Environmental Geology, Georg-August-University Göttingen, Germany
[3]Karst Research Institute, Slovenia
[4]Department of Geology, Faculty of Science, University of Zagreb, Croatia

Corresponding author: Nina Trinajstić (nina.trinajstic@hgi-cgs.hr)

Recent investigations of Quaternary outcrops at Bosiljevo and Plitvice Lakes, Croatia, have provided new insights into the role of karst environments as depositional archives for terrestrial sediments. These red, clay-rich deposits (Fig. 1), located in karst terrains, preserve a record of siliciclastic input. To elucidate these materials' origin and depositional history, we conducted X-ray diffraction (XRD), heavy mineral analysis, scanning electron microscopy (SEM), and U-Pb zircon geochronology using LA-ICP-MS on samples from three sites.

The mineral composition of Plitvice Lakes samples is dominated by kaolinite and gibbsite, with minimal quartz and hematite. Heavy mineral assemblages are characterised by opaque minerals, primarily lithics and idiomorphic ilmenite, and transparent minerals such as idiomorphic zircons. Quartz is abundant in the light mineral fraction. SEM analysis revealed idiomorphic ilmenite, zircons, and quartz grains, with idiomorphic quartz grains observed even in fractions larger than 250 microns. These mineralogical characteristics, combined with a narrow Miocene age distribution in the zircon population, indicate a volcanic source likely linked to Miocene eruptions from the Carpathian-Pannonian region, consistent with findings from other Dinaric karst areas (Brlek et al., 2021).

In contrast, the Bosiljevo sample shows a broader zircon age spectrum, with approximately 30% Miocene-age zircons indicating volcanic input, while additional zircon age groups and minerals such as illite suggest a mixed provenance, including detrital contributions.

The distinct mineralogical and geochronological profiles recorded at Plitvice Lakes and Bosiljevo emphasize the potential of karst deposits to capture diverse volcanic and sedimentary histories. This study highlights the value of karst environments as natural archives, providing insight into past volcanic events and their varying influences on sediment accumulation and alteration in karst landscapes.

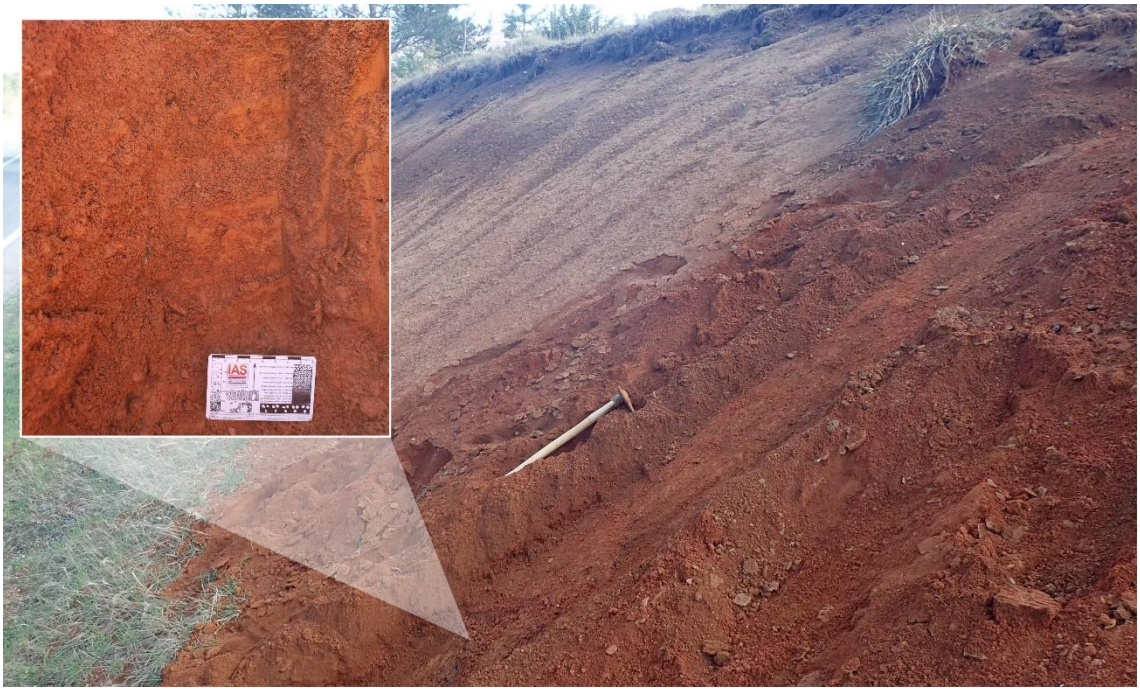

Figure 1: Red, clay-rich deposit from the area of Plitvice Lakes National Park (sampling site PRF-5).

REFERENCES

Brlek, M., Gaynor, S. P., Mongelli, G., Bauluz, B., Sinisi, R., Brčić, V., et al. (2021). Karst bauxite formation during miocene climatic optimum (central dalmatia, Croatia): mineralogical, compositional and geochronological perspectives. Int. J. Earth Sci. 110, 2899–2922. doi:10.1007/s00531-021-02091-z

HIGH-RESOLUTION LIDAR AND UAV-BASED GEOMORPHOLOGICAL STUDY REVEALS QUATERNARY SURFACE DISPLACEMENTS ALONG THE RAŠA FAULT IN SW SLOVENIA

Petra Jamšek Rupnik[1], Lovro Rupar[1], Ana Novak[1]

[1]Geological Survey of Slovenia, Dimičeva ul. 14, 1000 Ljubljana, Slovenia

Corresponding author: Petra Jamšek Rupnik (petra.jamsek@geo-zs.si)

A geomorphological investigation of the dextral strike-slip Raša Fault, part of the Dinaric Fault System in SW Slovenia, was conducted using high-resolution lidar and UAV-based aerial photogrammetry. The aim of this study was to delineate the geomorphological fault trace, identify signs of Quaternary fault activity, quantify the displacement markers along the fault between Branik and Košana (Figure 1A), and to complement the structural-geological mapping of the fault (Jež et al., 2022).

The lidar data were reprocessed in CloudCompare and QGIS into a digital elevation model (DEM) with a resolution of 0.5 x 0.5 meters, which served as a basis for geomorphological mapping. UAV photogrammetry provided higher-resolution DEMs with a resolution of 0.1 x 0.1 meters for selected locations. Using QGIS, the Relief Visualization Toolbox (Zakšek et al., 2011; Kokalj and Somrak, 2019), and Python, various visualizations of DTMs were created, including shaded relief, multidirectional shaded relief, slope map, aspect map, Sky-View Factor, local dominance, positive openness, negative openness and RRIM display (Chiba et al., 2008). These visualizations were combined into different composite bases in a GIS environment to improve the geomorphological interpretation.

The fault is geomorphologically well-expressed in karst areas, but less so in flysch areas. Clear lineaments indicating fault traces were mapped in the NW-SE orientation, especially between Senadole and Štanjel, where the fault zone runs along the Raša Valley (Figure 1A and 1B). Rightward deviations of streams north of the Raša Valley indicate ongoing tectonic activity (Figure 1A). Geomorphological indicators of fault activity, such as shifted stream courses, offset crests, slopes (Figure 1C), and alluvial fans, were systematically mapped and analyzed. North of Vremščica, a newly identified fault section branching towards Senožeče shows clear signs of activity with a consistent dextral offset of gullies (Figure 1D). The quantitative assessment of geomorphologic markers along the fault included both horizontal and vertical displacements. Dextral displacements ranged from 4 to 42 meters, while vertical movements varied between 8 and 40 meters. These measurements were validated by detailed topographic profiles, reconstruction analysis and field checks. The results indicate continuous surface displacements and a transpressive character of the Raša Fault, with the NE block being relatively uplifted.

The geomorphological analyses provided new insights into the Quaternary kinematics of the Raša Fault and indicated locations for geophysical and paleoseismological investigations, particularly in the Raša Valley where Quaternary deposits are available to better constrain fault activity.

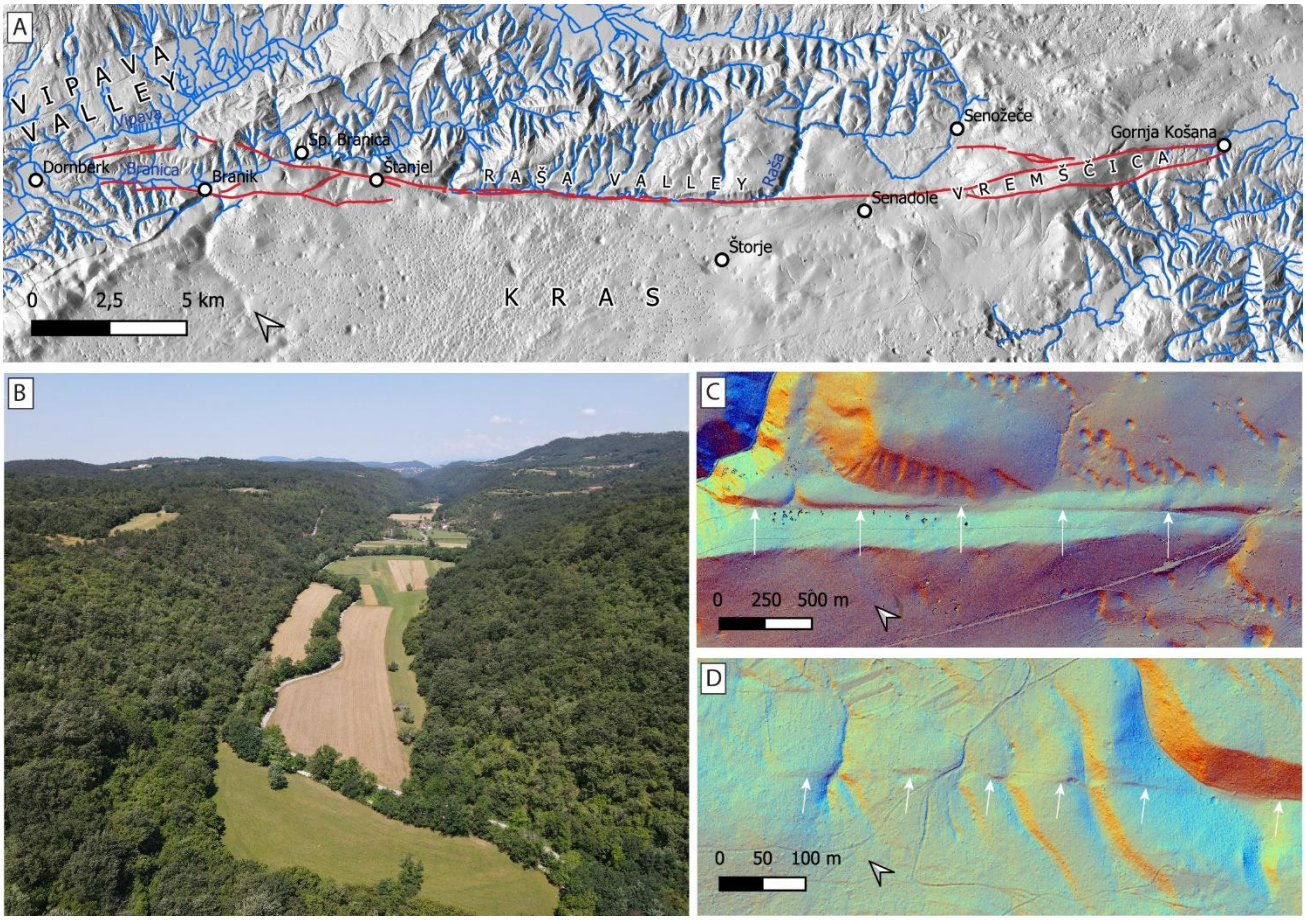

Figure 1: A – Geomorphological trace of the Raša Fault between Branik and Košana. B – View of the Raša Valley, developed along the fault. C – Fault trace dissecting the surface as visible on the multidirectional hillshade. D – Fault trace running through the slope and displacing the gullies, multidirectional hillshade.

Acknowledgments

The geomorphological study of the Raša Fault was funded by the Slovenian Environment Agency (ARSO, 2022-2024). L. Rupar acknowledges the funding by the Slovenian Research and Innovation Agency (ARIS) in the frame of the young researchers programme (program group Regional Geology P1-0011). We would like to thank Josipa Maslač (Croatian Geological Survey) for her help during the field checking of results.

REFERENCES

Chiba, T., Kaneta, S., Suzuki, Y. 2008. Red Relief Image Map: New visualization method for three dimensional data. The International Archives of the Photogrammetry, remote Sensing and Spatial Information Sciences, 27, B2: 1071-1076

Jež, J., Jamšek Rupnik, P., Atanackov, J., Novak, A., Milanič, B., Novak, M., Markelj, A., Ivančič, K., Slapnik, L., Valand, N., 2022. Strukturno-geološke raziskave Raškega preloma med Senadolami in Kobdiljem. Ljubljana, Geological survey of Slovenia, 52 p.

Kokalj, Ž. and Somrak, M., 2019. Why Not a Single Image? Combining Visualizations to Facilitate Fieldwork and On-Screen Mapping. Remote Sensing 11, 747, https://doi.org/10.3390/RS11070747.

Zakšek, K., Oštir, K. and Kokalj, Ž., 2011. Sky-View Factor as a Relief Visualization Technique. Remote Sensing 3, 398-415, https://doi.org/10.3390/RS3020398.

HIGH-RESOLUTION RECONSTRUCTION OF 4.5 KA RELATIVE SEA-LEVEL CHANGES AND COSEISMIC UPLIFTS USING ALGAL RIMS AND TIDAL NOTCHES FROM DUBROVNIK EPICENTRAL AREA

Sanja Faivre[1], Nina Lončar[2], Bruno Tomljenović[3], Marin Sečanj[4], Marijan Herak[4], Jadranka Barešić[5]

[1]University of Zagreb, Faculty of Science, Department of Geography, Marulićev trg 19/II, 10 000 Zagreb, Croatia
[2]University of Zadar, Department of Geography, Zadar, 23000, Croatia
[3]University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Pierottijeva 6, Zagreb 10000, Croatia
[4]University of Zagreb, Faculty of Science, Department of Geophysics, Horvatovac 95, Zagreb 10 000, Croatia
[5]Ruđer Bošković Institute, Radiocarbon Laboratory, Bijenička 54, 10 000 Zagreb, Croatia

Corresponding author: Sanja Faivre (sfaivre@geog.pmf.hr)

This study presents a comprehensive reconstruction of relative sea-level (RSL) changes and seismic uplifts in the Southern Adriatic region over the past 4,500 years. By analysing algal rims formed by *Lithophyllum byssoides* and tidal notches between Dubrovnik and Konavle, combined with high-resolution radiocarbon dating, we reveal significant spatial variability in RSL changes driven by local tectonics. The algal rims, growing continuously since the Middle Holocene, show a general slowing of RSL rise rates from approximately 1.03 mm/yr to 0.43 mm/yr during the Common Era, before accelerating to 1.2–1.35 mm/yr after the 1850s (Faivre et al., 2024). This acceleration aligns with global sea-level rise patterns, with rates comparable to those observed in the Western and Central Mediterranean (Tsimplis et al., 2012; Vacchi et al., 2021). The data also highlight periods of abrupt RSL drops, particularly during a 3.2 ka cold event, and multiple instances of coseismic uplifts associated with significant earthquakes.

Field evidence indicates that large-magnitude earthquakes caused abrupt RSL drop during the 4th–6th centuries AD, the 800–1360 cal AD period, and in 1395. The earthquakes in 1520 and 1667 have been precisely identified. The 1667 Dubrovnik earthquake caused 40–60 ± 15 cm of uplift along at least 40 km of coastline. Our findings suggest that the Dalmatian unit basal thrust and its NE-dipping fault splays, are the primary seismogenic source responsible for these coastal uplifts. Holocene deformation patterns reveal uplift rates varying between 0.1–0.9 mm/yr along different fault segments (Faivre et al., 2024), corresponding to fault slip rates modelled at 0.1–1.5 mm/yr by Kastelic et al. (2013) for the Pelješac – Kotor composite seismogenic source.

This research enhances our understanding of both documented and previously unknown paleo-earthquakes in the Southern Adriatic, providing valuable insights into active tectonic processes through the first field-based high-resolution evidence from algal rims. The quantified magnitudes of RSL changes and the identification of local tectonic contributions offer a framework for improving future sea-level projections and refining seismic hazard models for this seismically active region.

Acknowledgements

This research was supported by Croatian Science Foundation project: HRZZ-IP-2019-04-9445 – Relative sea-level change and climate change along the eastern Adriatic coast – SEALeveL and by HRZZ-IP-2020-02-3960 – Characterization and monitoring of the Dubrovnik fault system – DuFAULT.

REFERENCES

Faivre, S., Lončar, N., Tomljenović, B., Sečanj, M., Herak, M., Barešić, J., 2024. Impact of coseismic uplifting on relative sea level change in the Southern Adriatic during the past 4.500 years – New evidence from Dubrovnik epicentral area based on analysis of algal rims and tidal notches, 460, 109262, 1–20. https://doi.org/10.1016/j.geomorph.2024.109262.

Kastelic, V., Vannoli, P., Burrato, P., Fracassi, U., Tiberti, M.M., Valensise, G., 2013. Seismogenic sources in the Adriatic Domain. Mar. Pet. Geol. 42, 191–213. https://doi.org/10.1016/j.marpetgeo.2012.08.002.

Tsimplis, M.N., Raicich, F., Fenoglio-Marc, L., Shaw, A.G.P., Marcos, M., Somot, S., Bergamasco, A., 2012. Recent developments in understanding sea level rise at the Adriatic coasts. Phys. Chem. Earth 40-41, 59–71. https://doi.org/10.1016/j.pce.2009.11.007.

Vacchi, M., Joyse, K.M., Kopp, R.E., Marriner, N., Kaniewski, D., Rovere, A., 2021. Climate pacing of millennial sea-level change variability in the central and western Mediterranean. Nat. Commun. 12 (1), 1–9. https://doi.org/10.1038/s41467-021-24250-1.

QUATERNARY DEPOSITS OF RAB ISLAND AS PRESENTED ON THE NEW GEOLOGICAL MAP (1:50 000)

Tomislav Kurečić[1], Lara Wacha[1], Krešimir Petrinjak[1]

[1]Croatian Geological Survey, Department of Geology, Croatia

Corresponding author: tkurecic@hgi-cgs.hr

In the northern Adriatic Island of Rab, Quaternary clastic deposits cover a significant area. On older geological maps in the area, Quaternary deposits were described and mapped by the standards for the chronostratigraphic maps of the SFRY (Savezni geološki zavod, 1964) at a scale of 1:100 000. For the Adriatic region (including Rab) due to the character and the scale of the map, some lithological features or even some occurrences of Quaternary deposits were often neglected. However, since the development of the lithostratigraphic mapping approach for the new geological map of Croatia at the scale of 1:50 000 (Korbar et al., 2012), more attention has been given to the mapping of Quaternary deposits. In this study, exposed Quaternary deposits of Rab Island were recorded by field mapping, followed by sampling. Where it was adequate, type localities and detailed sedimentological columns were described (e.g. Pudarica and Fruga). To distinguish lithological differences of individual lithostratigraphic units their textures, structures, and the geometry of the sedimentary bodies were documented. Remote sensing methods based on LiDAR DEM (Provided by the State Geodetic Administration of the Republic of Croatia) model analysis were used in inaccessible areas such as cliffs. Mineralogical and petrographic characterization of different stratigraphic units were performed to understand the origin and genesis of deposits. On samples, grain size and shape (sphericity and roundness) analyses, as well as carbonate content, micro petrographic, modal light and heavy mineral fractions, and XRD analyses were performed.

On the Island of Rab, six Quaternary units were determined, based on its genesis and lithostratigraphic classification. The mapped units are as follows: eluvium (Qr), dunes (Qdp), alluvial deposits (Qal), talus and talus breccias (Qs), aeolian sand (Qpj) and the proposed lithostratigraphic unit Pudarica (PD; detail on Figure 1). While most units likely formed during the Pleistocene, the eluvium, talus, alluvial deposits, and related dunes formed recently, during the Holocene. Here, for the first time, a part of a new geological map of the island (in preparation) is presented.

The presented research was conducted in the scope of the internal research project „GORIK (Geological evolution of sinorogenetic and postorogenetic depositional sistems of islands Rab and Krk“ at the Croatian Geological Survey, funded by the National Recovery and Resilience Plan 2021–2026 of the European Union – NextGenerationEU, and monitored by the Ministry of Science and Education of the Republic of Croatia.

Figure 1: Coarse-grained deposits of Pudarica unit – Pudarica, Island of Rab.

REFERENCES

Korbar, T., Avanić, R., Bakrač, K., Belak, M., Bergant, S., Brčić, V., Brlek, M., Fuček, L., Grgasović, T., Grizelj, A., Halamić, J., Hećimović, I., Horvat, M., Jamičić, D., Koch, G., Matičec, D., Oštrić, N., Palenik, D., Slovenec, D. & Šorša, A., 2012. Guidelines for the development of a Basic geological map of Croatia in scale of 1:50,000 - In Croatian. Croatian Geological Survey, Zagreb, 132 p.

Savezni geološki zavod, 1964. Guidelines for the development of a Basic geological map of SFRY – In Croatian. Građevinska knjiga, Beograd, 100 p.

CAN OSTRACODS GIVE A NEW LIGHT FOR A BETTER UNDERSTANDING OF A SUBTERRANEAN ROUTE IN THE KARST BETWEEN THE DIFFERENT DRAINAGES; A CASE STUDY FROM A DEEP CAVE NJEMICA (BIOKOVO, MT., CROATIA)

Valentina Hajek–Tadesse[1], Tomislav Kurečić[1], Lara Wacha[1], Marija Horvat[1], Nina Trinajstić[1], Ivan Mišur[1]

[1]Croatian Geological Survey, Department of Geology, Milana Sachsa 2, 10000 Zagreb, Croatia

Corresponding author: Valentina Hajek – Tadesse (tadesse@hgi-cgs.hr)

Ostracods, as small, bivalved crustaceans, are not only found in all aquatic and some terrestrial habitats but are also common in subterranean environments. The diversity and ecology of stygobiont ostracods have the potential to significantly enhance our understanding of groundwater systems, a crucial aspect of our research.

According to Danielopol et al. (1994), the ability of ostracod species to migrate and inhabit subterranean and epigean aquatic habitats is influenced by factors such as ecological flexibility, the width of ecological tolerances, pre-adaptation, and the capacity to locate and colonise new habitats. Our investigation aims to answer the question: Can ostracods migrate through diverse subterranean habitats in a wider Dinaric area?

The Njemica Cave on the Biokovo Mt. is the fifth deepest cave in Croatia (–934 m). As part of a cave reconnaissance, two sampling sites were selected for cave sediment sampling. The first site is located close to an underground bivouac at a depth of 930 m, and the second site is located close to the siphon lake at the very bottom of the Njemica Cave (Kurečić et al., 2022). In both samples, we identified abundant and well-preserved ostracods of one species of the family Cyprididae (*Pseudocypridopsis sywulai*) together with specimens of the family Candonidae (*Phreatocandona* cf. *motasi*) (Kurečić et al., 2022; Hajek-Tadesse et al., 2022). These findings opened new avenues for understanding the distribution and ecology of ostracods in subterranean environments.

Petkovski et al. (2009) described the holotype of *Pseudocypridopsis sywulai* from a side siphon on the type locality Babina Pećina Cave at the Northern edge of the Popovo Polje karstic field. The species is present in several other caves within karstic fields in pools, on underwater rocky bottoms, on the walls and ceiling of the caves, and the rimstone pools and loamy undergrounds (Petkovski et al., 2009). The second identified species *Phreatocandona* cf. *motasi* belongs to the genus *Phreatocandona* (Danielopol, 1978). *P. motasi* was first identified in Romania, and is living in a porous aquifer (Danielopol, 1978, 1982). In the Dinaric area, the first finding of *P. motasi* outside of its type locality is recorded in Lake Skadar in Montenegro (Pešić et al., 2018).

The existence of the recent rich and diverse ostracod fauna in the caves and the interstitial habitat in the Dinaric Karst (Petkovski et al., 2009) is explained by the hydrographical situation in general following intense orogenic movements in the Pliocene. The same authors concluded that the widespread homogenous Pliocene fauna of this area was split into many isolated centers. Previous research conducted in Montenegro suggests that the drainage system of the Dinaric Karst area (i.e., Skadar Valley) gave refuge to many species that were withdrawing from the north during the ice expansion of the Last Glacial period (Karanovic & Petkovski, 1999).

However, according to our results (Kurečić et al., 2022; Hajek-Tadesse et al., 2022), deep caves in the Karst region may serve as ostracod depocenters. Ostracods of the deep cave Njemica are generally composed of known recent species from the Dinaric area. These data indicate the dispersal of the ostracod species through a subterranean route in the Karst between the different drainages.

REFERENCES

Danielopol, D.L., 1978. Über Herkunft und Morphologie der europäischen Süßwasser-Ostracoden. Sitzungsberichte der Österreichischen Akademie der Wissenschaften (Mathematischnaturwissenschaftliche Klasse, I), 187(1-5), 1-162. Danielopol, D.L., 1982. Three groundwater Candoninae (Ostracoda) from Romania. International Journal of Speleology, 12(1), 83-102. http://dx.doi.org/10.5038/1827-806X.12.1.9

Danielopol, D.L., Marmonier, P., Boulton, A., Bonaduce, G., 1994. World subterranean ostracod biogeography: dispersal or vicariance. Hydrobiologia, 287(1), 119-129. http://dx.doi.org/10.1007/BF00006901

Danielopol, D.L., 1982. Three groundwater Candoninae (Ostracoda) from Romania. International Journal of Speleology, 12(1), 83-102. http://dx.doi.org/10.5038/1827-806X.12.1.9

Hajek-Tadesse, V., Kurečić, T., Wacha, L., Horvat, M., Trinajstić, N., Mišur, I., 2022. Stygobiont ostracods from a deep cave Njemica (Biokovo Mt., Croatia) // ISO 19, Lyon, Abstract book. 2022. str. 21-21

Karanovic, I., Petkovski, T.K., 1999. Two interesting ostracod species from Montenegro (SE Europe). Annales de Limnologie–International Journal of Limnology, 35(2), 123-132. https://doi.org/10.1051/limn/1999017

Kurečić, T., Tadesse, V.H., Wacha, L., Horvat, M., Trinajstić N., Mišur, I., 2022. Sub-recent microfauna within allogenic sediments at the bottom of a deep cave, Njemica (Biokovo Mt., Croatia). International Journal of Speleology, 51(3), 223-233. https://doi.org/10.5038/1827-806X.51.3.2428

Pešić, V., Gadawski, P., Gligorović, B., Glöer, P., Grabowski, M., Kovács, T., Murányi, D., Płóciennik, M., Šundić, D., 2018. The diversity of the zoobenthos communities of the Lake Skadar/Shkodra Basin. In: Pešić, V., Karaman, G., Kostianoyet A.G., (Eds.), The Skadar/Shkodra Lake environment. The Handbook of Environmental Chemistry, 80, 255-294. https://doi.org/10.1007/698_2018_303

Petkovski, T., Scharf, B.W., Keyser, D., 2009. Freshwater ostracoda (Crustacea) collected from caves and the interstitial habitat in Herzegovina, NW Balkan, with the description of two new species. Bulletin de la Société eds naturalistes luxembourgeois, 110, 173-182. Karanovic, I., Petkovski, T.K., 1999. Two interesting ostracod species from Montenegro (SE Europe). Annales de Limnologie–International Journal of Limnology, 35(2), 123-132. https://doi.org/10.1051/limn/1999017

LATEST APPEARANCE OF *CRICETULUS MIGRATORIUS* IN THE COASTAL CROATIA

Vibor Novak[1], Borut Toškan[2]

[1]Institute for Quaternary Paleontology and Geology, Croatian Academy of Sciences and Arts, Croatia
[2]Research centre SAZU, Institute of Archaeology, Slovenia

Corresponding author: Vibor Novak (vnovak@hazu.hr)

Pupićina Cave, located in northeastern Istria along Croatia's coastal region, has yielded an abundance of archaeological remains, including a significant later prehistoric sequence (Miracle, 2006). Alongside these archaeological finds, numerous microvertebrate remains were also collected, which have only recently begun to be studied in detail. Here, we report the latest recorded occurrence of the grey dwarf hamster (*Cricetulus migratorius* Pallas, 1773) in the coastal region of Croatia.

The stratigraphic sequence of Pupićina Cave is divided into 25 major horizons, labeled A to AC, with A being the youngest, dating from Roman times to the present, and AC being the oldest, with the uppermost Late Upper Palaeolithic layers dated to 12,470 cal BP (Miracle, 2001). A first upper molar of *C. migratorius* (sample number PUP98, □N23, lv. 361, 209) was recovered from horizon R, which is subdivided into R1 and R2. Based on isotope analysis of two red deer teeth, horizon R1 is dated to 11,960–12,970 cal BP (Birch, 2012). However, in square N23, where the molar was found, the distinction between subhorizons was unclear. Additionally, bone fragments and teeth were recovered from level 361 in square N23 (Miracle, 2003).

Small hamsters are commonly found in Central European faunal communities of the Early and Middle Pleistocene and are typically attributed to the species *Allocricetus bursae*. However, due to significant overlaps in both metric and non-metric characters between *A. bursae* and *C. migratorius*, it has been proposed that *Allocricetus* be subsumed into the genus *Cricetulus* (van den Hoek Oestende et al., 2015). Similar size overlaps have been observed between *C. migratorius* and *Phodopus sungorus* (Horáček & Lebedevá, 2022), but distinct morphological features (e.g., the presence of para- and metafossests) allow for the cricetid tooth from Pupićina Cave to be confidently assigned to *C. migratorius*.

Previous research by Malez (1986) documented *C. migratorius* at several localities across the former Yugoslavia, with ages ranging from the Riss/Würm interglacial period to the Younger Dryas. The discovery of *C. migratorius* in the uppermost Pleistocene sediments of Pupićina Cave represents the youngest known occurrence of this species on the Croatian coast and aligns with Late Glacial and Early Holocene finds of the same species on the Karst Plateau, about 50 km to the northwest (Toškan & Kryštufek, 2006), offering valuable palaeoecological insights.

REFERENCES

Horáček, I., Lebedevá, K., 2022. Cricetinae in the Quaternary fossil record of the Czech Republic and Slovakia (Rodentia: Cricetidae). Lynx, 53, 365-415.

Miracle, P., 2001. Feast or famine? Epi-Paleolithic subsistence in the northern Adriatic basin. Documenta Praehistorica, 26, 177-197.

Miracle, P., 2003. Excavations at Pupićina Cave: Preliminary Results of the 1999, 2001 and 2002 Field Seasons. Histria Archaeologica, 34, 5-36.

Miracle, P., 2006. Introduction to the Pupićina Cave Project, in: Miracle, P., Forenbaher, S. (Ed.), Prehistoric herders of northern Istria: the archaelogy of Pupićina cave. Arheološki muzej Istre, pp. 1-29.

Pilaar Birch, S.E., 2012. Human Adaptations to Climate Change and Sea Level Rise at the Pleistocene-Holocene Transition in the Northeastern Adriatic. PhD Thesis, St John's College, University of Cambridge, United Kingdom, pp. 1-286.

Toškan B., Kryštufek B., 2006. Noteworthy records of small mammals from Upper Pleistocene and Holocene of Slovenia. Mammalia, 70, 98-105.

van den Hoek Oestende, L. W., Diepeveen, F., Tesakov, A., Sarac, G., Mayhew, D., Alçiçek, M. C., 2015. On the brink: micromammals from the latest Villanyian from Bıçakçı (Anatolia). Geological Journal, 50, 230–245.

THE LARGEST SYSTEM OF LGM CONTINENTAL DUNES OF THE ITALIAN PENINSULA: THE DUNES OF BELVEDERE – SAN MARCO OF AQUILEIA (NE ITALY)

Alessandro Fontana[1], Federica Vanzani[1], Livio Ronchi[1], Jacopo Boaga[1], Irka Hajdas[2]

[1]Department of Geosciences, University of Padova, Italy.
[2]Ion Beam Lab, ETH Zurich, Switzerland

Corresponding author: Alessandro Fontana (alessandro.fontana@unipd.it)

Generally continental aeolian landforms and deposits related to the climate conditions of the Last Glacial Maximum are typical feature in Central and Western Europe, whereas they are almost unknown in the alluvial plains of northern Italy. Thanks to the analysis of aerial images, Lidar DEMs, Ground Probing Radar (GPR) profiles and field survey we identified a large system of dunes formed at the end of the Last Glacial Maximum in the coastal portion of the Friulian Plain, between the city of Aquileia and the Grado Lagoon. They are locally called "dunes of Belvedere – San Marco" and they cover an area of about 25 km^2, elongating in ENE-WSW direction. Their highest crests reach up to 10 m above sea level (asl), in contrast with the surrounding reclaimed coastal plain (-1 m asl).

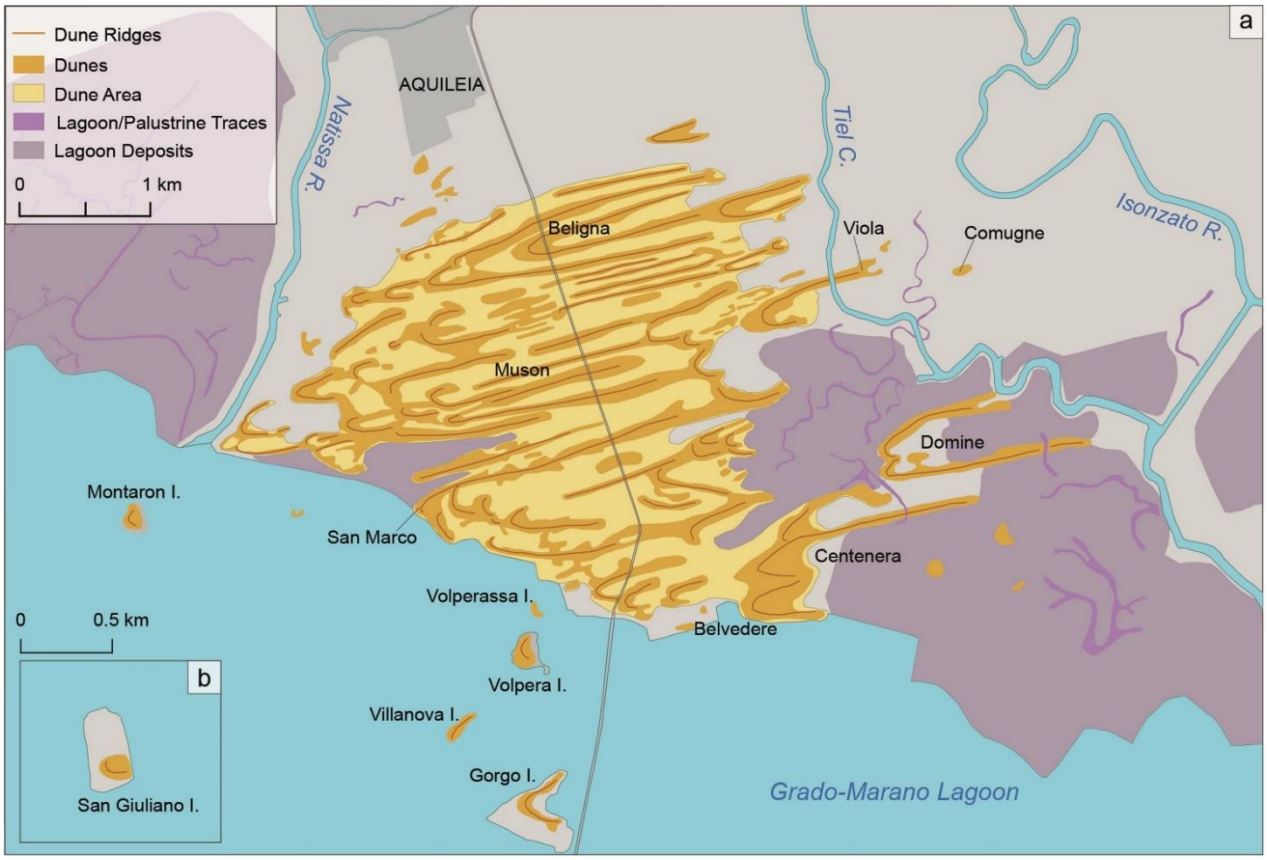

Figure 2: Map of the reconstructed planar morphology of the Belvedere–San Marco dunes. The planar morphology was reconstructed by combining historical cartography, topographic data obtained from LiDAR and optical traces visible in aerial photos and satellite images. Examples of the integrated analyses are shown in Figures 6–8. (a) Main study area; (b) San Giuliano Island.

The deposits range from fine to medium-coarse sands, and concretions of cemented sand are abundant on the surface. In outcrops and GPR radargrams the cross sections document an internal structure made of few centimeters thick, 20-30° inclined foresets. They lay on top of the distal portion of the Isonzo River megafan, and their base and preserved top are radiocarbon dated to 21 ky cal BP. The new data allow to interpret the Belvedere – San Marco reliefs as a system of parabolic dunes, which currently represent the largest and most complex continental dune field in Italy. Moreover, the orientation of the dunes is concordant with that of Bora, a katabatic wind which blows in northern Adriatic and even today can reach peak velocity of 40 m/s. Similar winds, supported by the North European and Alpine ice caps could blow stronger and more frequently at the end of LGM and during the onset of deglaciation. Furthermore, the sparsity of vegetation due to the dry cold climate, and the large availability of sandy sediment, supplied by braided channels of the Isonzo River, created favorable conditions for the deposition of aeolian dunes. This discovery underlines the importance of wind-driven processes in the evolution of alluvial plain in northern Italy and suggests the presence of other continental dune systems with similar age, even on the present floor of the Adriatic.

REFERENCES

Vanzani, F., Fontana, A., Ronchi, L., Boaga, J., Chiarini, V., Hajdas, I., 2024. The Dunes of Belvedere–San Marco of Aquileia: Integrating High-Resolution Digital Terrain Models and Multispectral Images with Ground-Penetrating Radar Survey to Map the Largest System of Continental Dunes of Northern Italy. Remote Sensing, 16, 765. https://doi.org/10.3390/rs16050765