EX-AQUA 2019
PALAEOHYDROLOGICAL EXTREME EVENTS EVIDENCE AND ARCHIVES

September 26th - 29th 2019, Zagreb, CROATIA

Croatian Academy of Sciences and Arts

Scientific Committee

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ABSTRACT VOLUME

WORKSHOP EX-AQUA 2019
"PALAEOHYDROLOGICAL EXTREME EVENTS: EVIDENCE AND ARCHIVES"

Croatian Academy of Sciences and Arts
27th September 2019, Zagreb, CROATIA

EX-AQUA is a project supported by the INQUA Commission on Terrestrial Processes, Deposits, and History (TERPRO) and HEX (INQUA Focus Area on Palaeohydrology and fluvial archives – extreme and critical events). This scientific project aims at creating a network of researchers of different disciplines to work together for improving the knowledge on magnitude, recurrence time and other characteristics of the palaeohydrological extreme events (floods and droughts). EX-AQUA considers the whole Quaternary, but with special interest in the last millennia, for extending the useful records in the assessment of present and future extreme events.

The workshop planned in Zagreb is also supported by the Croatian National Committee of INQUA and it follows the workshops organized in Italy (Padova, September 2016), India (Noida, November 2017) and Hungary (Szeged, September 2018). The aim of the meeting is to bring together scientists interested in topics related to palaeohydrology for scientific exchange, facilitating the participation of early career scientists and PhD students.

Based on a grant generously provided by INQUA (International Union for Quaternary Research) commission on Terrestrial and continental processes, part of the participants is sponsored and no conference fees are required.

The title EX-AQUA consists of the Latin words "ex" (meaning "from" but also "ancient") and "aqua" (water) and it symbolizes the processes related to the lack or the abundance of water in the past.
People involved in EX-AQUA forms an open community of geologists, physical geographers, geochronologists, historians, archaeologists, palaeobotanists, engineers and modellers.

Thursday 26th – Meeting
Meeting from 18:30 at Hotel Livris (Rapska Ulica 12) where most of the participants are accommodated and light dinner at Batlak Grill (Radnička cesta 37c).

Friday 27th – Workshop
The workshop is locally organized by Mladen Juračić (Croatian National Committee of INQUA) and Igor Felja (Department of Geology of University of Zagreb) and will be held at the Croatian Academy of Sciences and Arts (Trg Nikole Šubića Zrinskog 11), which is also the hosting institution for the Croatian National INQUA Committee.

Saturday 28th and Sunday 29th – Field Trips
On Saturday 28th September there will be the opportunity to visit the area near the Lakes of Plitvice, which are included in the list of UNESCO sites and are among the most famous naturalistic places in Europe. The visit will bring the group in some key locations for understanding the palaeohydrological evolution of the area during the Late Quaternary.
On Sunday 29th September a half-day field trip is planned in the valley of the Sava River (retention basin of Lonjsko polje), with return to Zagreb around 15:00.

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27th September 2019, Zagreb - Croatian Academy of Sciences and Arts

9:00 – 9:10 Greetings and opening

9:10 – 9:40 **Jürgen HERGET** - Reconstructing discharges of historic flood levels (invited)

9:40-11:00

Ivona IVKIĆ - Late Quaternary karst paleohydrology, geomorphology and sedimentology of Prološko Blato paleolake in Imotsko Polje, Croatia

Ivan RAZUM - Holocene paleoclimatic conditions recorded in Sr/Ca ratio of inorganic aragonites from Veliko Jjezero, Mljet Island (Croatia)

Katarina PAVLEK - Changes in channel morphology of the Cetina River since the end of the 19th century (central Mediterranean)

Robert LONČARIĆ - A history of the occurence of Blidinje Lake (Bosnia and Herzegovina)

11:00-11:20, coffee break

11:20-13:00

Manudeo SINGH - Paleohydrology and evolutionary pathways of floodplain wetlands in north Bihar, east Ganga Plains, India

Kartika GOSWAMI - Response of the modern and late Holocene floods to climate change: Evidence from sedimentary archives from the upper Kaveri basin (India)

Rajiv SINHA - Mapping historical-scale planform dynamics for sediment budgeting of the Ganga River (India)

Ekaterina MATLAKHOVA - Late Pleistocene hydrological extreme events in middle Don River basin (Khoper and Vorona key study)

13:00-14:00, lunch (free)

14:00-14:30 **Maša SURIĆ** - The use of speleothemes in paleohydrologic reconstruction (invited)

14:30-15:30

Dea BRUNOVIĆ - Cyclicity of the marine, lacustrine and fluvial environments during the late Quaternary in the Lošinj Channel isolation basin, Croatia

Ana NOVAK - Late Quaternary evolution of the submerged northern Adriatic shelf – a concealed fluvial archive

Ozren HASAN - Paleolandscapes of karst rivers on the Dalmatian coast submerged as a consequence of the Holocene sea-level rise

15:30-16:00, coffee break

16:00-17:00

Luca GASPERI - Paleohydrology along the Musone River (Venetian Plain, NE Italy)

Katarina BOTIĆ - Change in settlement positions regarding some major Holocene climate events case study of two sites in Drava region

Alessandro FONTANA - The medieval deluge in Northern Italy: from myth to geoarchaeological evidence

19:00, Social dinner at Pivnica Medvedgrad, (Zagreb, Ilica Street 49)

RECONSTRUCTING DISCHARGES OF HISTORIC FLOOD LEVELS

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For historic settlement areas numerous flood level descriptions from times before the installation of river gauges are passed on, most of them are even dated. Typically, these written descriptions are qualitative such as “the water level peaked at 2 feet above the floor of the church” or “the water level topped the bridge before it failed”. Furthermore, historic flood water levels are frequently marked at buildings and constructions. Such descriptions of flood water levels are used to determine periods of increased flood frequencies but are rarely transferred into palaeodischarge numbers due to methodological problems. One major problem is the estimation of the cross section area due to missing information on the topography and hydraulic roughness of the floodplain and the river channel in historic times.

For the historic flood level records from the cities of Cologne (River Rhine) and Prague (River Vltava) an approach to estimate peak discharge is developed. Based on historic etchings, paintings and descriptions it is possible to reconstruct the characteristics of the river channel and floodplains to estimate cross-section areas during flood events. The reconstruction made use of all available data and estimations regarding channel incision as well as anthropogenic modification of the river and its floodplain. The mean flow velocity at the time of the historic flood events is estimated by the Manning-equation, based on the reconstructed river channel and floodplains.

The slope of the water level is assumed to be comparable to recent values, while the estimation of the hydraulic roughness is a challenge as no studies on the hydraulic roughness of settled floodplains have been carried out so far. Sensitivity studies with different n-values within a reliable range are carried out to estimate the influence of this uncertainty. Finally, the reconstructed data are tested by estimating peak discharges of recent floods by the application of the described method and comparing the results with measured discharge data from the gauges located at Cologne and Prague.

Keywords: Flood reconstruction, historic flood, urban hydrology, hydraulics

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LATE QUATERNARY KARST PALEOHYDROLOGY, GEOMORPHOLOGY AND SEDIMENTOLOGY OF PROLOŠKO BLATO PALEOLAKE IN IMOTSKO POLJE, CROATIA

Ivkić, I.[1], Ilijanić, N.[1], Miko, S.[1], Hajek Tadesse, V.[1], Hasan, O.[1], Navratil, D.[1], Barudžija, U.[2]

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Prološko Blato represents a remarkable karst phenomenon situated in the central part of the Dinaric karst, i.e. in the north-western part of the Imotsko polje. Multidisciplinary research enabled the classification of this karstified area and produced several hypotheses regarding its formation and development. Prološko blato is a seasonally flooded karst landscape developed within Cretaceous limestones and dolomites covered with a thick sequence of Quaternary paleolake sediments in its central and western part. The complexity of the Prološko Blato arises from its eastern part (the Prološko Lake), where a present day lake was formed probably due to combined processes of dissolution, tectonic activity and collapsing of both the limestone bedrock and overlying paleolake sediments. Thus, the Prološko Lake was determined as collapsed sinkhole (Ford & Williams, 2007), whose underground cracks and cavities serve as springs in winter, and sinks in the summer period, i.e. as estavelle (Bonacci & Roje-Bonacci, 2000). The repetitive water fluctuations are a major modern modifier of the landscape, eroding the loose Quaternary paleolake sediments and leaving distinctive erosional channels suitable for geological mapping and sampling. The Quaternary paleolake consists of a thick sequence of lake sediments divided into lower Pleistocene and upper Holocene part. The Pleistocene deposits consist of coarser-grained lake sediments (sand, sandy silt, silt) with a clear alluvial influence marked by gravel paleochannels. The Holocene deposits consist of lake sediments whose deposition started approximately 11,250 cal yr BP. The sedimentation is characterised with dark siliciclastic mud in the base of the Holocene sequence abruptly followed by light calcareous lake sediments (lake marl).

The lower Pleistocene deposits probably formed as a result of an intense fluvial, possibly fluvioglacial processes related to the snow melting in the Bosnian mountains situated north-east from the Imotsko polje. The fluvioglacial processes probably ended with the deposition of the dark siliciclastic mud in the early Holocene, as seen from mineralogical, geochemical and magnetic properties which suggest strong erosional input from the catchment area. This is followed by a calm period of the paleolake's history (approximately 9 600 cal yr. BP) marked with the deposition of lake carbonates determined as lacustrine chalk (lake marl), rich in calcium and well-preserved fossils of ostracods, gastropods, and charophytes. The paleolake with relatively constant water level existed throughout the Holocene until it was disrupted by the collapse of the sinkhole in its eastern part, which probably led to the modern hydrological regime with the seasonally controlled water level, i.e. drought versus swampy-like environment. This hypothesis needs to be further investigated, but a recent analysis of Sentinel satellite images showed a distinctive pattern of water withdrawal along the western and northern edge during the summer periods which suggests potential subsidence and collapse in the future in this part of the area. Further investigations are planned with an emphasis on drilling and geophysics to determine the paleolake's extent, its relationship with the modern Prološko Lake and underground karst features. Giving the fact that the Prološko Blato is of great importance to the local community, its status of a protected landscape within the vulnerable Dinaric karst, as well as tourism, sports and recreation, future research will undoubtedly serve this exceptional karst phenomenon in the terms of environmental protection and managing for sustainable use.

Keywords: Dinaric karst, karst lake, sinkholes, lake sediments

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HOLOCENE PALEOCLIMATIC CONDITIONS RECORDED IN Sr/Ca RATIO OF INORGANIC ARAGONITES FROM VELIKO JEZERO, MLJET

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The Sr/Ca ratio is often used as a proxy for SST (Beck et al., 1992). It is considered that the value of the Sr/Ca ratio in the aragonite *inter alia* is a function of temperature i.e. increase in the temperature lowers the ratio in inorganic aragonite (Dietzel et al., 2004; Kinsman and Holland, 1969). In this study bulk Sr/Ca ratio obtained by μ-XRF from the laminated marine lake sediments is used as a relative paleoclimatic proxy. Study was done in the Veliko jezero, Mljet, Croatia. In the large part of the sediment core M1-A inorganic needle-like aragonite is the only carbonate phase present. This was proved with XRD analysis. Detrital influence is very limited, thus Sr/Ca ratio from the bulk sediment reflects the ratio from the aragonite. Other than temperature conditioning, the Sr/Ca ratio was influenced by hydrological regime. Main Holocene climatic events like 8.2 event, pluvial phase from 8.1-7 cal ka BP, cold spell at 6 cal ka BP, 4.2 event and cold spell at 2.9 cal ka BP were recognized. Stable carbon isotopes and total organic carbon helped to support conclusions about nature of the cold spells and the provenance of the organic matter.

Keywords: aragonite, Sr/Ca, paleoclimate, Veliko jezero, Mljet

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CHANGES IN CHANNEL MORPHOLOGY OF THE CETINA RIVER SINCE THE END OF THE 19TH CENTURY (CENTRAL MEDITERRANEAN)

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Since the end of the 19th century, river channels across Europe have been noticeably modified by human impacts and climate change. Channel narrowing and incision, followed by changes in river ecosystem and habitat loss are mostly caused by dam construction, river channelization and land cover changes (Gregory, 2006). Channel morphology of the Cetina River in southern Croatia has also been significantly affected by climate changes, construction of hydropower plants, and socio-economic changes. This study investigates geomorphological changes of the Cetina River channels over the last 130 years using historical maps, archival aerial images and contemporary orthophotos. The river was divided in 15 segments based on geomorphological, geological and hydrological features of the river valley. A detailed digitalisation and analysis of the channel features was performed in GIS. In the period up to the mid-20th century, partial narrowing of the channel and drying of marsh zones in the source area were recorded, possibly due to reduced humidity and discharge following the end of the Little Ice Age (Grove, 2001; Faivre et al., 2019). The expansion of fluvial bars can also be connected to the drop in discharge and an increased sediment flux caused by noted population growth and agricultural intensification (Magliulo et al., 2016). A considerable progradation of the river delta during this period can be primarily seen as a consequence of the increased erosion rate of the flysch hinterland. Similar results were found for the river mouths on the Istrian Peninsula (Faivre et al., 2011; Benac et al., 2017). In the last 50 years, five big hydroelectric power plants (HPPs) were built in the catchment. The operation of the HPPs caused severe reductions in discharge (Bonacci and Roje-Bonacci, 2003), which led to channel narrowing by about 50% in the third of the river length. Apart from the dam construction, a reduction in the area of fluvial bars by 85% and an increase in the number of islands by 103% can be related to a decreased sediment supply following land abandonment and natural reforestation in the catchment (Boix-Fayos et al., 2007). Recent degradation of the river channel is thus largely caused by human activities. In the light of climate change projections, which forecast further drying and warming in the Mediterranean region during summer months (Giorgi and Lionello, 2008), the sustainability of the present situation is questionable. The results of this study add to the knowledge on river morphology in the Mediterranean environment and represent a starting point for the potential restoration plans of the Cetina River.

Keywords: fluvial geomorphology, aerial images, historical maps, Croatia

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A HISTORY OF THE OCCURRENCE OF BLIDINJE LAKE (BOSNIA AND HERZEGOVINA)

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Blidinje Lake is the largest mountain lake in Bosnia and Herzegovina with an area up to 6 km^2 depending on the water level. It is situated in the south of Bosnia and Herzegovina, between the mountains Vran and Čvrsnica, at an altitude of approximately 1180 m. Some publications refer to it as a glacial lake (Musa, 2005). Although undoubtedly there is evidence of the prior existence of glaciers and glacial relief in the area around the lake, the morphology of the lake's bottom and shores, variability of the surface, and a number of records on the lake's origin challenge the theory of the lake's glacial origin.

The aim of this presentation is to use cartographic sources of spatial data, historical records, geomorphological analysis, existing literature and interviews with the local population in order to determine how and when Blidinje Lake was formed. The existing historical and contemporary maps were used to perform measuring of the lake area in GIS environment. All data acquired were used to disprove the glacial origin theory and to provide evidence that the lake was formed artificially by the end of the 19^{th} century (Radoš, 2017).

Keywords: Blidinje Lake, lake genesis, history, Bosnia and Herzegovina

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PALEOHYDROLOGY AND EVOLUTIONARY PATHWAYS OF FLOODPLAIN WETLANDS IN NORTH BIHAR, EAST GANGA PLAINS (INDIA)

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Floodplain wetlands form an important ecosystem in alluvial settings. They play an essential role in the hydrological processes responsible for the development and sustenance of floodplains. The Kosi-Ganga interfluve of the north Bihar region in the East Ganga Plains (EGP) hosts numerous floodplain wetlands. The distribution and geomorphic evolution of the embedded wetlands have been established by using multi-source remotely sensed data such as Landsat, Sentinal-2, Corona, Cartosat DEM, and very high-resolution aerial imagery obtained using the UAV. These datasets have been used to map the geomorphic units, elements, and the associated geomorphic features of the interfluve region. The abundance of oxbow lakes, abandoned channels, and abandoned meanders in this region is a testament to the highly active fluvial regime. Several of these abandoned fluvial features have evolved into large wetland complexes. Here, we investigate the contemporary geomorphic phenomena to understand the origin of the wetlands and wetland complexes of this interfluve region of the EGP. Accordingly, the space-for-time substitution approach has been used to develop an evolutionary pathway for the floodplain wetlands of the interfluve region.

Our analysis shows that the distribution of these wetlands is highly localised and associated with the regional geomorphic setting and the fluvial dynamics. It has been established that the evolution of the wetlands in a dynamic fluvial system such as this interfluve region of EGP is a function of two different processes, (a) fluvial scouring and channel abandonment, which provides negative relief, followed by (b) erosional activities (cut-fill), which transforms the narrow and deep fluvial scours into large and shallow wetland systems. The cut-fill induced fusion of the relict fluvial features is the dominant pathway for the formation of large wetland systems of this area.

Keywords: fluvial geomorphology, remote sensing, Holocene

RESPONSE OF THE MODERN AND LATE HOLOCENE FLOODS TO CLIMATE CHANGE: EVIDENCE FROM SEDIMENTARY ARCHIVES FROM THE UPPER KAVERI BASIN (INDIA)

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Climatic floods are natural hydrological disasters that occur when the river overflows its normal confines and submerges the land that is usually dry. Such floods cause significant geomorphic changes and their impact also includes loss of human life, damage of natural heritage, ecosystem losses etc. thus largely affecting the economy of a nation. Recent increasing trends for high magnitude and devastating floods in southern India (November 2016 and 2017 in Chennai, Tamil Nadu, parts of Andhra Pradesh and Pondicherry) pose several open questions to climate scientists seeking to understand the flood causes and their relation to climatic or human impact. It is also important to ascertain the occurrence of these extremes or similar events from the past. Estimation of palaeoflood discharges is needed for better mitigation of flood risks and for the formulation of better flood-related policies.

We have attempted to identify paleoflood deposits from the upper reaches of Kaveri river and give them time framework using Optically Stimulated Luminescence (OSL) dating technique. Kaveri is one of the most important southern peninsular rivers, lying close to the sourthern tip of India. Thus, it is expected to be most sensitive to the Indian summer monsoon. The unit discharge of Kaveri is as low as (0.15 $m^3/s/km^2$). Nearly 16 flood events were dated successfully, and the relationship between extreme flooding events and rapid changing climate during the late Quaternary was analysed.

Current study shows distinct flood clusters occurred in the Upper Kaveri basin during the times of major shifts in the monsoon climate; from fluvial dormancy to sudden outburst of monsoons (~2 ka), from warmer to colder (onset of LIA ~13th century), from colder to warmer (end of LIA ~19th century), and ~20th century. The two major flood events of the 20th century reported from the upper Kaveri, were analysed to be produced by high intensity short duration storms. Palaeodischarge estimations reveal that flooding events during the 20th and 19th century were higher in magnitude than the flooding events during the 13th century in the upper reaches of Kaveri. The study also demonstrates based on the rainfall analysis of the last twenty years that the rainfall in the study area has become erratic thus, droughts and floods are not occurring just because of the decline or increase in rainfall, but it is also the higher variability is the distribution of the rainfall that is posing a serious problem. We also observe that although climatic floods are caused by extreme monsoon-related precipitation, there remains a crucial role of other hydrological variables in flooding events to occur as well such as soil moisture, basin shape and size.

Keywords: OSL dating, Palaeofloods, Kaveri, Late Holocene

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MAPPING HISTORICAL-SCALE PLANFORM DYNAMICS FOR SEDIMENT BUDGETING OF THE GANGA RIVER (INDIA)

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The Himalayan rivers are characterized by exceptionally high sediment flux from the tectonically active hinterland compared to the rivers draining from the peninsular India. Apart from high sediment production, monsoonal rainfall in the Himalayan hinterland further helps to bring these sediments down into the alluvial reaches of the rivers where lower slopes and wider channels encourage natural deposition of sediments. As a result, many rivers have been aggrading through time in their alluvial reaches, and the lower reaches of the Ganga River is a good example to illustrate this problem. Several stretches of the lower Ganga are completely filled with sediments resulting in major morphological changes leading to migration of rivers and flooding in unexpected areas and at unexpected times. Identification of such 'hotspots' of siltation and a first order sediment budgeting are important steps for designing sustainable river management strategies. Sediment budgeting in large rivers based on hydrological data is problematic due to the lack of close interval measurement stations and overestimation as it does not account for natural aggradation-degradation cycles in river systems.

This study in the lower reaches of the Ganga River used a combination of hydrologic and geomorphic approaches to identify the 'hotspots' of planform dynamics and sediment budgeting. We quantify the morphological changes in terms of relative changes in channel and bar area changes with the aim of identifying the major hotspots of siltation along the Ganga River between Buxar and Farakka. We then estimate the volume of 'total' and 'extractable' silt; the former based on the total bar area in the entire stretch while the latter based on the bar area for the hotspots only. The study shows that several stretches of the Ganga River have developed major 'hotspots' of siltation during the last 4-5 decades. Even though some reaches record minor degradation (erosion) in certain reaches, they do not balance the overall aggradation in the stretch between Buxar and Farakka. The first order estimates for total and extractable silt accumulated in this stretch are of the order of ~3000 x 10^6 m^3 and ~1700 x 10^6 m^3 respectively, and these are very high volumes. The study also highlights that the Farakka barrage, a major intervention in this stretch constructed in 1975, has affected the morphology of the Ganga River significantly both upstream and downstream of the barrage since its construction.

Keywords: fluvial geomorphology, hydrology, river channel management

LATE PLEISTOCENE HYDROLOGICAL EXTREME EVENTS IN MIDDLE DON RIVER BASIN (KHOPER AND VORONA KEY STUDY)

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Our study area is situated in central part of the East European Plain. We studied Khoper and Vorona river valleys near Borisoglebsk town (Voronezh region, Russia). On these sites Khoper and Vorona rivers have wide floodplains with big paleochannels on their surface, which have widths few times larger than the resent meanders of the same rivers. These paleochannels are the signs of high flood activity epochs.

The main aims of our study were reconstruction of Late Pleistocene river valleys' development, establishing of absolute chronology of large paleochannels formation and periodization of the phase of extremely high river flow in Middle Don River basin.

In our research we used hand and mechanical coring, examination of natural and human-made exposures, topographic profiling; radiocarbon and OSL dating, spore-pollen and grain-size analysis, microscopic study of quartz grains. Radiocarbon dates were calibrated (IntCal13) using the online version of OxCal 4.3 program (Reimer et.al., 2013). Also, we made the reconstructions of paleo-discharges of Khoper and Vorona rivers based on paleochannels' parameters.

Data analysis shows the following results. River incision took place between 35-25 ka BP and was connected with high runoff in the region. So, before LGM rivers were incised deeper than the modern river levels. LGM time (23-20 ka BP) was characterized by low runoff and cryoaridic conditions, that lead to accumulation in river valleys and activation of aeolian processes. In that time aeolian covers and aprons few meters thick were formed in river valleys (mostly on the terraces' surfaces). After LGM epoch of high runoff and macromeanders formation started, which was dated 19-12 ka BP. Also, modern wide high floodplains were formed in the studied river valleys at that time. This high runoff epoch was interrupted by a short low runoff period (~16-15 ka BP). This time was also characterized by activation of aeolian processes: the signs of aeolian activity were detected in Khoper river valley on the levels of the modern floodplain. So, the Late Pleistocene epoch of high floods and macromeanders formation was divided into two periods – 19-17 ka BP and 15-12 ka BP. For quantitative estimates of Late Pleistocene paleo-discharges we used the method developed by Alexey Sidorchuk (Sydorchuk and Borisova, 2000). Quantitative estimates show that Late Pleistocene mean annual paleo-discharges were 2-4 times higher than the modern ones. In Holocene runoff became much lower than in Late Pleistocene, the characteristics of the rivers became more comparable to the modern ones.

This study contributes to the Russian Foundation for Basic Research (RFBR) Project № 18-35-00028 "Geochronology of extreme hydrological events in Don river basin in the end of the Pleistocene".

Keywords: paleohydrological extreme events, river valleys, macromeanders.

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SPELEOTHEM-BASED QUATERNARY HYDROCLIMATE RECONSTRUCTION A VIEW FROM CROATIA

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After the dominance of ice and deep-sea cores, it is most probable that the future in Quaternary palaeoclimate studies might belong to speleothem science (Henderson, 2006), not only due to their complementary spatial distribution, but also for the many other advantages such as: very precise chronology, resolvable stratigraphy, high-resolution proxy records, precipitation reflecting mean annual climate conditions, simplicity of preservation for future studies etc. (Fairchild and Baker, 2012). Speleothems are secondary carbonate deposits that precipitate in caves from the groundwater supersaturated with respect to $CaCO_3$ which percolates through overlying karstified beds. Within their crystal lattice, speleothems may archive time series of data related to changes in the atmosphere, biosphere, hydrosphere and lithosphere that occurred during their deposition. Namely, on its way from the ocean, via air masses through soil and epikarst into the cave system, water undergoes multiple isotopic fractionations. Due to various causes (temperature, distance from the vapour source, altitude, amount of precipitation), ratios of oxygen ($^{18}O/^{16}O$) and hydrogen ($^{2}H/^{1}H$) stable isotopes vary, and remain recorded in precipitated speleothems. In addition, carbon stable isotopes ratio ($^{13}C/^{12}C$) in spelean carbonate indirectly indicates hydroclimate conditions as it predominantly depends on the vegetation situation above the studied cave/speleothems.

Apart from palaeoclimate reconstruction, the most significant Quaternary hydrological changes that are the sea level changes, could also be revealed from the speleothems, particularly those from the submarine caves. Namely, speleothems, as typical subaerial features, found below the present sea level prove the lower sea stands during the cold periods, but are also evidence of favorable regional environmental conditions (biological activity and running water essential for speleothem deposition) in spite of globally deteriorated climate.

Croatia, as a part of *classical karst,* hosts countless speleothems in probably more than 10,000 caves (Bočić, 2017) offering extraordinary opportunity to reconstruct palaeo-hydroclimate changes in this bordering region between the western and eastern Mediterranean, deeply indented into the European continent. Thus, several monitoring campaign (e.g. Surić et al. 2017; 2018; Czuppon et al., 2018) followed by speleothem analyses have been conducted. Up to date, many depositional episodes from MIS 10 to the Recent have been reconstructed, completing wider regional hydroclimate picture. Besides, submerged speleothems partially revealed local palaeoenvironmental history for the last 220 ky (Surić & Juračić, 2010).

Keywords: speleothems, stable isotopes, hydroclimate changes,

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CYCLICITY OF THE MARINE, LACUSTRINE AND FLUVIAL ENVIRONMENTS DURING THE LATE QUATERNARY IN THE LOŠINJ CHANNEL ISOLATION BASIN, CROATIA

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The submerged paleoenvironments along the Croatian part of the Adriatic Sea have long been overlooked. The project "Lost Lake Landscapes of the Eastern Adriatic Shelf" aimed to change that. Our research of the Lošinj Channel, located between the islands Cres and Lošinj, suggests that different factors influenced the paleoenvironmental evolution of the study area during the Late Pleistocene and Holocene. The combined impact of climate changes, sea level oscillations, karstification of the coast and the existence of a sill enabled the development of very different depositional environments. The Lošinj Channel is nowadays a submerged karst basin filled with sediments. High-resolution seismic survey, coupled with the multi-proxy sediment core analysis, facilitated the deciphering of its evolution. During the Marine Isotope Stage (MIS) 5a, marine environmental conditions likely prevailed due to high relative sea level (RSL) and warm climate conditions. Significant changes in these factors caused a strong erosional surface visible on the seismic profiles and a hiatus recognized in sediment core, which probably corresponds to the MIS 4 lowstand. During this period a karst polje likely existed. As a result of RSL rise and associated rise in groundwater level during MIS 3 (46.5-44.7 cal kyr BP) karst lake was formed ("Lošinj paleolake"). The RSL was lower than the sill depth (-50 m) and the investigated karst basin was an isolated lacustrine environment. „Lošinj paleolake" was characterized by carbonate production and a decrease in terrestrial detrital input from the catchment. The latter possibly suggests drier climate conditions in comparison to the MIS 5a marine environment. The drop in RSL and groundwater level, leading to the Last Glacial Maximum (LGM) (?44.7-13.7 cal kyr BP), resulted in the desiccation of the lake and the re-establishment of a karst polje. Fluvial processes and rill erosion modified the karst polje relief, with several phases of channel development and migration identified in seismic profiles. The post-LGM period (13.7-10.5 cal kyr BP) was marked by the establishment of the sedimentation in a brackish water marine lake. This environmental change occurred due to the rise in RSL and groundwater. However, the RSL was below the sill depth and seawater seepage occurred through the karstified sill. The RSL reached a sill depth of -50 m at the beginning of the Holocene (at 10.5 cal kyr B.P.), which led to the marine flooding of the Lošinj Channel karst depression. The Holocene pluvial climate period was recognized in sediment core data, with significant soil erosion processes occurring within the catchment. We can also assume that there is a cyclicity in the paleoenvironmental development of the deep silled karst basins, in relation to climate and sea level changes. Therefore, coring of a longer sediment succession could provide further valuable Quaternary environmental data.

Keywords: submerged paleoenvironments, Late Quaternary, sediment cores, high-resolution seismic

LATE QUATERNARY EVOLUTION OF THE SUBMERGED NORTHERN ADRIATIC SHELF – A CONCEALED FLUVIAL ARCHIVE

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The Last Glacial Maximum (LGM) sea-level lowstand subaerially exposed vast areas of present day shallow continental shelves. One such example is the present day northern Adriatic Sea which represented a vast alluvial plain of the Po, Appenine, Alpine and Dinaric alluvial systems during the LGM. We focused our study in the southeastern part of the Gulf of Trieste where pre-transgressional meandering fluvial channels are visible in the seafloor morphology indicating that this offshore site could contain a well-preserved Late Quaternary fluvial archive which, contrary to several well studied sites in the western Adriatic, endured only negligible erosion during the Early Holocene transgression.
We investigated the study site with the Innomar SES-2000 compact parametric sub-bottom sonar and determined four main acoustic facies which we later sampled with the Uwitec gravity corer. The sediment samples were analysed with the Fritsch Analysette 22 Laser particle sizer and were AMS radiocarbon dated. The bottom part of the studied sequence is composed of Last Glacial to Younger Dryas alluvial sediments which are buried by Early Holocene transgressive and Holocene shallow marine sediments. The oldest sampled alluvial sediment is represented by cross-stratified sandy mud of braided/wandering rivers which exhibits an acoustic facies with low-amplitude chaotic reflection geometries. It is overlain by graded deposits (sandy mud and sandy clay grading into clay) of braided/wandering rivers which show a characteristic acoustic facies with high-amplitude and high-frequency sub-horizontal reflection geometries. The topmost alluvial unit is composed of fine-grained overbank sediments (clay, mud and sandy mud) with occasional peat horizons and can be visible in the geophysical record as a transparent acoustic facies with individual discontinuous low to moderate amplitude reflections. The moderate to high-amplitude top reflection of this unit corresponds to the Younger Dryas and contains the previously mentioned pre-transgressive channel geometry. The alluvial sediments are overlain by bioclastic transgressive sandy mud with brackish (acoustic facies with concordant moderate to low amplitude reflections) and shallow marine mollusc assemblages (transparent acoustic facies).

We demonstrate that our study site represents a valuable archive of the Last Glacial to Younger Dryas evolution of the northern Adriatic alluvial plain. Our study site contains the braided/wandering river deposits which are characteristic for the region during the Last Glacial-LGM period and most probably represent the distal part of the Tagliamento-Isonzo megafan systems. The graded top part of this unit was redeposited by extensive floods. Fine-grained overbank deposition with slow sedimentation rates prevailed after the LGM when the area was dominated by meandering river channels presumably fed by the Timavo river and numerous karstic springs characteristic for the eastern part of the Gulf. The fluvial sedimentary environments in the study site persisted until the Younger Dryas after which they were transgressed without significant erosion during the Early Holocene. Transgressive and shallow marine deposits then buried and preserved the continental succession. In addition to the new insights in the Late Quaternary alluvial evolution in the area, our study allowed us to recognize the acoustic facies corresponding to the different alluvial deposits which will facilitate future offshore investigations and sampling. Finally, this study shows that the northern Adriatic submerged continental shelf represents a potential hotspot for Late Quaternary alluvial sedimentary environment investigations.

Keywords: northern Adriatic, alluvial plain evolution, Late Quaternary, acoustic stratigraphy

PALEOLANDSCAPES OF KARST RIVERS ON THE DALMATIAN COAST SUBMERGED AS A CONSEQUENCE OF THE HOLOCENE SEA-LEVEL RISE

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Large areas of the Adriatic shelf were exposed during the Last Glacial Maximum (LGM) lowstand. At that time relative sea level (RSL) was at least 125m lower than present (Lambeck et al., 2014; Benjamin et al., 2017), enabling formation of lakes, river valleys and their floodplains. Those areas were consecutively submerged during Holocene transgression (Vacchi et al., 2016).

We present a palaeohydrological study of karst rivers Zrmanja, Krka, Cetina and Neretva located along the Eastern Adriatic Coast. We used high-resolution acoustic geophysical methods (sub-bottom profiler, SBP) coupled with bathymetric data to detect well-preserved submerged river valleys. We compared interpreted SBP data to RSL curve (Benjamin et al., 2017, Lambeck et al., 2014).

SBP data for paleo-Zrmanja River shows channels incised into Pleistocene clastic rocks exposed during the early Holocene. Larger valley, flowing from east, joined Zrmanja and continued into Velebit Channel. Numerous channels visible in SBP data point to the existence of braided river system. Western part of the depression in today's Novigrad Sea hosted a small lake. RSL rise caused marine sediments to overlie fluvial and terrestrial sediments at depth 35,7 m below sea level (b.s.l.), an event dated at 11.44 ka BP (Hasan, 2017).

Submerged Krka river valley is visible in SBP data recorded in the Prokljan lake, a kryptodepression located approximately 10 km from the Krka estuary. River valley was incised up to 32 m b.s.l. indicating that fluvial sediment deposition started after 9400 BP (Lambeck et al., 2014). SBP records suggest existence of submerged tufa barrier at the northern part of the Prokljan lake. Fluvial sediments are overlain by up to 7 m thick marine sediment sequence.

Present floodplain of Neretva River extends over 10 km. SBP data shows similar floodplain formed approximately 60 km to the west, between islands Hvar, Šćedro and Korčula, at sea depth of 65-70 m b.s.l. Fluvial sediments with parallel to subparallel stratified reflectors onlap on the basin edges and overlie limestone. According to RSL curve (Lambeck et al., 2014) fluvial sedimentation began approximately 13.9 ka BP at 85 m b.s.l. After the sediments filled up the basin up to 70 m b.s.l. floodplain extended 10 km to Korčula Island. Two meters of marine sediments overlie fluvial sediments.

Cetina river mouth is located at the canyon exit in the town of Omiš. SBP data reveals that during the LGM river did not flow in NW direction as a continuation of today's flow but created a valley along the coast in SSE direction. During the postglacial period, Cetina created over 15 m deep and 350 m wide river valley. River valley incised up to 81 m b.s.l. indicating that deposition of fluvial sediments started after 13.8 ka BP (Lambeck et al., 2014). Due to a Holocene RSL rise, channel was infilled with retrogradational fluvial sediments. As sediments filled in the channel, Cetina created a 3 km wide floodplain overlain by 3-5 m thick marine sediment sequence.

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Keywords: sub-bottom profiler, submerged landscape, Holocene climate change, Eastern Adriatic

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PALEOHYDROLOGY IN THE MUSONE RIVER OF THE VENETIAN PLAIN (NE ITALY)

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One of the major issues in alluvial geomorphology and paleohydrological reconstructions is the possibility to assess the time interval intercurred for the formation of a channel morphology or the deposition of its sedimentary infill. Numerical geochronology is a key tool (e.g. Radiocarbon, OSL), but in some archaeological contexts the use of chronology supplied by cultural differentiation allow an even precise and detailed dates.

We present the case study of the Musone River, in the apical portion of the Venetian Plain, where the construction of the new highway road along the piedmont sector has allowed to describe long stratigraphic sections and to discover several new archaeological sites. One of the major finding corresponds to the Protostoric settlement located slightly east of the present river channel, north of the city of Riese. The ancient settlements were located along the active channels of the river and the new data allow to describe the interactions between the river changes and the settlement locations. In particular, at least 4 different channels of Musone dating between 1500 and 600 BC have been recognized. They display diverse characteristics, from meandering to braided typology. In some cases it is possible to follow the channel shifting with decadal precision.

The Musone is a minor stream fed by a catchment of 40 km^2 extending in the pede-Alpine area, where the bedrock consists of Tertiary siliciclastic formations prone to erosive processes. In the alluvial plain the Musone formed a narrow and elongated alluvial system along the interfluve between the alluvial megafan of Brenta River and the Montebelluna megafan, formed by Piave River before LGM. Since LGM the Musone aggraded of about 5 m over the aforementioned megafans and some buried soils testify significant depositional stasis. Musone River experienced an evolution that is strongly different from the depositional systems of the Alpine rivers, so, the study of this area supplies several data that are complementary to the ones collected in the rest of NE Italy for reconstructing the evolution of the Venetian Plain.

Keywords: Geoarchaeology, river channel morphology, alluvial stratigraphy, Holocene

CHANGE IN SETTLEMENT POSITIONS REGARDING SOME MAJOR HOLOCENE CLIMATE EVENTS - CASE STUDY OF TWO SITES IN DRAVA REGION

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Institute of Archaeology (Zagreb) carried out a project “Strategic use of landscape” (IP-11-2013-3700) founded by Croatian Science Foundation in the period between 2014 and 2016 (Botić 2016a; Marković et al. 2016). Project included the study of use of landscape in various time segments as well as data concerning natural resources (water, woods, arable land etc.) in a wider region of Našice in the middle Drava valley (Botić 2016a; Marković et al. 2016). During this project several field surveys were conducted. In the last field survey conducted in the region east of Našice, Stipanovci – Planina 1 site was discovered (Marković, Botić 2017; Botić 2017). This site presents very interesting situation: finds from the late Iron Age (1st c. AD) were collected at the lowest altitude, finds from the final Neolithic and the beginning of the Eneolithic (4500-4000 BC) at the somewhat elevated position while finds from the beginning of the Bronze Age (2400-2200 BC) were collected at the most elevated position (Marković, Botić 2017; Botić 2017). These specific micro positions and estimated time sequences of finds indicate possible link to specific Holocene climate events: 4.2 ka BP event in the case of Early Bronze Age (2400-2200 BC), 6.0 ka BP event in the case of final Neolithic (4500-4000 BC) and so-called Roman optimum in the case of late Iron Age (McCormick et al. 2012; Botić 2017).
Another site very close to Drava river in Donji Miholjac was excavated during Spring of 2015 on a southern by-pass road which yielded two waste pits from Early Bronze Age and two from late Iron Age (Botić 2016b). However, position of pits in a lowland area in the case of the Early Bronze Age finds suggests earlier temporal occupation of the site in comparison to the Stipanovci – Planina 1 site which was confirmed by one radiocarbon date and which could be placed at the very beginning of the 4.2 ka BP event.

On both sites in wider Drava region link between paleohydrological condition changes and site position changes can be identified, spanning over various time segments. Examples chosen are by no means isolated.

Keywords: northern Croatia, Drava region, settlment position change, Holocene climate events

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THE DILUVIUM AQUARUM: GEOLOGIC EVIDENCE AND GEOARCHAEOLOGICAL CONSTRAINS OF EXTREME FLOODS IN NORTHERN ITALY DURING EARLY MIDDLE AGES

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Between the second part of the sixth century and the seventh century, many regions of Europe have been characterized by dramatic changes in the hydrographic setting, probably related to a strong cooling phase (Büntgen et al., 2016; Helama et al., 2017). In the Mediterranean region the period following the collapse of the Roman Empire is described by many authors as an interval characterized by important alluvial processes (e.g. floods, river avulsions and alluvial aggradation in the mountain valleys), strongly contrasting with the general geomorphological stability of Roman Age and Late Antiquity. Some important chronicles of early Middle Ages report the occurrence of very high-magnitude floods, often described by ancient historians as diluvium (deluge), contributing to create a sort of myth around an out-of-scale event or a longer meteo-climatic phase (Cremonini et al., 2013).

In the framework of the INQUA project "EX-AQUA: Palaeohydrological Extreme Events, evidence and archives" (1623P), a review of the traces of early Medieval floods occurred in Northern Italy was carried out. The study considered new information and critically re-analyses previous available data, supplied by geomorphological, stratigraphic and geoarchaeological evidence, ancient documents and written sources.

In Northern Italy a fast and strong sedimentary phase occurred between 5th and 9th century AD, leading many large Alpine rivers to avulse. In the system of Tagliamento, thanks to recent geoarchaeological excavations and geochronological analyses, a major extreme event is clearly constrained between the second half of the 6th and the first part of the 7th century, when the river avulsed and destroyed the ancient city of Concordia Sagittaria (Fontana et al., 2019). This episode overlaps with the one reported by the Lombard historian Paolo Diacono, dated to 589 AD, which strongly damaged Verona and, downstream of this city, possibly triggered the avulsion phase of Adige River near the so-called "Rotta della Cucca". Important fluvial changes affected also the Piave and Livenza rivers, while an avulsion channel of Brenta River started to form in the 6th century AD.

Notwithstanding, for some minor alluvial systems the detailed chronology supported by archaeological and radiocarbon chronology allows to detect the existence of earlier flooding units, formed since the 2nd and 3rd century AD. Recent data in the Alpine valley of Adige River, around the city of Trento, point to the occurrence of some important flood events in the alluvial cones of the major tributary creeks already during the 3rd century AD. However, in the same area the floor of Adige valley experienced a vertical aggradation only since the 4th and 5th century AD, with an enhanced rate of deposition between 6th and 10th century AD. A rather comparable chronology characterizes part of the alluvial cones of the main Apennine streams flowing towards the Po Plain (e.g. near Modena), which aggraded during early Medieval, but this trend started already in the 3rd century AD (Cremonini et al., 2013).

This research supports new data for comparing the palaeoflood record of early Middle Ages with palaeoclimatic proxies, with the aim of distinguishing global forcing factors from regional constrains and anthropogenic disturbance.

Keywords: avulsions, radiocarbon dating, Venetian-Friulian Plain, Tagliamento River

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