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CONTENTS

OPTICALLY STIMULATED LUMINESCENCE (OSL) DATING OF THE ĐURĐEVAC SANDS (NORTHERN CROATIA): FIRST RESULTS

Koen Beerten[1], Lidija Galović[2], Branko Kordić[2], Ajka Šorša[2]

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The Đurđevac Sands are named after its informal type-locality near the town of Đurđevac, where they form a unique terrestrial dune landscape that covers Late Pleistocene loess deposits and Holocene river Drava fluvial and associated marshy deposits (Galović and Posilović, submitted). Based on the superposition principle, Hećimović (1989) concluded that the Đurđevac Sands must be Holocene in age. However, recent ^{14}C dating results of charcoal found in palaeosoils within the dune sands suggest that they were, at least partially, deposited during the Late Pleistocene (Galović and Posilović, submitted). The aim of the current study is to verify those recent findings using optically stimulated luminescence (OSL) dating of the aeolian sands that are covered by and covering the palaeosoils. OSL dating is proven to be a reliable technique to determine the burial ages of Late Pleistocene and Holocene aeolian sands in similar landscapes in northwestern Europe (Vandenberghe et al., 2013).

Samples were taken in an abandonned sand quarry, Draganci, in the town of Kalinovac (Figure 1a). The quarry is carved out into what seems to have been a massive (hummocky) dune, bordering a partially degraded large-scale parabolic dune created by northern winds (Figure 1b). Samples were taken after clearing the excavation wall, turning it partially into a staircase. Stainless steel cylinders were hammered into each of the steps. After removing the steel cylinders and taping the caps until fixed, surrounding sediment was sampled for determining the radioactivity concentrations. After removing the outer material from the cylinders (dark room lab), a portion of each sample was subjected to a 10% HCl, a 15% H_2O_2 treatment, a 2.8 g/cm³ polytungstate treatment, and, finally, a 45% HF treatment in order to purify the quartz. Equivalent doses were determined on individual aliquots using the 100-200 µm quartz fraction fixed onto disks with a 4 mm mask. A single aliquot regenerative (SAR) dose procedure (Murray and Wintle, 2003) was used, stimulating the samples for 40s with blue light diodes. A preheat of 240°C was used, and early background subtraction was applied to isolate the fast component. In addition, after drying, 500 g of surrounding sediment was analysed using high-resolution gamma-spectrometry. Dose rates were calculated taking into account beta and gamma contributions from all relevant radionuclides, a fixed internal dose and a depth-dependent cosmic dose contribution.

The preheat plateau test, applied on one sample only, did not show any significant dose dependency on preheat, even though the individual data points showed significant scattering. The dose recovery test for the a cutheat/preheat combination of 200°C/240°C yielded a recovery ratio of 1.00 ± 0.02 (23 aliquots) and an overdispersion of 9.0% (± 0.4%).

The resulting OSL ages are shown in Figure 1c-d. Overdispersion ranged from 42% for the second lowermost sample to 10% for the uppermost sample. However, given the fact that the distributions are rather symmetrical, and there is no reason to assume significant incomplete bleaching in this depositional setting, the ages are simply based on a central age model. The two lowermost samples yield OSL ages of around 14.5 ka, with a rather large uncertainty, and seem to be in agreement, within error limits, with the radiocarbon age

of charcoal from the lower palaeosoil (LPS), i.e., 15147 ± 265 cal yr BP. Furthermore, the two uppermost samples seem to place the position of the Pleistocene-Holocene boundary in this sediment-soil archive on top of the uppermost palaeosoil (UPS). A more detailed OSL sampling scheme will be set out in the near future, in the framework of the ACCENT project (Galović et al., submitted), in conjuction with (palaeo)pedological, geomorphological and geophysical techniques to elucidate the evolution of the Đurđevac landscape during the later Pleistocene and the Holocene, against a background of climate, land use and socio-economic change.

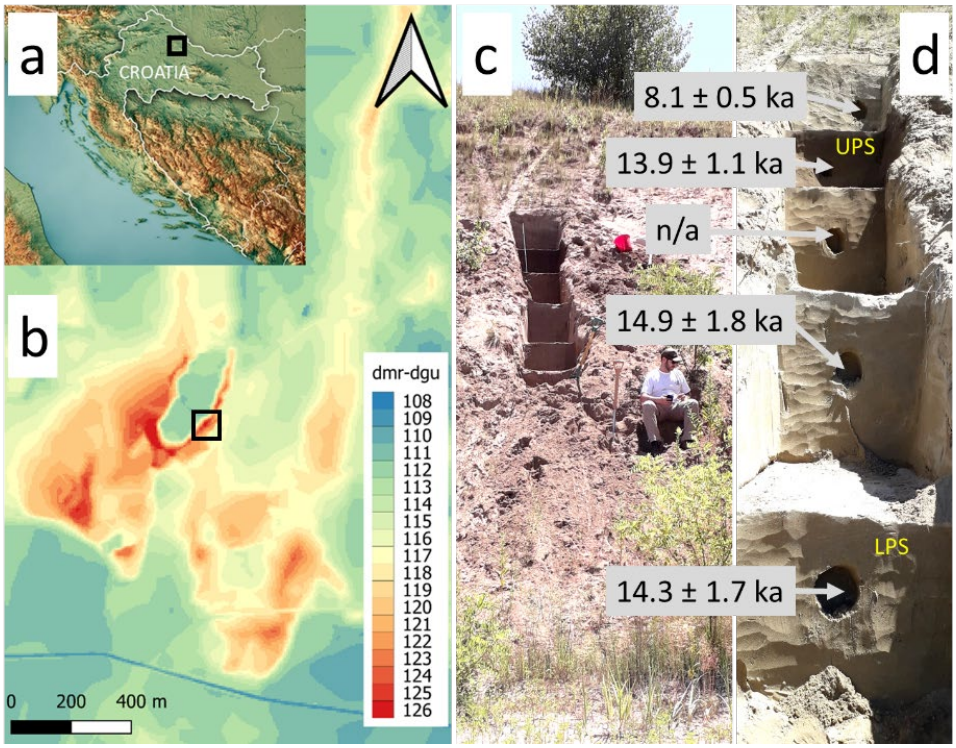

Figure 1: (a) Location of the sampling site in Croatia as indicated by the black rectangle. (b) Digital Elevation Model of the Draganci sand pit and surroundings; black rectangle indicates the position of the stepped profile shown in (c); note the parabolic dune to the east of the sampling location, with a very long right arm. (c) View of the sampled cross-section. (d) Detailed photograph of the profile sampled for OSL dating; OSL ages are given in grey boxes. The approximate position of the upper palaeosoil (UPS) and lower palaeosoil (LPS) is indicated.

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FIRST CONTINUOUS RECONSTRUCTION OF CLIMATIC AND HUMAN IMPACT ON THE HIGHLANDS OF THE JULIAN ALPS

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Fragile alpine environment is primarily influenced by climatic fluctuations, with steep climatic gradient having additional influence. Secondly, human impact is also an important factor, with centuries of land use for economic activities like grazing, ore processing, logging etc. By investigating natural archives e.g. lakes, we can understand which factors were the main drivers of environmental change through landscape evolution. Here, we selected a small, mountainous lake Planina pri jezeru (lake PNI) located in the Julian Alps. In order to investigate vegetation changes and sedimentary processes in the catchment area of the lake, mineralogical (XRD analysis), geochemical (XRF analysis and isotopes $\delta^{13}C$ and $\delta^{15}N$) and palynological methods (pollen, stomata, charcoal, NPP) were applied on a sedimentary core that covers the last 13 000 years.

Results suggest that in the Younger Drias, vegetation around the lake was a steppe-like tundra, with *Pinus*, Chenopodiaceae, *Artemisia* prevailing. At the beginning of the Holocene, vegetation quickly reacted to the climate warming and the area became forested (mostly *Picea, Larix and Ulmus*). Between 11 400 – 10 000 cal. BP pyrite and gypsum minerals were detected, which is due to the occasional anaerobic conditions (formation of pyrite) in the lake that were interrupted by influxes of calcium–rich waters, which resulted in the formation of gypsum minerals. At ca. 10 200 cal. BP, *Corylus* and *Fagus* expanded. Higher percentages of *Corylus* and no establishment of *Abies* (expansion at 8200 cal. BP) indicate drier conditions, probably with higher seasonal contrasts. However, with the expansion of *Fagus* (up to 25%), climatic conditions were still favorable enough for the beech to expand.

Sporadic pollen of anthropogenic indicators (*Plantago l.*, *Sporormiella*) was observed in the Early Neolithic (7500 cal. BP), which indicates low human impact, mostly limited to small scale pastures. More prominent human impact was observed since the Bronze Age (4300 cal. BP) onwards and was gradually increasing until the 430 cal. BP, with ore processing becoming additional activity (increased Pb in the Roman Times, High to Late Medieval Times). Major impact was observed in the Modern Period (430 cal. BP onwards), where mosaic anthropogenic landscape formed (30–60% of tree taxa), with intense grazing and logging for metallurgical purposes. That resulted in eutrophication of the lake, mainly by developing the large pastoral area around the lake.

THE RELATION BETWEEN THE COMPOSITION OF FORAMINIFERAL ASSEMBLAGES AND GRANULOMETRIC PROPERTIES OF THE SEDIMENTS FROM THREE SALT MARSHES (EASTERN ADRIATIC COAST, CROATIA)

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Being located at the boundary between the marine and continental environments, the marginal marine areas are very important for the study of sea-level changes, reconstruction of the coastal marine paleoenvironments, archeological studies and biomonitoring. Along the eastern Adriatic coast, a few studies have been conducted in such areas (Ćosović et al., 2011; Shaw et al., 2016). For this study, three locations were selected: the mouth of the Mirna River, the Čižići salt marsh and the Nin Bay. Shallow (up to 10 cm long) sediment cores were collected along the land-to-sea transect, using an Eijkelkamp hand auger. The sediment cores were sliced into 2 cm thick intervals from the surface to the bottom, and two intervals were studied in detail for micropaleontological and granulometric analyses, the uppermost (0 – 2 cm) and the lowermost (8 – 10 cm) interval. Following the micropaleontological procedures, including sample standardization, foraminiferal genera and species were determined, as well as absolute and relative abundance and ecological (biodiversity) indices.

Fine-grained muddy sediments from the salt marsh at the mouth of the Mirna River, show low diversity (14 foraminiferal genera and 8 species were found). In the shallower interval (0 – 2 cm), the values of Shannon-Wiener (H) index ranged from 0.9 to 1.93, and in the deeper interval (8 – 10 cm) from 0.7 to 1.5. *Ammonia tepida* (Cushman), *Trochamina inflata* (Montagu), *Porosononion granosum* (d'Orbigny) and *Haynesina depressula* (Walker & Jacob) are the dominant species, all indicative of a restricted marginal, shallow-marine environment with possible salinity fluctuations (brackish conditions). Abundance of *T. inflata* increases at deeper intervals, which may be a consequence of accumulation of tests over time (seasonal, a time averaging process) or the occupation of deeper sediment habitats. A total of 27 foraminiferal genera and 42 species were identified in the sandy-muddy sediments of the Čižići salt marsh. The most abundant species is *A. tepida*, followed by *A. parkinsoniana* (d'Orbigny), *Haynesina* sp. and *T. inflata*. Biodiversity indices increase with distance from the sea (H= 1.38 – 2.40 in shallower interval; H= 1.68 – 2.58 in deeper interval). A total of 30 genera and 44 species were identified in the sandy sediments of the Nin Bay, with *A. beccarii* (Linnaeus) as the most abundant species. Diversity index values are consistent (H= 2.29 – 2.76 for shallower and 1.62 – 2.51 for deeper intervals), suggesting a marine environment with normal to variable salinity.

Common features of all foraminiferal assemblages are the dominance of shallow infaunal species, among which representatives of genus *Ammonia* predominate. The constant presence of deformed tests characterized assemblages. A large proportion of the sand component with many reworked foraminiferal tests in Nin Bay and Čižići indicates a larger input from the surrounding flysch deposits, in contrast to the Mirna area were the terrigenous input is limited.

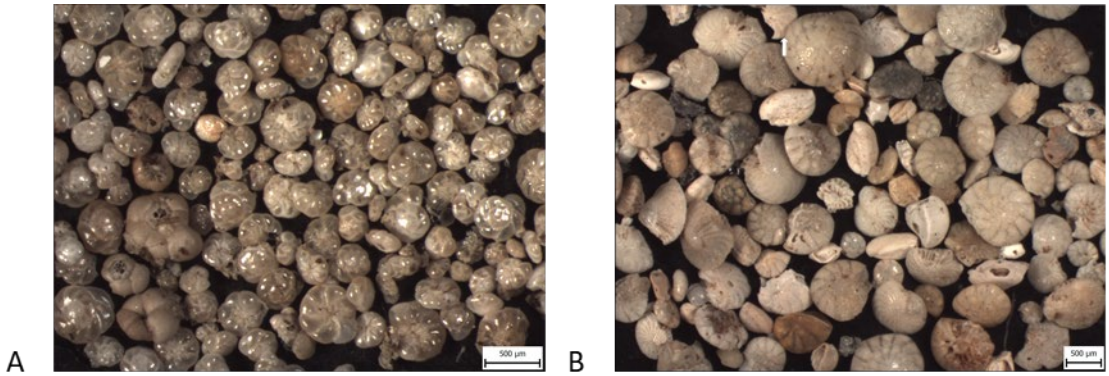

Figure 1: Two foraminiferal assemblages from muddy and sandy prevalent habitats. A) Salt marsh at Mirna River mount (core M2, 0 – 2 cm interval), B) Nin Bay (core N1, 8 – 10 cm interval).

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THE RECENT SEDIMENTS OF THE GULF OF TRIESTE, THE MOST NORTHERN PART OF THE ADRIATIC – AN OVERVIEW OF THE LAST 5 DECADES OF THE BIOGEOCHEMICAL AND SEDIMENTOLOGICAL RESEARCH

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The first oceanographic and sedimentological research expeditions in the Adriatic began in the nineteenth century. Nevertheless, they became more systematic and frequent only from the mid-1950s. The reason was that the Second World War, tragic as it was, provided scientists with new technologies for marine research. But even if cruises in the 1950s and 1960s covered the entire western and sometimes central Adriatic from the Gulf of Trieste (GoT) to the Strait of Otranto, this was not true of the eastern side, which was excluded from expeditions for well-known political reasons. The more intensive timeline of research on the sediments of the GoT starts in the 1960s with several publications dealing with the morphological, sedimentological and geochemical characteristics of the seabed along the Italian coast from the northwestern part of the GoT down to Venice. In this coastal area, there are numerous fluvial and eolian deposits with surface erosion occurring at the same time. Although with limited resources, the research group of Trieste University and C.N.R. provided the first interesting insights into this coastal sedimentation. The sediments of the southeastern part of the GoT remained less well studied until a decade later. In the mid-1970s, a group of German geologists, supported mainly by German Science Fundation, studied the coastal and marine sediments along the Istrian peninsula from the Bay of Piran down to the area of Rovinj (Croatia). Its main objective was to study the process of sedimentation. A more systematic exploration of the then Yugoslav part of the Gulf by Slovenian research institutions started a few years later. The release of the sedimentological, textural map of the northern Adriatic by Brambati et al. (1983) somehow stimulated Slovenian marine geologists and geochemists to tackle the same issue on the SE side of the GoT Two significant publications in 1991 that focused on sedimentological (Ogorelec et al.) and geochemical (Faganeli et al.) sediment properties were just the first two in a series of research publication that in the next two decades significantly increased the knowledge of GoT sediments. This also was the time when researchers from both sides of the GoT began to collaborate more intensively in planning future research activities. In addition, marine research, at least on the Slovenian side, received more funding through national research programmes and projects. Grain size composition studies and geochemical investigations of major, minor and trace elements were additionally extended to the GoT areas not previously considered. Several research projects focused on the presence of mercury and methylmercury in the marine environment for specific geological, hydrological, historical and economic reasons (Faganeli et al., 2003). Biogeochemical (total organic carbon, black carbon, total nitrogen, isotopic carbon, nitrogen, phosphorus and sulphur composition), mineralogical (carbonate content, clay minerals) and pollution parameters (trace metals, polycyclic aromatic hydrocarbons) were intensively studied together with sediment-water interactions (early diagenesis and benthic fluxes). To assess pelagic-benthic coupling, biologically mediated processes (primary production and bioturbation) in the sediment were investigated or modelled, along with more physical processes like advection and turbulence.

In the last 10-15 years, the use of acoustic technology has made it possible to study the morphology of Sea Floor. Analysed from a distance, the seafloor presents a different perspective, with submarine sand dunes and

paleo-river beds (Trobec et al., 2017) that are not visible from the sea surface or with standard gravity collectors. In general, the sediments of the GoT have been extensively studied over the last 50 years, but there is still room for improvement. A unique sedimentological and textural map of the Gulf is still lacking. Although some attempts have been made to reconstruct the Holocene paleoenvironment of the Gulf of Trieste and the surrounding bays, no borehole in the central part of the Gulf has ever reached a depth of more than 4 meters, and yet we suspect that there are more than 10 m of Holocene sediments. It is also worth noting that Sea Floor is a dynamic environment. Some acoustic surveys were conducted 10 or more years ago. If they are accurate enough, repeating the sampling would reveal changes over the last decade due to bottom currents.

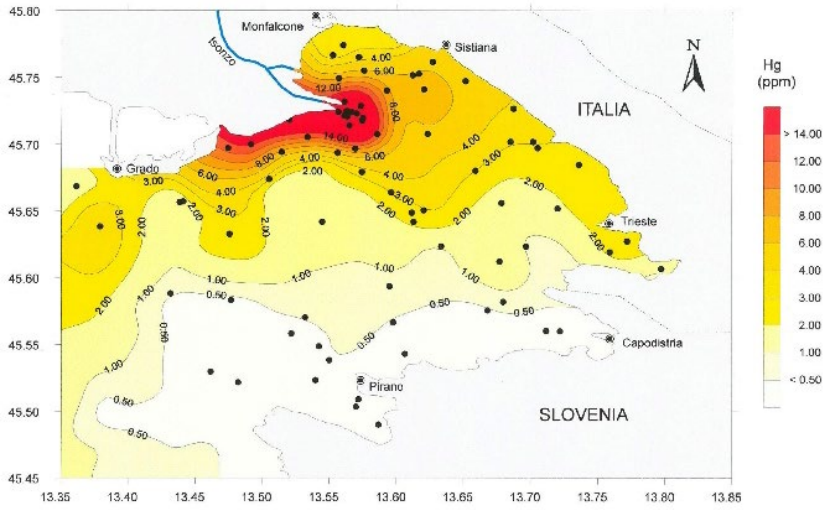

Figure 1: The distribution of the total Hg in the surface sediment of the Gulf of Trieste (Covelli et al., 2001).

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HOW REMOTE SENSING OF ACTIVE TECTONICS CAN FAIL IN THE SLOWLY DEFORMING KARST LANDSCAPE OF SLOVENIA

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Remote sensing methods are commonly used to analyse the tectonic activity of large regions. Such studies focus on characteristic landscape features that are formed or modified by fault activity and/or tectonic uplift (e.g., Mahmoud & Gloaguen, 2012; Riley et al., 2019). The drainage network reacts to tectonic activity that can be evaluated by analysing for example geometric river and valley properties, stream knickpoints, basin shapes, or drainage divides. Additional constraints on active tectonics come from topographic properties such as slope, aspect, surface roughness, or mountain front sinuosity. While these methods have proven successful in areas with high deformation rates and vertical tectonic motion, they are more difficult to apply in strike-slip settings and regions with low tectonic activity. This is the case in Western Slovenia, where several strike-slip faults with slip rates mostly below 1 mm/yr accommodate right-lateral shear caused by the northward motion of the Adriatic plate with respect to stable Europe (Placer et al., 2010; Moulin et al., 2016; Atanackov et al., 2021). A further complication roots in the famous karst, which severely modifies the surface directly by the formation of dolines and poljes. Furthermore, karst affects surface run-off and can lead to subsurface drainage. This hampers the application of tectonic geomorphology techniques that use drainage properties. So far, only few studies have investigated the applicability of remote sensing for active tectonics research in this setting in detail, e.g., Žibret & Žibret, (2017).

Here we apply a range of standard remote sensing techniques on Western Slovenia. Using the open-source software TecGEMs version 0.4.2 (Andreani et al., 2014, Shahzad & Gloaguen, 2011), we combined surface roughness and hypsometric integral to the surface index and calculated the local relief and the topographic position index. For detailed investigations on local fault traces (Atanackov et al., 2021) we used surface roughness and the terrain ruggedness index (Riley et al., 1999). We used topographic profiles and swath profiles to detect fault scarps of faults that were not previously investigated, and to determine their geometry. Knickpoints were mapped using the TopoToolbox knickpoint finder function and we calculated χ-maps to see if the drainage divide between the catchments of the Soča and Sava rivers is in equilibrium (Schwanghart & Scherler, 2014). The normalised steepness index k_{sn} was calculated to check if river profiles are in steady state (Fig. 1). We used a 5 m digital elevation model (DEM) derived from the 1 m LiDAR data for Slovenia (ARSO) and Friuli (Protezione Civile) and compared our results to those gathered using the ALOS 2 DEM with a pixel size of 21 by 31 m.

We show that almost all standard techniques yield ambiguous results although we used state-of-the-art methods and datasets. The morphometric indices do mostly not show any anomalies that align with the known active faults of the area. High-resolution DEMs greatly enhance the quality of the morphometric analyses, compared to the ALOS 2 data. However, we demonstrate that even the availability of high-resolution DEMs cannot overcome the challenges of this study area. Remote sensing of active tectonics reaches its limits under these conditions: the slip rates are too small, the erosion is too fast, and the karst often prohibits analysing

the drainage anomalies. Our study shows that caution is advised when applying well-established remote sensing methods in challenging settings such as Western Slovenia.

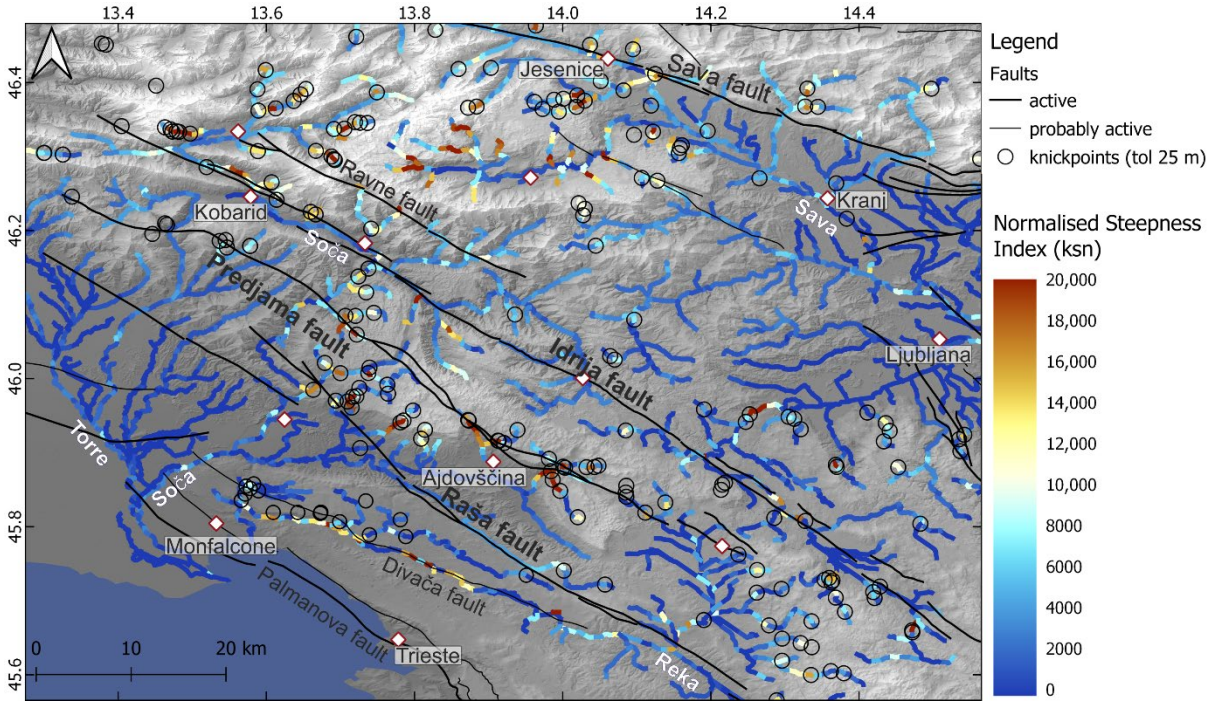

Figure 1: Normalised steepness index and knickpoints of the Soča, Sava, Reka, and Tagliamento networks, extracted from a 5 m DEM with a tolerance (tol) of 25 m. Faults are from Atanackov et al., 2021. The index anomalies and the knickpoints show a poor correlation with the known active faults. Topography is downsampled from the 1 m LiDAR DEMs of Slovenia and Friuli.

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LITHOPHYLLUM RIMS AS MARKERS OF RELATIVE SEA-LEVEL CHANGE AND PALAEOEARTHQUAKES ALONG THE EASTERN ADRIATIC COAST

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Coralline algae are the most significant framework builders outside the coral-reef belt (Blanc and Molinier, 1955; Huvé, 1970). Among them, littoral rims built by the coralline rhodophyte *Lithophyllum byssoides* are a particularly precise archive of relative sea-level histories (Laborel et al., 1994). Their vertical precision, in the microtidal environment, comes from the restricted environmental conditions of the alga as their living range is constrained around sea-level (Pérès and Picard, 1952, 1964). The temporal component is obtained through 14C dating, consequently vertical and temporal components allow the construction of precise geochronologies. Their potential has been up to now underutilized due to the unresolved question of size of the marine radiocarbon reservoir effect (MRE), prerequisite for accurate calibration of dates obtained from marine-derived carbon samples. In order to approach the 14C reservoir effect different studies of MRE of the alga and shells in the Adriatic and in the other parts of the Mediterranean have been engaged using samples of known age from museum collections (Faivre et al., 2015, 2019a). The corrections of MRE and local ΔR are fundamental particularly for the short, late Holocene sea-level and palaeoenvironmental chronologies. This have been demonstrated in the study of RSL change in Istria in the northern Adriatic (Faivre et al., 2019b) and confirmed in the study of Lopud Island in the southern Adriatic (Faivre et al., 2021).

On the Istrian peninsula the high resolution relative sea-level (RSL) reconstruction, based on 47 radiocarbon dates, has been done for the past 1500 yr (Faivre et al., 2019b) what allows to relate sea-level changes to periods of climate changes and to distinguish land-level changes in the studied area. To identify sea-level trends with full consideration of the available uncertainty, the RSL reconstruction was quantitatively analysed using an error in-variables integrated Gaussian process (EIV-IGP) model based on Cahill et al. (2015).

A detailed survey of Lopud Island in the Southern Adriatic allowed the distinction of seismotectonically uplifted sector of coast. The established high-resolution algal rim geochronology (based on 23 AMS radiocarbon dates) enable to separate the Late Holocene transgression periods from seismically triggered regression events. Consequently, we distinguished local tectonic uplift (the local non-linear component of RSL change) and provide the first reconstruction of assumed number, timing, and displacements of past seismic events. The most important uplift occurred in well-known AD 1667 Dubrovnik earthquake (Faivre et al., 2021).

After correction for local coseismic displacements the sea-level trends with full consideration of the available uncertainty were quantified using an Errors-In-Variables Integrated Gaussian Process model, like in Istria, what allow us to approach the drivers of relative sea-level change and to compare the results.

This high-resolution geochronology obtained at Lopud Island allows us to distinguish the effects of coseismic movements on RSL histories what confirmed the precision of *L. byssoides* bioconstructions not only in the studies of RSL variations but also in the studies of palaeoearthquakes in seismotectonically active areas.

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CORE MIR1: A 34-M LONG HOLOCENE ARCHIVE AT THE MOUTH OF MIRNA RIVER (NORTHERN ISTRIA, CROATIA)

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Along the eastern side of the Adriatic the index points of past relative sea level are few and almost completely related to the upper Holocene. The possibility to find significant information about the relative sea level during the Early and middle Holocene is related to the rare settings where sedimentary sequences recorded that interval, as in the few deltaic plains and enclosed basins (e.g. Brunović et al., 2019). This situation exists at the mouth of the Mirna River, near the city of Novigrad (Croatia), that has the largest fluvial catchment of Istria and experienced a deltaic progradation of about 12 km along the final tract of its karst valley (Felja et al., 2015).

This research analysed the Holocene deposits recorded in core MIR1, that was drilled near the mouth of the Mirna River down to a depth of 120 m and documented that the thickness of Holocene sediments is about 34 m. The core was investigated for its sedimentology and stratigraphy, supported by several analytical methods which considered in detail the following properties: grain size, radiocarbon, C/N, molluscs, foraminifers, pollen, magnetic susceptibility.

The Holocene sequence documented in core MIR1 is an expanded record that allows a detailed investigation of the paleoenvironmental evolution. In particular, the quantitative analyses of pollen and foraminifers, coupled with nine radiocarbon dates, support the detection of the subtle variations of salinity and vegetation cover.

The marine transgression reached the area about 10.4 ka cal BP and was afterwards characterized by a lagoon environment with a relative temporary stillstand of the sea between 9.7-9.3 ka cal BP, when the level was around -31 m Mean Sea Level (MSL). This setting was after modified by the rapid drowning of the valley and transformed into an estuary. The maximum flooding occurred in the valley around 7 ka cal BP, when the coastal environment probably almost reached the area of Ponte Porton, 12 km inland, and the deltaic progradation started. The coast reached its present position only few centuries ago, when the reclamation activities started and were completed during the first part of the 20th century.

A vertical aggradation of over 10 m occurred in MIR1 between 5.5 and 4.0 ka cal BP, when the delta front was near the borehole site, creating a very expanded record of the alluvial history of the river. During the Late Roman period salt marshes characterized the present mouth area, where their sedimentary facies are found at a depth of -2.5 m MSL.

Core MIR1 also documents an expanded and continuous sequence of the Last Interglacial, thus the Holocene interval represents an important analogue for inferring changes and similarities between the present and the Last interglacial conditions along the eastern side of the Adriatic.

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HOLOCENE EVOLUTION OF THE DELTA PLAIN OF NERETVA RIVER (CROATIA) AND ITS POTENTIAL FOR RECONSTRUCTING THE RELATIVE SEA-LEVEL CHANGES

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Neretva River developed the largest delta plain along the Istrian and Dalmatian coast and this evolution has been favoured by the wide mountain basin of the river and the occurrence in the upper part of the catchment of siliciclastic rocks. This setting allowed the sedimentary supply of the fluvial system and permitted a Holocene progradation of about 15 km along the final sector of the Neretva river valley.

The aim of this research is to describe the succession of depositional facies which developed during Holocene in a sector of the Neretva River delta plain. A main goal is to collect and assess the availability of high-quality index points for reconstructing past Relative Sea Level (RSL), selecting a protected site where the direct action of marine waves had not been felt and the coastal deposits directly sedimented over the bedrock. For this purpose, sedimentological, chronological and paleontological features of two adjacent sediment cores were analysed, sampling the Holocene sequence in the wetlands near Opuzen and reaching the Mesozoic substrate.

The paleontological investigations analysed the foraminifera, ostracoda and mollusc associations, mainly consisting of benthic foraminifera and ostracods, that are abundant microorganisms in shallow and marginal-marine environments and are widely applied in the analysis of Holocene sea-level changes and in paleoenvironmental reconstructions of estuarine systems. The research is also supported by the analyses of grain size, radiocarbon and carbonate content. The vertical markers of the RSL have been described with a standardized methodology, following the recent IGCP protocol developed for creating database of past sea-level index points (e.g. Vacchi et al., 2016).

Here we present the results related to the cores NER5 and NER6, which were drilled 5 m a part one form the other along the flank of a limestone hill, up to found the bedrock, and they reached 4.9 and 8.2 m of depth, respectively.

The base of sediments on top of the limestone bedrock is dating to 3.2 cal BP and its meaning is that sediment started to arrive in that moment, while before the area was already submerged by the sea, but there were no favourable conditions to record the paleo-environment. The combined use of sedimentological and paleontological analyses of two sediment cores and ^{14}C dating allowed recognizing different depositional environments and their succession in the marginal part of the Neretva delta plain during Holocene highstand. These interpretations permit to reconstructing sea-level and give some constraining features for documenting the evolution of Neretva delta area in the last 3000 years.

The top portion of both cores, from 3.2 m of depth in NER6, consists of paludal deposits that are representative of the moment in which Neretva River passed the threshold of Opuzen and blocked the outflow of the fresh water coming from the tributary valleys and created a freshwater swamp/ lacustrine environment. Since that

moment that is dated about 100-200 AD the situation has been remained almost stable. In both cores, before anthropogenic deposition on top (last 100-200 years) there was only accumulation of plant remains.

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INCOMING RESEARCH PROJECT: ABRUPT CLIMATE CHANGES – EVIDENCE FROM QUATERNARY SEDIMENTARY SEQUENCES IN CROATIA (ACCENT)

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"Abrupt climate changes–Evidence from Quaternary sedimentary sequences in Croatia" is a four-year investigation project that is funded by the Croatian Science Foundation and started on April 1st 2021. We propose a fundamental and multidisciplinary approach to produce meaningful data on past abrupt climate changes (CC). Interpretation of these data can help create the basis both for comparison of paleo- and modern climate changes and for predicting their dynamics in the future.

The specific geological, pedological geomorphological and climatic diversity of Croatia enables to study in high-resolution study the parallel development of abrupt CC during the Late Pleistocene and Holocene at four locations only 300 km apart.

A stepwise fieldwork approach will be applied. Initial fieldwork is required to investigate four different geological successions and harmonize terminology and research approaches in different scientific fields and among various experts. Further, dedicated and focused fieldwork will be exercised including outcrop and core sampling. Several analytic methods will be applied to characterise soils and sediments, together with their paleoenvironmental significance and age: micromorphology and stable isotope analysis, granulometry, radiocarbon and optically stimulated luminescence dating. Gathered data will be subjected to geostatistical analysis. For selected sites, digital elevation model analysis and geoelectrical soundings will be performed.

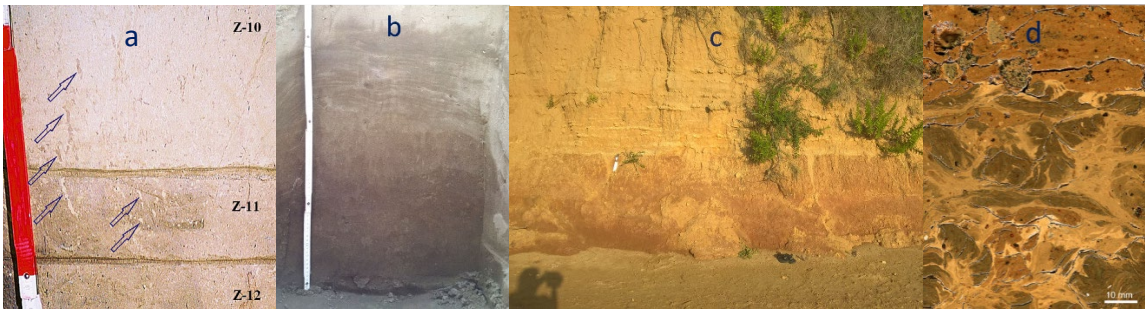

Figure 1**:** (a) Bioturbated cumulic horizon Z-10 overlaying palaeosoils in loess; (b) Buried paleosoil in a dune sequence; (c) Fluvio-glacial sedimentation overlaying *terra rossa* and infilling desiccation cracks; (d) Disturbed laminated lake sediments with soft sediment deformations on the contact between clay and lacustrine chalk.

The **loess–palaeosol sequences** of NE Croatia show great potential in reconstructing the Upper Pleistocene climate and environmental changes. The cumulic horizons are mentioned in descriptions of the sections and geochronologically framed by IRSL-dating as weakly developed incipient soils representing the sedimentological record of short-term warming that preceded the long-term cooling and sedimentation of loess (Fig. 1a). The lower parts of the horizons are bioturbated, indicating intensive life in cumulic horizons (soils), while the silty texture and pale color indicate short exposure to pedogenic processes. 14 horizons represent paleoclimate archives of 14 CC episodes. Preliminary studies on **dune sands** (Đurđevac Sands) were conducted in the Podravina area. Within the dunes sets, two paleosoils, type arenosol, were discovered. Preserved bioturbations confirm their in situ formation (Fig. 1b). Radiocarbon analysis of charcoal from the paleosoils showed that they developed before the very beginning of the Holocene, and, consequently, the oldest dune sediments were already formed before the end of the Pleistocene. Glacial features and forms in karst indicate different ages of glaciations on the Velebit Mountain. Presumably **fluvioglacial features** can be observed (Fig. 1c) 1 m above the sea level. Their properties and age of formation will be the subject of detailed analysis. Finally, the Vrgoračko Polje is a karst field situated at the southern edge of the Dalmatian Zagora. During the Quaternary, the polje was flooded for variable periods and a **lacustrine environment** was established. The multidisciplinary study of drilling cores, outcrops and geoelectric measurements recognized five main sedimentary facies: laminated sediment, redeposited sediment, coarse-grained carbonate debris, littoral clay and lacustrine chalk. A stratigraphic break between littoral clay and lacustrine chalk could be time-equivalent to the disturbed laminated sediments deposited in deeper water (Fig. 1d). According to radiocarbon dating, deposition of the lacustrine chalk started at the beginning of the Holocene and lasts until today. The described depositional environments and sediment facies found in the Vrgoračko Polje are considered to represent a typical Quaternary lacustrine sedimentary pattern for other Dinaric poljes.

So far, preliminary investigations and a short literature survey suggest that the four proposed Croatian sites represent meaningful archives in the context of Late Pleistocene and Holocene CC. The main objectives of the project are: 1) Understanding of the spatial extent and differences in appearance of paleoclimatic events in the Pannonian and Dinaric areas; 2) Determine teleconnections in SE Europe and compare it with abrupt CC in the European Sand Belt, and 3) Correlate it with climate archives from the Adriatic Sea.

Reaching the set objectives and goals will help researchers to identify and map critical ecological conditions during the Quaternary, where major geomorphological, hydrogeological and pedological changes had occurred and where current ecotones can be expected to exist in the future in different climatic regions. Ultimately, the outcomes can be applied by land-use planners and stakeholders to check whether the present land-use will be sustainable any longer under changing conditions and, if not, to suggest alternative management of land-use changes, especially concerning geohazards like landslides, slumps, debris flows, floods and drifting dunes.

UNDERWATER ARCHAEOLOGICAL INVESTIGATIONS OF THE TERRITORIAL SEA AND INLAND WATERS IN SLOVENIA: A REVIEW

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The lecture will give an overview of the most important results of underwater archaeological research in the Slovenian territorial sea, lakes and rivers in recent decades. We focus on the study of sites that have contributed to the knowledge of the development of local geological phenomena or their chronological classification through the cultural, functional and chronological determinaton of the remains. In addition to the findings from underwater field surveys and excavations, as well as direct observation of remains, we also rely on the results of research using remote sensing techniques, particularly data from high-resolution multibeam sonar survey (MBES). The data presented refer to research conducted by the Group for Underwater Archeology of the Institute for the Protection of Cultural Heritage of Slovenia (2002–2012), the Institute for Underwater Archeology (2016–2021) and Centre for Preventive Archaeology of the IPCHS.

Recorded sites in the high seas that show greater potential but are still in the early stages of research include the presumed wreck of a smaller 1st century AD fishing boat, covered with coralline formations, and other areas of solid seabed, that largerly conceal the archaeological remains of boats&ships, but are also interesting from a biodiversity perspective. Studies aimed at investigating the evolution of the submerged Late Pleistocene and Holocene landscapes of the relevant part of the Gulf of Trieste are of particular interest due to the identified riverbeds with banks as potential sites with traces of Stone Age communities. Archaeological aspects of relative sea-level rise over the last 3500 years include data on the location and chronology of Bronze Age deposits (16th-14th century BC) from the area of the Židovski kare in Piran and accurate geodetic measurements of Roman submerged architecture from the period between the 1st and 5th centuries AD. These include fish farms and piers in Jernejeva draga near Ankaran, the port of the brickworks in Viližan and maritime villa in Simon's Bay near Izola, sunken buildings near Roman settlement in Strunjan and the remains of a fish farm and harbour in the settlement complex in Fizine near Portorož. Recent research at Fizine has uncovered a piece of spruce log, secondarily used as a mooring pile and radiocarbon dated to the 3rd/4th century AD, which is probably part of a diagonal support beam (spar) of a sprit sail, as used in antiquity on smaller ships. Also recovered were several tubular ceramic elements for the construction of vaults (*tubi fitilli*), probably made in late Roman workshops on the territory of present-day Tunisia.

Research in inland waters includes surveys and soundings in the Ljubljanica River and analyzes of lidar scanning of the Ljubljana Marshes, major highlights of Sava riverbed research and high-resolution bathygraphic measurements and underwater research in the Lake Bled. Sites investigated in the western part of Ljubljana Marshes include the remains of an Early Mesolithic hunting camp (8th millennium BC) in the Ljubija riverbed near Verd and the discovery of a Paleolithic hunting point made of yew wood in the Ljubljanica riverbed near Sinja Gorica. The wood of the point was radiocarbon dated to the time before 37 ka cal. BP, while thermoluminescence dating (TL) of the buried sediments at the site gave an age of 19.2-7.7 ka cal. BP. Research also focused on the development of the hydrographic network in the Ljubljana Marshes after the middle of

the 2nd millennium BC, when the Ljubljanica settled in approximately present course, and on alleged Roman interventions to improve navigability. Of particular interest are the investigations of pre-Roman and Roman boats and ships in the riverbed in the area of the Celtic and early Roman Nauportus (Vrhnika), data on archeological finds from the crest of the Ljubljanica embankment (levees) and from the floodplain, as well as the meandering of the riverbed on certain sections, documented on aerial photographs and Lidar images and by test excavations in the Livada area near Ljubljana.

Albeit on a limited scale, experiments on the downstream movement of objects made of different materials along different sections of the river have been conducted to understand the spatial distribution of archaeological finds. Among the resulst related to the exploration of other rivers, we highlight the dendrochronological study of wooden piles of the Roman bridge in Ptuj, which shows the felling of tree trunks in the first half or middle of the 2nd century AD, which roughly coincides with the reconstruction of the road section along the Amber Route under Emperor Hadrian. Also of interest are the results of radiocarbon dating of wooden beams from the foundations of the bridge over the Sava at Črnuče, long considered to be the remains of a Roman structure from the the time of the legionary uprising in 14 AD. ^{14}C analysis, on the other hand, revealed that the foundations were made after the mid-17th century and support the assumption that they belonged to an unfinished bridge construction on the main commercial road between Vienna and Trieste from the second quarter of the 18th century. The areas of underwater investigations of the Sava riverbed in its middle reached between Litija and Krško, selected partially on the basis of information from local enthusiasts and connoisseurs. Few individual and collective finds of metal objects from the Late Bronze Age, Late Iron Age, Roman period and the late Middle Ages were documented, while a large quantity of World War II weapons was collected in the riverbed at Šmarčna near Radeče, as a result of an attack by Allied aircraft on a German train composition. As part of these interventions, preventive 3D scanning of the navigable canal at Beli slap above Hrastnik from 1736, and documentation of individual bridges on the riverside towpaths from the period before the construction of the Zidani Most - Sisak railway line were carried out.

Research at Lake Bled received a new impetus after the discovery of a bronze sword from the early period of the Urnfield culture (14th–12th century BC) in 2006, which strengthened the assumptions about the existence of a prehistoric cult site in the area of the lake outlet to the Jezernica stream. This was followed by high-resolution batigraphic surveys of the entire lake shell and verification of the detected anomalies. The latter led to closer cooperation with the local society for Underwater Activities, during which the early medieval logboat was photogrammetrically documented. The boat was hollowed from a larch tree felled between the late 7th and mid 8th centuries. Also explored was an area of shallow submerged abraded bedrock with the remains of subglacial moraine gravels and archaeological features indicating the possible presence of a high or late-medieval wooden platform or other construction. Probably dating from the early modern period are two fish-traps made of willow wickerwork from the central part of the lake, and among the more interesting discoveries from more recent times is a perfectly preserved boat, perhaps identical to the one in which the heir to the Yugoslav throne Peter II Karađorđević rowed on the lake in the summer of 1930.

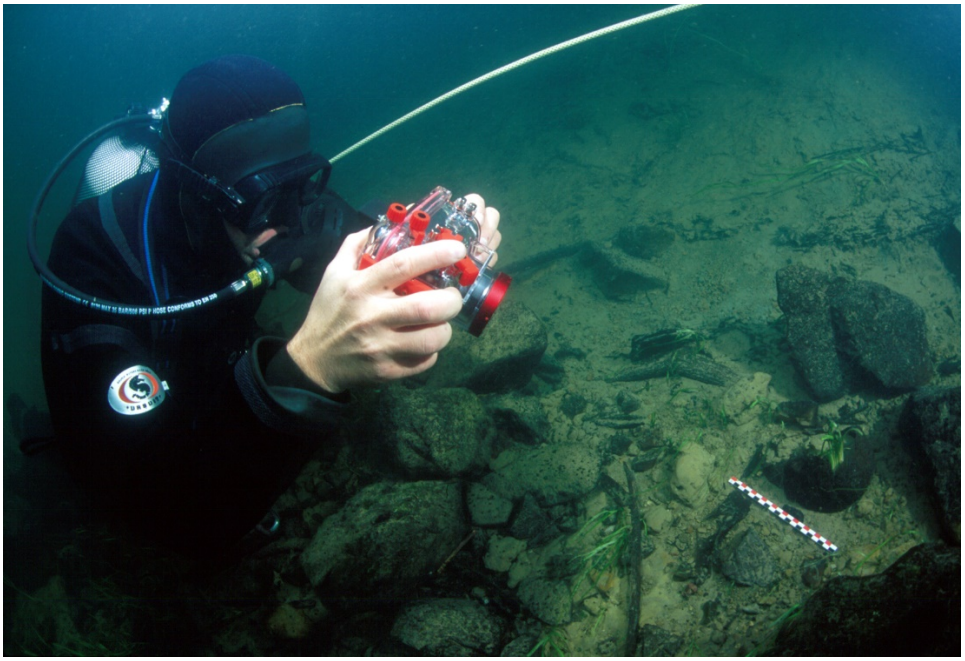

Figure 2: Ljubija Stream near Verd, western edge of the Ljubljana Moor. Diver taking photographs of the skull of a young woman from the 8th millenium BC, discovered at the site of Early Mesolithic hunter's camp in 2004 (photo: Arne Hodalič).

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HOW ACTIVE IS THE SELCE FAULT IN SW SLOVENIA?

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In Western Slovenia, a right-lateral strike-slip fault system runs NW-SE and accommodates the northward motion of Adria with respect to stable Europe. The strike-slip fault system is ~100 km long and consists of a series of parallel subvertical faults (Placer et al., 2010). While the active tectonics of the largest of these faults are relatively well investigated (e.g., Vrabec, 2012; Moulin et al., 2016; Grützner et al., 2021), relatively little is known about the activity of the shorter fault segments close to the border with Croatia. However, smaller faults may contribute significantly to the seismic hazard as shown by recent earthquakes. For example, the 1999 Athens earthquake with a magnitude of M_S=5.9 occurred on a 10 km-long fault and caused severe damage as well as fatalities (Pavlides et al., 2002).

The Selce Fault in the Pivka Basin is mapped as a ~15 km long structure (Gospodarič, 1989; Šebela, 2005). Near the town of Selce, a 4 km long, linear scarp is visible in the field. The fault was only recently found to be associated with a ~40 km long zone of microseismicity between 5-18 km depth, which pointed to its activity (Vičič et al., 2019). In 2008 and 2014, earthquakes with magnitudes of M_L3.0 and M_L4.7, respectively, showed a right-lateral focal mechanism (Vičič et al., 2019). Therefore, several questions arise: (i) What is the fault's slip rate? (ii) When was the last large earthquake on the fault? (iii) What is the maximum credible earthquake or, in other words, how long is the fault? So far, essentially nothing is known about the potential for large earthquakes on this fault and about the relationship between seismicity and its surface expression.

In this study we use tectonic geomorphology, paleoseismological trenching, and chronology obtained by optically stimulated luminescence (OSL) and radiocarbon (^{14}C) dating to argue that this strike-slip fault has probably been active in the Holocene. A surface-rupturing earthquake, creep, or a combination thereof affected the youngest geological units. In a paleoseismological trench we found fractured limestones with slickolites and striated red clay as kinematic indicators that indicate right-lateral motion, which is in line with the seismological data (Vičič et al., 2019). The age of the last significant fault motion is determined by the age of the red clay, which pre-dates the striations. However, several problems hamper a detailed assessment. Firstly, we were only able to excavate the fault in one place so far. Thus, our observations may not be representative of the entire fault. Secondly, there is a significant age difference between the OSL ages and the ^{14}C ages of the red clay. On the one hand, radiocarbon dating shows that charcoal fragments within the clay are 3.5-4.5 ka. On the other hand, OSL ages using the minimum age model and very small aliquots point to around 12 ka, which fits very well the age of a single charcoal above the red clay. This conundrum might be explained with a very complex history of the charcoal samples. However, young charcoal samples always provide a maximum depositional age of a layer. OSL samples might suffer from incomplete bleaching before (re-)deposition. In these cases, OSL will return ages that are too old. In conclusion, it remains unclear when

the last earthquake happened, but deformation happened within the last 12 ka. We are also not able to estimate the magnitude of the event, but we can show that right-lateral slip with a minor dip-slip component occurred at or near the surface. It is not yet clear how these observations relate to the ~40 km-long zone of microseismicity and to the topographic scarp of 4 km length. The Selce Fault example illustrates the difficulties one has to deal with in slowly deforming regions, especially in strike-slip settings, and in intensely karstified areas that prohibit the application of many classical tectonic geomorphology techniques.

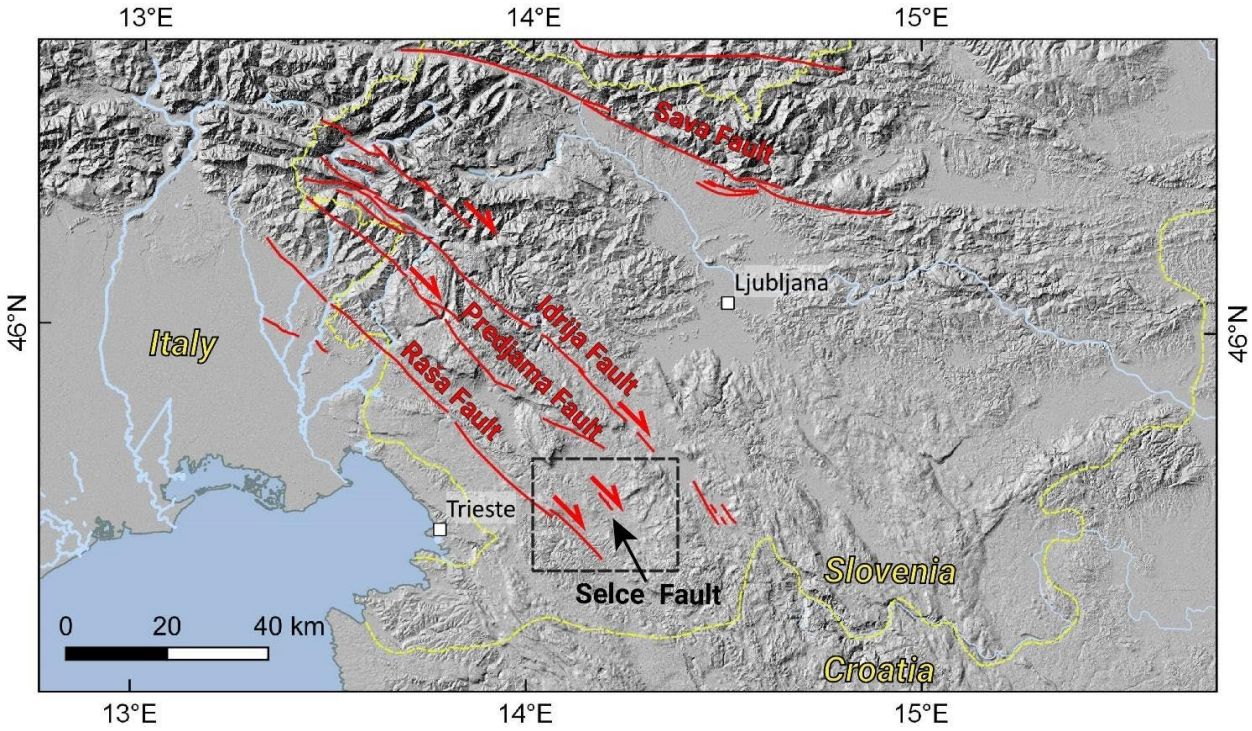

Figure 1: Location of the Selce Fault in SW Slovenia. Hillshade is from the 1 m LiDAR DEM of Slovenia (ARSO).

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PLEISTOCENE AND HOLOCENE ENVIRONMENTAL CHANGES IN THE EASTERN PART OF THE MID ADRIATIC DEEP INFLUENCED BY SEA-LEVEL RISE AND SHORELINE RETREAT

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During a 21-day long cruise onboard the RV Poseidon in the year 2017, a multinational team of scientists collected water and sediment samples in the Adriatic Sea. The cruise POS514 entitled „Micropaleontology, Actuopaleontology, and Environmental Baseline Study of the Holocene to latest Pleistocene in the northern and eastern Adriatic Sea basin" comprised scientists from German, Italian, Croatian, and Austrian institutions. Scientists measured water column properties with CTD probe, collected biological samples with plankton multi net, and collected sediments with long gravity cores, short multi-cores, Van Veen grabs, Box cores, and Frahm corer on 40 sampling stations (Figure 1a).

The gravity core POS514-40-11 GC was collected along the Eastern Adriatic Coast in the northern rim of the Mid Adriatic Pit (Figure 1a) at a water depth of 212.5 m b.s.l. Its total length is 690 cm. The core is of special interest due to the focus of the Croatian Science Foundation project QMAD, with extensive studies in the area of the Krka River estuary and its development towards the MAD during the Pleistocene and Holocene eustatic sea-level fluctuations. The dating of the core was established with five dates using the AMS 14C method, calibrated with the IntCal20 calibration curve in the Clam software (Blaauw, 2010). The oldest date reached 17 900 cal BP at the core depth of 628 cm. The dates were used to create the age-depth model and calculate sedimentation rates (SR) in the MAD (Figure 1b). The peaks of the measured 137Cs activity were not completely conclusive. Other methods used for the core determination include measurements of the particle size (PSA), magnetic susceptibility (MS), carbon and nitrogen (Total C, Total N, C/N ratio, Total Organic Carbon (TOC%), Total Inorganic Carbon (TIC%)), bulk density (BD) (wet and dry), mineralogical (XRD) and derived values as Mass Accumulation Rates (MAR) and Accumulation Rates of C, N, TOC%, and TIC% (Figure 1c).

A distinct change in SR, BD, as well as in MAR that starts from 9 440 cal BP to 12 100 cal BP and remains high until the end of the core. Values of the TOC% show the opposite pattern. There is a sudden rise in TIC % and MS at the lower part of the core, at 15 150 cal BP, coincident with a PSA peak of sand particles (Figure 1c). In general, sediments of the whole core are dominantly silty with 20% to 30% of clay-sized particles, with two short sand intervals. The other peak of sand particles occurs at 8 800 cal BP and can also be observed in MAR and TIC%. The C/N ratio is uniform in a range of 7 to 8, with one distinct peak at 13 000 cal BP reaching 9.8.

Based on XRD analyses the main difference throughout the core is the amount of two dominant minerals – quartz and calcite. Within the top 2.7 meters (9 700 cal BP) of the core, the amount of the calcite is higher than the quartz, while in the part from the third to the fifth meter (14 700 cal BP) the amount of the quartz is higher. From the fifth meter to the bottom the amount of calcite is again higher than the amount of quartz. This coincides with changes in the other parameters measured within the core (MS, TIC MAR) (Fig 1a).

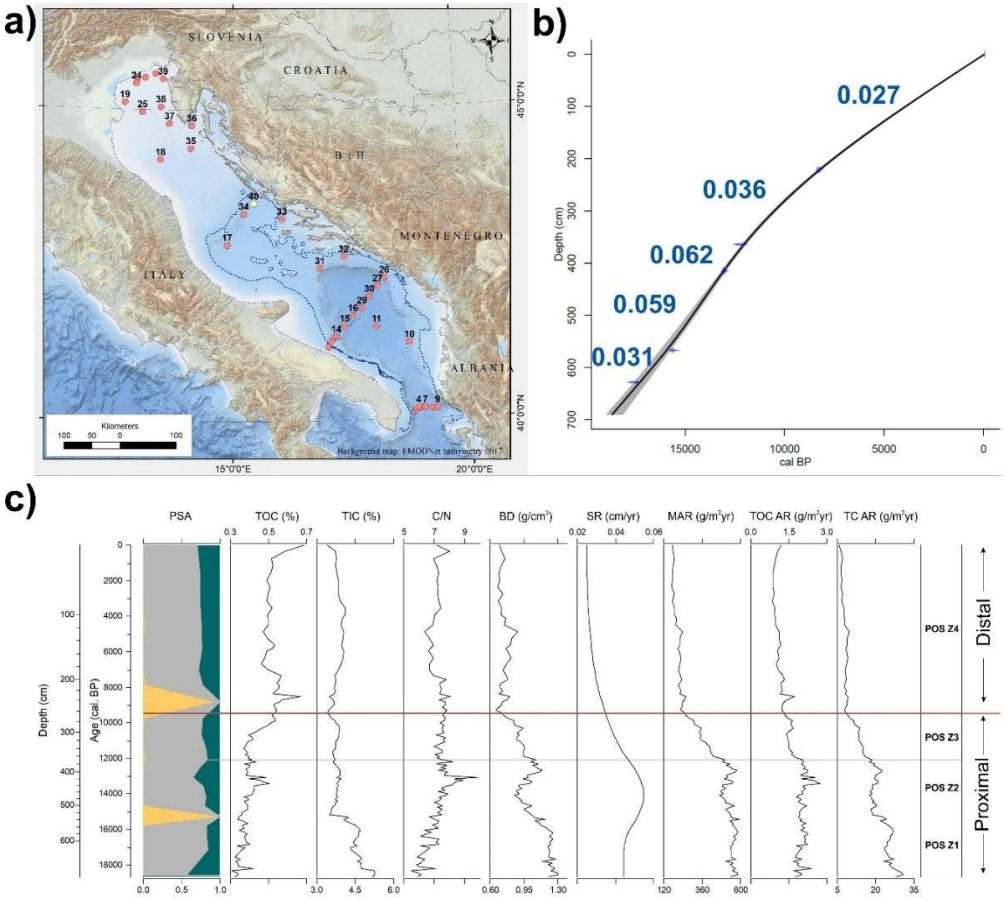

Figure 1: a) Sampling locations of the POS514 scientific cruise. A location POS-40 is marked in yellow. Dashed blue line represents LGM lowstand paleocoastline at -123 m b.s.l.; b) Age depth model based on five AMS 14C calibrated dates. Sedimentation rates are marked with blue numbers in mm/yr; c) graph with the main result of the core analyses and defined zones. Yellow background in PSA graph represents sand grain size particles, grey color represents silt, green color clay size particles.

Collected data enabled us to define four distinct zones throughout the core (Figure 1c). The zone POS Z1 extends from the bottom of the core until 15 150 cal BP. It is followed by the POS Z2 zone with a transition to the third zone (POS Z3) at 12 090 cal BP. The youngest and the longest zone POS Z4 extends from the 9 440 cal BP to the surface. Zones Z1 and Z2 deposited in the environment proximal to the coastline, with more pronounced terrestrial and coastal influence on the sedimentation. Zone Z3 represents gradual coastal retreat further from the location due to sea-level rise, with diminishing coastal effect. The youngest zone Z1 was sedimented in the deeper water distal environment that lasts until the present. The obtained results will be extremely helpful in the interpretation of high-resolution acoustic profiling that is planned for the next project period.

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PROPERTIES OF THE UPPER PART OF THE LAST GLACIAL LOESS-PALAEOSOL SEQUENCE AT SAVUDRIJA (ISTRIA, CROATIA)

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As part of the investigations carried out under the bilateral Croatian-German project NALPS (North Adriatic Loess-Paleosol Sequences), the 7.5 m thick loess-paleosol sequence was investigated with a modern soil on top, overlying the Cretaceous limestone at Savudrija. Within the 7.5 m thick profile, a total of 17 samples (Figure 1) were taken and subjected to various analyses in order to determine the provenance of the modern soil/palaeosol parent material and to reconstruct the conditions of its paleopedological evolution.

The subject of this study was the upper part of the 7.5 m thick profile, consisting of modern soil on the top of the loess-paleosol sequence (between 0 and 205 cm). Six horizons were recognized within the studied sequence, arranged from top to bottom: AB-B-BC-CB-2BC-2C. Laboratory work included chemical analyses, particle size analyses, analyses of iron and manganese oxides and hydroxides soluble in dithionite citrate bicarbonate and oxalate, detailed physical and chemical analysis of the palaeosols (including measurements of CEC and base saturation), mineral composition analysis (using the XRD method), quartz optically stimulated luminescence (OSL) dating and micromorphological analysis of thin sections.

This study showed that the uppermost part of the sequence studied was represented by presumably polygenetic soil developed on loess (AB-B-BC-CB) underlain by brown palaeosol developed on older loess (2BC-2C). Based on the Sm/Nd and La/Ce geochemical ratios (Sheldon & Tabor, 2009), it was also determined that the loess parent material examined in this study has the same provenance as the materials examined in Baniček (2016) and Durn et al. (2018a, b).

XRD analysis revealed that all soil samples contain a significant amount of quartz, plagioclase, alkali feldspar, illitic material, kaolinite, chlorite, 14 Å minerals (vermiculite and/or smectite), mostly irregular mixed-layer clay minerals, goethite and amorphous components, whose content increases with depth. The micromorphological investigations have shown a significant proportion of rhizoconcretions, iron-manganese concretions and clay coatings, indicating significant illuviation in the horizons of the uppermost part of the Savudrija pedosediment complex. Based on quartz OSL dating, the age of the studied soil horizon CB is 9 ± 0.8 ka and of soil horizon 2C is 20.9 ± 2.1 ka (Zhang et al., 2018).

As part of the research preparation, this work has been supported in part by the Croatian Science Foundation under the projects ACCENT (3274) and WIANLab (8054).

Figure 1: A photo of the profile through pedosedimentary complex in Savudrija, with demonstrated sampling locations (left) and the part of the pedosedimentary complex that was investigated in Hećej (2017) (right)

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LOESS-PALAEOSOL SEQUENCES IN UKRAINE: A POTENTIAL LINK BETWEEN EUROPEAN AND ASIAN PLEISTOCENE ENVIROMAGNETIC RECORDS

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The loess-palaeosol succession of Ukraine represents one of the thickest and the most complete terrestrial archives of the Pleistocene environmental changes in Europe. Nevertheless, it has not been yet studied fully, particularly from the viewpoint of geochronology and magnetostratigraphy. The loess-palaeosol sequences (LPS) provide possibilities for high-resolution stratigraphic subdivisions and, thus, the reconstruction of short-period palaeoclimatic changes, which can be quantified for intensity using lithopedology, pollen and rock magnetic properties of the studied sub-units, supported by geochronometric data.

Here we provide a summary of recently investigated LPS of Ukraine: at Vyazivok and Stari Kaydaky (the Middle Dnieper area), Roksolany and Kurortne (the NW shore of the Black Sea), Boyanychi and Korshiv (Volhynian Upland; Bakhmutov et al., 2017; Hlavatskyi and Bakhmutov, 2020; Hlavatskyi et al., 2021). The results are compared with those from the previous studies (Rousseau et al., 2001; Buggle et al., 2009; Nawrocki et al., 1999), and with the other sites, which we investigated by the multidisciplinary approach (Medzhybizh, Holovchyntsi, Adzhamka, Muzychi etc., including a new profile of Dolynske).

In the reference sections of the Ukrainian LPS (at Vyazivok, Roksolany and Muzychi), the Matuyama–Brunhes boundary (MBB) has been established in the lower part of the Shyrokyne soil unit; it was not revealed in the upper part of the Shyrokyne unit at Stari Kaydaky (the study of this section is in progress). At some sites, multiple geomagnetic excursions were detected as well. The succession below the MBB shows the alternation of north-boreal environments in loess-like clayey loams with subtropical or transitional to subtropical environments in palaeosols. In the succession between the MBB and the Lower Zavadivka unit (the correlative of the Holsteinian), the periglacial environments detected in loesses alternated with forest and prairie-like ecosystems of warm-temperate climate revealed in the palaeosols. Starting from the Tyligul loess (MIS 12), loess accumulation rates increased upwards in response to relatively more arid steppe environments (with exception of the loess units, correlated with MIS 10 and MIS 4). The palaeosols of the Late Middle Pleistocene were formed under warm-temperate climate, and those of the last interglacial under temperate forest and forest-steppe ecosystems. Palaeosols of the Upper Pleistocene interstadials developed in the forest-steppe and steppe environments of a boreal climate. Tundra elements were abundant in the vegetation during the Upper Pleistocene loesses accumulation. The contrasting environments of the periods of loess and palaeosol formation are reflected clearly in the changes of rock magnetic parameters. In central and southern Ukrainian LPS, the magnetic susceptibility increases and decreases in a very good correspondence with the amplitude of palaeoenvironmental changes recorded within the warm and cold stages (the alternation of interstadials and stadials), but it does not depend on lithostratigraphy in the Volhynian Upland (due to gley process development).

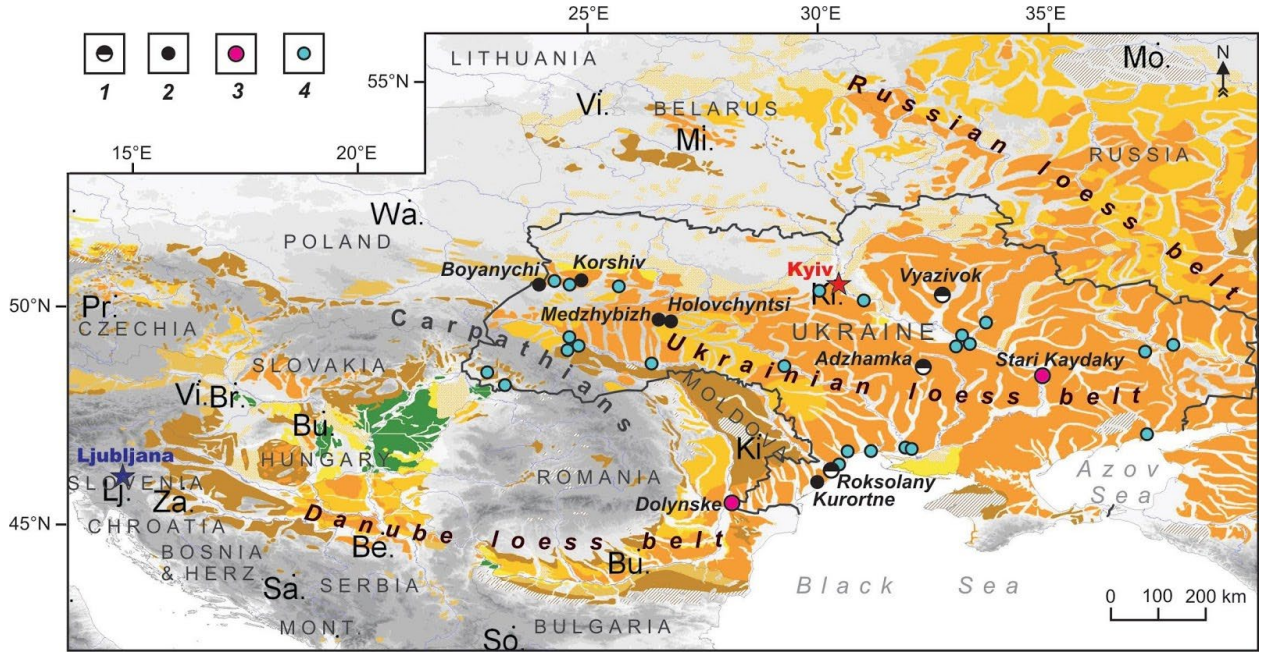

Figure 1: Location map of the sections studied against the background of the map of loess deposits in Europe (Haase et al., 2007): 1 – the sites with recently detected MBB (Hlavatskyi, Bakhmutov, 2020 and references therein); 2 – the sites with recently studied rock magnetic indices (Bakhmutov et al., 2017); 3 – the sites studied formerly with palaeoenvironmental proxies and palaeomagnetic approach; 4 – the sites under the present multidisciplinary studies.

The revealed succession of palaeoclimatic events represented in the LPS of Ukraine is preliminarily correlated with that from the Danube Basin and China, and the correlation problems are discussed in detail.

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FIDELITY OF (PALEO)ECOLOGICAL INTERPRETATION BASED ON STUDIES LIVING AND DEAD BENTHIC FORAMINIFERAL ASSEMBLAGES: A CASE STUDY FROM THE NORTHEASTERN ADRIATIC SHELF (KOPER BAY, SLOVENIA)

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Benthic foraminifera collected in coastal to deep-marine environments are widely used for (paleo) ecological interpretations. The use of foraminifera as proxies for ecological parameters requires the necessary study of living foraminifera to assess their ecology and test geochemistry. It is necessary to define the original environmental conditions, which is almost impossible in the case of coastal and transitional marine settings due to human activities. A good alternative is to study sedimentary records (Alves Martinis et al., 2019). Comparison of living (LA) and dead (DA) assemblages is not straightforward because of the role of taphonomic processes in preservation of DAs.

The studies of benthic foraminiferal assemblages from different locations along the eastern Adriatic coast show a low percentage of stained tests. The samples were collected from different habitats (intertidal salt marshes, bays and lagoons and open marine settings), with different sampling techniques (gravity corers, Eckman grabs or simple manual sampling by divers), at different depths (from 0.3 to 44 m), and from spring to late autumn during the last two decades. The question arises what conclusion we can draw from the discrepancies between LAs and DAs. Should we study the total (TA), or the living or dead assemblages? For biomonitoring, the FOMIBO protocol is clear (Schönfeld et al., 2012), only living. Since, the inner part of the shelf, where most studies were conducted (Popadić et al., 2013; Vidović et al., 2014 and references), is considered a dynamic area (waves, currents) where the sedimentary processes prevent the development of large LAs and strongly influence the preservations of DAs, the TAs seemed to contain most of the information and therefore were analyzed.

This study compared the composition and biodiversity indices of TAs, DAs and LAs from two 10 cm long sediment cores KPF1 and REF (surface 0 – 2 cm and 4 – 6 cm, and due to a low number of specimens in the surface interval for REF the 2-4 cm interval was analysed) recovered from 13.6 and 18.5 m water depths in August 2014 in Koper Bay (NE Adriatic Sea). The DAs have higher diversity than LAs, while TAs have the highest. The LAs show lower values of species richness and the larger values of the Fisher and Evenness indices. In general, the lower discrepancy occurs when the values of Shannon-Weaver H' biodiversity and Simpson 1 - D dominance indices are compared between three types of assemblages. When stained tests were rare, the differences between the indices values were large, indicating the role of depositional processes in preservation and accumulation of empty tests. The study showed that interpretation of ecological condition based on biodiversity indices was highly variable when stained tests accounted for less than 10% of the total assemblages. Although the LAs show the small number of species, the indices suggesting environmental stability, heterogeneity and dominance are similar except for evenness (a small number of tests means that 90% of species are represented by single specimen).

The interpretation presented in this study was carried out in the context of investigations within the BREEMECO project founded by the Croatian Scientific Foundation IP- 2019-04-5775. The sampling was taken by the technical support of National Institute of Biology, Marine Biology Station in Piran.

	KPF 1 (0-2 cm)			KPF 1 (4-6 cm)			REF (0-2 cm)			REF (2-4 cm)			REF (4-6 cm)		
	TA	DA	LA	TA	DA	LA	TA	DA	LA	TA	DA	LA	TA	DA	LA
S	40	37	12	36	29	26	31	31	3	32	30	15	42	38	23
1-D	0.89	0.88	0.89	0.89	0.86	0.93	0.90	0.89	0.62	0.82	0.83	0.89	0.86	0.89	0.92
H'	2.68	2.59	2.56	2.67	2.40	2.30	2.77	2.70	1.04	2.39	2.30	2.44	2.70	2.65	2.86
e	0.37	0.38	0.90	0.40	0.38	0.50	0.50	0.52	0.94	0.33	0.60	0.76	0.72	0.73	0.76
α	12.65	11.60	13.98	8.87	7.19	16.57	10.06	9.23	5.40	9.20	9.02	9.94	13.08	13,86	13.64

Figure 1: Comparison of the values of the indices. TA= total assemblages, DA= dead assemblages, LA= living assemblages, S= species richness, 1 - D= Simpson dominance index, H'= Shannon-Weaver index, e= evenness index and, α= Fisher index.

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THE ARCHAEO-GEOPHYSICAL EVIDENCE OF THE PILE-DWELLING SETTLEMENT GORNJE MOSTIŠČE ON LJUBLJANA MOOR

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Geophysical surveys as complementary techniques to archaeological excavations of prehistoric pile-dwelling sites on Ljubljana Moor were practically non-existent until the last decade. Therefore, the multi-method geophysical approach applied at Gornje Mostišče can be considered as the most comprehensive geophysical study of a prehistoric settlement at Ljubljana Moor thus far.

The Eneolithic pile-dwelling site of Gornje Mostišče is located in the SE part of Ljubljana Moor on the modern floodplain of the Ižica river (Fig. 1a), about 0.5 km SE from the well-known pile-dwelling site of Maharski prekop and 150 m NE from the site of Resnikov prekop (e.g., Budja, Mlekuž, 2008). It was first noticed based on lidar images, which showed an area of 100 × 44 m with a topographic relief of up to 0.6 m above the surrounding area. Archaeological excavations with three small-scale trenches on the southern side of the site uncovered several mostly burnt Eneolithic cultural horizons with preserved wooden construction underneath (Fig. 1e: S4, S1 and S3), interpreted as a plateau (Mlekuž, 2013).

To gain a more detailed insight into the overall settlement structure and its surroundings, a multi-method geophysical approach was essential. Using gradient mode magnetometry, earth resistance mapping, ground penetrating radar (GPR), and electrical resistivity tomography (ERT), which are all established techniques in the field of archaeo-geophysical research (e.g., Mušič et al. 2014; Horn et al., 2018), we were able to outline the extent of the settlement area and describe its internal structure in more detail.

Stronger magnetic gradient anomalies (Fig. 1b) caused by thermoremanent magnetization in burnt archaeological horizons are present throughout the settlement, the strongest anomalies with regular shapes are located on the western side of the settlement and most likely reflect dwellings. Stronger GPR reflections (Fig. 1c) occur at the interface between the sediments and the burnt archaeological layers, explaining the extent of occupation at different depth levels. Earth resistance anomaly map within the bulk depth interval 0 - 1.5 m (Fig. 1d) shows about 20 separate high resistance anomalies, probably associated with separate dwellings/buildings. The purpose of the ERT survey was to provide stratigraphic and structural information of the study area. The correlation of the resistivity layers observed in the ERT 1 inversion model and archaeological horizons in trenches S4, S1 and S3 (Fig. 1e) was analogously applied to the ERT survey areas in the central part of the settlement, where in addition to 2D ERT profiles, we carried out a quasi-3D ERT survey at the site of the strongest regularly shaped magnetic anomalies (Fig. 1b).

The further integration of geophysical data provides additional information about the settlement structure and the surrounding natural environment. However, the interpretation of the geophysical data is not straightforward due to the rather complex past environmental conditions, which have not yet been fully elucidated (e.g., Andrič, 2009; Verbič, 2011).

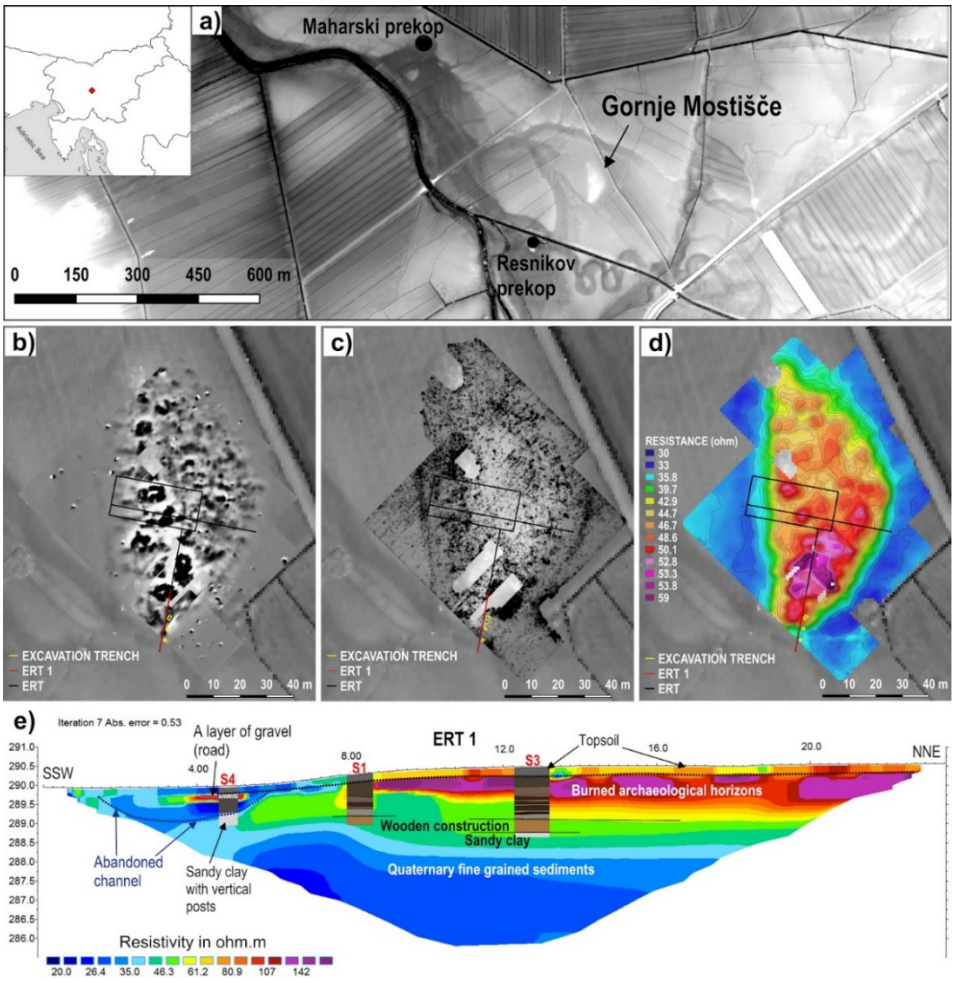

Figure 1: a) DMR from lidar data with the shown location of archaeological site Gornje Mostišče; b) Magnetic gradient anomaly map; c) GPR results at depth 1.4 – 1.7 m; d) Earth resistance map within the bulk depth interval 0 – 1.5 m; e) Inversion resistivity model of the profile ERT 1 and projected profiles of excavation trenches S4, S1 and S3.

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PALEOLIMNOLOGY OF HOLOCENE KARST LAKES ALONG THE EASTERN ADRIATIC COAST

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Lake sediments provide opportunities to reconstruct aquatic ecosystems through the past. Evaluating the stored environmental information in the sediments depends on the knowledge about the ecosystem and the understanding of the present-day lake response to environmental variability. Lake sediments are the result of the input material from the catchment and the lake productivity itself. Terrestrial input to the lake is carried through erosional processes and anthropogenic paths. Knowing the processes driving the terrestrial input is essential to understand for instance carbon deposition and nutrient input, which are linked to climate through weathering and transport processes. On the other hand, understanding the anthropogenic impact is key to assess the environmental status of a lake today and in recent history. Karstic lakes, wetlands, paleolakes as present karstic poljes in the central Mediterranean, Eastern Adriatic, are studied to determine depositional environmental changes. In carbonate bedrock, karstic processes such as dissolution and collapse are very effective in creating drainage patterns and depressions for lake development, which leads to the formation of dolines filled with water. Development of lakes on limestone substrate favors carbonate-rich waters. Therefore, endogenic carbonates are the main components of the Eastern Adriatic lake sediments in Croatia. The lakes are relatively small and relatively shallow (3 to 55 m). The depositional environment in such lakes is dynamic, with abrupt changes in geochemical and sedimentological parameters. Hydrology is dominated by groundwater inflow, with none with a direct connection to the fluvial drainage. Direct connection to aquifers makes the system very sensitive to regional hydrological balances, evident in lake level fluctuations. The key compositional properties for the karstic area are carbonate versus siliciclastic and organic material, to reconstruct environmental changes. Karstic freshwater lakes are subject to endogenic carbonate production during the dry summer periods, triggered by aquatic productivity. The main aspects considered in the present work are lake evolution under the light of sedimentary, geochemical and mineralogical processes; endogenic lake carbonate production/formation; and the association between limnological evolution and climatic changes. The endogenic carbonate production in karstic lakes is tested to the registration of the climatic signals throughout the Holocene and the influence of the seawater on the lake ecosystem. In studied lakes, the main sedimentological and geochemical characteristics in mainly profundal environments were described and paleoenvironmental changes during the Late Pleistocene/Holocene were interpreted. There will be mentioned karstic barrier lake on the Eastern Adriatic coast, Lake Prokljan as marine lake and Lake Visovac in River Krka, alongside submerged paleolake systems in the karstic isolated basins, like present marine lake Veliko jezero on the Island of Mljet, as well as paleolakes in Pirovac and Lošinj Bay.

THE PAKOŠTANE LOESS PLATEAU REVISITED; DATING, SEDIMENTOLOGICAL, MINERALOGICAL AND GEOCHEMICAL CHARACTERIZATION

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Loess and loess-like deposits represent valuable material of past climate change in areas where long-term terrestrial records are scarce, such as Dinaric karst on the Eastern Adriatic coast. Quaternary sediments of the so-called Pakoštane Loess Plateau (Marković-Marjanović, 1975) are exposed on the steep vertical profiles on the coast and extend 1 km in length east from the town Pakoštane in central Dalmatia, Croatia. Previously, it was described based on the lithological composition as the sediment of eolian origin (Marković-Marjanović, 1975). Here, we present the time frame and the environmental significance of variations in the magnetic susceptibility (χ), frequency-dependent magnetic susceptibility (χfd), rock-magnetic data, the grain size, clay and heavy mineral and geochemical composition of the sediment profile. The sediment succession developed on limestone bedrock consists of red paleosol, brown paleosol, sand, conglomerate, loess and topsoil. It has been dated by the optically stimulated luminescence (OSL) method to the marine isotope stages MIS 4, 71.2 ± 5.9 ky BP (base of the loess). Brown paleosol and sandy deposits below conglomerate indicate ages between 122.5 ± 9.3 and 203 ± 18 ky BP. Our results indicate that the paleosol and loess deposits consist of both detrital dust and material produced during pedogenesis. An integrated analysis of records of magnetic susceptibility and remanence data (χ, χfd, ARM, SIRM) indicates the magnetic enhancement in red and brown paleosol compared to the rest of the profile, as well as higher clay content. The proportion of the clay fraction decreases upwards, suggesting a relatively drier and colder climate. Bulk grain sizes are compared to the non-carbonate fraction, which showed that upper parts of the loess profile belong to fine-sand fraction, while lower loess to the coarse-grained silt fraction. Clay and heavy minerals reveal the similar composition of paleosol and loess deposits and similarity to the loess deposits on the Island of Susak. The presence of calcite suggests reduced weathering. The REE distribution patterns of the loess and paleosol samples are remarkably similar in shape, with enriched LREE and fairly flat HREE profiles and clear negative Eu anomaly. These chemical characteristics provide further evidence for eolian sedimentation of the loess deposits. Determination of Pakoštane loess plateau as eolian material from the river Po, as the well-known loess on the Island of Susak (northern Adriatic Sea), would make it an important site as the southernmost loess in Croatia.

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LATE QUATERNARY SEDIMENTOLOGICAL AND GEOMORPHOLOGICAL PROCESSES IN THE PROLOŠKO BLATO KARST POLJE (IMOTSKO POLJE, CROATIA)

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Prološko Blato is a karst wetland situated in the NW part of the Imotsko polje (Dalmatian hinterland). It is a typical example of Dinaric karst polje, with many hydrogeological and geomorphological features such as lakes, springs, estavelles, making it suitable for multidisciplinary paleolimnological research. We conducted percussion drilling in the polje and geophysical survey (GPR, geoacoustics), supported with aerial photogrammetry, to determine the paleoenvironmental conditions, geomorphological and hydrological changes from the Late Pleistocene through the Holocene. Two sediment cores (6,5 m and 9,2 m long) were analyzed by multiproxy approach (sedimentology, mineralogy, geochemistry, micropaleontology) and radiocarbon dating, to determine the time-span of the lake sediments and timing of significant sedimentary changes. Results show that the Last Glacial Period (from ~30 ka cal yr BP to the Early Holocene) is marked by sedimentation of fluvial and possibly fluvioglacial material, that was transported from the mountainous area of western Herzegovina (elevations greater than 2000 m) into the karst polje depression. Numerous dolines (sinkholes) distributed along the NW part of the polje served as depocenters for sedimentary material, while the morphology of these dolines implies their relatively young age of formation and active karstification processes. The Early Holocene (9,3 - 8 ka cal yr BP) is characterized with siliciclastic sedimentation in an „early lake“ environment of the Prološko Blato, while the Early-Late Holocene (8 – 0,8 ka yr BP) is marked by the lake deepening and authigenic carbonate sedimentation of lake marl, rich in ostracods, gastropods, and Charophytes. A distinctive lithological change in sedimentation occured at approximately 800 cal yr BP, from lake marl to greyish-brown clay, associated with transition from lacustrine to floodplain environment. Most probably, it is caused by the formation of the Prološko Lake in the eastern part of the Prološko Blato, associated with dissolution processes of limestones, and roof collapsing into an underground cavern, similar to the famous collapse dolines Red Lake and Blue Lake near the city of Imotski. This event corresponds to the well-known period of significant seismic activity in the Dinarides between 1000 and 1200 yr AD. The Imotski region is a seismically very active region, where earthquakes and their primary and secondary effects are historically well documented. The „collapse“ hypothesis is investigated by the paleolimnological research methods since we identified several historical and geomorphological evidence of collapse doline formation, usually after a stronger earthquake (M>5). Final results will contribute to our understanding of the geomorphological and sedimentological processes in the high karst zone of the Dinarides and will give us an insight into the timing and circumstances of the formation of karst lakes in the NW part of the Imotsko Polje.

THE LATEST ARCHEOLOGICAL AND PALEOENVIRONMENTAL FINDINGS REGARDING THE STUDIES OF THE PREHISTORIC PILE-DWELLING SETTLEMENT IN ZAMBRATIJA BAY, WHICH WAS SUBMERGED BY THE ADVANCING TRANSGRESSION

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The seabed of Zambratija Cove stores significant and unique archaeological finds that, once discovered, have added new pieces to the puzzle concerning the way of life and customs of prehistoric inhabitants of Istria.

The oldest underwater archaeological site in Zambratija Bay is a submerged prehistoric pile-dwelling settlement which was in use between around 4200 and 3700 years BC. The remains lie on the outer edges of a submerged karstic sinkhole (doline), 3 metres under the sea (3 mbsl). The site was initially recognised after finding a large number of finds such as pottery fragments, stone tools, as well as more than one hundred visible wooden piles protruding out of the seabed and peat platform. Interdisciplinary investigations showed that during the occupation, the settlement was still a terrestrial/wetland environment and that the abandonment of the pile-dwelling is chronologically connected with the marine transgression which happened sometime in mid-4th century BC. The found architectural features of the settlement showed a cultural and chronological connection to the UNESCO-protected prehistoric pile dwellings around the Alpine lakes and wetlands.

Other archaeological finds have also been discovered on the ridges in Zambratija Cove, indicating the continuity of human settlement all the way from the Bronze Age to the Roman period, when the ridges were part of the mainland. A 72-metre long structure interpreted as a probable Roman road has been preserved along the natural limestone reef that spreads towards the western side of the coast. The cove is also known for the discovery of the Zambratija boat, the oldest example of a completely sewn boat found in the Mediterranean, which was discovered in 2008 at a depth of around 2 meters. The hull remains measure 6.7 m in length and 1.6 m in width at the widest section. The boat remains date back to the period between the last quarter of the 12th and the last quarter of the 10th centuries BC. The analysis of the wood from the boat showed the use of different species which indicated that the species available near the coast, a rich freshwater environment characterized by marshes and coastal lagoons, were used. The construction principle applied to the Zambratija boat is based on the shell concept for the hull structure, and on a longitudinal, strake-oriented concept for its shape. This boat is the only evidence of sewn vessels in the Mediterranean in the transition period from the Bronze Age to the Iron Age, and it can be used as a determinant of the local shipbuilding tradition of later sewn boats in the North Adriatic region.

Figure 1: Aerial photo of Zambratija Cove bounded by natural limestone ridges (photo by: Löic Damelet).

Figure 2: The wooden pile that is a part of the radiocarbon dated 62-year oak dendrochronological sequence (photo K. Jerbić).

Figure 3: Architectural remains of the boat (left; photo by: P. Groscaux), and submerged structure, probably Roman road (right; photo by: I. Koncani Uhač), both found on the ridges of Zambratija Cove.

Figure 4: A 3D model of the submerged wreck (made by: Vincent Dumas, Pierre Poveda).

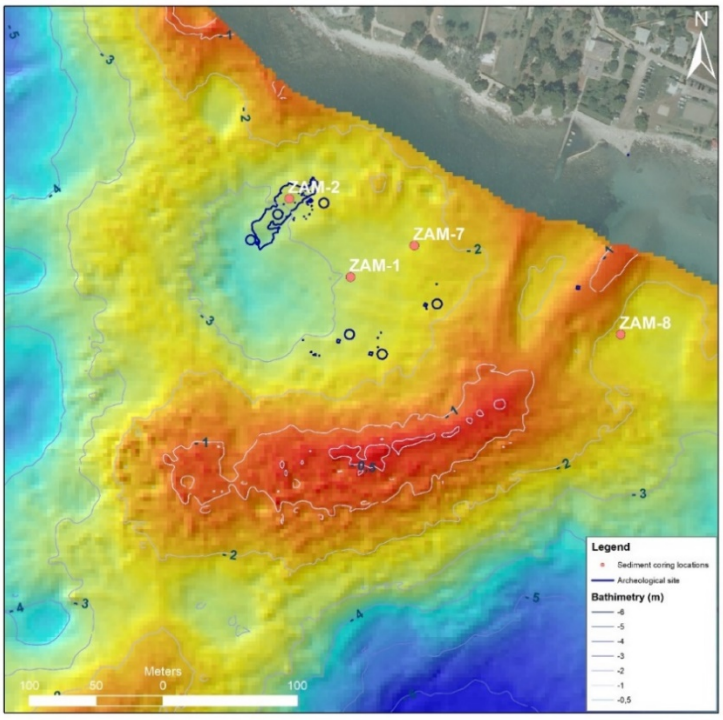

Figure 5: Bathymetry map of Zambratija Bay (multibeam sonar data), with marked archaeological site and sediment core locations used in paleoenvironmental interpretation (prepared by Ozren Hasan).

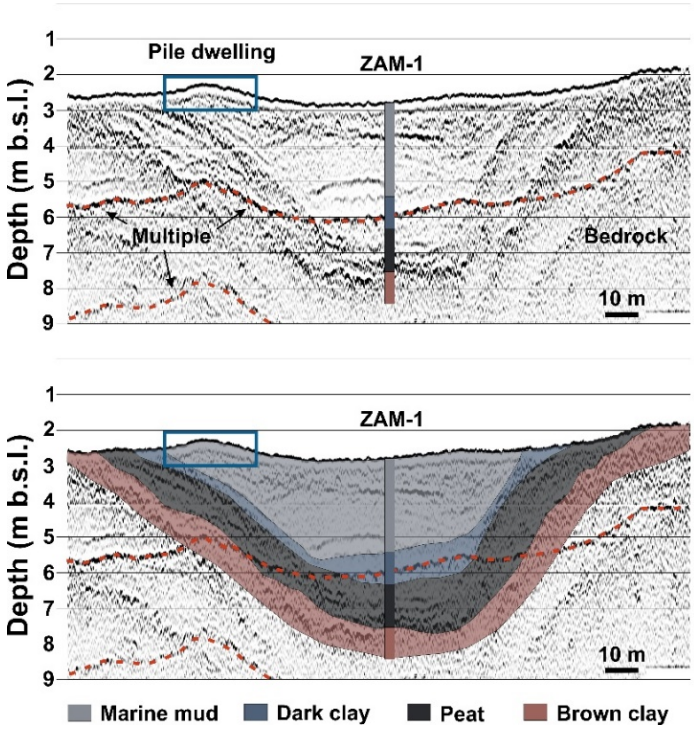

Figure 6: Sub-bottom profile and the position of ZAM-1 in the seabed in relation to the archaeological site (prepared by Ozren Hasan)

Geological research in Zambratija Bay was based on geophysical surveys (multi-beam and sub-bottom profiling) and seabed sediment coring. Sediment thickness in the submerged sinkhole reached up to 8 metres, with the maximum thickness at the eastern end of the sinkhole facing modern day shore, rather than the more expected central part of the sinkhole. The 5.7-metre long sediment core (ZAM-1) represents a record of paleoenvironmental and sea-level rise changes throughout the Holocene. Brown clay and terrestrial wetland and freshwater lake sediments were superimposed with thick marine sediments, deposited during the marine transgression since mid- to late Holocene until present times. Holocene marine transgression is evident by marine carbonate sediments containing marine shells and foraminiferas, covering terrestrial grey and brown clay sediments. The brown clay, which is situated at the very bottom of the sinkhole, represents the soil layer which served as foundation for prehistoric settlement wooden piles, found in situ. These clayey sediments show succession from highly magnetic sediments containing pyrhotite minerals, formed under marine influence through karstic underground. One-meter thick organic sediments are composed of peaty sediments with high TOC (15-30 %) and N (1.1-2.8 %) and compact fine-grained peat with high P, Fe and Mo, as well as significant amounts of vivianite. These organic sediments are characterized by lower values of $\delta^{13}C$ and $\delta^{15}N$ implying freshwater environment. Occurrences of vivianite are still visible in underlying brown clay freshwater pond sediments, containing much more siliciclastic material compared to above organic sediments. Lastly, indications of coastal freshwater springs in the bay provided additional environmental evidence for a sustainable lifestyle at the time of settlement occupation.

SEISMICITY OF ACTIVE FAULTS TRACKED BY ARCHAEOSEISMOLOGY IN TWO ROMAN TOWNS: SISCIA (CROATIA) AND CELEIA (SLOVENIA)

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Activity of faults in the Alps and Dinarides is being studied by archaeoseismology. Due to (literally) low-level preservation of Roman monuments in the region, we were limited to study deformed structures below ground.

Excavations of the Roman city of Siscia (Sisak, Croatia) yielded large chunks of thick brick walls (considered to be the city wall), collapsed in the adjacent ditch in their entirety. The wall is made of brick masonry on both sides and a thick concrete infill between them. Wall chunks are found in various orientations: the original layering of masonry is now mostly vertical or overturned. The remaining foundation displays features of twisting and shearing. We suggest that a major earthquake damaged the city wall of Siscia. Excitated by site effects of loose soil, high peak ground acceleration caused the wall to be removed from its foundation, landing it ultimately in the ditch nearby. Presumed intensity of the earthquake was IX. Fault activity within a couple of kilometres was responsible for this collapse. Rebuilding of the city wall in the late antique period suggests that the first wall collapsed between the beginning of the 3rd and the middle of the 4th century. This earthquake between ~200 AD and ~350 AD is missing from historical catalogues (Kázmér and Škrgulja, 2021).

The „City beneath the city" museum in Celje exhibits a paved Roman road, which suffered severe deformation. Built on fine gravel and sand of the Savinja river the road displays >40 cm difference in elevation between centre and edges. The city wall was built over the deformed road in Late Roman times. Foundation of the new structure contains statues and column plinths, suggesting that a surplus of decorative stones were available for construction. We hypothesize that a severe earthquake hit the town (intensity VIII-IX on the Environmental Seismic Intensity (ESI07 scale), causing widespread destruction, and seismic-induced liquefaction caused differential subsidence, deforming the road. Possibly the Sava Fault, running right next to the town, was the seismic source of this event.

Archaeosesimology is a powerful tool to recognize and parametrize past earthquakes.

Figure 1: Earthquake-induced deformation of Roman constructions. Left: city wall of Siscia, sheared off its foundation and collapsed in adjacent ditch. Right: Roman city wall of Celeia, built unconformably over the deformed road. Seismic-induced liquefaction occurred here during Roman times.

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SUBMERGED SPELEOTHEMS AND PHREATIC OVERGROWTHS ON SPELEOTHEMS (POS) AS INDICATORS OF RELATIVE SEA-LEVEL CHANGE ALONG THE EASTERN ADRIATIC COAST

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We present the preliminary results of U-Th dating and XRD, XRF analyses of 3 submerged speleothems collected within the project SEALeveL (HRZZ-IP-2019-04-9445) funded by Croatian Science Foundation. The main objective of the project is the study of algal rims and speleothems in order to reconstruct the relative sea-level changes and climate changes in different parts of the eastern Adriatic coast. One of the goals is to detect phreatic overgrowths on speleothems (POS), a secondary depositional structure (carbonate phreatic encrustation) which precipitates at the water table around pre-existing vadose speleothems if favourable geochemical conditions are acquired. So far, it has been used in sea-level research in only several locations in the world while most of the investigated sites are located in Mallorca (Onac et al. 2012). Recently, POS is presumed to be developed in eastern Adriatic coastal cave, offering a new tool for the study of relative sea-level change.

Up to now, 2 presumably POS samples (SIP-1 and SIP-2) have been collected from Šipun Cave (Cavtat, southern Dalmatia) and one speleothem with biogenic overgrowth from Kravljačica pit (Kornat, northern Dalmatia) (Lončar et al. 2020). To determine the Mg content in the collected samples and thus provide a quick feedback on the POS, four points on the cross section of sample SIP2 were selected for XRF analysis and a thin section for the XRD analysis. The obtained results show only minimal values of Mg and do not indicate marine or brackish origin of the analysed carbonates. The most promising is the outer crust (spot sample SIP2-4). XRD was performed to determine whether the fabrics of the collected samples resemble those of POS found elsewhere. Most of the observed fabrics of SIP-2 do not resemble characteristic fabrics observed in known POS. The zoned crystals from the inner part of SIP-2 sample resemble some crystals observed in POS from Japan (Miklavič et al. 2018), but they are also very similar to diagenetic crystals observed in normal speleothems.

U-Th dating was performed on 2 subsamples of SIP-1, one subsample of SIP-2, one subsample of KRA-1and a worm tube from KRA-1. Age of SIP-1 (6mm) is 479 394 ± 33 634 BP while the dating of SIP-1 (37mm) and SIP-2 (10mm) showed that they are deposited beyond the U-Th method, meaning that they are older than 600 000 years or that the calcite was lightly altered. The U-Th age of KRA-1 stalactite is 436 013 ± 25 099 years BP, while the worm tube incrustated at KRA-1, taken from a few mm depth into the outer layer is 12 146 ± 4 479 years BP. As such, SIP-1 and KRA-1 represents one of the oldest dated speleothem in Croatia and further stable isotope analyses will be conducted in order to gain the paleoclimate records.

Research of speleothems with biogenic overgrowth, POS and related vadose speleothems, will contribute to increase the knowledge on relative sea-level change along the eastern Adriatic, obtained from different recent studies. Since the POS investigation is the first of that kind in the Adriatic, information on their morphology, conditions and time of deposition, will contribute to a better understanding of the POS as sea-level indicator and will allow comparison with results from other parts of the Mediterranean basin.

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PETRINJA FAULT GEOMETRY AND ITS ACTIVITY REVEALED FROM RECONNAISSANCE GEOMORPHOLOGICAL OBSERVATIONS

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Petrinja Fault, also known as Pokupsko Fault, is a dextral strike-slip fault at the transition from the External Dinarides into the Pannonian Basin System in NE Croatia (Fig. 1A). In the past, it was recognised as a potential seismogenic source and included in the European Database of Seismogenic Faults (Basili et al., 2013). Recently, the M_w5.2, and M_w4.8 magnitude foreshocks on 28 December 2020, M_w6.4 magnitude mainshock of 29 December 2020, and the associated seismic crisis in Petrinja occurred here (Markušić et al., 2021). Field survey of the earthquake's environmental effects revealed a segmented surface rupture along the Petrinja Fault (Baize et al., in rev.).

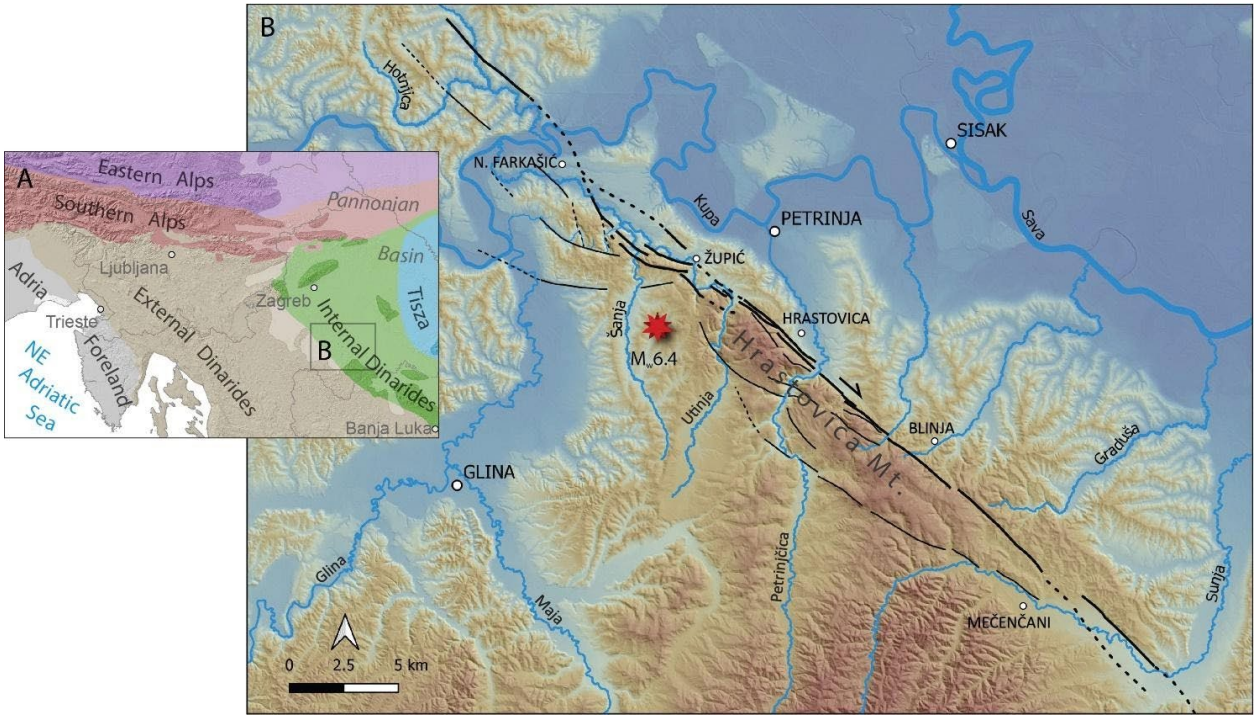

Figure 1: A – Study area and main tectonic units (simplified from Schmid et al., 2020); B – Lineaments associated with the structure along the Petrinja Fault

To better characterise this seismogenic fault and its long-term activity, we performed geomorphological analyses on Hrastovica Mountain and its surroundings (Fig. 1B). We mapped the lineaments that could represent active fault sections and compared them with published geological maps by Pikija (1987) and Šikić (2014). Stream sinuosity analysis of the main streams crossing the structure was performed to detect distinct changes in channel patterns that may be associated with vertical movement along the predominantly strike-slip fault. We observed changes in the shape of the valleys, particularly changes in width, height and direction associated with the faults.

The mapping of the lineaments, supported by field investigations, indicates fairly good correlation between the most abrupt changes in the stream sinuosity index and previously mapped faults. Some of the changes in stream sinuosity correspond to locations where coseismic surface ruptures occurred during the 2020 earthquake (Baize et al., in rev.). Long-term uplift of the Hrastovica Mountain is evident from the shape of valleys crossing the mountain; the wide valleys of Petrinjčica, Utinja and Šanja become narrow and deeply incised where they cross the uplifted structure. Geomorphological observations therefore suggest a dextral-transpressive structure with a series of subparallel fault strands branching from the main fault. The entire structure is 2-5 kilometres wide at the surface and corresponds to uplifted Neogene strata overlying Paleocene and Eocene strata. Steeper NE slopes, decrease in mountain elevation toward SW, and outcropping Paleocene and Eocene strata in the NE parts of the fluvial breakthroughs indicate asymmetric uplift, with the greatest uplift occurring on the NE side of the mountain. These observations suggest that the main active fault runs on the NE side of the Hrastovica Mountain, strikes NW-SE, and dips steeply toward SW.

While the focal mechanism of the 2020 earthquake is pure strike-slip, the transpressive nature of the structure may reflect its long-term activity or show the distribution of faulting toward the surface compared to a simpler structure at depth. In the future, more detailed studies using LiDAR data and age dating will provide quantitative estimates of fault activity.

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LATE QUATERNARY SEDIMENTARY EVOLUTION AND DEFORMATIONS OF DEPOSITS NEAR MOST NA SOČI (JULIAN ALPS)

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We studied Late Quaternary sedimentary succession in Modrejce near Most na Soči, located in an ice-marginal area during the Last Glacial Maximum and within the deformation zone of the Idrija Fault, a large, active, dextral strike-slip fault (Fig. 1). The succession preserves a record of palaeoenvironmental changes and a record of deformations. We studied the landforms and sediments by geomorphological and structural geological mapping, sedimentary facies analysis and optically stimulated luminescence dating. Our results show that the succession consists of glaciofluvial, glaciolacustrine, glacial and slope deposits deposited during two different glacial advances of the Soča Glacier reaching the Most na Soči area (Jamšek Rupnik et al., 2020): during the Penultimate Glaciation and the Last Glacial Maximum. The present staircase-shaped slope developed during and after the Last Glacial Maximum, when glacial and post-glacial processes carved into the older deposits. Slope deposition established during the Holocene.

The older glaciofluvial succession is tilted and cut by a series of faults and joints, glaciolacustrine layers also exhibit soft-sediment deformations. The deformations were studied using photogrammetric and levelling surveys, paleoseismological techniques and ground penetrating radar survey. Reconstruction of the deformation history indicates that at least five deformation events occurred during deposition of the studied succession in Penultimate Glaciation. Ground penetrating radar profiles and outcrop observations show an anticline with a N-S to NE-SW oriented axis, dissected with NE-SW striking faults that are approximately perpendicular to the primary Idrija Fault. Based on the local geologic setting, we considered three possible deformation mechanisms: glaciotectonics, gravitational faulting due to ice-decay or slope instability, and tectonic faulting. Following a detailed structural analysis, we interpret the observed deformations as secondary structures resulting from paleoseismic activity of the Idrija Fault and as structures resulting from glaciotectonics and gravitational faulting. The transtensional nature of the deformations at the studied site indicates the local character of the Idrija Fault, which can be explained by a local releasing bend in Modrejce Valley.

Our study sheds new light on the late Quaternary glacial history of the Most na Soči area and the seismic activity of the Idrija Fault and suggests a highly dynamic environment resulting from climatic changes and tectonic activity. First paleoseismic evidence from Penultimate Glaciation provides valuable new data for understanding the seismic hazard of this important fault.

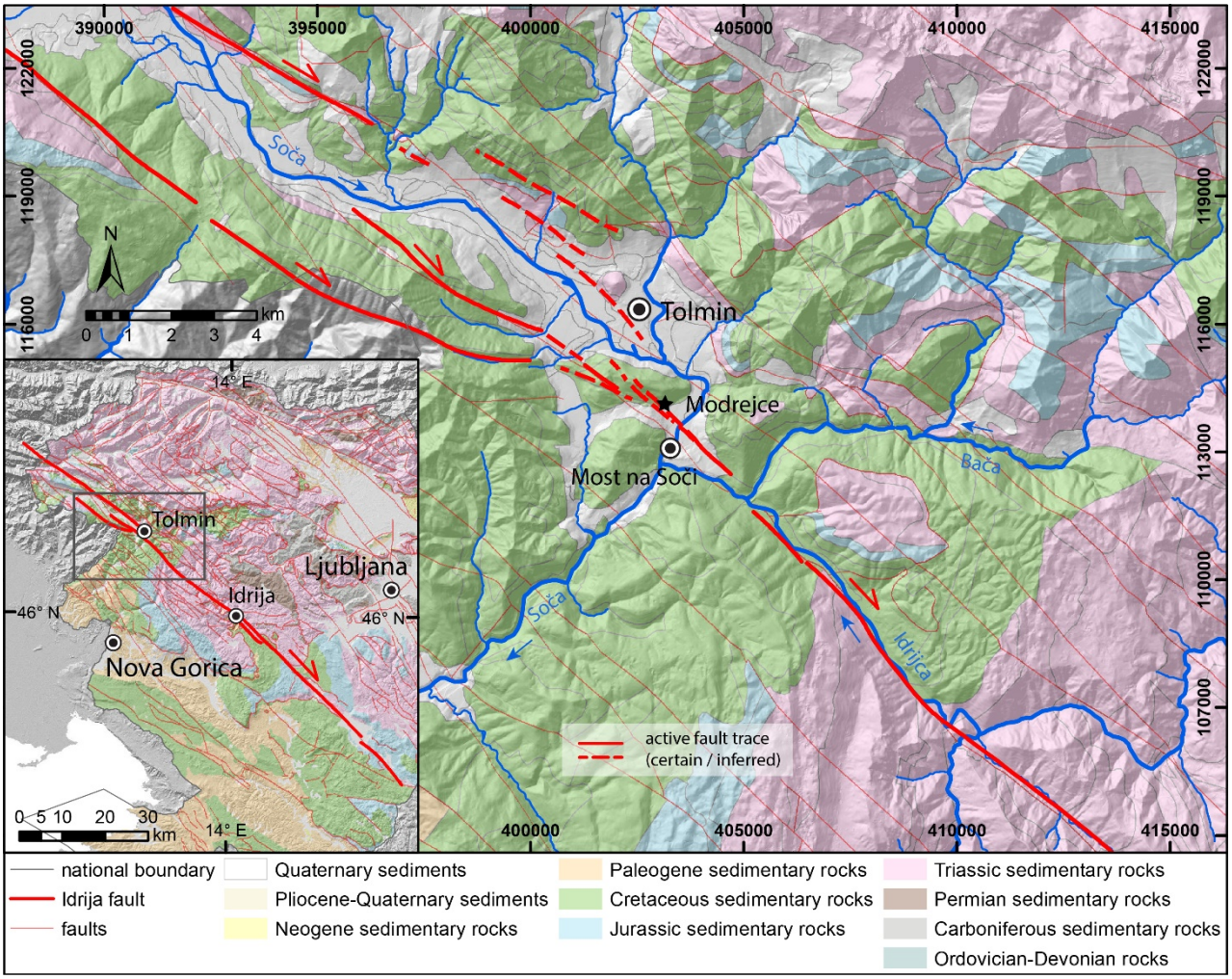

Figure 3: Overview of the study area with simplified geological units (from Buser, 2009), active trace of the Idrija Fault (as mapped in this study) and location of the investigated Modrejce outcrops near Most na Soči. Coordinates: WGS84 (inset map) and D48 (main map).

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MIDDLE PLEISTOCENE TO HOLOCENE PALAEOENVIRONMENTAL EVOLUTION OF THE SOUTH-EASTERN ALPINE FORELAND BASIN FROM MULTI-PROXY ANALYSIS

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The multidisciplinary analysis of two long sedimentary successions of continental and shallow marine deposits from the Venetian plain (NE Italy) provides new data on the stratigraphic architecture and the landscape evolution of the south-eastern Alpine foreland basin during the last 210-220 ka, with further evidences of a warm temperate phase older than MIS 8.
We present and discuss a detailed multi-proxy data set from these successions (GER1 and CB cores) (Marcolla et al., 2021). The results of stratigraphic, palynological and micropalaeontological analyses are cross-interpreted, showing the potentiality of building a composite section of two close continental successions within the same alluvial system, the Brenta megafan. The chronology of the upper part of the cores is supported by radiocarbon dating, showing the presence of Last Glacial Maximum (LGM) and post-LGM fluvial deposits. Lower down, the estimated chronology relies on the tight integration between palynostratigraphy and lithostratigraphy, on the recognition of main unconformities, as well as on the correlation with other regional biostratigraphic records and the Northern Hemisphere/global isotopic record.

The only marine transgression recorded in the studied successions is attributed to the MIS 7.3 and represents the basal tiepoint for the correlation between the two cores. Below the MIS 7.3 transgressive marine surface there is a fluvial succession with weakly-developed palaeosoils and a poor pollen content suggesting cold climate (possibly MIS 8), that lies on top of a thick peat layer showing palynological evidence of a warm temperate climate.

Whilst mixed temperate forest persisted throughout MIS 7c-7a, conifers spread during MIS 6. By this time, a glaciofluvial aggradation phase is recorded, highlighting the strong relationship between glacial maxima and alluvial aggradation in the Venetian plain. None of the drilling sites were reached by the Last Interglacial sea transgression. However, the Eemian forest signature is well recorded in CB core, and the following Early to Middle Würm stadial-interstadial sequence is clearly outlined thanks to the joint analysis of the two successions. Broad-leaved thermophilous forests disappeared at the end of the Early Würm and only *Pinus* and *Betula* persisted throughout the LGM, during which a chronologically well-constrained glaciofluvial aggradation occurred. The last depositional event corresponds to the post-LGM cut-and-fill of fluvial incised valleys in GER1 core, and to soil evolution and very thin burial by Brenta River fluvial deposits in CB core. The comparison between the results of this study with data of previous deep cores in the distal alluvial plain remarks an increasing long-term subsidence towards Venice area (Fig. 1).

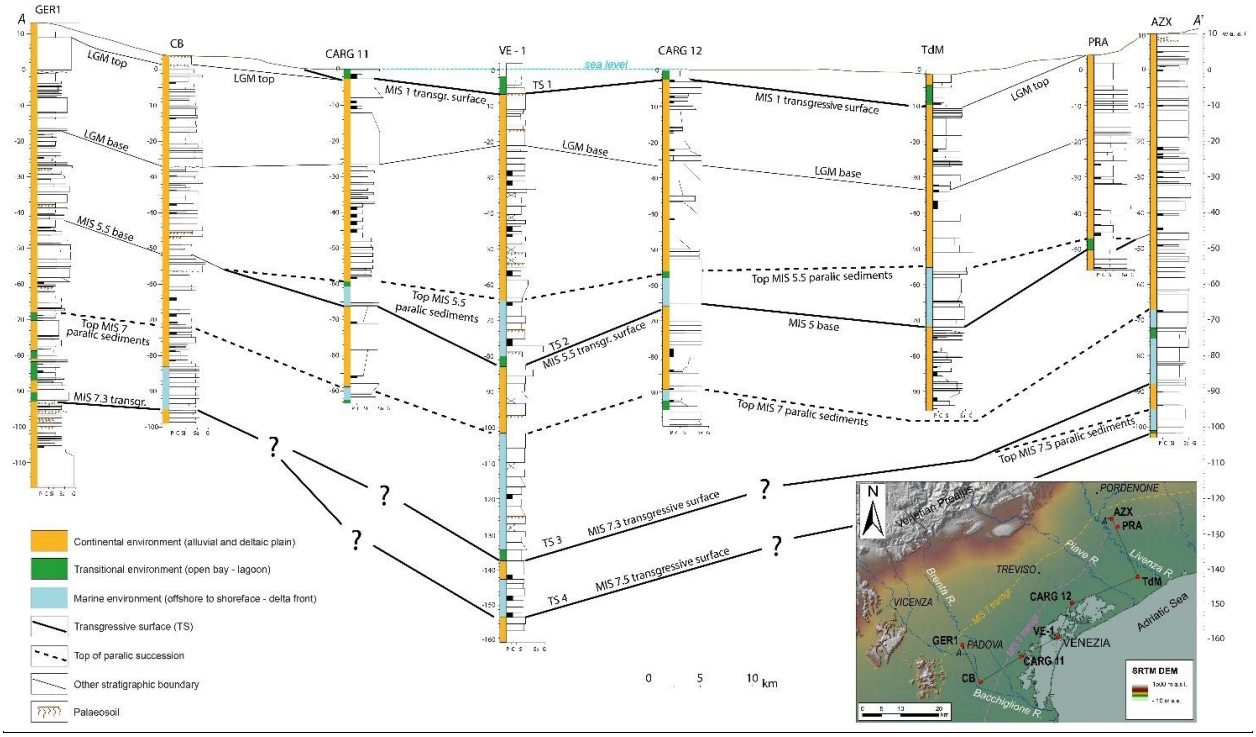

Figure 1: Stratigraphic section across the Venetian-Friulian plain from GER1 and CB cores (Marcolla et al., 2021) to Azzano Decimo (AZX) core (Pini et al., 2009); VE-1 is after Kent et al. (2002) and Massari et al. (2004); CARG 11 is after Tosi et al. (2007); TdM and PRA are after Fontana et al. (2010). The figure is from Marcolla et al. (2021).

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SUBMERGED LANDSCAPES OF THE EASTERN ADRIATIC SEA

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Submerged paleolandscapes of the Eastern Adriatic Sea host a large diversity of landscapes containing records of long-term paleoenvironmental change, climate, and sea level. The Croatian coastal region (Fig 1.) is a part of Maritime Dinaric Alps (termed also as the Dalmatian coast) which and coincides with the Mesozoic Adriatic Carbonate Platform (AdCP). To date, there is a very limited knowledge concerning the submerged karst paleolandscapes of the eastern Adriatic coast and the Late Quaternary sedimentary sequences along the eastern part of the Mid Adriatic Deep (MAD). Multidisciplinary research by application of the high-resolution geophysical surveys (multibeam, side-scan sonar and subbottom profiler), in combination with sedimentological, petrophysical, geochemical (trace elements and isotopes), micropaleontological allowed an unique insight to the geomorphology and processes that shaped the Eastern Adriatic seafloor. The submerged Late Pleistocene and Holocene environments that occur include isolation basins (karst poljes, dolines, lakes), lagoons, deltas, estuaries, submarine channels and shelf slopes. In the central part of the Adriatic these different environments compose an integrated system; thus, they can't be analysed separately. The existing gaps in understanding of the climatic and environmental changes, including sea-level related landscape changes and their interplay during the last Late Quaternary eustatic cycle.

A landscape reconstruction of selected sites, based on high resolution geophysical methods, allowed insight to the preserved changes of marine sediments, submerged landscapes and the morphology of paleo-lakes in Lošinjski kanal (Brunović et al., 2020), Kvarnerić, Novigradsko more and Karinsko more (Hasan et al.2020), Veliko jezero on Mljet Island (Razum et al., 2020), Telašćica bay, Pirovački zaljev bay and Koločepski kanal. The LGM lakes of Lošinjski kanal and Valun bay were flooded at onset of the Holocene (Brunović et al., 2020), while the Pleistocene lake in Pirovac bay was flooded by the sea 8 ky cal. BP and Veliko jezero on Mljet Island at 3 ky cal. BP (Razum et al., 2020). Flooding of the Kornati channel basin began 10,2 ky cal. BP. Based on detailed high resolution geophysical surveys it was possible to determine the thickness of Holocene sediments and the timing of drowning of the Krka river channel from its early Holocene mouth at Zlarin Island and the formation of the estuary 7500 years ago. The Pleistocene landscape of the Jadro river consists of an incised valley in Eocene flysch beds in Kaštela bay and a wide Pleistocene floodplain in the channel between the islands of Čiovo, Šolta and Brač, draining into the southern part of the MAD. Due to the low sediment yield from the Dinaric karst (Milliman et al., 2016) the sediment influx in basins during the Holocene the thickness of these deposits is in the range of less than < 3m. High-resolution seismic data were interpreted to reveal the structure of the late Pleistocene to Holocene deposits and determine the location of the paleoshorelines. Offshore Žirje Island it was possible to identify submerged high sea cliffs and marine abrasion platforms formed during standstills indicating paleoshorlines along the eastern slopes of the MAD, with relative sea level of: − 25m, − 55, -70m to-75, − 95, − 120 and − 135 m for MIS 5d, MIS 5b, MIS 3, MIS 4, and MIS 2 respectively. The geophysical and core data, as well as paleoecological reconstructions suggest that the route along the eastern Adriatic Sea was a land surface and habitable by at least about 11,000 years ago.

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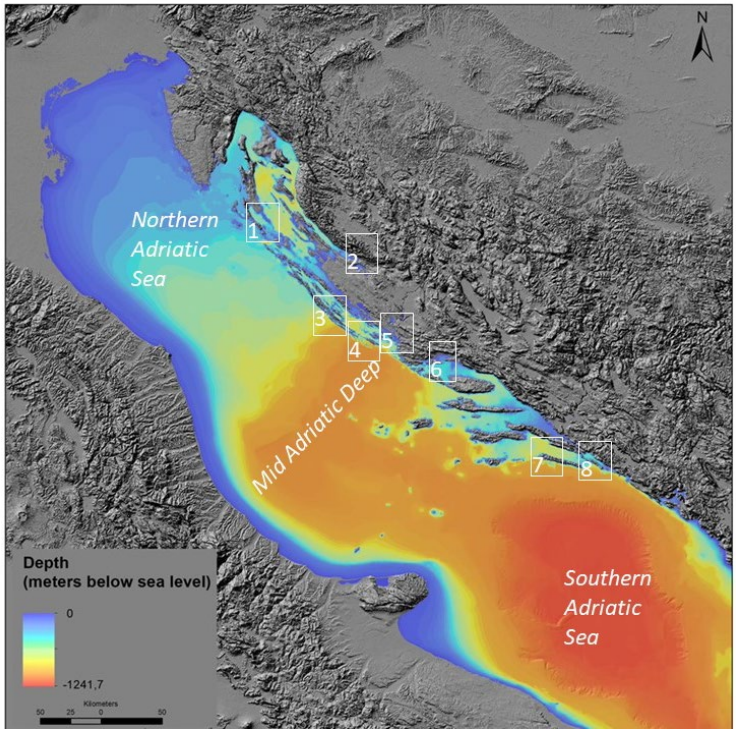

Figure 1: Bathymetry of the Adriatic with the studied site 1. Lošinj channel, 2. Novigradsko more, 3. Telašćica and Kornati channel, 4. Žirje Island and the eastern slope of MAD, 5. Krka river estuary, 6. Jadro river, 7. Veliko jezero, Mljet Isand, 8. Koločep channel.

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THE POST-LGM TRANSGRESSION AND THE CHANGE FROM FLUVIAL TO MARINE SEDIMENTARY ENVIRONMENTS IN THE GULF OF TRIESTE

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The northern Adriatic represents one of the many areas that were subaerially exposed during the global sea level lowstand which occurred during the Last Glacial Maximum. We focus on the Gulf of Trieste which is located in the northeasternmost corner of the Adriatic Sea and contains one of the most well-preserved, presently submerged and buried, pre-transgressional fluvial sequences known to date.

The transition from fluvial to marine sediments in this area was documented already in the 80s and 90s from studies of sedimentary material from boreholes (Ogorelec et al., 1981, 1984, 1991, 1997). However, the seafloor relief of the Gulf of Trieste was considered quite flat and monotonous. All of this changed more than 10 years ago when the first multibeam sonar-derived high resolution bathymetric models of the seafloor unveiled, among other things, a spectacular meandering belt and a distinct fluvial channel in the present seabed relief (Slavec, 2012). Later geophysical investigations revealed that these fluvial features were buried by a few meters of marine sediment, which has been depositing since the post-LGM transgression (Trobec et al., 2017, 2018). Detailed interpretations allowed to recognize different seismo-acoustic facies of the seabed sediments which were later ascribed a sedimentary facies interpretation (Novak et al., 2020, Ronchi et al., in preparation). Up until recently, the course or the aforementioned fluvial channel was reconstructed only on the Slovenian side of the Gulf (Trobec et al., 2017). New bathymetric data and interpretation of previously unpublished Chirp data from the Italian side of the Gulf allowed to extend the reconstructed course of the river to a total length of approximately 50 kilometers (Ronchi et al., in preparation), further corroborating the hypothesis that the river originates from the northernmost part of the Gulf of Trieste.

This collaboration, as many before it, demonstrates the importance of cross-border cooperation in geoscientific studies in order to better understand past and present geological processes

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A COMBINED STUDY OF GRAIN SIZE ANALYSIS AND SURFACE MONITORING OF ACTIVE SIEVE DEPOSITS IN THE PLANICA VALLEY (NW SLOVENIA)

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Sieve deposits (Figure 1) are common lobe-shaped sedimentary deposits typical for gravel-rich and matrix-poor alluvial fans and perennial streams. An individual sieve lobe deposit is composed of angular to sub-angular, open framework, clast-supported, moderately-sorted gravels. The thickness of an individual lobe can vary from a few centimetres up to three metres, while the length can be up to a few tens of metres. The only hydrodynamic requirement for sieve lobe generation is a high water infiltration rate due to an unsaturated, permeable ground composed of a low number of fine grains (Milana, 2010).

While sieve lobes were documented in the field, their formation process remained unclear until fairly recently. The sieve deposition process was first proposed on the basis of a laboratory experiment (Hook, 1967), which was later used as an analogy for interpreting naturally occurring deposits. The proposed process was strongly disputed by several studies (Blair and McPherson, 2009, 1994, 1992) proposing that open framework sieve lobe deposit are the end-product of winnowing matrix-rich debris flows by water, a process which, likewise has also not yet been observed in nature. Only recently the process of sieve deposition has been documented under natural conditions, confirming the original depositional paradigm (Milana, 2010). Because the original paradigm was only confirmed by qualitative field observations, questions remain about their depositional activity and data on quantitative properties. The aim of this study is to (i) provide a quantitative grain size analysis of sieve deposit lobes, (ii) monitor their depositional activity, and (iii) link their depositional activity with precipitation triggering mechanisms.

The study was done in the Planica Valley (NW Slovenia), a typical post-glacial alpine valley bounded by steep slopes composed mainly of Upper Triassic carbonates (Gale et al., 2015). The valley floor and its lower slopes are covered by several gravel-rich Holocene alluvial fans, on which sediment is deposited in the form of sheetflood deposits and sieve deposit lobes during sporadic intense precipitation events (Novak et al., 2020, 2018). We performed detailed analysis on one of the more active alluvial fans, which is predominantly built of sieve deposits. On eleven sieve deposit lobes, which differ in size and relative age, we extracted samples at the proximal, middle, and distal parts of an individual lobe. In total, we collected 29 samples on which we performed granulometric analysis using dry-sieving technique. The surface changes on the alluvial fan were detected by aerial surveying using Small Unmanned Aircraft (SAM) and photogrammetric modelling of the surface of the deposits. A network of permanent ground control points was installed to ensure centimetre-level accuracy of photogrammetric modelling and monitoring of surface changes. Control points coordinates were obtained with a rapid static GNSS survey and postprocessed using IGS precise ephemeris and observation data from a base station located in the survey area. Detected surface changes were temporally correlated with precipitation records from the nearby meteorological station.

The majority of the samples belong to a textural group of gravel and occasional sandy gravel, with an almost negligible percentage of mud fraction, which rarely exceeds 2.0%. Samples from the distal part of an individual lobe have a larger percentage of gravel and a smaller percentage of sand compared to the samples from the

proximal parts of an individual lobe. Additionally, distal parts of individual lobes have larger mean clast size than proximal parts. This clearly shows the internal heterogeneity in the clast size of individual sieve lobe which derives from the depositional process of backfilling, a process observed in nature and in the laboratory by previous studies. Temporal surface changes are clearly visible on SAM-derived digital orthophoto and digital elevation models (DEMs). The difference of DEMs demonstrates the areas of transport and deposition of an individual lobe. Correlation of surface changes with meteorological records indicates that sieve deposits were deposited during short and intense precipitation events exceeding 50 mm of rainfall in 24 hours.

Figure 1: Surface of the studied alluvial fan, photographed from a height of approximately 50 m, composed predominately by sieve lobe deposits.

This study provides the first detailed quantified grain size analysis of sieve deposits observed in nature. Monitoring of their deposition shows that they represent major building blocks of gravel-rich alluvial fans and their deposition is directly linked to intense precipitation triggering events.

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VISUALISATION TECHNIQUES OF DIGITAL ELEVATION MODELS FOR ANALYSING ALPINE LANDSCAPE FEATURES

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The alpine environment is a heterogeneous and a complex landscape formed by the combined effect of tectonics, bedrock geology and Quaternary sedimentary processes. The latter form sedimentary bodies with a distinctive shape, sedimentary architecture and spatial distribution related to past or recent sedimentary transport and deposition processes. In recent years digital elevation models (DEMs) derived from airborne laser scanning (ALS) have been widely used as a tool for detailed studies of Earth surface processes. More often than not, DEMs are visualised as analytical hillshading, a terrain visualisation technique existing in all GIS programmes. This visualisation technique relies on illuminating surface from a single light source from only one direction and as a result, features can be barely visible or even invisible when they are hidden in the shadow or parallel to the light source. This can be particularly challenging in surface analysis of topographically complex alpine environments.

To overcome these challenges, DEMs can be presented by various visualisation techniques (Zakšek et al., 2011; Štular et al., 2012; Kokalj and Hesse, 2017; Kokalj and Somrak, 2019). In this study we qualitatively compared eleven different visualisations of Quaternary sedimentary bodies typical for alpine landscapes. The analysis was performed on terrain model of the Planica Valley in the Julian Alps, NW Slovenia, where several previous studies field mapped and identified a diverse set of Quaternary sedimentary bodies (Bohinec, 1935; Triglav Čekada et al., 2013; Šmuc et al., 2015; Novak et al., 2018). We tested eleven visualisation techniques to visually identify previously documented small- and large-scale sedimentary and geomorphological Quaternary features. Visualisations were produced from a DEM with resolution of 0.5 m, using Raster Visualisation Toolbox software (RVT, 2021). Based on success rate we qualitatively compared the functionality of different visualisation techniques for identifying alpine landforms (Figure 1).

The comparison shows that hillshading from multiple directions, 8-bit sky view factor, and 8-bit slope visualisations allow better identification of multiple low-gradient, subtle, small- and large-scale morphological and sedimentary features compared to analytical hillshading or aerial photographs. Hillshading from multiple directions could be used as a general-purpose visualisation for identifying and mapping Quaternary sedimentary bodies, because it provides a clear delineation of landforms without regard to their size, surface inclination and regardless of light orientation. On the other hand, 8-bit sky view factor and 8-bit slope visualisations provide more unambiguous recognition of small-scale and subtle sedimentary and morphological features, such as boulders, channels and channel bars, sieve and grain flow deposits. A combined use of these three visualisation techniques allow superior surface analysis of mountainous and hilly terrain compared to the more commonly used analytical hillshading.

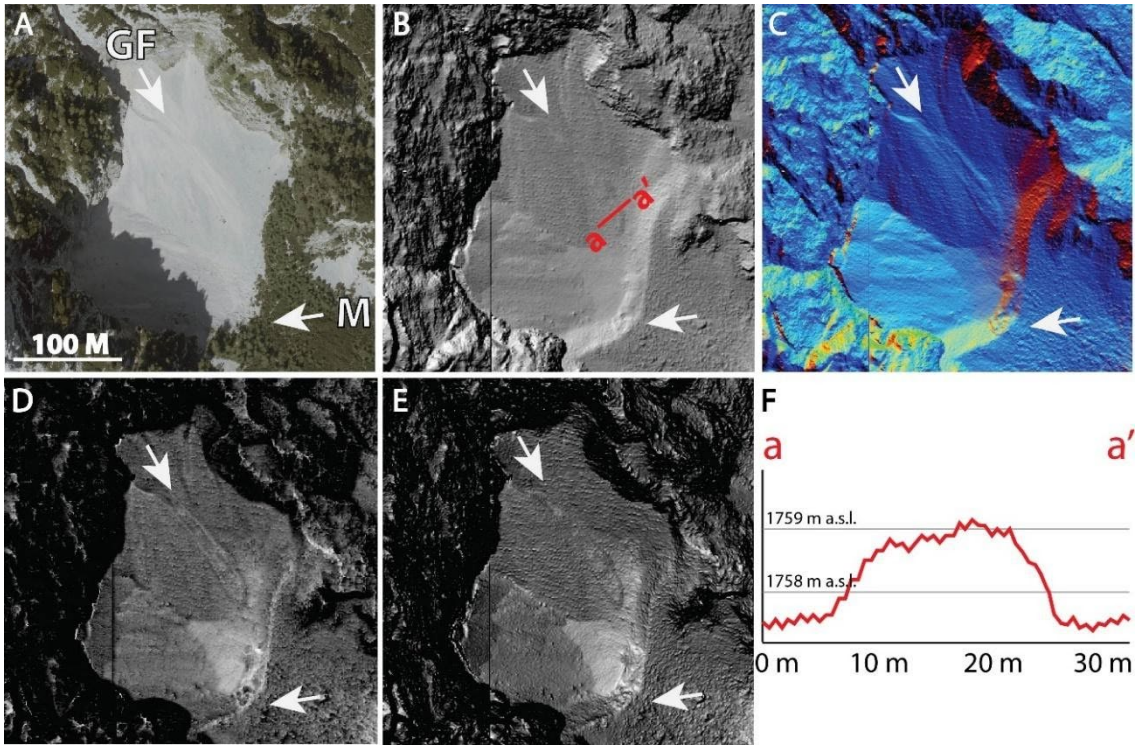

Figure 1: Example of grain flow deposit (Gf) on a scree deposit and moraine ridge (M). A) Aerial photograph, B) analytical hillshading (azimuth 315°, angle 35°), C) hillshading from multiple directions RGB (16 colours, angle 35°), D) 8-bit sky view factor and E) 8-bit slope visualisations, F) topographic profile (a-a') over the distal part of the grain flow deposit. ALS data © ARSO Slovenia.

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THE EXPANDED RECORD OF CORE MIR1 (ISTRIA PENINSULA, CROATIA): A NEW PALEO-ENVIRONMENTAL ARCHIVE FOR THE EEMIAN AND THE LAST INTERGLACIAL

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The Northern Adriatic coastal area displays dichotomic settings, with the western side characterised by low-lying sandy beaches and the eastern one marked by rocky coasts. This strong difference is also mirrored by the available mid and late Pleistocene record contained in the Northern Adriatic continental shelf, which is rather well investigated in the Po and Venetian-Friulian plains, whereas it is yet completely unexplored along the coasts of Istria and Dalmatia.

Furthermore, due to the gentle bathymetric gradient of its continental shelf, the Northern Adriatic sequence contains an accurate record of the Middle to Late Pleistocene transgression and regression cycles and allows for recording even subtle marine fluctuations.

In the framework of a joined research project between Padova and Zagreb universities, a 120-m long core (MIR1) was drilled near the city of Novigrad in the coastal SW Istria Peninsula (Croatia). This sedimentary sequence consists of Quaternary deposits filling the karst valley in the final tract of the Mirna River, documenting the alternance of alluvial, brackish, and marine facies, from the middle Pleistocene onward.

Moreover, the mountain catchment of the Mirna River consists of flysch formation that supplies a large quantity of sediments and could support the construction of delta. In this perspective, it is worth noting that during the Holocene the river prograded along its valley for over 12 km, reaching the present coast.

Core MIR1, in collaboration with CNR-IGAG Milan and CNR-ISMAR Bologna, was investigated for its sedimentological and stratigraphic features, including analysis of microbotanical proxies (pollen, spores, algae), micropaleontology, molluscs, radiocarbon datings and magnetic susceptibility.

Along the sequence at least four marine transgression sequences are documented. Data testify that most part of the stratigraphy is related to the Holocene and the Last Interglacial, with its boundary between MIS 6 and MIS 5 recognized at about 75 m depth. The Eemian biostratigraphic unit of terrestrial (pollen) proxies is represented by an expanded sequence spanning for over 20 m and consisting of brackish and marine deposits displaying continuous sedimentation and an apparent absence of *hiatus*, providing a great potential for high resolution paleoenvironmental reconstructions.

MIR1 stratigraphy provides another unique value, with the occurrence of a 34 m-thick Holocene expanded sequence covering the last 10000 years. It allows for a direct link between sea level and ecosystems changes, including man interactions and the forcing by climate change in comparison with the Last Interglacial.

The MIR1 sequence represents a *unicum*, preserving a high-resolution record from the eastern side of the Adriatic Sea, covering most of both the Holocene and the Last Interglacial. Moreover, MIR1 is only 100 km east of core Venice and from other Pleistocene archives, documented in different cores from the Friulian-Venetian plain (Fig.1), such as Azzano X (AZX) and Lake Fimon (FIM).

The comparison among sequences spanning the two sides of Adriatic coast will allow us to depict the vegetation patterns and plant species distribution changes in time inside the Adriatic area.

Figure 1: Location of core MIR1 and other stratigraphic archives preserving segments of the Eemian period.

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FROM LAKE TO PEATLAND (ŠIJEC BOG, SLOVENIA)

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The Šijec bog on the Pokljuka plateau in northwestern Slovenia is one of the southernmost ombrotrophic peatlands in Europe (Kutnar, 2000). It is located 1194 meters above sea level and covers approximately 15 hectares. We have determined the peat thickness and morphology of the Šijec bog using a ground penetrating radar (GPR) with an unshielded 50 MHz RTA (Rough Terrain Antenna) and acquired information about the stratigraphy below the peat/clay boundary with electrical resistivity tomography (ERT) using ARES equipment with 48 electrodes. We measured 13 GPR profiles with 50 MHz RTA, 3 GPR profiles with 250 MHz antenna, and 2 ERT profiles. The penetration depth of 250 MHz antenna was not sufficient to determine the peat/clay boundary, while the use of 50 MHz RTA with 15 m penetration depth provided a clear boundary between peat and clay sediments as the latter caused strong attenuation of GPR signal. The GPR results were complemented with results of manual probing using peat probe. Since the ERT investigation aimed to determine stratigraphy below the peat layer, larger electrode spacings were used for ERT survey (2 m and 3 m) to attain greater depths (17 and 27 m, respectively).

The GPR results reveal four depressions within the peat bog. Depressions in western part of the peat bog are larger (approximately 15000 m^2) and deeper (7–9 m), while depressions in eastern part of the bog cover less than 5000 m^2 with peat thickness of 6 to 8 m. Between the depressions there are elevated ridges where peat thickness measures up to 6 m. The peat thickness on the edges of the bog ranges from 2 to 4 m. No reflections occurred below the peat/clay boundary due to clay layers. Radargrams show chaotic reflection patterns that are probably related to heterogenous layers with increased sand and clay content, especially within the depressions (Fig. 1). They could be explained by the variation in climate conditions in the early stages, where occasionally the whole area could be exposed to flooding/fluvial sedimentation. The results of the manual probing are in good correspondence with the depths determined by GPR at the edges and elevated areas within the bog. Within the depressions the peat probe did not reach the peat/clay boundary but stopped due to the increased resistance at the sandy and clayey layers within the peat.

The ERT results showed a similar peat thickness of 6-10 m in depressions and 3-4 m at the edges (Fig. 1). The peat layer has significantly higher resistivity values than the underlying clayey sediment and can be followed very well throughout the profiles with a sharp contrast in resistivity. Under the peat depressions are larger clayey depression that reach a thickness of more than 20 m. Clayey sediments are also present below the shallower peat, where they reach approximately 5 m in thickness. In shallower peat areas, the ERT detected medium resistivity body (MRB). Based on resistivity values, MRB lithology cannot be accurately determined. The associated resistivity values are more frequently observed in sediments (e.g. Žebre et al., 2019) rather than hard rocks (e.g. Redhaounia et al., 2016). Considering the thicknesses of the clayey deposits above the MRB, it could be attributed to an older moraine or carbonate bedrock, but not to a younger moraine as the peat at 6 m is approximately 11,000 years old (Maja Andrič, personal communication, 2019).

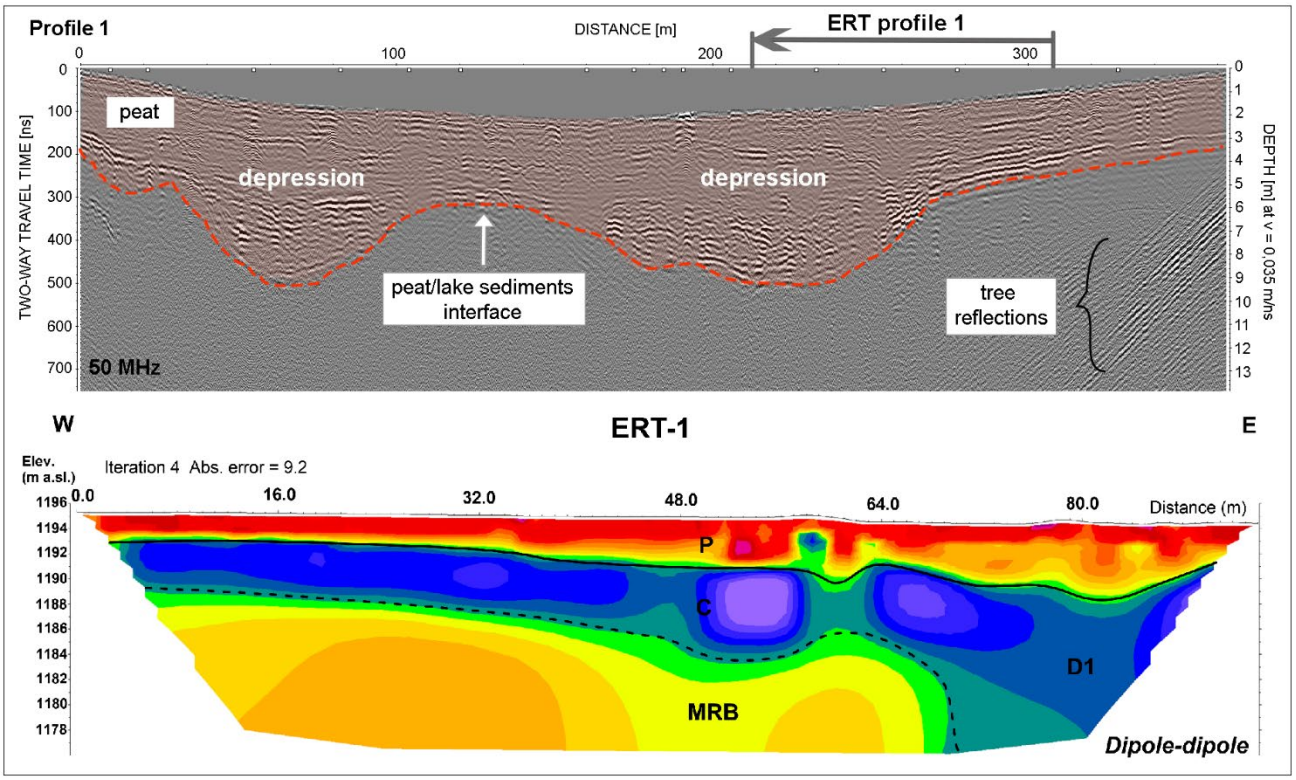

Figure 1: Radargram of profile 1 and ERT-1 profile. P – peat, C – clay, MRB – medium resistivity body, D1 – clayey depression.

The results indicate that the bog has developed from one lake or several smaller lakes. Further research is needed to determine stronger reflections in the peat and MRB lithology. The complementary geophysical methods proved to be an efficient approach to delineate the peat morphology and the underlying stratigraphy, which indicate the development of the studied bog.

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LGM TO LATEGLACIAL VEGETATION HISTORY AND CLIMATE VARIABILITY DOCUMENTED IN THE PALEOECOLOGICAL RECORD FROM LAKE FIMON (NORTHERN ITALY): WHAT SENSITIVE ARCHIVES TELL US ABOUT THE PAST

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The past is regarded as the key to understand the present and to predict the future. While instrumental records and written sources report about events of the recent history, reconstructions for older periods rely on information from *proxy data*. This expression indicates preserved biological and physical characteristics of the environment that can replace direct measurements and extend our understanding of the past far beyond instrumental and written records. Proxy data from lake sediments are bio- and geo-archives of the past and their microbotanical, sedimentological, chronological and geochemical information can be used to reconstruct and constrain temporal changes in vegetation communities and dynamics, depositional processes and climate parameters. High-resolution of stratigraphic investigations is essential to decipher the effects of centennial to millennial scale climate variability pervading the last glaciation.

This presentation focuses on the results of a multiproxy investigation on the stratigraphic succession of Lake Fimon (23 m asl, northern Italy) covering the period 31 - 12 ka BP. This period encompasses the whole Last Glacial Maximum (LGM), the most recent period in Earth's history with maximum globally-integrated ice volume (Mix et al. 2001). To account for the regional effects of millennial-scale climate variability on terrestrial ecosystems and sedimentary processes, the use of representative stratigraphic records is essential. In this respect, the Lake Fimon record is unique at the scale of the European subcontinent and proved to be a continuous and multifaceted archive of well-preserved environmental information (Pini et al. 2010; Monegato et al. 2011; Pini et al. submitted). Its exploitation adds value to paleoecological and paleoclimatological investigations south of the Alps.

Lake Fimon formed sometimes during the late Middle Pleistocene. Its sediments document a fairly continuous lacustrine and palustrine sedimentation recovered in more than 40 m of total sediment core length. Extended palynological analysis on the 31-12 ka BP core succession revealed a high microbotanical diversity, with rapid compositional changes testifying to the sensitivity of plant descriptors to climatic variations. The main ecological gradient derived from a PCA ordination on pollen data is connected to climate continentality: during the LGM mixed cool temperate forests with *Pinus sylvestris/mugo* were replaced by *Larix* forest steppe facing *Artemisia* and *Juniperus* semideserts. Warm-temperate broad-leaved trees stepped in only at the onset of the Bølling-Alleröd interstadial. The occurrence of sensitive microbotanical descriptors in the Lake Fimon record allowed to investigate their climatic signature through the quantitative estimation of temperature and

precipitation parameters (Tjan, Tjul, Pann, Annual T Range) using the Modern Analogue Technique (MAT; Chevalier et al. 2020). The modern climate values of more than 6100 sites stored in the Eurasian Modern Pollen Database (Davis et al. 2020) and in the Chinese Pollen Database (Herzschuh et al. 2019) were used for past climate inferences. Interestingly, most of the closest modern analogue for the Lake Fimon pollen spectra occur in southern Siberia and in the Urals. Previous authors (Chytrý et al. 2008; Kuneš et al. 2008) already identified these areas as hosting ecosystems resembling full-glacial plant communities of Central Europe. Corrections accounting for the impact of low glacial CO_2 concentrations on plant water-use efficiency (Prentice et al. 2017, Cleator et al. 2020) were applied to pollen-based estimated moisture parameters.

Phases of enhanced seasonality (Annual T Range > 36°C) and cold boreal winters (Tjan between -20°/-25°C), identified in the reconstructed pollen-based climate time series , correspond to periods of forest withdrawal (total Arboreal Pollen < 40%) and dust input evidenced by particle-size data and elemental analysis. The chronological model for the Lake Fimon record allows to match these periods with the timing of Heinrich Stadials 1 and 2. Extreme continental climate spells on the continent thus coincide with episodes of iceberg discharge and ice-rafted debris (IRD) release in the North Atlantic. Research on the Lake Fimon record contributes to the understanding of the impact and timing of LGM atmospheric circulation changes over the North Atlantic on the southern European continent, a topic that still remains largely unknown. The availability of more high-resolution records will hopefully provide insights into the LGM moisture gradients over the large and orographically-complex landscape that characterizes the European continent.

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CIRQUE, VALLEY, AND PLATEAU GLACIERS IN THE MONTE-CAVALLO GROUP (NE-ITALY) AND THEIR RESPONSE TO CLIMATIC CHANGES DURING THE LAST GLACIAL MAXIMUM

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Mountain glaciers are excellent indicators of climatic change since their Equilibrium Line Altitudes (ELAs) are primarily controlled by temperature and precipitation (Ohmura et al., 1992). The reconstruction of past glacier extent is therefore not only key for deriving quantitative paleoclimatic information, but also for better understanding and modelling the future fate of the alpine cryosphere. Throughout the European Alps, such glacier-based reconstructions have been conducted for most of the Late Glacial stages (e.g., Kerschner & Ivy-Ochs, 2008). Concerning the Last Glacial Maximum (LGM), however, this task is more difficult, as most of the central and northern parts of the mountain range were covered by an extensive ice sheet with outlet glaciers extending into the forelands on both sides of the Alpine range. Although first numerical models of this LGM ice sheet have been recently performed (e.g., Seguinot et al. 2018), the results of such studies are not always consistent with the geomorphological evidence and therefore require independent validation.

Along the southern fringe of the Alps, some ice caps and mountain glaciers remained disconnected from the large outlet streams throughout the LGM. Thanks to their small size and independent dynamics, such peripheral glaciers are both less complicated to reconstruct and probably reacted highly sensitive to paleoclimatic changes. While some of these sites in the south-eastern Alps have been subject to detailed investigations during the previous decades (e.g., Baratto et al. 2003, Monegato 2012), past glaciations in the Monte-Cavallo Group are still less well constrained. With several peaks exceeding an altitude of 2000 m, this mountain range represents the highest part of the Venetian Prealps (NE-Italy). First geomorphological observations suggest that during the LGM the Monte-Cavallo Group was covered by a glacial system which was composed of high-altitude cirque-, lower-lying plateau-, and valley glaciers. This makes it an ideal location not only to calculate paleoclimatic parameters but also to assess how glaciers with different hypsometry, aspect or elevation range were affected by changes in the LGM climate.

Here, we present a detailed overview of the LGM glacial system in the Monte-Cavallo Group, based on geomorphological mapping and the application of recently developed GIS-models for the reconstruction of paleoglacier geometries and ELAs (Pellitero et al. 2015, 2016). Past glacier extent was primarily derived from mapping frontal and lateral moraine ridges and the distribution of glacial sediments in the main valleys. Erosional features related to glacial activity provided additional information on ice extent and flow direction. This was particularly helpful in the accumulation areas, where the glacially moulded bedrock is in sharp contrast to the otherwise deeply karstified landscape. Age control on glacier advances is inferred from a succession of lacustrine sediments covered by glacial till in the main valley. Although parts of this succession may in fact date back to earlier interglacials, a previously calculated radiocarbon date of 29350 ± 460 yr. B.P. (uncalibrated ^{14}C; Fuchs, 1969) points to an LGM age of the overlying glacial deposits.

Combining the geomorphological and sedimentological evidence, at least two distinct stages of glacier stabilisation during the LGM could be distinguished:

1. An early stage at which ice was accumulating both within high-altitude cirques and on the lower-lying plateaus. The ice from both areas was locally merging downstream to form glacial tongues flowing into the main valleys.
2. A later stage at which the plateau glaciers had partly receded, and the valley glaciers were primarily fed by ice from the cirques.

Despite these notable changes in the configuration of the glaciers, reconstructed ELAs for the two stages differ only by a small order. This shows that even subtle changes in the LGM climate had a profound impact on the geometry of the glacial system, especially in areas where plateau ice was present in proximity to the ELA.

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SEA, LAKES AND RIVER: THE BURIED LATE GLACIAL INCISED VALLEY OF CONCORDIA SAGITTARIA AND ITS INFILL (TAGLIAMENTO MEGAFAN, NE ITALY)

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At the end of LGM the alluvial plains extending along the southern side of the Alps experienced a strong phase of fluvial entrenchment as a consequence of the stark decrease of sediment delivery to the alluvial plain which followed the withdrawn of the Alpine glaciers within their valleys. Since 19 ka cal BP and up to the Early Holocene, few incised valleys formed from the apex of the alluvial megafans to their distal sector but, along the northern Adriatic, the mid and late Holocene fluvial and coastal deposits have largely buried these landforms. During the Late Glacial the transport and deposition was limited to the incised valleys, while the former alluvial plain was abandoned and starved of sediments.

We investigated the distal sector of the alluvial megafan of Tagliamento River through the analysis of a dataset consisting of ca. 2300 mechanical and hand-made cores. This dataset, compared with LIDAR-derived DEM, radiocarbon and paleoenvironmental analyses, allowed a detailed reconstruction of the formation and evolution of the buried incised valley characterizing the area of Portogruaro and Concordia Sagittaria. The valley has been traced for over 25 km, is up to 1.2 km wide and with a depth of 20 m below the top of LGM surface.

The erosive valley has been mainly formed between 19 and 14 ka cal BP, leading also to its partial infill with about 10 m of gravels which was recognized along the entire reconstructed valley down to the present coast. After the deposition of this coarse unit the fluvial activity led to the deposition of fine sediment almost until the end of Late Glacial and, according to paleobotanical information, these deposits recorded the vegetation of the Younger Dryas period for the first time in the Venetian–Friulian Plain.

After the disconnection from the active Tagliamento, swampy environments occupied the valley and the Holocene marine transgression started to indirectly affect the valley around 9.5 ka cal BP, hampering the drainage and leading to the formation of widespread lacustrine environments. Since 8 ka cal BP, following the sea-level rise, the valley was occupied by a lagoon which formed a ca. 15 m thick unit of lagoon muds up to historical time. The infill of the valley documents the evidence of anthropogenic activity since 6-5 ka cal BP, probably in relation to wood clearance and soil degradation. Anyhow, significant human impact occurred during Iron and Roman Age, when Concordia became an important city. In 6th century AD high-magnitude floods deposited up to 5 m of sediments and largely obliterated the valley (Fontana et al., 2020).

The detailed 3D reconstruction of the valley of Concordia allowed also to recognize the relation between the presence of groundwater-fed streams and the formation of this and other large incised valleys of the Tagliamento megafan. In particular, we produced evidence that river piracy by minor rivers triggered the creation of other incised valleys in the distal sector of Tagliamento megafan (Ronchi et al., 2021).

The buried incised valley of Concordia represents a reference for the evolution of the main Alpine rivers and related plains in the coastal sector of the whole Venetian-Friulian Plain during the Late Glacial and Early Holocene periods.

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SUBMERGED PALEO TIDAL INLETS OF THE NORTHERN ADRIATIC SHELF: EARLY-HOLOCENE INDICATORS OF THE LAST RSL RISE

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The scarceness of available sea-level indicators as a consequence of bad preservation, lack of formation or difficult accessibility often hampers the reconstruction of the timing and modes of the last marine transgression.

This statement is particularly true for the early Holocene, in the period between 11.7 and 7.5 ka cal BP, which was characterized by a high rate of transgression which allowed the relative sea level to rose from -80 to -10 m MSL (Vacchi et al., 2016).

In order to reconstruct the ancient sea-level position a number of geomorphological indicators spanning from shoreline deposits to erosional landforms have been recognized. Such features, which include, for instance, beach ridges and tidal notches, can only form and be preserved only in peculiar morphological settings and within a certain range of slope of the shelf (Cattaneo & Steel, 2003).

Among the indicators paleo tidal inlets are largely underrepresented in the current literature. Tidal inlets are deep channel excavated by the tidal currents draining a lagoon and allow the communication between the lagoon and the open sea. Such features are filled during the migration or deactivation of the inlet, which is often a consequence of the deactivation of the lagoon itself. Such landforms may represent outstanding archives due to the high chance of preservation from erosion. Moreover, paleo tidal inlets can be recognized and cataloged through shallow sub-bottom profiling methods.

The analysis of the vast database of CHIRP profiles available for the northern Adriatic Shelf, consisting of almost 7000 km of high resolution seismic profiles, allowed to recognized more than 100 paleo tidal inlets. Such features date to the early Holocene and constitute one of the few available witnesses of the post-LGM marine transgression over the Adriatic Shelf.

Given the absence of alternative widespread indicators, the paleo tidal inlets of the northern Adriatic represent an invaluable record for the reconstruction of the paleo-geographic and paleo-environmental settings of the area and provide new data to constrain the position of transgressive coastlines. Reference examples of paleo tidal inlets have been recognized near the Po Delta (Ronchi et al., 2019), offshore of Chioggia (Ronchi et al., 2018), but also in the Gulf of Trieste.

While the presence of lagoon environments during a phase of strong RSL rise might be unexpected it can be explained by considering the peculiar geometry of the shelf, characterized by a low gradient, and the interplay between the sediment dispersion operated by the main fluvial actors of the area and phases of slowdown of the RSL rise.

With this work we recognize the extensive distribution of paleo tidal inlets on a regional scale and illustrate the phenomena affecting coastal plains in response to RSL rise, a topic of prominent importance for the adaptation policies involving coastal areas.

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WAS THE ALPINE YOUNGER DRYAS REALLY DRY? NEW INSIGHTS FROM THE ITALIAN DOLOMITES (SOUTHERN EASTERN ALPS)

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After the Last Glacial Maximum, the Alpine Lateglacial was characterized by an alternance of mild interstadials and cold stadials, the former being usually more humid compared to the latter. The youngest of such stadial is called Younger Dryas (YD or Greenland Stadial (GS) 1) and corresponds to the last major glacial advance, with temperatures similar to glacial periods. In the European Alps such phase dates back to ~12.8 to 11.7 ka . Temperature reconstructions suggest a temperature drop during the YD, compared to present, ranging from ~10 °C to 3-4 °C (Koltai et al., 2021). The paleoprecipitation trend in Europe during the YD is debated, with most studies affirming that that the first half of the YD was colder and drier than the second one. Equilibrium line altitude (ELA) reconstructions suggest that the southern Alps were affected by precipitation similar to present values, whilst precipitation in the central part of the Alps was depleted by ~20-30%. However, as can be seen in Fig. 1, such reconstructions are grouped in the central and western sectors of the Alps, with a wide gap comprising the whole eastern side, where our study area is located.

We studied the deposits related to the YD in Venegia Valley, a narrow valley located in the Dolomites, about SE-to-NW oriented. The main glacier, which still survives as a very small debris-covered glacier, is named Travignolo, after the pass where it originates. The Travignolo pass (2925 m a.s.l.), separates the two main peaks of the area: the Cimon della Pala (3184 m a.s.l.), to the south, and the Cima della Vezzana (3192 m a.s.l.), to the north. During the YD, the Travignolo glacier was merging with the northern Bureloni and Venegiotta glaciers to form a single tongue that almost reached the exit of the valley, about 6 km downstream, at 1700 m a.s.l.. At its front, this glacier built a well-expressed morainic arc, made of at least three main ridges. Paleoglaciers from the southern Alps show evidence of a double response, whereby the outermost and innermost moraines stabilised at ~12.3±0.7 ka and before 11.2±0.8 ka, respectively (Baroni et al., 2021). Cosmogenic dates performed on boulders located on top of the Venegia Valley frontal moraines confirmed these arcs to be YD in age, well-fitting the older phase. By means of the ArcGIS toolbox “GlaRe” we reconstructed the YD glacier with the AABR method, which gave us a ELA of about 2150 m a.s.l.. With the same approach and basing on the data by Zanoner et al. (2017), we obtained the Little Ice Age (LIA) ELA for the same glacier: 2600 m a.s.l., that is in good agreement with the nearby ELA calculated at Mt. Antelao for the LIA. At the Alpine scale, the obtained LIA depression between the LIA and the YD (i.e., ~450 m) is high, but comparable to the values obtained for the Western and Maritime Alps. Most of all, is the only available data of this kind for the Southern Alps, exception made for a single site in the Maritime Italian Alps.

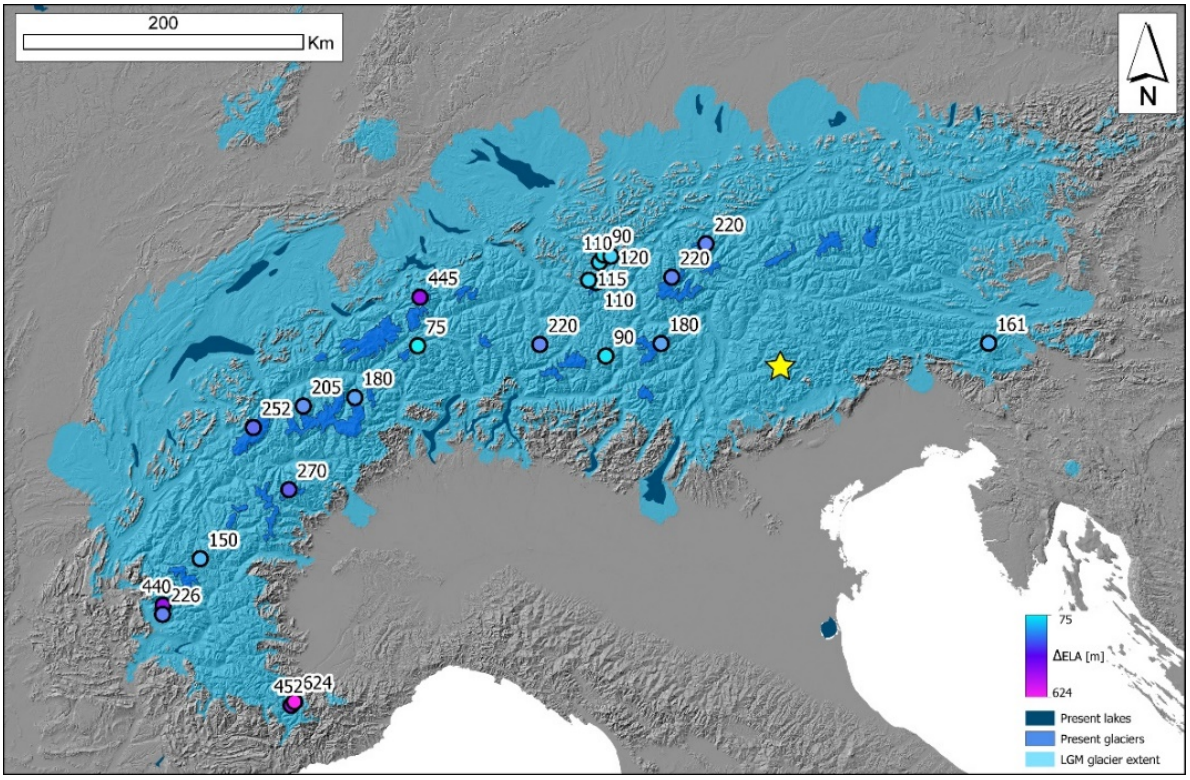

Figure 4: map of the ELA depressions (Little Ice Age value minus Younger Dryas value) in the European Alps, with the location of the study area (yellow star) (modified from Baroni et al., 2021).

The obtained data allow for an inference of paleoprecipitations and/or paleotemperatures occurring at the time of glaciers' growth by means of the diagrams developed by Ohmura and Boettcher (2018) and Rea et al. (2020). The summer temperature depressions calculated for the YD (Heiri et al., 2007) and the LIA (e.g., Frank et al., 2010) suggest a marked increase in precipitations (up to double of present values). On the contrary, postulating percentage variations in respect to current precipitations would result in an unrealistic temperature drop (>3°C in respect of the independent reconstructions). In the Dolomites, a recent study suggested the occurrence of a snow-rich early YD that evolved into a snow-poor late YD autumns and early winters (Koltai et al., 2021). This is in good agreement with our results, that suggest an increase in precipitation. Such an increase may be the result of the larger amount of snow precipitation, even if the annual precipitation amount may be not that large as the diagrams suggest.

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SPELEOTHEM RECORD OF HOLOCENE NATURAL AND ANTHROPOGENIC ENVIRONMENTAL CHANGES IN CONTINENTAL CROATIA

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The Holocene is on global multimillenial scale generally regarded as a relative stable in hydroclimate terms, but at the finer scale, it is characterized by frequent changes both in temperature and precipitation. Based on stable isotope ($\delta^{13}C$ and $\delta^{18}O$) records of two coeval stalagmites from Nova Grgosova Cave (Croatia), we identified several centennial to millennial hydroclimate oscillations. During the 9.2-8.8 ka period local environmental conditions were improved in terms of vegetation dynamics, while the following 8.2 ka event was characterized by change in seasonal distribution of precipitation with somewhat drier autumn/winter seasons. The most remarkable excursion in $\delta^{13}C$ series occurred around 7.4 ka within the Holocene Climate Optimum (HCO), due to reduced vegetation and soil microbial activity in response to enhanced spring/summer aridity, and likely also reduced autumn/winter precipitation. Regional signal of aridity during the 4.2 ka event is relatively small in magnitude, and must be confirmed in other coeval speleothems.

Since the lowlands along the rivers further to east were preferred for human settlement over hilly region of Nova Grgosova Cave, Neolithic agricultural revolution and associated anthropogenic deforestation left no trace in studied speleothems, supporting hydroclimate causes of isotopic variations rather than anthropogenic. However, potential record of the short-term (centennial) climatic variability during the last millennium has been overprinted by the human intervention into natural forest landscape related to the mining activity. Namely, increased copper production required more arable land for increased population, mine timber (supporting pillars), as well as wood for smelting, which all lead to intensified deforestation and consequently masked $\delta^{13}C$ signal of concurrent rapid climate changes such as those of Medieval Warm Period and Little Ice Age.

LATE QUATERNARY SEABED GEOMORPHOLOGY OF THE PROKLJAN LAKE (KRKA RIVER ESTUARY)

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A multiproxy investigation has been carried out to study the seabed geomorphology of the Krka River estuary located in the central Dalmatia. A detailed multibeam survey (MBES bathymetry and MBES backscatter), side scan sonar imaging, subbottom acoustics coupled with piston sediment cores and bottom samples were used to characterize 6.2 km^2 of submerged paleolandscape of the Krka River valley and the Prokljan Lake. The bathymetry and side scan sonar indicate that the submerged paleolandscape is well perserved and consists of partly buried tufa barrier system with small lakes and carbonate mounds. Geophysical survey consisted of a total of 70 km of seismic profiles, whereas 5 long (4–9 m long) piston sediment cores were collected in the lake area. We identified three sedimentary units, fluvial, brackish and marine, spanning up to 9000 y BP and with thickness up to 15 m. Ground truth data, in the form of grab samples and video transects, were collected at 36 locations in order to create geomorphological and geological classifications of the seabed. Sediment samples were processed for grain size, magnetic susceptibility, bulk density, carbon and nitrogen concetrations and mineralogical analysis. A map of seabed classification was produced using Object-Based Image Analysis (OBIA) by integrating information obtained from multibeam and ground truth data.

Tufa barriers are unique karst features and great paleoclimate indicators. They enabled formation of lakes and had a predominant influence on the Holocene flooding of the river canyon. They can be used as an indicator of sea level given their morphology, i.e. depth of each barrier, in connection to the onset of marine sedimentation in the Lake. The results of this study reinforce the idea that submerged tufa barriers in the Prokljan Lake began forming during early Holocene or even during the transition from the Pleistocene into Holocene. Flooding of the river canyons (Guduča River and Krka River) due to sea level rise in the Prokljan Lake started at about 9300 y BP and the formation of estuary at approx. 7500 y BP. Consequently, this multiproxy study allowed a reconstruction of the seabed geomorphology and paleoenvironmental evolution of the upper part of the Krka estuary since the Holocene sea level rise.

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HOLOCENE SEISMIC ACTIVITY, VEGETATION AND EROSION HISTORY AND THE HUMAN IMPACT ON THE ENVIRONMENT RECORDED IN THE LACUSTRINE SEDIMENTS OF LAKE BOHINJ

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LAKE BOHINJ

Lake Bohinj is the largest permanent natural freshwater lake in Slovenia (3.2 km^2, max. water depth 45 m). It is a glacial lake located in the alpine environment of the Triglav National Park (Julian Alps). This area exhibits high seismic activity and a long tradition of human activity dating back to the Bronze Age. The lake is therefore an ideal archive for studying past environmental changes. Recently completed studies of the lake sediments investigated the Holocene seismic activity, the vegetation and erosion history of the catchment area and the human impact on the environment (Rapuc et al. 2018; Andrič et al. 2020). The study was based on mineralogical, sedimentological, geochemical and stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) and on the pollen analysis of a 12 m long core, with a detailed palaeoenvironmental reconstruction of the last 6600 years for the upper 4.4 m of the core.

During the last 6600 years 29 earthquake triggered event beds have been recorded in the lake. The earthquakes triggered homogenite-type gravity flow deposits up to several tenths of a cm thick, which can be clearly separated from the pelagic deposits of the lake. The most recent homogenites are related to historical regional earthquakes (i.e. 1348 AD, 1511 AD and 1690 AD) with strong epicentral intensity [greater than "damage" (VIII) on the Medvedev-Sponheuer-Karnik scale]. The lake also recorded a major seismic event, dated 6711-6523 yr cal BP which caused a debris flow of more than 4 m in thickness.

Several periods of increased siliciclastic terrigenous input were recorded at 6100-6000, 5700-5550, 5000-4600, 3900, 3700-3550, 2300-2200 yr cal BP. The increased input is related to a mobilisation of the river inflow from the eastern flysch-bearing catchment due to river migration during periods of more humid climate. These flood patterns coincide with periods of increased flood activity in the wider Alpine region.

At 6600 yr cal BP Lake Bohinj was surrounded by mixed forest of *Fagus* (beech), *Picea* (spruce), *Abies* (fir) and *Quercus* (oak). Neolithic human impact on the vegetation was very weak. At ca. 6000 yr cal BP *Fagus* declined and individual pollen grains of anthropogenic indicator taxa: cerals (Ceralia type pollen), *Linum* (flax), *Centaurea* (knapweeds), *Plantago lanceloata* (ribwort plantain), Chenopodiaceae (goosefoot), *Artemisia* (mugwort), Poacaeae (grasses) occurred. Increased concentration of microscopic charcoal suggests small scale forest clearance. Agricultural fields and grazing areas were probably located in the vicinity of Lake Bohinj. However, to date no Neo/Eneolithic settlements (only individual artefacts from uncertain archaeological contexts) were discovered in the area.

After 5800 yr cal BP human impact on the environment is less visible, but *Fagus* (with the exception of individual peaks) stays low. Human impact on the environment started to increase again in the Bronze Age

(3500 yr cal BP). The sporadic occurrence of cereal pollen (Cerealia type and *Secale*), ruderal taxa (e.g. Chenopodiaceae) and grazing indicators (*Plantago lanceolata* and *Sporomiella* spores of coprophilous fungi) suggest an intensification of farming activities. *Abies* pollen declined below ca. 15% and in the last 3000 years (due to fire and browsing) and never recovered to pre-Bronze Age values again. The results of archaeological research confirm human presence in the area. Bronze Age archaeological sites were discovered higher in the mountains (1500 and 1640 m a.s.l) and it is possible that alpine grazing areas were already in use, similarly as in the Swiss and Austrian Alps.

At 3300 cal BP the forest composition changed: *Fagus* dominated forests spread, whereas *Picea* and *Abies* started to decline. The main reasons for this vegetation change are presumably linked to wetter climate and human impact. It was demonstrated that in Europe *Fagus* and *Abies* advanced in periods of wetter conditions, but small-scale disturbance by fire and human impact can also promote the spread of *Fagus*. Due to lack of palaeoclimatological studies in the Bohinj region it is difficult to estimate the impact of climate on the vegetation. *Fagus* increase can be associated with globally wetter (and probably colder) climate. Lakes south of the Alps experienced high lake levels and higher flood frequency between 4200 and 2400 cal BP. Grazing which became increasingly important (Poaceae, *Plantago lanceolata* and *Sporormiella*) also affected forest composition. Due to clearance and/or grazing of *Fagus* forest more *Carpinus betulus* (hornbeam) and *Carpinus orientalis/Ostrya* (hop hornbeam) types were growing in the area. The erosion rate increased at that time with an input of terrigenous material (higher values for K/Ti ratio, silicate and carbonate suggesting both east and west origins of the sediment).

During the Iron Age (3500–2500 yr cal BP), when the region was densely populated, deforestation through agriculture, livestock and metallurgical activities caused massive soil erosion in a relatively short (ca. 50–100 years) time period. At 2600 yr cal BP tree taxa (*Fagus, Abies* and *Quercus*) declined, whereas *Corylus* (hazel), Poaceae and other herb taxa (e.g. Chenopodiaceae, *Artemisia*, Cichoriaceae, Filicales) increased due to human impact (forest cutting/burning). Numerous early Iron Age lowland sites were discovered in the area suggesting that people from the Soča valley settled Bohinj in their quest for new sources of (iron) ore. Iron ore (bobovec) and slag remains were found at two lowland hilltop Iron Age archaeological settlements east of Lake Bohinj. Only a few mountain Iron Age sites were discovered, which is in contrast to the Bronze Age situation. It is possible that archaeological settlement pattern and economy were affected by climatic fluctuations, e.g. colder Iron Age climate between ca. 2800–2300 yr cal BP. Therefore, we propose that erosion at Lake Bohinj was triggered by human impact and presumably further strengthened by a wet climate.

In the following centuries forest recovered, but although the human influence on the environment continued (intensified), it seems that the watershed was not destabilised again. In the early Roman period (1800 cal. BP) *Fagus* declined again, whereas pollen of *Juglans* (walnut tree), which was popular with the Romans, started to occur regularly in pollen samples. At the beginning of the early Middle Ages (1300–1200 cal. BP, i.e. AD 650–750) a short-term forest regrowth was followed by forest clearance and burning. Medieval archaeological sites dated to the end of 8th century AD were located east of Lake Bohinj and in the mountains. Afterwards forest clearance intensified, historical sources mention numerous ironworks, which were located east of Lake Bohinj and dated to the 12^{th}-14^{th} centuries AD.

The period of most intensive ironwork and massive exploitation of forest is dated to AD 1580–1880. A new smelting furnace for better exploitation of ore and charcoal was built in Bohinjska Bistrica in AD 1791, which used huge amounts of charcoal (9500 t of mostly beech charcoal per year). This could explain the extremely low percentages of *Fagus* pollen (0.7 %) and an increase in microcharcoal concentration. Historical sources mention vast forest devastation, conflicts between miners (charcoal production) and farmers (forest grazing),

clear cuts, soil erosion, and reforestation with *Picea* seedlings. After 1890 the main economic activities in the area were agriculture and wood production. Agrarian overpopulation at ca. 1900 AD was followed by farming decline after the second world war and forest regrowth.

To summarize, our research demonstrated that:

1. Strong earthquakes are possible in the region. A major seismic event happened at ca. 6600 cal. BP.

2. Climatic fluctuations (wetter climate and flood events) affected hydrology and chemical composition of the sediment

3. Significant human impact on the alpine ecosystems is visible for at least the last 3500 years (decline of *Abies* due to forest grazing and *Fagus* due to charcoal production for ironworks)

4. Because of a major soil erosion in the Iron Age (2600 cal. BP), Lake Bohinj catchment lost fertile soil, this event affected catchment stability in the next centuries (no material left to erode)

Multi-proxy paleoecological research was carried out also at Lake Planina pri jezeru to compare lowland and montane environmental changes.

PLANINA

Lake Planina pri jezeru or shortly Lake PNI is situated above Lake Bohinj at the 1430 m of altitude. Compared to Lake Bohinj is quite small, with only ca. 150 m in diameter. Mineralogical, geochemical and palynological methods were used, in order to understand long–term vegetation dynamics and in–lake sedimentary processes.

Sedimentary core that was obtained covers the last ca. 13 000 years (Caf et al., submitted). Palynological data shows that after the Pleistocene–Holocene boundary, vegetation around the lake changed from open steppe–like tundra to the treeline shifting to higher elevation causing afforestation of the area around the lake. Between 11 400 to 10 100 years cal. BP, mineralogical data shows that pyrite and gypsum occur in the samples indicating occasional anaerobic conditions (occurrence of pyrite). Gypsum minerals formed when the pyrite minerals were exposed to oxygenated carbonated waters, therefore the formation of those minerals was probably diagenetic. At the same time, values of OC/TN and δ13C were relatively high, which indicates mixed terrigenous and autochthonous input of organic matter into the lake, possibly due to short periods of increased precipitation.

At around 7500 years cal. BP, both ribwort plantain (Plantago lanceolata) and spores of Sporormiella appear, which could be indicative of pastoralism in the catchment area, especially due to both occurring at the same time. Since we unfortunately do not have a whole Holocene sequence in Lake Bohinj, we cannot with certainty say when the human impact started in the lowlands and compare it to Lake PNI. However, in the lowlands around Lake Bohinj, the continuous occurrence of Plantago lanceolata started at around 3000 cal. BP, suggesting that pastoralism was established earlier in the highlands than in the lowlands. On the contrary, the appearance of cereals in the lowlands (Lake Bohinj) is earlier (in late Bronze Age) than in the montane zone (Lake PNI, late Antiquity).

At around 4500 years cal. BP, beech (Fagus) became the dominant taxon in the area, with spruce (Picea) probably growing in the higher altitudes. From 3500 years to 450 cal. BP, Ca levels were really low, probably due to the establishment of beech forests. Broad–leaved forests regulate soil erosion by limiting the severe rainfall events resulting in the catchment area being more stabilized compared to coniferous forests. In Lake

Bohinj, that was probably not possible, since the lake is much bigger and has a larger catchment area that reacted to various instantaneous events, which lake PNI seemed more immune to. At the same time, no drastic anthropogenic interference is visible in the pollen record at Lake PNI, since the human impact seems to increase more gradually throughout the prehistory to the late Middle Ages, as oppose to Lake Bohinj where the human impact destabilized the area in the Iron Age.

However, more intense human impact in the Modern Period disrupted the stable period in the lake PNI, mostly by opening up the area for pastoralism (increase of pastoral indicators) and logging (mostly by drop in tree taxa, more specifically drop in percentages of beech that was the main choice for loggers). That caused the erosion and with more organic matter being washed into the lake, it became highly eutrophic with autochthonous input being the most important source of calcite in the sedimentary record during that time.

So to conclude, we can see the differences between two lakes that are basically "on top of each other" and how differently they seem to react to environmental changes. Mainly, Lake Bohinj has more "intense" sedimentary record with earthquake, flood events and drastic human impact as oppose to Lake PNI that has more "gradual" disruptions caused by vegetation and human impact affecting the catchment.

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GEOMORPHOLOGY OF A SUBMERGED KARST BASIN IN THE SEISMICALLY ACTIVE AREA OF THE KOLOČEP BAY

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One of the most widespread and successful applications of sub bottom profiler in shallow-water environment is in the study of Quaternary sediment successions. Acoustic mapping techniques are used for the determination of the geomorphology of the seabed, submerged karst relief and river channels (Gràcia et al., 2012). Using high-resolution seismic imaging methods, we can detect stratigraphic evidence of past and recent seismic activity, identify the displaced seismic horizons, folded and faulted reflectors, erosional bases, and zones of discontinuities (Gràcia et al., 2012). The Koločep Bay is an area between the mainland and the Elaphite Islands in the South Dalmatia, Adriatic Sea. According to the structural classifications, the area is placed in the contact zone of the regional structural units of the Adriatic microplate and the Outer Dinarides (Korbar 2009). The wider region is tectonically active and characterized by moderate to strong earthquakes. High-resolution seismic data were collected during April 2016. Seventy-four evenly distributed high-resolution seismic profiles were recorded with a 3.5 kHz sub bottom profiler-Chirp for investigation of the preserved sediment sequence. Two sediment cores of undisturbed marine sediments were collected on locations based on the previously recorded seismic data. A 4,70 m and 2,77 m long cores were sampled using the floating platform of the Croatian Geological Survey "Q2". The results show three seismostratigraphic sequences (Unit 1, 2, 3) which are divided into nine individual acoustic units. The boundary of seismostratigraphic sequences is characterized with erosional surface. The lower seismostratigraphic sequence (Unit 3) that can be observed on profiles has a maximum depth of -108 m and indicates tectonic movements in the form of folds. In the northern part, the lower units are uplifted and eroded, while in the southern part they are submerged. Comparing with the lower sequence, the two upper seismostratigraphic sequences in the bay area are horizontal and imply tectonic stability. Correlation with sediment core (Figure 1) and dating, gave us information on the environment that existed during the time of deposition. The marine environments have been identified in the upper (Unit 1) and middle units (Unit 2), with lacustrine and terrestrial environments between them. Other geomorphological features as vruljas (submarine spring) and paleochannels (doline) are also visible on seismic profiles. On the paleo bathymetric map of the middle seismostratigraphic sequence, we can easily follow the paleo river that existed in the northern part of the Koločep Bay.

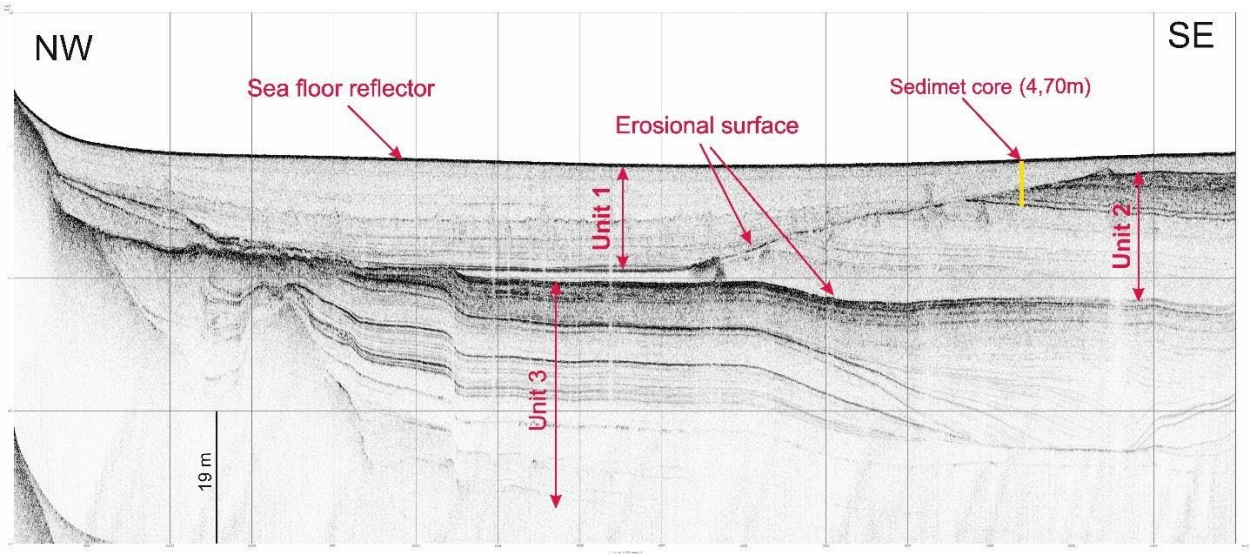

Figure 1: Representative seismic profile with sediment core and seismostratigraphic sequences (Unit 1, 2, 3).

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PROJECT SIMONA: TRANSNATIONALLY HARMONIZED SEDIMENT SAMPLING AND LABORATORY PROTOCOLS FOR HSs IN DRB's SURFACE WATERS PROPOSAL

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The Interreg project "Sediment-quality Information, MONitoring and Assessment System" (SIMONA) is designed to ensure support for transnational cooperation in joint Danube Basin Water Management. The main task of the project is a proposal of a SIMONA tool for harmonized monitoring of the hazardous substances (HSs) in drainage sediment in the Danube River Basin (DRB) countries. The participants in the SIMONA project include various institutions from the DRB countries: Austria, Bosnia and Herzegovina, Bulgaria, Croatia, Germany, Hungary, Moldova, Montenegro, Romania, Serbia, Slovakia, Slovenia, and Ukraine (Figure 1a). The Croatian Geological Survey (HGI-CGS) participated in all Work packages and it is responsible for Working Package 4 (WP4) of the SIMONA project. The objective of the WP4 is to develop transnationally harmonized sampling and laboratory analysis protocols for mid- and long-time surface water sediment quality monitoring and assessment to assist the water authorities in their daily work across the DRB countries. The sampling and laboratory analysis protocols will be parts of the SIMONA System. HGI-CGS with the contribution of its Associated Strategic Partners Croatian Waters (Croatia) and Waters of Srpska (Bosnia and Herzegovina) completed both protocols.

The protocols were tested at the three test areas: River Drava, South Danube, and Upper Tisa, and additionally at the 26 national sites, two sites in each participating country (Figure 1b, c).

The aim of the protocols is to provide proposals for harmonized sampling strategy and laboratory analyses of the HSs in sediments. Monitoring of sediments should be carried out according to the 2000/60/EC Water Framework Directive (WFD), the other relevant directives and CIS Guidance Documents, ISO standards, then ICPDR (ISPDR, 2003), and taking into consideration geological background and anthropogenic influences.

The drainage sediment in a river environment considered as suitable for monitoring are stream/bottom sediments and suspended sediment or suspended solids, and optional, active floodplain sediment. A sampling procedure include: selections of compounds to be monitored in sediments, selection of sediment sampling station, sediment collection (composite samples, sampling depth and frequency, sample fraction for analysis, sample volume), sampling equipment, field observation sheet, wet–sieving in the field, transport, quality control and safety measure (Šorša and SIMONA Project team, 2019).

The ISO and/or EPA standards for chemical analytical methods for the determination of heavy metals, and for the organic substances are proposed in the Laboratory analysis protocol. The HSs for monitoring in the protocol were selected under WFD and other related directives. Additionally, 5 heavy metals and their compounds from the List of Priority Substances for the Danube River Basin are included in this protocol (ICPDR, 2003). The Laboratory analyses protocol proposes procedures for sieving and drying sediment samples, their

storage and archive, if necessary some kind of normalization (grain size correction, quartz correction, Al- and Li-normalization) and proper quality control (Čaić Janković et al., 2019).

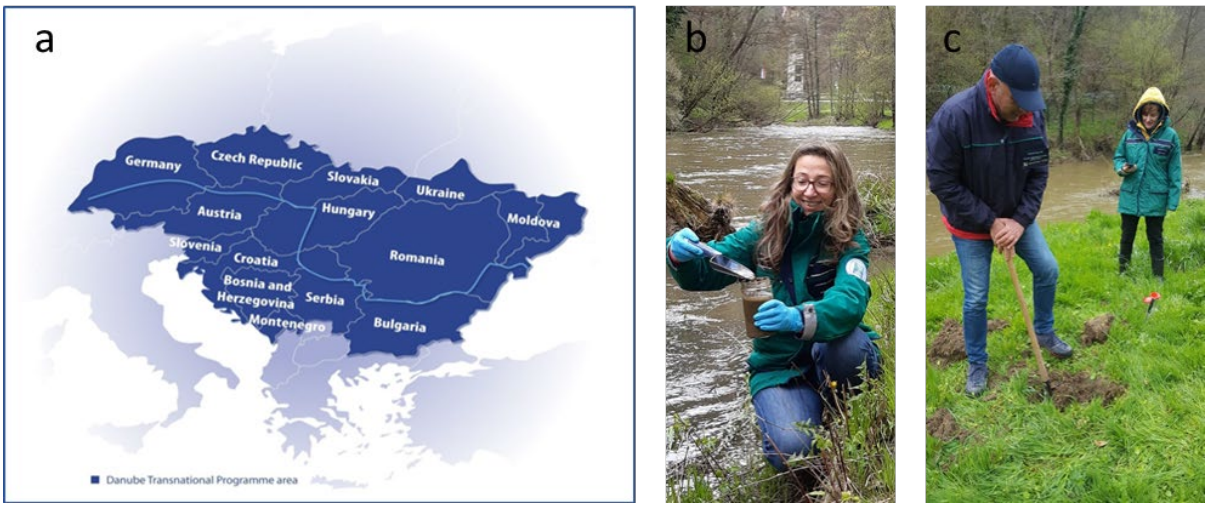

Figure 1: The participants in the SIMONA project (a). Sampling of stream/bottom sediment at the River Sutla (b). Sampling of overbank/floodplain sediments at the River Sutla (c).

The testing of Sampling protocol in Croatia was performed at the two selected locations; one sampling site on the River Sutla near Kumrovec, at the CRO/SLO border, and one sampling site near the confluence of the River Drava and the River Danube at the CRO/SRB border. At the sampling sites were collected samples of overbank/floodplain sediments (at 2 depths, 0-5 cm and 40-50 cm), stream/bottom sediments and suspended sediment. The water pH, water electrical conductivity and temperature of water were measured. Detailed description of the water body, location, characteristic sediment samples, and other significant information were written in the Field Observation Sheets for Sediment Sampling, which is a part of the Sampling protocol. Collected samples were stored and transported in refrigerator to the laboratory.

The testing of the protocols is undertaken before recommendation of their implementation in the monitoring of sediment in the DRB countries. A complete guidance for the monitoring incorporate procedures which comprehensively investigate sediment-associated HSs in the Danube river basin according to the WFD requirements and other relevant regulative documents in Europe. The guidance will be proposed in December 2021, at the end of the SIMONA project.

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DEFORMATION EVOLUTION OF EASTERN SICHUAN–WESTERN HUNAN AND HUBEI FOLD-THRUST BELT IN SOUTH CHINA: INSIGHTS FROM ANALOGUE MODELLING

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GEOLOGICAL SETTING AND KEY ISSUES

The Eastern Sichuan–Xuefeng fold-thrust belt (CXFTB) is located in the middle and upper Yangtze block of South China. It is bounded by the Dabashan fold-thrust belt to the northeast, the Youjiang fold-thrust belt to the southwest, the Dayong fault to the southeast and the Huayingshan fault to the northwest and has an area of ~2.4 × 105 km^2 (Fig. 1). The folds and thrusts generally strike NE–SW and show a curvature convex toward northwest. The CXFTB comprises two deformation domains with apparently different deformation features (Fig. 1). The thick-skinned Western Hunan–Hubei domain between the Dayong and Qiyueshan faults is characterized by box-shaped anticlines with relatively wide spaced synclines, while the thin-skinned Eastern Sichuan domain between the Qiyueshan and Huayingshan faults is characterized by Jura-type folds (Bonini, 2007). The CXFTB has apparently different deformation features from some classical fold-thrust belts in the world, although the deformation in the fold-thrust belts has been controlled commonly by a weak décollement (e.g. Chapple, 1978; Bonini, 2007; Boutoux et al., 2016). The deformation in the CXFTB is generally considered to be caused by northwestward shortening from the Xuefeng domain and progressively propagated northwestward from the Dayong fault (at ~235 Ma) to the Qiyueshan fault (at ~208 Ma) and then to the Huayingshan fault (at ~135 Ma) (Liu et al., 2015), with a total shortening of ~83 km (~16% shortening) and a shortening rate of ~1 mm/yr (Yan et al., 2003; Mei et al., 2010). but its deformation evolution still remains controversial. Analogue modelling is an effective method of structural geology and has been widely used for studies of deformation process and mechanism of fold-thrust belts (Bonini, 2007; Graveleau et a., 2012). In order to study further this issue, we designed three sets of analogue models.

ANALOGUE MODELLING RESULTS AND DISCUSSION

All the three models show that the Western Hunan-Hubei domain is dominated by wide box-shaped anticlines while the Eastern Sichuan domain is dominated by narrow anticlines, which suggests the control of depth of décollements or thickness of brittle overburden on the pattern of folds in the CXFTB. And the final results of these two models disagree with the natural structures of the CXFTB, suggesting that the basement of the Eastern Sichuan domain is unlikely to be rigid as that of the Western Sichuan domain or weak as that of the Western Hunan-Hubei domain. In contrast, Model-3 with a brittle basement under the Eastern Sichuan domain showed more similar deformation features to the natural.

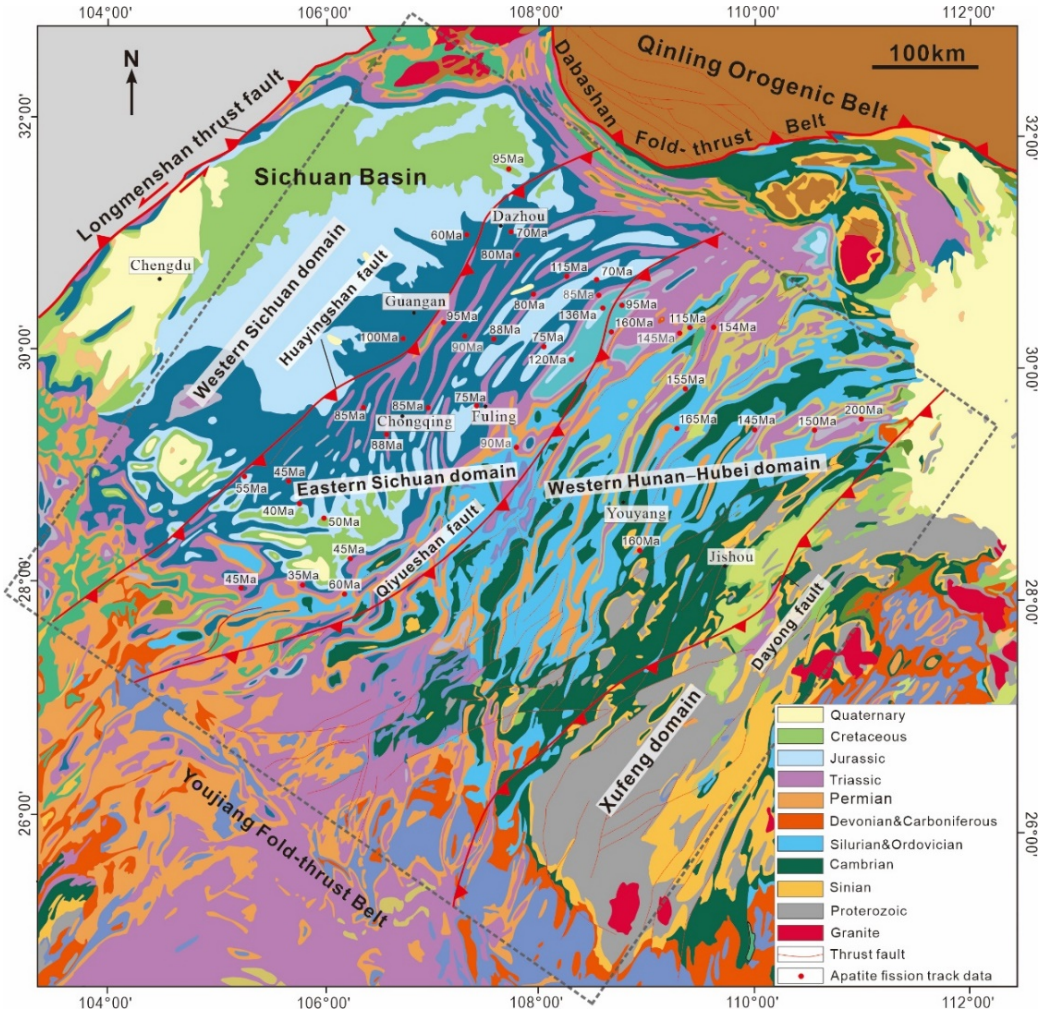

Figure 1: Regional geology of study area

CONCLUSIONS

1) the deformation in the CXFTB may simultaneously initiate along two zones nearby the Dayong and Qiyueshan faults at ~190 Ma, and then progressively propagate into the interiors of the Western Hunan-Hubei and Eastern Sichuan domains at ~140–150 Ma, and finally reach the front of the Huayingshan fault at ~120 Ma;

2) the difference in décollement depth is the main factor determining the patterns of folds in different domains of the CXFTB;

and 3) the Eastern Sichuan domain may have a basement significantly different from those of the Western Sichuan and Western Hunan-Hubei domains.

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SEDIMENTS OF A SINKING RIVER IN KARST OVER TIME: THE ŠKOCJANSKE JAME AS A CASE STUDY

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The Škocjanske jame (Škocjan Caves, UNESCO World Heritage and RAMSAR) are located in the area of the Divaški kras (Divača Karst), the SE part of Kras Plateau (Classical Karst). River Reka sinks into the Škocjanske jame and its waters flow about 250 m below the surface towards Kačna jama and through known and unknown caves to the Timavo springs north of Trieste (Italy). On its approximately 35 km underground route to the springs, the river is reached in 8 caves.

The Reka is the main sinking river on the edge of the Kras Plateau. The catchment area of the river is more than 350 km^2, with about 60% of the surface drainage network on Eocene flysch. The river flows for about 50 km in a river valley formed in impermeable flysch bedrock. As the valley enters limestone bedrock, the river begins to lose water into ponors located immediately after the contact. When the discharge of the Reka is bigger than 1 m^3/s, the river continues to flow in the limestone valley for another 7 km and then sinks into the Škocjanske jame. The Reka sinks into the cave at 317 m a.s.l., and the sump in Martelova dvorana is at 214 m a.s.l. In the period 1961-1990, the lowest measured discharge of the Reka was 0.18 m^3/s and the mean discharge was 8.26 m^3/s. During extreme floods, the discharge can exceed 300 m^3/s. The ratio between maximum and minimum discharge is thus over 1,700, which also causes about 100 m high oscillation zone (flood zone) in the karst underground (Gabrovšek et al., 2018).

The Škocjanske jame are caves with active water and dry passages which are located at different elevations (Fig. 1): at and above the active water flow and at the surface as unroofed caves (e.g. Mihevc 2001). The passages contain many allogenic clastic sediments derived from the flysch catchment of the river Reka and deposited in various cave environments in all hydrological karst zones.

Figure 1: Passages of Škocjanske jame with their sediments: a. active river flow in Hankejev kanal (photo M. Burkey), b. dry passages with old fluvial sediments in Tiha dvorana (photo M. Burkey), c. unroofed cave Lipove doline with fluvial sediments and exposed stalagmite.

The sedimentary fill of the caves consists of allogenic and autogenic clastic sediments deposited in a diverse environment. Individual layers and/or cycles of clastic sediments may consist of a single sedimentary facies,

such as slackwater, channel or breakdown deposits, or a succession of elementary facies indicating changes in various sedimentary processes within the depositional environment.

In the sediments of the river, its nearest tributary Sušica and the caves, quartz predominates with some clay minerals (illite/muscovite group), plagioclase and chlorite. The recent fluvial sediments are dominated by gravel clasts of flysch sandstone, while limestone pebbles predominate in the riverbed upstream of the sump (Kranjc, 1989). Recent flood clay at the end of the cave (Martelova dvorana) contains mainly quartz, some plagioclase, illite, kaolinite, chlorite, calcite and traces of montmorillonite (Zupan Hajna, 1995). In an older flood loam from the dray parts (Tiha jama at 334 m a.s.l.; Fig. 1b) quartz predominates, with some plagioclase, illite, chlorite, and traces of microcline. In Černigojeva dvorana (334 m a.s.l.; Gospodarič, 1984) relict pebbles of chert, flysch sandstone and limestone were described. Characteristics and locations of all fluvial sediments indicate their origin from the flysch. The sediments from unroofed caves above Škocjanske jame have a very similar mineral composition. The yellow-brown soil from the Lipove doline unroofed cave (Fig. 1c) consists of quartz, the muscovite/illite group of minerals, plagioclase, chlorite, vermiculite and amphibole. Amphibole does not occur in flysch, but indicates an eolian origin (e.g. from a volcanic eruption, desert sand or even loess). In the unroofed cave of the Risnik Industrial Zone, sandy clay and sand consist mainly of quartz, calcite, muscovite/illite group of minerals, kaolinite, chlorite and microcline with traces of plagioclase. Fluvial sediments in other unroofed caves in the wider area have very similar mineral composition but possible finds of tourmaline and rutile suggest an additional origin of sediments (Mihevc & Zupan Hajna, 1996).

The process of transport of eroded flysch particles into the caves continues for at least five million years, but the intensity of deposition and also the direction of water flow varied over time (Zupan Hajna et al., 2008, 2010, 2020). The results of the study indicate that the origin and succession of deposition conditions in the cave have not changed for several million years, but that the individual passages have been uplifted among hydrological profile most possibly due to regional uplift.

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NEW ^{36}CL GLACIAL CHRONOLOGY OF THE NORTHERN DINARIC MOUNTAINS (SLOVENIA)

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The timing of glacier build-ups over the last glacial cycle (120–0 ka) shows asynchrony worldwide. Many glaciers and ice sheets reached their maximum extent at the global Last Glacial Maximum (LGM, 27–19 ka BP; Clark et al., 2009), but some of them advanced early in the glacial cycle or even reached their maximum extent before the last glacial cycle. The timing of maximum glacier extent in the Dinaric Mountains has found to be asynchronous (e.g., Çiner et al., 2019; Hughes et al., 2011, 2010; Sarıkaya et al., 2020; Žebre et al., 2019), although chronological data for this area are still relatively scarce. One of the reasons for scarce absolute ages is very limited material availability that can be used to date glacial landforms in carbonate environments, such as Dinaric Mountains. Moreover, results are challenging to interpret due to many unknown variables, one of the most critical being the karst denudation rate. Here we present preliminary glacial chronological data from two high karst plateaux in the northern Dinaric Mountains of Slovenia: Snežnik (1796 m asl) and Trnovski Gozd (1495 m asl). These two areas have been the focus of glacial geomorphological research in the last decade (e.g., Žebre et al., 2019, 2016, 2013), but questions about the timing of former glaciations remain to be answered. We used the cosmogenic ^{36}Cl surface exposure dating technique to constrain the timing of the maximum glacier extent in both areas. We sampled 12 limestone and dolostone boulders in total from the crests of 3 moraines. To evaluate the magnitude of moraine denudation and determine the sediment deposition age independent from the boulder age, we also collected 11 samples in 30 cm interval to a depth of 300 cm from the crest of one moraine. Our landform ages are based on the oldest sample from the same landform corrected for erosion rate and snow cover. Younger ages from the same moraine are likely a result of moraine degradation, toppling and/or boulder exhumation. We used 15 mm ka-1 of erosion to correct our ages, which is supported by our preliminary results of long-term denudation rate from SW Slovenia as well as by other studies from Dinarides (Furlani et al., 2009; Krklec et al., 2018). The results from moraine boulders suggest that the glaciers on Trnovski Gozd reached their maximum extent during the global LGM, whereas boulders from the Snežnik area yielded Lateglacial age. In the latter study area, we also performed a depth profile technique that still needs further processing but will hopefully indicate the plausibility of boulder ages.

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PRESENTATION PROGRAM

6th Regional Scientific Meeting on Quaternary Geology: Seas, Lakes and Rivers

Presentation program

27.9.2021; Atrium ZRC SAZU & virtual

8:40-8:55	Arrival of participants to the Atrium ZRC SAZU & ZOOM log-in	
8:55-9:10	**Opening program**	
Session chair: Ana Novak		**SEAS & TRANSITIONAL ENVIRONMENTS**
9:10-9:50	**Branko Čermelj**	**Keynote: The recent sediments of the Gulf of Trieste, the most northern part of the Adriatic – An overview of the last 5 decades of the biogeochemical and sedimentological research**
9:50-9:55	Ana Hlebec et al.	Fidelity of (paleo)ecological interpretation based on studies living and dead benthic foraminiferal assemblages: A case study from the northeastern Adriatic shelf (Koper bay, Slovenia)
9:55-10:10	Livio Ronchi et al.	Submerged paleo tidal inlets of the northern Adriatic shelf: Early-Holocene indicators of the last RSL rise
10:10-10:25	Alessandro Fontana et al.	Core MIR1: A 34-m long Holocene archive at the mouth of Mirna River (Northern Istria, Croatia)
10:25-10:40	Massimo Novellino et al.	The expanded record of core MIR1 (Istria peninsula, Croatia): A new paleo environmental archive for the Eemian and the Last Interglacial
10:40-10:55	Sanja Faivre et al.	Lithophyllum rims as markers of relative sea-level change and palaeoearthquakes along the eastern Adriatic coast
10:55-11:15	Coffee break 20'	
Session chair: Slobodan Miko		**SEAS & TRANSITIONAL ENVIRONMENTS**
11:15-11:55	**Slobodan Miko**	**Keynote: Submerged landscapes of the Eastern Adriatic Sea**
11:55-12:10	Natalia Šenolt et al.	Late Quaternary seabed geomorphology of the Prokljan Lake (Krka River Estuary)
12:10-12:25	Alessandro Fontana et al.	Holocene evolution of the Neretva River Delta (Croatia) and its potential for reconstructing the relative sea-level changes
12:25-12:40	Dragana Šolaja et al.	Geomorphology of a submerged karst basin in the seismically active area of the Koločep Bay
12:40-12:55	Ozren Hasan et al.	Pleistocene and Holocene environmental changes in the eastern part of the Mid Adriatic Deep influenced by sea-level rise and shoreline retreat
12:55-13:00	Marina Čančar et al.	The relation between the composition of foraminiferal assemblages and granulometric properties of the sediments from three salt marshes (eastern Adriatic coast, Croatia)
13:00-14:20	Lunch break	

Session chair: Miloš Bavec		ARCHEOLOGY, EARTHQUAKES & STRUCTURAL GEOLOGY
14:20-15:00	**Andrej Gaspari**	**Keynote: Underwater archaeological investigations in Slovenia (the Slovenian sea and Ljubljana moor)**
15:00-15:05	Barbara Horn et al.	The archaeo-geophysical evidence of the pile-dwelling settlement Gornje Mostišče on Ljubljana Moor
15:05-15:20	Miklós Kázmér et al.	Seismicity of active faults tracked by archaeoseismology in two roman towns: Siscia (Croatia) and Celeia (Slovenia)
15:20-15:25	Petra Jamšek Rupnik et al.	Petrinja fault geometry and its activity revealed from reconnaissance geomorphological observations
15:25-15:40	Christoph Grützner et al.	How active is the Selce fault in SW Slovenia?
15:40-15:45	Manuel Diericks et al.	How remote sensing of active tectonics can fail in the slowly deforming karst landscape of Slovenia
15:45-16:00	Wengang He	Deformation evolution of Eastern Sichuan–western Hunan and Hubei fold-thrust belt in South China: Insights from analogue modelling
16:00-16:10	Break 10'	
Session chair: Petra Jamšek Rupnik		**PROJECTS**
16:10-16:25	Lidija Galović et al.	Incoming research project: Abrupt climate changes – Evidence from Quaternary sedimentary sequences in Croatia (ACCENT)
16:25-16:40	Ajka Šorša et al.	Project SIMONA: Transnationally harmonized sediment sampling and laboratory protocols for HSs in DRB's surface waters proposal

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9:00-9:20	Arrival of participants to the Atrium ZRC SAZU & ZOOM log-in	
Session chair: Maja Andrič		**LAKES, FORELANDS & MOUNTAINS**
9:20-9:35	Nina Caf et al.	First continuous reconstruction of climatic and human impact on the highlands of the Julian Alps
9:35-9:50	Valentina Pezdir et al.	From lake to peatland (Šijec bog, Slovenia)
9:50-10:05	Arianna Marcolla et al.	Middle Pleistocene to Holocene palaeoenvironmental evolution of the south-eastern Alpine foreland basin from multi-proxy analysis
10:05-10:20	Livio Ronchi et al.	Sea, lakes and river: The buried Late Glacial incised valley of Concordia Sagittaria and its infill (Tagliamento megafan, NE Italy)
10:20-10:40	Coffee break 20'	
Session chair: Giovanni Monegato		**LAKES, FORELANDS & MOUNTAINS**
10:40-10:55	Lukas Rettig et al.	Cirque, valley, and plateau glaciers in the Monte-Cavallo Group (NE-Italy) and their response to climatic changes during the Last Glacial Maximum
10:55-11:10	Manja Žebre et al.	New 36Cl glacial chronology of the northern Dinaric Mountains (Slovenia)
11:10-11:25	Sandro Rossato et al.	Was the Alpine Younger Dryas really dry? New insight from the Italian Dolomites (southern Eastern Alps)
11:25-11:40	Andrej Novak et al.	A combined study of grain size analysis and surface monitoring of active sieve deposits in the Planica Valley (NW Slovenia)
11:40-11:45	Andrej Novak et al.	Visualisation techniques of digital elevation models for analysing alpine landscape features
11:45-13:15	Lunch break	
Session chair: Nadja Zupan Hajna		**KARST**
13:15-13:55	**Nadja Zupan Hajna**	**Keynote: Sediments of a sinking river in karst over time: Škocjan Caves as a case study**
13:55-14:10	Maša Surić et al.	Speleothem record of Holocene natural and anthropogenic environmental changes in continental Croatia
14:10-14:15	Nina Lončar et al.	Submerged speleothems and phreatic overgrowths on speleothems (POS) as indicators of relative sea-level change along the eastern Adriatic coast
14:15-14:30	Ivona Ivkić Filipović et al.	Late Quaternary sedimentological and geomorphological processes in the Prološko Blato karst polje (Imotsko polje, Croatia)
14:30-15:10	**Nikolina Ilijanić**	**Keynote: Paleolimnology of Holocene karst lakes along the Eastern Adriatic coast**
15:10-15:25	Coffee break 15'	

Session chair: Lidija Galović		AEOLIAN SEDIMENTS
15:25-15:40	Nina Hećej et al.	Properties of the upper part of the Last Glacial loess-palaeosol sequence at Savudrija (Istria, Croatia)
15:40-15:55	Koen Beerten et al.	Optically stimulated luminescence (OSL) dating of the Đurđevac sands (northern Croatia): First results
15:55-16:10	Nikolina Ilijanić et al.	The Pakoštane loess plateau revisited; Dating, sedimentological, mineralogical and geochemical characterization
16:10-16:15	Dmytro Hlavatsky et al.	Loess-palaeosol sequences in Ukraine: A potential link between European and Asian Pleistocene enviromagnetic records
16:15-16:25	Break 10'	
16:25-17:00	**RMQG open discussion**	
17:00-18:00	**Matevž Novak**	**Geological tour of Ljubljana**

6th Regional Scientific Meeting on Quaternary Geology: Seas, Lakes and Rivers

Presentation program

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8:40-9:00	Arrival of participants to the Atrium ZRC SAZU & ZOOM log-in	
VIRTUAL EXCURSION		
9:00-9:10	Ana Novak	Introduction to the virtual excursion
9:10-10:30	Alessandro Fontana, Giovanni Monegato	The Tapogliano outcrop of the LGM to present day alluvial sequence of the Torre River which contains LGM paleosol
		LGM dunes near Grado which later interacted with Lateglacial fluvial and Holocene lagoonal environments
		Lateglacial terraces near Gorizia which formed in the Soča/Isonzo LGM fluvioglacial fan
10:30-10:45	Coffee break 15'	
10:45-11:05	Giovanni Monegato	The Renče clay pit, one of the best preserved paleovegetation records of the Alpine LGM
11:05-11:30	Petra Jamšek Rupnik	Deformed glaciofluvial and glaciolacustrine sediments in a profile at Most na Soči
11:30-12:15	Maja Andrič, Andrej Šmuc, Nina Caf	Holocene seismic activity, vegetation and erosion history and the human impact on the environment recorded in the lacustrine sediments of lake Bohinj
12:15-13:45	Lunch break	
13:45-14:30	Nikolina Ilijanić, Katarina Jerbić	The latest archeological and paleoenvironmental findings regarding the studies of the prehistoric pile-dwelling settlement in Zambratija bay, which was submerged by the advancing transgression
14:30-15:15	Ana Novak, Livio Ronchi	The post-LGM transgression and the change from fluvial to marine sedimentary environments in the Gulf of Trieste
15:15-15:25	Closing of the 6th RMQG	

6th Regional Scientific Meeting on Quaternary Geology: Seas, Lakes and Rivers

September 27-29, 2021, Ljubljana, Slovenia

See you at the 7th Regional Scientific Meeting on Quaternary Geology in 2024 in Croatia!