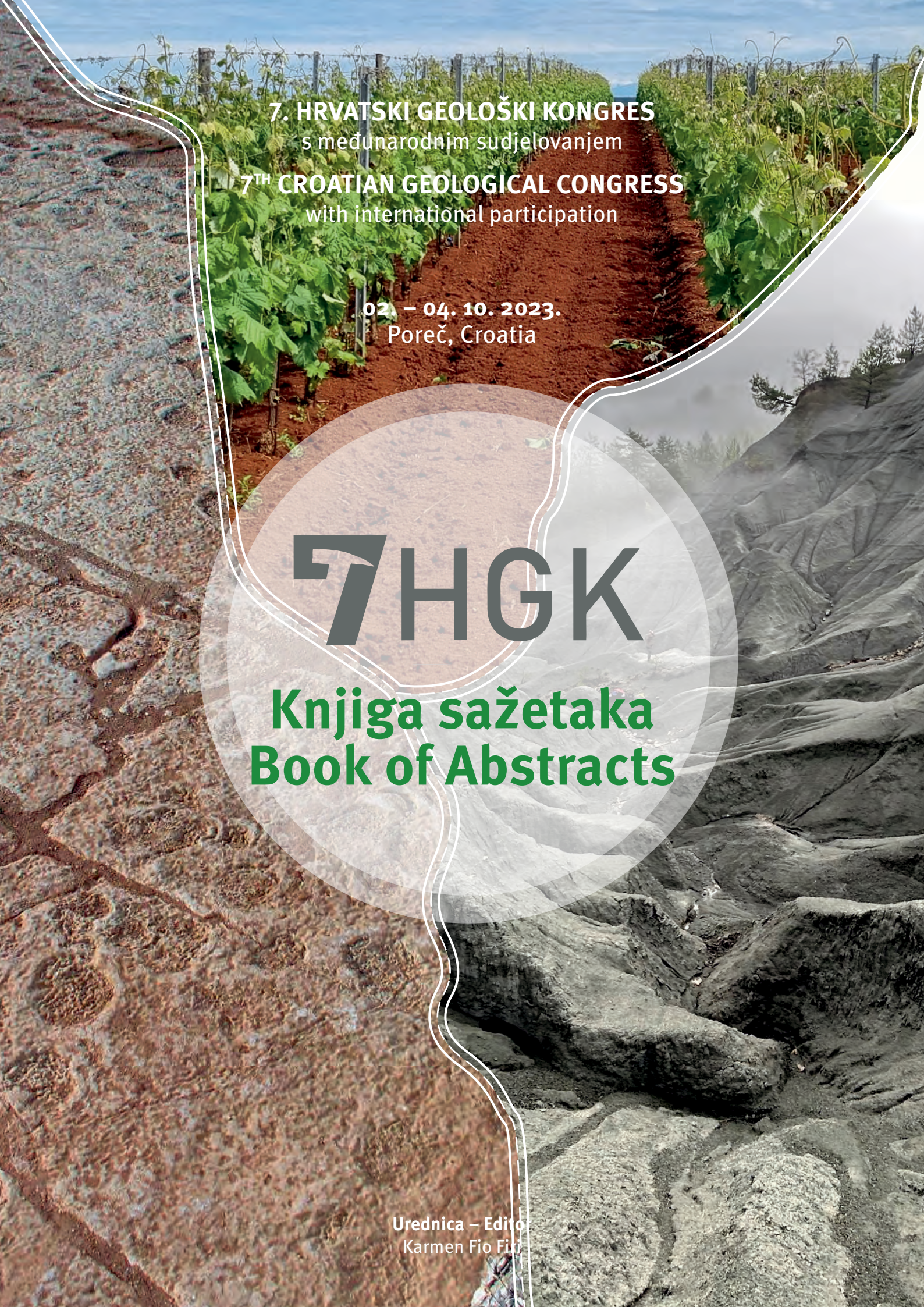

7. HRVATSKI GEOLOŠKI KONGRES
s međunarodnim sudjelovanjem

7TH CROATIAN GEOLOGICAL CONGRESS
with international participation

02. – 04. 10. 2023.
Poreč, Croatia

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Knjiga sažetaka
Book of Abstracts

Urednica – Editor
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CONTENT

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CRITICAL RAW MATERIALS ACT AND ITS IMPLICATIONS FOR THE ADRIA REGION
UTJECAJ AKTA O KRITIČNIM MINERALNIM SIROVINAMA NA PODRUČJE ADRIA ZEMALJA

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Keywords: *critical raw materials, mineral resources, Europe, resilience*

Since 2011, one of the major concerns of the European Commission is a sustainable supply of the raw materials critical for maintenance and development of the European industries (Ref 1). Among 28 critical raw materials listed by the European Commission Communication in 2020 (Ref 2), the ADRIA region (Albania, Bosnia and Herzegovina, Croatia, Montenegro, North Macedonia, and Serbia) hosts significant primary geological potential of antimony, barite, borate, lithium, magnesium and to some extent titanium, Rare Earth Elements (REE) and graphite.

BOROJEVIĆ ŠOŠTARIĆ *et al.* (2022) indicated the major strengths of the regional mineral sector: favourable geological setting hosting significant mineral potential and reserves, a long mining tradition, numerous exploration targets, high exploration budget (Fig. 1), as well as the availability of extraction of the secondary raw materials. However, authors also found many challenges that the mineral sector faces, including lack of regional exploration campaigns, international codes and standards in resource estimation, as well as regulations related to environmental issues that do not comply with European legislation.

New CRM Act (Ref 3) aim to strengthen the different stages of the European critical raw materials value chain. The implementation of the Act at the national member states level will include monitoring, data collection, guidelines development and coordination of the general exploration programmes; strategic national Raw Materials projects; permitting processes, Raw Materials related companies risk preparedness; specifying which end-of-life products and waste streams contain relevant amounts of critical raw materials; customs codes and recycling content for products incorporating permanent magnets; and the calculation and verification rules and performance classes for the environmental footprint. The implementation of the CRM Act to the West Balkan candidate countries is expected to follow their negotiation and harmonization process.

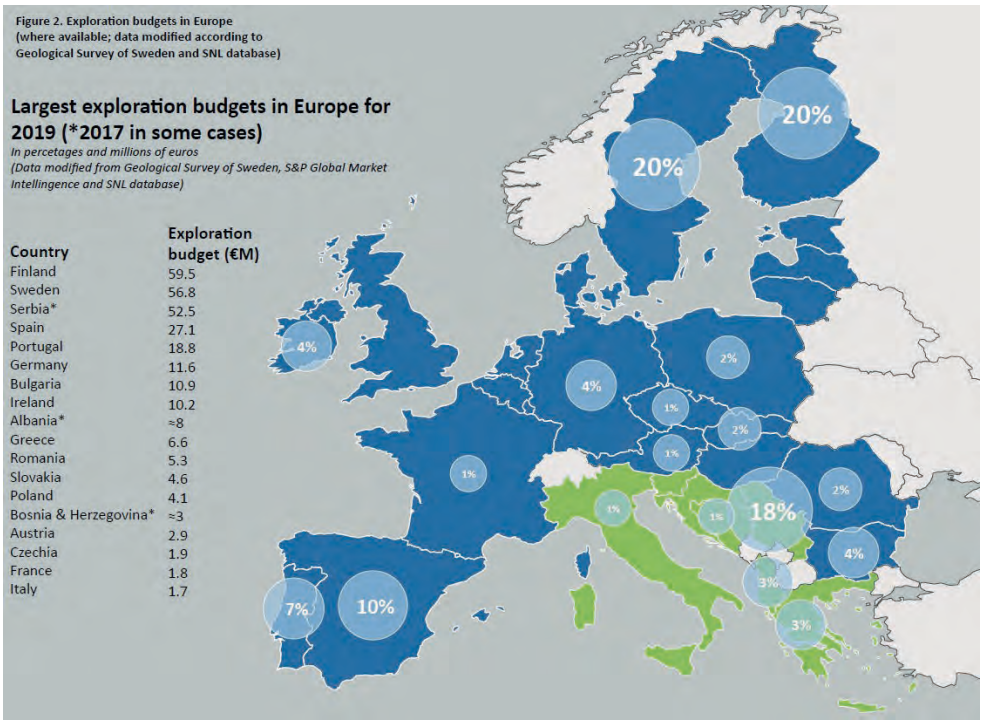

Figure 1. Exploration budgets in Europe (data modified after Geological survey of Sweden, S&P Global Market Intelligence and SNL database)

Therefore, actions and measures proposed by the CRM Act such as National exploration programmes for general exploration targeted at critical raw materials including deep ore deposits, mineral mapping, geochemical campaigns, geophysical surveys, data processing, development of predictive maps, reprocessing of existing geoscientific survey data and development of database with Strategic national Raw Materials projects should be taken as serious steps in further development of the Adria region's mineral sector in a sustainable manner.

Ref 1: Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions tackling the challenges in commodity markets and on raw materials, European commission, Brussels, 2.2.2011 COM (2011) 25 final.

Ref 2: European Commission, Study on the EU's list of Critical Raw Materials (2020), Factsheets on Critical Raw Materials, Brussels, COM (2020), 819 p.

Ref 3: Regulation of the European parliament and of the Council establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/1020, Brussels, 16.3.2023, COM(2023) 160 final, 2023/0079 (COD)

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CHANGES IN MICROFOSSIL ASSEMBLAGES: A CASE STUDY FROM THE MIOCENE DEPOSITS OF THE NORTH CROATIAN BASIN

PROMJENE U MIKROFOSILNIM ZAJEDNICAMA: PRIMJERI ISTRAŽIVANJA IZ MIOCENSKIH NASLAGA SJEVERNOHRVATSKOG BAZENA

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Keywords: *microfossils, Miocene, biostratigraphy, paleoecology, paleobiogeography, paleoclimatology*

During the last years in the Croatian Geology Survey, Department of Geology, a comprehensive micropaleontological investigation has been performed on Miocene samples from the North Croatian Basin (NCB). Micropaleontological investigations were a part of past and active scientific projects: Basic geological map of the Republic of Croatia and Nacional competitive projects.

North Croatian Basin belongs to the south-western margin of the Central Paratethys, and its evolution is connected to the Miocene global sea level changes and the connection with the Mediterranean Sea. NCB evolved in north Croatia during the Early and Middle Miocene (PAVELIĆ & KOVAČIĆ, 2018). It is an elongated rift-type basin covering almost the entire area of northern Croatia. Two phases of basin evolution are distinguished in the NCB: the syn-rift phase, which lasted from the Ottnangian until the middle Badenian, characterized by depositional environments that changed from continental to marine environments, and the late Badenian to the Quaternary post-rift phase, characterized by a shift from marine to continental depositional environments (PAVELIĆ & KOVAČIĆ, 2018).

The main results of the microfossil investigation have been carried out in this work. The Miocene microfossils are crucial in biostratigraphy, paleobiogeography, paleoenvironments reconstruction, and paleoclimatic changes. Based on a different group of microfossils (calcareous nannoplankton, palynomorphs, planktonic and benthic foraminifera, ostracods, molluscs, fish, reptilian and plant remains), we can determine age and biozones for Miocene epochs, as well as the more accurate positioning of the border between them. Clearly defined biozones can be easier correlated to the other regional basins of Paratethys and the Mediterranean (GALOVIĆ & BAJRAKTAREVIĆ, 2006; BAKRAČ, 2007; HAJEK-TADESSE & PRTOLJAN, 2009; BAKRAČ *et al.*, 2012; GALOVIĆ & YOUNG, 2012; SEBE *et al.*, 2020; GRIZELJ *et al.*, 2020, 2023; SREMAC *et al.*, 2022; ĆORIĆ *et al.*, 2023). Considering the species paleobiogeography, the presence of marine and non-marine "migrated species" can detect an open connection with Central Europe and Dinaride Lake System in Lower Miocene, the Mediterranean Sea and the Indian Ocean in the Middle Miocene, and to the different Basins of Lake Pannon and the Paleo-Mediterranean during the Late Miocene (HAJEK-TADESSE & PRTOLJAN, 2009; HAJEK-TADESSE *et al.*, 2023; PREMEC FUČEK *et al.*, 2023; MARINŠEK *et al.*, 2023 accepted; MUŽEK *et al.*, 2023, under review).

Main paleoenvironmental changes in NCB could correspond to eustatic cycles of sea-level history (HAQ *et al.*, 1988). According to microfossils, we could precisely and clearly distinguish non-marine, marine, and brackish environments in the Early, Middle, and Late Miocene (HAJEK TADESSE, 2006; BAKRAČ *et al.*, 2010; BRLEK *et al.*, 2016: MARKOVIĆ *et al.*, 2020; KOPECKA *et al.*, 2022); and barely noticeable environmental changes like the first intrusions of marine water into the Early and Middle Miocene lakes (HAJEK-TADESSE *et al.*, 2006; MANDIC *et al.*, 2019; HAJEK-TADESSE *et al.*, 2023). Most Miocene sediments were deposited during the Miocene Climate Optimum (MCO). Microfossils proved higher temperatures in NCB during MCO (~17–14.7 Ma), two warming peaks (METHNER *et al.*, 2020), as well as climatic instability (HAJEK-TADESSE *et al.*, 2023; PREMEC FUČEK *et al.*, 2023).

The different Miocene microfossil assemblages can identify local to global events. They are essential geological archives for a better understanding regional tectonics, paleoenvironments, paleogeography, and paleoclimate. We can predict future biodiversity, environment, and climate changes if we know Miocene's micro life and events well.

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INA HC EXPLORATION ACTIVITIES IN CROATIA
AKTIVNOSTI INA-e U ISTRAŽIVANJU UGLJIKOVODIKA U HRVATSKOJ

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Keywords: *Exploration, Pannonian Basin System, Adriatic, Drava-03, SZH-01, 3D seismic*

The current energy crisis requires major changes in energy supply routes, which negatively affects the security of supply in the EU. As a result, domestic HC production is gaining more and more strategic importance. The share of domestic HC production in the energy mix of the Republic of Croatia has been decreasing for years due to the natural decline in the production of mature fields. Although both the Pannonian basin and the northern Adriatic are highly explored basins, INA continuously carries out exploration activities. In the last three years, besides Severovci-1 gas discovery and Jankovac-1 oil discovery on Drava-02 licence INA started a new onshore exploration cycle in 2020 by signing PSA for exploration concessions Drava-03 and SZH-01. Exploration activities are utilizing new advanced technologies which should increase chance of success in exploring gas reservoirs. In the first phase 750 km^2 of new high-quality 3D seismic was acquired using wireless technology, enabling high density subsurface sampling and increase of both vertical and spatial resolution of the data. High density data was suitable for advanced direct hydrocarbon indicators (DHI) interpretation techniques thus allowing significant exploration prospect portfolio generation. So far, five wells have been selected for drilling in 2023 and 2024, and optionally few more wells could be drilled in the second exploration phase. Also, the extensive drilling campaign in the northern Adriatic is continuing with a combination of development and appraisal wells planning to reverse the trend of declining production of Adriatic gas fields. It is expected that those activities could significantly increase domestic gas resources facilitating energy crisis and transition in the Republic of Croatia.

COASTAL EROSION – GLOBAL PROBLEM AND CROATIAN EXPERIENCE
EROZIJA OBALA – GLOBALNI PROBLEM I HRVATSKA ISKUSTVA

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Keywords: *carbonate coast, artificial beach*

Coasts are among the most inherently dynamic areas of our planet, reflecting the complex interplay of processes related to land, sea and air. In this context, coastal erosion refers to a complex natural geomorphological process that leads to an adjustment of the coastline, eventually reaching a new equilibrium. The main characteristic of coastal erosion is the continued loss of coastal material that causes the shoreline to retreat landward.

All coasts tend to erode at some point, but not all coasts are the same, nor do they all erode. Currently, coastal erosion is considered a geologic hazard that causes numerous environmental problems worldwide: 70 % of the world's beaches are thought to be eroding (BIRD, 1996), while > 50 % (or as much as > 70 % according to some authors) of the world's coastline consists of eroding cliffs and other rocky morphologies (BIRD, 2000; YOUNG & CARILLI, 2018). Many eroding coastal landscapes are valued for their beauty and contribute to the economy, especially the tourism industry. Great efforts are being made to preserve these eroding landscapes. Therefore, it can be concluded that coastal erosion has only become a problem due to anthropogenic use of coastal areas.

Three basic natural factors controlling coastal erosion are relative sea-level rise (including eustatic and isostatic changes), depletion of local sediment supply (i.e., a deficit in sediment budget), and changes in wave climate. In addition to these causes, human interventions on shorelines can exacerbate existing erosion processes or trigger erosion in places where it did not previously exist. Most human interventions are related to changes in sediment budget, while human-induced changes in wave climate are less common. Major responses to eroding shorelines include: hard stabilization (structures such as piers, seawalls and groins), soft stabilization (beach nourishment), and relocation or retreat.

The Croatian coast is a primary and transgressive steep rocky coast, formed by the submersion of the karstified relief during the post-Pleistocene sea-level rise. Most of the Croatian coast is developed in Mesozoic – Palaeogene carbonates (> 90 %), while a minor part of the coastal lithology belongs to the Eocene and Quaternary clastites (~6 %) (PIKELJ & JURAČIĆ, 2013).

The coast formed in carbonates is considered hard-rocky coast. It is generally inaccessible, steep, and resistant to the classic erosion processes. In some places (e.g. Dugi Otok, Kornati, Konavle, etc.) tectonic cliffs have formed. Coastal processes typical for carbonate coasts include bioerosion and bioconstruction. Submerged tidal notches can be found several tens of centimetres below the current sea-level (BENAC *et al.*, 2008), indicating recent tectonics and sea-level rise. Similarly, algal rims are another indicator of recent tectonics and a useful tool for sea-level change reconstruction (FAIVRE *et al.*, 2021). Typical erosional processes have been were recognized along steep sections of the Croatian carbonate coast at sites exposed to extreme waves from the stormy Sirocco. At such sites, coarse-grained boulders detach from bedrock and are displaced several tens of meters landward. Such a process is highly dependent on the local orientation of bedding and the general geomorphology of the coast combined with the coastal exposure (BIOLCHI *et al.*, 2019; KORBAR *et al.*, 2022). Other hazards, as rockfalls or debris flows occur on other steep coastal sections where weakened or karstified carbonate rocks are present, e.g. at Konavle and Biševo. Some slope processes can be triggered by earthquakes, as happened in February 2023 on the Krk Island (Sršćica Bay).

Eocene flysch and Quaternary clastites are the most common soft rocks on the Croatian coast. Due to pronounced mechanical weathering, such coastal sections are lined with a higher proportion of beaches and cliffs, the latter being the most naturally erosive coastal forms along the Croatian coast (PIKELJ & JURAČIĆ, 2013). Soft rocky cliffs are greatly developed on Rab and Pag Islands, in the Zadar and Split regions. The longest flysch zone facing the sea is located in the Kaštela–Ploče zone. However, a large part of this zone consists of basal flysch members (carbonate breccias), which are extremely important for the gravel beach formation along the Makarska Riviera. The erosion rates of soft rock cliffs are still largely unknown, with the exception of the first estimate of the flysch cliff retreat in the Split urban area, which ranges from 3–18 cm/year (VLASTELICA *et al.*, 2017; PIKELJ *et al.*, 2018). Recently studied coastal cliff developed in Pleistocene clastites on the Vrgada island showed indications of high retreat rate during the last century. Another unique coastal cliff system coast that should be mentioned is the entire coast of Susak Island, where Pleistocene paleosols and loess deposits are actively eroding. This erosion occurs naturally and is aided by anthropogenic activities (WACHA *et al.*, 2011). Efforts by locals to prevent the erosion by building seawalls have yielded few results, as erosion continues behind the walls.

The total length of Croatian beaches does not exceed 6% of the total length of the coast. Beaches formed in carbonates are numerous, but small and mostly gravel beaches. Their development is generally related to the confluence of fossil or recent ephemeral surface flows, while some of them were formed by wave erosion of the weakened carbonate rocks (PIKELJ & JURAČIĆ, 2013). Beaches formed in clastites are more common and their sediment composition varies between sand and gravel. Some examples of beaches formed in clastic bedrock are Baška on the Krk Island, Lopar and San Marino on the Rab Island, beaches in the area of Nin and Zaton, Saplunara on the Mljet Island, etc. Sandy beaches composed of marine biogenous sand are rare along the Croatian coast, and therefore extremely valuable. Such beaches have been found on the Dugi Otok Island (e.g. Lojišće beach).

Regardless of the lithology of the substrate, all Croatian beaches are valuable resources suitable and widely used for recreation and tourism. However, due to their small total length, there is a demand for beach capacities. Therefore, many natural beaches are being widened, while the trend is to build artificial beaches. Unfortunately, the procedures for beach construction and beach nourishment have not been adequately defined in legislation to date, and the two procedures are used interchangeably. This allows improper construction and leads to inappropriate and unsustainable beach management, as demonstrated by the BEACHEX project (CSF PZS-2019-02-3081). These inappropriate practices and interference with coastal dynamics are leading to erosion of artificial beaches, which is expected to increase in the future due anthropogenic and natural pressures (sea-level rise and increased storminess). Enlarged natural beaches, also experience similar problems, usually due to the inadequate material used for beach nourishment and lack of systematic management. In addition, the recent example of the Sakarun beach showed another man-made example of beach erosion: removal of the Posidonia oceanica banquette for tourism purposes led to erosion of the sandy sediment of the beach over the years (PIKELJ *et al.*, 2022).

The results of intensive studies of beach sediments and morphodynamics (and coastal erosion in general) in the last decade have shown increasing number of problems along the Croatian coast. Some of them are the result of the natural sensitivity of the local lithology and the tendency to erosion. However, many of them are man-induced, mainly due to the inappropriate practices of beach nourishment and general interference with the coastal morphodynamics. Therefore, there is a constant need for systematic research in coastal sciences, in particular beach monitoring.

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DEVELOPMENT AND APPLICATION OF GEOTHERMAL ENERGY IN THE REPUBLIC OF CROATIA WITHIN THE NRRF PROJECT

RAZVOJ I PRIMJENA GEOTERMALNE ENERGIJE U REPUBLICI HRVATSKOJ U OKVIRU NPOO PROJEKTA

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Keywords: *Energy transition, Geothermal energy, NRRP Project, Croatian Hydrocarbon Agency, Republic of Croatia*

The energy transition towards low-carbon energy requires significant changes in the energy sector. In order to achieve these goals in the period up to 2050, accelerated implementation of the transformation processes in the energy sector is required. A particular challenge is to reduce greenhouse gas emissions while increasing energy consumption from RES and gradually reducing fossil fuel consumption, and at the same time ensuring available, secure, affordable and competitive energy. Accordingly, the energy transition requires major technical, technological and social changes in all sectors of the economy. The transition to low-carbon energy requires an innovative approach from a technical, social and political perspective.

Geothermal energy in Croatia has a strong symbolic power because among the first in Europe it has opportunity to show what a possible energy transition looks like in practise. Indeed, the geothermal projects announced in Croatia are mainly based on wells that were originally created for the exploration and exploitation of oil and gas. The earlier "failure" of an engineer or a depleted well is now a great advantage because it significantly reduces the risk and costs for potential investors.

The transition in the Republic of Croatia started already in 2018 with the new Act on Exploration and Exploitation of Hydrocarbons, which clearly regulated the possibility of exploration and exploitation of geothermal energy, ensuring the conditions for investors to start preparing projects under clear regulatory conditions. To achieve the goals of the energy transition, the Republic of Croatia has defined a project for the use of geothermal energy for heating purposes in its National RRF, with the aim of decarbonising heating in cities with existing central heating systems. The Croatian Hydrocarbon Agency is responsible for a project in which six exploration areas will be additionally de-risked by acquiring new geophysical data and two geothermal exploration wells will be drilled to test the geothermal potential for heating purposes.

THE BENEFITS OF SYSTEMIZING THE NEW COLLECTION OF CROATIAN NATURAL HISTORY MUSEUM RELATED TO OIL AND GAS EXPLORATION DATA IN CROATIA

PREDNOSTI SISTEMATIZACIJE PODATAKA NOVE ZBIRKE HRVATSKOG PRIRODOSLOVNOG MUZEJA PRIKUPLJENE TIJEKOM ISTRAŽIVANJA UGLJIKOVODIKA U HRVATSKOJ

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Ključne riječi: *HPM, muzejska zbirka, baza podataka, mikropetrografski i mikropaleontološki preparati*

Hrvatski prirodoslovni muzej (HPM) godinama surađuje sa znanstvenom zajednicom, te njeguje i čuva različite zbirke nastojeći pritom pridonijeti u odgonetanju geološke prošlosti i života na Zemlji. Jedna od glavnih zadaća Muzeja je osigurati sigurno i zaštićeno okruženje za brojne zbirke. U 2018. godini INA-Industrija nafte, d.d. je Hrvatskom prirodoslovnom muzeju donirala vrijednu zbirku podataka koji su rezultat dugogodišnjeg istraživanja nafte i plina u Hrvatskoj. Zbirka se sastoji od podataka karotažnih mjerenja petrografskih, mikropaleontoloških odredbi stijena i fosila određenih na 37 000 mikroskopskih preparata, integriranih stratigrafskih i naftno-geoloških interpretacija i korelacija te geoloških stupova i karata istraživanih područja (u Hrvatskoj) sažetih u 70 pisanih izvješća.

Podaci ove zbirke predstavljaju iznimno dragocjen izvor geoloških informacija. Stoga je bilo važno organizirati sve podatke i postaviti mogućnosti uvida u iste. Zbirka kao takva može i treba poslužiti kao izvor podataka u budućim znanstveno-strukovnim istraživanjima.

HPM je pokrenuo projekt koji ima za cilj dokumentirati, i tekstualno i grafički, sve podatke iz donirane zbirke (lokacije bušotina, petrografske, mikropaleontološke analize, kao i sve druge laboratorijske podatke) te omogućiti javni pristup zbirci na osnovi odabranih kriterija pretraživanja (npr. lokacija/područje, stratigrafski raspon, vrste stijena, vrste/rodovi fosila). Sistematizacija zbirke izvršit će se u programu Microsoft Access i ArcGIS. Važno je naglasiti da će već poznati fosili iz zbirke biti ponovno ispitani i dopunjeni novim podacima/odredbama. Pristup zbirci bit će besplatan, mrežni, a ažuriranja ili relevantne vijesti bit će omogućene znanstvenicima koji se žele uključiti u projekt. Zbirka podataka prikupljenih tijekom istraživanja ugljikovodika pohranjena u HPM-u može postati važna i sveobuhvatna baza podataka tog tipa u Hrvatskoj.

THE PERMIAN–TRIASSIC BOUNDARY INTERVAL IN THE VELEBIT MOUNTAINS: NEW FACIES, BIO- AND CHEMOSTRATIGRAPHIC FEATURES

GRANICA PERM–TRIJAS NA VELEBITU: NOVA FACIJESNA, BIOSTRATIGRAFSKA I KEMOSTRATIGRAFSKA OBILJEŽJA

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Keywords: *External Dinarides, Late Permian and Early Triassic dolostone facies, Late Permian foraminifers, Hindeodus parvus, carbon isotope curve, microbially influenced dolomitization*

The Permian–Triassic boundary (PTB), one of the most investigated stratigraphic boundaries, is marked by dramatic changes in oceanic and atmospheric chemistry that consequently caused the most severe mass extinction of all time. These changes can be seen in the type and style of deposition in the PTB interval that is characterized by transition from skeletal-dominated to microbial-dominated carbonate production. Most of the studies concerning this important time interval have been made in shallow to deep marine depositional environments in addition to some terrestrial sections. However, there is very little information about how shallow lagoonal, sabkha and intertidal sediments reacted to these drastic changes. Indeed, shallow marine deposition was often prone to dolomitization and thus difficult to date. In the Brušane-Sy section located south of the village Brušane (Velebit Mountains) in the External Dinarides (Croatia), we have observed continuous dolostone sedimentation throughout the Permian-Triassic boundary interval and obtained new facies, bio- and chemostratigraphic data (conodonts, foraminifers, $\delta^{13}C$ curve). A high-resolution micropetrographic study shows different dolostone texture and preservation of primary constituents in the Permian vs. the Early Triassic dolostone. The Permian dolostone deposits are differentiated as: 1) dolomicrite/mudstone with microbial (cyanobacterial) interlayers, the occurrences of stromatactoid fabric, desiccation cracks/tepee structures signifying deposition in intertidal/supratidal conditions; and 2) dolobiomicrite/wackestone and dolobiomicrite/packstone microfacies types with fairly preserved abundant calcareous algae and their spores (acritarchs), foraminifers (Hemigordiopsids with some Nodosariids and Fusulinids), gastropods, bivalves and ostracods that were deposited in the subtidal low energy zone of a shallow lagoon. Primary structures of the Permian dolostone show well-preserved fabric due to favourable dolomitizing conditions, i.e., primary dolomitization. However, significant appearances of dissolution voids indicate diagenesis in the meteoric/marine vadose zone. The presence of the vadose sediment features is not likely for the *sabkha*-dolomitizing conditions under arid climate conditions usually related to this type of dolomitization. The influence of microbial activity should rather be taken into consideration for interpreting the intense dolomitizing process. On the contrary, the Triassic dolostone, whose age is confirmed by finding of the conodont species *Hindeodus parvus* for the first time in the PTB interval of the Velebit Mts., exhibits a completely different dolostone texture in comparison to the Permian microcrystalline dolomite type. Early Triassic dolostone strata conformably overlie Late Permian dolostone deposits and exhibit medium- to coarse crystalline unimodal planar-s type texture, possibly indicating exceptional aftermath dolomitizing conditions (shallow burial-like) and the influence of microbial and decaying organisms to the formation of the coarse crystalline dolomite texture. The $\delta^{13}C$ values do not represent the global oceanic signal but either depict the values of a restricted basin or were influenced by the early dolomitization. Moreover, the meteoric diagenesis subsequently overprinted this signal.

RECONSTRUCTION OF LATE MIOCENE AND EARLY PLIOCENE DIACHRONOUS INFILL OF MURA AND DRAVA DEPRESSION

REKONSTRUKCIJA GORNJOMIOCENSKE I DONJOPLIOCENSKE DIJAKRONE ISPUNE MURSKE I DRAVSKE DEPRESIJE

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Keywords: *Pannonian Basin System, clinoforms, clinothems, seismic stratigraphy, Mura Depression, Drava Depression*

The Upper Miocene to Pliocene sediments, referred to as Pannonian Stage in the Central Paratethyan regional chronostratigraphic terminology, were initially deposited in an underfilled lake basin displaying gradual a lake level rise. It was followed by a powerful lake level fall characterized by prograding and aggrading clinothems visible on seismic data sourced from the surrounding mountain chains and filling the basin system mainly from the NW and NE.

Detailed studies and analyses of the Pannonian sedimentary architecture were published mostly from the eastern part of the basin system, such as the Makó and Derecske troughs and the Békés basin, whereas from the western basins only interpretations of loosely spaced 2D seismic sections or small individual 3D volumes are available, all mainly restricted within the political boundaries of Hungary. Despite various related research in the southwestern part of the Pannonian Basin System (PBS), the overall geometry of the Lake Pannon progradational infill remained insufficiently known. The Mura and Drava basins, located in the SW part of the PBS in NE Croatia and SW Hungary, once took up a large portion of Lake Pannon and now hold several km thicknesses of Pannonian sediments.

Long-standing hydrocarbon exploration activity in the southwestern PBS resulted in the immense availability of reflection 2D and 3D seismic data. Over hundreds of 2D lines and over twenty 3D seismic cubes across the 20 000 km2 area were interpreted to create framework of clinoform system infill. Detailed seismic stratigraphic interpretation of the prograding clinoform complex enabled attribute analysis of 3D seismic data to fully investigate depositional processes and lithofacies associations, and sediment fairways. In order to reconstruct gradual progradation and to visualize paleogeographic evolution of the area in time and space, rollover trajectories of selected clinothems were mapped. The upper and lower subaqueous rollover boundaries of the slope (PELLEGRINI *et al.*, 2020) were marked throughout the study area by flattening the seismic sections onto shallower alluvial and delta plain surfaces which approximate palaeo-horizontals. Throughout the area 15 regional clinothem surfaces were mapped (Pa-1 to Pa-15).

Seismic-stratigraphy principles used resulted in clinothem framework representing short time intervals from 10^5 – 10^6 Ma deposited in various depositional environments. Clinothems reflect interaction of sediment supply and accommodation space controlled by thermal subsidence and climate-change.

Based on stratigraphic data linked with seismic, the rate of progradation and slope advance was calculated, and closing of Lake Pannon over time was visualized. Clinothems were mapped for the first time over the large Drava basin spatially defining closing of Lake Pannon during the Late Miocene and the Early Pliocene. Although often aggravated by lack or poor quality of the data, such framework considerably improved reconstruction of paleogeographic evolution and sediment fairways.

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FIRST PALYNOLOGICAL RESULTS FROM SPILA NAD PROCJEPOM CAVE, MLJET
PRVI PALINOLOŠKI REZULTATI IZ SPILE NAD PROCJEPOM, MLJET

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Keywords: *palynology, Holocene, Mljet, Croatia*

Spila nad Procjepom cave is situated on the southern slope of the Briježina Hill at 210 m a.s.l. above the Procjep Bay of the Mljet National Park. The cave is 35 m long chamber partly filled with sediments.

Samples for palynology were taken during the summer of 2022, as part of the project *Preliminarna paleobotanička istraživanja Spile nad Procjepom u nacionalnom parku Mljet (Preliminary palaeobotanical investigations of the Spila nad Procjepom cave, Mljet National Park)*, supported by Foundation of Croatian Academy of Sciences and Arts.

Palynofacies of all three studied samples are dominated by phytoclasts, mostly gelified woody tissue often observed in hydromorphic soils (NOËL *et al.*, 2001). Rare findings of the palynomorph Pseudoschizaea, probably related to Zygnemataceae family, indicate the runoff due to periods of enhanced soil erosion (LEROY, 2007). Abundant macroscopic charcoal (> 100 μm) confirm the local fire event (WHITLOCK *et al.*, 2002).

Palynomorph concentrations (STOCKMAR, 1971) are relatively low ranging from 1083 to 2998 palynomorphs per gram. During the formation of the studied deposits, there was a forest-steppe landscape. Vegetation consisted mainly of the Cichoriaceae, Asteraceae, and Poaceae families. Freshwater environment existed, along the banks of which aquatic and coastal water plants grew. The presence of aquatic and coastal aquatic plants in the spore-pollen spectra can also be interpreted as evidence of hydromorphic conditions. Shrubs of the Oleaceae family, with a low rate of Ericaceae, predominated in the composition of the forest (trees and shrub group) during the deposition of SP 22 P1 sample. Forests included *Pinus*, belonging mainly to the subgenus *Pinus* (previously *Diploxylon*). During the formation of SP 22 P2 sample, the forest was predominantly represented by shrubs of the families Oleaceae and Ericaceae. According to the amount of *Pinus* pollen in the spectrum, pines did not take part in the local plant groups but were transported from a distance. Shrub forms of Oleaceae were dominating the forest group during the formation of the SP 22 P3 sample. *Pinus* also grew in small numbers.

It should be noted that the palynological remains are in good agreement with the faunistic data from MAUCH LENARDIĆ *et al.* (2017), according to which remains of different animals related to forests and dense thickets of bushes, as well as aquatic environment, were found in the Spila nad Procjepom deposits. In the current study, the latter was confirmed based on palynological data.

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EXPERIENCES OF APPLYING THE COMBINED APPROACH METHODOLOGY ON THE EXAMPLE OF THE SUTLA RIVER RECIPIENT

ISKUSTVA PRIMJENE METODOLOGIJE KOMBINIRANOG PRISTUPA NA PRIMJERU RECIPIJENTA RIJEKE SUTLE

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Ključne riječi: *metodologija kombiniranog pristupa, Sutla, postizanje dobrog stanja*

Za potrebe izrade Stručne podloge za izmjenu i dopunu okolišne dozvole – Rekonstrukcija proizvodnog pogona peći 63 (F63) u tvornici Vetropack Straža izrađen je elaborat primjene kombiniranog pristupa kako bi se utvrdilo da li vodno tijelo Sutla zadovoljava za prihvat pročišćenih industrijskih otpadnih voda. Metodologijom kombiniranog pristupa obuhvaćeno je određivanje graničnih vrijednosti emisija (GVE), odnosno opterećenja onečišćujućih tvari u pročišćenim otpadnim vodama za ispuštanje u površinske vode, uzimajući u obzir granične vrijednosti kategorija ekološkog stanja (GVK) za osnovne fizikalno-kemijske pokazatelje i za specifične onečišćujuće tvari te standarde kakvoće vodnog okoliša (SKVO) za prioritetne i prioritetne opasne tvari.

U nedostatku izmjerenih vrijednosti uzvodno od ispusta izrađen je proračun metodologije kombiniranog pristupa temeljen na pretpostavljenim podacima ulaznih opterećenja sukladno Uredbi o standardu kakvoće voda (NN 96/19). Primjenom načela kombiniranog pristupa analizirana je kvaliteta ispuštenih tehnoloških otpadnih voda i njihov utjecaj na stanje voda recipijenta. Ovisno o stanju recipijenta utvrđene su granične vrijednosti emisija i opterećenje onečišćujućih tvari u pročišćenim tehnološkim otpadnim vodama a radi postizanja dobrog stanja. Proračun je pokazao da je površinsko vodno tijelo Sutla uvjetno prihvatljiv recipijent s obzirom na povećane koncentracije KPK. Dobro stanje vodotoka Sutla neće se uspjeti postići sve dok svi onečišćivači na slivu ne primijene barem osnovne mjere zaštite prema Pravilniku o graničnim vrijednostima emisija otpadnih voda (NN 26/2020). Ukoliko se ne postigne dobro stanje u narednom planskom razdoblju definirat će se dopunske mjere zaštite odnosno pročišćavanja kako bi se postigle prihvatljive koncentracije.

Primjena metodologije kombiniranog pristupa ukazala je na nedostatak podataka vezano uz monitoring stanja vodnih tijela i monitoring protoka uzvodno od postrojenja odnosno uzvodno od mjesta ispusta, na specifičnost same lokacije koja zahtjeva izračun specifičnih kriterija, na utjecaj drugih onečišćivača na slivu ovog vodnog tijela uzvodno od postrojenja, na potencijalan prekogranični utjecaj iz Slovenije te na utjecaj od poljoprivrednih aktivnosti. Jasnijim i potpunijim definiranjem navedenih nedostatka i specifičnosti te kvalitetnijim ulaznim podacima, doprinijet će se unaprjeđivanju metodologije kombiniranog pristupa te njenoj praktičnoj provedbi i primjeni u postizanju dobrog stanja ili zadržavanja vrlo dobrog i dobrog stanja svih površinskih voda.

SIGNIFICANCE OF THE GARNETS FOR THE INTERPRETATION OF THE POLYMETAMORPHIC TERRANE COMPLEX EVOLUTION IN THE SLAVONIAN MTS.

ZNAČAJ GRANATA U INTERPRETACIJI SLOŽENE EVOLUCIJE POLIMETAMORFNIH TERENA U SLAVONIJI

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Ključne riječi: *granat, metamorfizam, Psunj, Papuk, Krndija*

Već dugi niz godina mikrostrukturne i (geo)kemijske značajke granata koriste se kao izvrsni pokazatelji evolucije metamorfnih terena. Pojedine litodemske jedinice magmatsko-metamorfnog kompleksa Slavonskih planina pokazuju polimetamorfni karakter te se uobičajeno smatraju svojevrsnim prirodnim laboratorijem za studij složenih metamorfnih procesa tijekom čak tri značajne orogeneze (predvariscijske, variscijske i alpske), a u dijelu svojih litologija sadrže granate. Takva okolnost kroz studij značajki granata i njihovih paragenetskih odnosa omogućava dodatnu interpretaciju složenih geoloških događaja.

Granati (~2–3 vol.%) u tinjčevim škriljavcima i paragnajsevima Psunja, Papuka i Krndije u promjeru dosižu do ~200 μm, zonalne su građe, a ponekad tvore i tzv. „atol" (*atoll*) strukture. Tipični su za metapelite srednjeg stupnja metamorfizma (amfibolitni facijes) i dolaze u mineralnoj zajednici koju čine biotit (20–30 vol.%), plagioklas (~40–50 vol.%) i kvarc (~20 vol.%) uz podređeni staurolit, andaluzit te akcesorni rutil, ilmenit i monacit. Zonalni granati sadrže resorbiranu jezgru granata, omotač granata pun sitnih inkluzija starije mineralne parageneze (među kojima dominiraju kvarc, biotit, plagioklas i ilmenit), te rub granata koji je gotovo u potpunosti bez inkluzija. Opažene strukture „atol granata" praktički su ograničene na sačuvani obrub sitnih zrna granata oko sada nepostojeće jezgre.

Jezgra zonalnih granata u pravilu pokazuje viši sadržaj Ca u odnosu na rub zrna (12–16 vs. 4–5 mol.% grosularske komponente), niži sadržaj Fe (68–69 vs. 75–76 mol.% almandinske komponente), dok su sadržaji Mg i Mn vrlo slični i u jezgri i na rubu zrna. Kemijski sastav rubova oba pojavna oblika granata je isti. Tri izdvojene mikrodomene zonalnih granata (jezgra, omotač i rub) pokazuju obrise pravilnih kristalografskih formi, ali i tragove resorpcije.

Pomoću modeliranja pseudopresjeka (*pseudosection modelling*) u 11-komponentnom kemijskom sustavu MnNCKFMASHTO rekonstruirani su P–T metamorfni putevi posebno za svaku mikrodomenu uzimajući u obzir izoplete i izomode granata, kemijski sastav čvrstih mineralnih uklopaka i starost monacita. Tijekom rasta jezgre zonalnog granata uklopljeni su rutil te starija generacija monacita. Maksimalne vrijednosti P=~1.0–1.2 GPa i T=~650 °C slijedi gotovo izotermalna dekompresija koja uzrokuje smanjenje volumnog udjela granata, odnosno njegovu resorpciju (*clockwise* P–T put). U novoj fazi rasta javljaju se brojni uklopci starije generacije uglavnom istih minerala koje možemo pronaći u matriksu, uz značajnu pojavu ilmenita kao sada stabilne Ti-faze te druge nešto mlađe generacije monacita. Rekonstruirani P–T put za tu fazu također je unutar P–T područja amfibolitnog facijesa s maksimalnim vrijednostima P=700–800 MPa i T=570–630 °C te pokazuje *clockwise* obrazac uz rast staurolita. *In-situ* određivanje starosti monacita unutar granata tinjčevih škriljavaca za ta dva rekonstruirana P–T puta daje dvije skupine predvariscijskih starosti: 522±6 Ma i 473±11 Ma (2σ). Treći rekonstruirani put odgovara variscijskom HTLP (*high-temperature/low-pressure*) događaju poznatom u karbonu što potvrđuju starosti monacita u matriksu (BALEN & MASSONNE, 2020), dosiže P=300–400 MPa i T=530–570 °C te je karakteriziran rastom ruba granata uz andaluzit i ilmenitom kao stabilnom Ti-fazom. Taj P–T put također pokazuje c*lockwise* obrazac. Fizikalno-kemijski parametri dakle pokazuju tri stepeničasta (*cascade*) *clockwise* obrasca srednjeg stupnja metamorfizma pri različitim tlakovima.

Postanak zonalnih granata kao i „atol granata" vezan je uz predvariscijski metamorfizam koji je omogućio infiltraciju fluida u sitnozrnati protolit (pelit), izmjenu kationa uslijed promjene P–T uvjeta između tada postojećih unutarnjih i vanjskih dijelova granata, resorpciju granata te rast novih ovoja (omotača i ruba) tijekom mlađeg predvariscijskog i variscijskog metamorfizma.

BALEN, D., MASSONNE, H.-J. (2020): Variscan monazite ages and peak metamorphic P–T conditions recorded in gneiss/migmatite from the Pannonian Basin Basement (Mt. Papuk, Croatia). EGU General Assembly 2020, EGU2020-2621, https://doi.org/10.5194/egusphere-egu2020-2621.

IMPACT OF MECHANICAL STRATIGRAPHY ON DEFORMATION STYLE IN THE CENTRAL EXTERNAL DINARIDES: A 2D FORWARD KINEMATIC MODELLING STUDY

UTJECAJ MEHANIČKE STRATIGRAFIJE NA DEFORMACIJSKI STIL U SREDIŠNJEM DIJELU VANJSKIH DINARIDA: STUDIJA KINEMATSKIM 2D MODELIRANJEM

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Keywords: *mechanical stratigraphy, 2D kinematic modelling, Velebit Mt., Dinarides*

The External Dinarides fold-thrust belt formed during Mid-Eocene – Oligocene times by SW-propagating thrusting from the Internal Dinarides towards the Adriatic foreland. Although previously considered as structurally quite uniform, recent work of BALLING *et al.* (2021) reported along-strike contrasting deformation styles in two structural domains within this fold-thrust belt. The two structural domains with very contrasting deformation styles are separated by the N-S-striking dextral Split–Karlovac Fault, a 250 km long, transpressive transfer fault. The southeastern domain is characterized by a thin-skinned SW-vergent nappe stack in contrast to the northwestern domain, where a set of blind, thick-skinned top-SW thrust duplexes prevail underneath the passive NE-vergent backthrusts. To better understand possible causes that controlled these contrasting along-strike deformation styles, we firstly analysed a spatial-temporal along- and across-strike distribution of Paleo-Mesozoic lithofacies to both sides of the Split-Karlovac Fault. We further estimated the role of mechanical stratigraphy on deformation styles in this part of the fold-thrust belt. This analysis was used to construct a new 2D kinematic forward model across the northwestern backthrust-dominated domain. Our best-fit forward-modelled balanced cross section traversing the central Velebit Mtn. portrays a 75 km wide triangle zone. This zone took up at least 47 km of shortening during Eo-Oligocene times. It comprises a set of thin-skinned NE-vergent backthrusts detached in the upper Paleozoic basement atop a SW-vergent thick-skinned antiformal stack detached in the lower Paleozoic Adriatic basement. The NE-vergent backthrusts likely nucleated at lateral facies boundaries related to extensional half grabens that locally formed during Permian to Middle Triassic and Late Jurassic phases of a passive margin extension. During the Eo-Oligocene shortening, the selective inversion of inherited Mesozoic half grabens boundary faults into the NE-vergent backthrusts in the northwestern domain led to the observed along-strike changes in the deformation style of the External Dinarides. Thus, our results indicate that both the variations in the mechanical stratigraphy and the pre-orogenic structural inheritance obtained during rifting and passive margin stages exert control on Eocene–Oligocene contractional structures within the central part of the External Dinarides.

BALLING, P., TOMLJENOVIĆ, B., SCHMID, M.S., USTASZEWSKI, K. (2021): Contrasting along-strike deformational styles in the central external Dinarides assessed by balanced cross-sections: Implications for the tectonic evolution of its Paleogene flexural foreland basin system. Global and Planetary Change, 205, 1–24.

HOW COMPATIBLE ARE THE N-ALKANE BIOMARKERS AND POLLEN? A CASE STUDY OF THE LAKE VRANA DEPOSITS, CROATIA

KOLIKO SU KOMPATIBILNI BIOMARKERI N-ALKANI I PELUD? STUDIJA NA SEDIMENTIMA VRANSKOG JEZERA U HRVATSKOJ

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Keywords: *Palynology, Geochemistry, Paleoclimatology, Holocene, Croatia*

Paleoenvironmental proxies such as lipid biomarkers and pollen records are often used for Holocene climate change reconstructions. Plant-derived lipids are source indicators (aquatic or terrestrial origin) and impervious to degradation which enables them to survive for longer geological time periods. They are characterized by a shorter transport allowing them to exhibit local plant footprint. Pollen analysis provide a taxa-level understanding of plant distribution yielding an invaluable quantification tool. Both lipid biomarkers and pollen offer an intrinsic insight into the vegetational transformation and inferred climate development, yet not without limitations. A setback of *n*-alkane biomarkers is that different plant species could have indistinguishable lipid compositions which constrains their use. Issues with pollen analysis stem from inconclusive bias in respect to varying pollination rates and longer transportation.

This study includes the comparison of pollen, compound-specific biomarkers, and stable isotopes of *n*-alkanes to reconstruct the shifts in precipitation and vegetation cover recorded in an 11 m sediment core taken from the Lake Vrana in central Dalmatia, Croatia. The core spans the last 12,000 years encapsulating a varying climate period from the cold episode of Younger Dryas, followed by the humid, warming phase right after and concluded with arid environmental conditions of the Late Holocene. The study record is supported by a shorter 7.4 m long sediment core of the adjacent artificial channel Prosika that connects Lake Vrana with the Adriatic Sea. According to pollen analysis, the vegetation of the area belonged to conifer-deciduous forests dominated by Pinus and the Mediterranean oak with open grasslands mixed with herbaceous communities thriving in arid conditions. We aim to identify possible discrepancies in the *n*-alkane and palynological data in order to accentuate the need for a multy-proxy approach towards past climate studies, as well as impart new discoveries to illustrate the regional paleoenvironment.

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UPPER TRIASSIC LITHOFACIES AT LOKVE SECTION, GORSKI KOTAR AREA – INDICATORS OF PALAEOENVIRONMENTAL AND PALAEOCLIMATIC CHANGES

GORNJOTRIJASKI LITOFACIJESI NA LOKALITETU LOKVE U GORSKOM KOTARU – INDIKATORI PALEOOKOLIŠNIH I PALEOKLIMATSKIH PROMJENA

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Keywords: *Gorski Kotar, External/Karst Dinarides, Upper Triassic, lithofacies, palaeoclimate, palaeoenvironment*

The Upper Triassic deposits in the entire Western Tethys realm are widely recognized in the form of the Main Dolomite (Hauptdolomit/Dolomia Principale). However, the lower part of the Upper Triassic is lithologically more diverse, and of variable thicknesses, sometimes even missing in the External Dinarides. It is represented by different lithofacies ranging from fine to coarse grained clastics, marls, limestones, dolomites as well as coal and bauxite occurrences. This heterogeneous lithology archives several palaeoclimatic events that punctuated the otherwise predominantly arid monsoonal regime of the Late Triassic. On such climatic episode in the lower part of the Carnian (Julian 2–Tuvalian 2), is the Carnian Pluvial/Humid Episode (CPE, SIMMS & RUFFELL 1989; RUFFELL *et al.*, 2016); a rather short episode of climatic change, indicated by a shift from arid to relatively more humid conditions, an enhanced hydrological cycling, and increased weathering intensity linked to global carbon cycle perturbations triggered by large-scale volcanism (e.g., DAL CORSO *et al.*, 2020). The CPE is distinguished in the sedimentary record as a period of intensive weathering and clastic influx into the marine realm, paralleled by a reduced carbonate deposition, as well as coal or bauxite accumulation on land.

The aim of this research was to identify this climatic episode in the Lokve section, Gorski Kotar area, in the External/Karst Dinarides with the help of petrography, clay mineral analysis and palynology. In this area, the Upper Triassic strata directly lays on Permian siliciclastics (SAVIĆ & DOZET, 1983). The recorded Upper Triassic succession is composed of sandstones, followed by an interval of red shale and dolomite intercalations, as well as grey shales between dolomite layers, and finally well-bedded dolomites in its uppermost part. Sandstones are determined as feldspar arenites to greywackes. They are composed of angular to rounded clasts and exhibit good sorting. The matrix is composed of clay minerals which are cemented by calcite. The shales are irregularly laminated, with very dispersed irregular dark laminae. Only rare quartz silt-size clasts are observed. Dolomites are mostly primary with well-preserved textures and alochem fabrics. Four types of dolomites are determined: dolomicrite, dolobiomicrite, dolobiosparite and dolobiolitite. XRD analysis of shales and sandstones showed a general increase in micaceous and clay minerals, coupled with a decrease in albite, hematite, and quartz along the section. Among the clay minerals only chlorite was distinguished, but no kaolinite was recognized.

The increase in carbonate sedimentation is interpreted as stabilization of the sedimentary environments, and cessation of siliciclastic input. Decrease in grains size of clastic component up section indicates more quiet environments and possibly more distal position on the stabilized shelf. The increase in clay sized particles is also related to the increase in micaceous minerals, and consequently to the decrease in quartz content. Although K-feldspar and plagioclase were recognized in XRD analysis, the lack of kaolinite, as a weathering product of such minerals indicates the climatic conditions were not humid tropical but rather warm arid. Change in shale colour, from red to grey is related to the reduction of iron, as the red clastic bare hematite, and in the grey shales pyrite is recognized. The "Carnian Pluvial Episode" sediments have some similar characteristics with the recorded Lokve section, but clear evidence for such an episode is not seen here. The Lokve section probably represents a younger Upper Triassic stratigraphic interval, representing the stabilization of carbonate production and deposition of the regionally recognized Main Dolomite.

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LITHOLOGY, MINERALOGY, GEOCHEMISTRY AND CHRONOSTRATIGRAPHY OF DUNE SAND AND INTRAFORMATIONAL SOILS RICH IN HEAVY MINERALS IN PODRAVINA, NORTHEASTERN CROATIA

LITOLOGIJA, MINERALOGIJA, GEOKEMIJA I KRONOSTRATIGRAFIJA PIJESAKA DINA I INTRAFORMACIJSKIH TALA BOGATIH TEŠKIM MINERALIMA U PODRAVINI, SJEVEROISTOČNA HRVATSKA

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Keywords: *aeolian sediments, palaeosoils, Late Pleistocene, Holocene*

The Đurđevac Sands constitute a wide area of extraordinary small-scale dune relief in the Podravina (northeastern Croatia), along the central part of the southern Drava River valley. They are thought to have been formed by reworking of fluvial material due to strong northern winds during the Holocene (HEĆIMOVIĆ, 1987). Later investigations have shown that the dune sands are, at least partially, deposited during the Late Pleistocene (GALOVIĆ *et al.*, 2023). Their importance derives from the geometry of the dunes (shape, orientation, thickness) and the presence of intra- and post-formational alteration (pedogenesis). In addition, the elevated heavy mineral content makes these sands a potential ore deposit.

The objective of this study is to explore this aeolian archive in an attempt to extract relevant palaeo-environmental information and to compare it with similar landscapes in Europe. Lithology (grain size) and intra-formational alteration (palaeosoils) as well as geochemical signatures were investigated on outcrops in an abandoned sand pit to define phases of sand movement and landscape stability. Radiocarbon dating of charcoal, optically stimulated luminescence (OSL) dating of quartz, and historical archives were used to constrain the geochronological evolution of the site (BEERTEN *et al.*, 2023). The heavy and light mineral fractions of the sands are used to determine their composition, provenance and detailed sedimentological context at the time of deposition. A digital elevation model of the region is used to gain insight into the geometry of the dunes, while geo-electric soundings and mechanical coring were applied to investigate the vertical and lateral variations in sand lithology and thickness, as well as intra-formational soils.

The dune landscape at and near the sand pit appears to be chaotic in character, showing an irregular distribution of smaller parabolic, linear and dome shaped dunes. Larger structures may also be classified as complex long-walled transgressive dunes or compound en-echelon parabolic dunes. The local distribution and thickness of the dune sands can clearly be traced on geo-electrical profiles, where the dry dune sand appears to generate a different signal than the underlying water-saturated fluvial material. Furthermore, the results show that phases of sand movement occurred before the Bølling-Allerød (B-A) interstadial, the Younger Dryas and/or the Pleistocene–Holocene transition, as well as during the early Holocene. A major phase of landscape stability and palaeosoil formation is witnessed by the presence of slightly altered parent material (different colour, decalcified and a slightly finer grain size) and dated to the B-A interstadial. This palaeosoil is often visible as a double soil, a so-called pedocomplex. A subsequent phase of landscape stability is defined by an orange-yellowish soil, decalcified, and is dated to the early Holocene.

The dune sands have a similar heavy mineral content as the source material, deposits from the Drava River, but overall have a slightly lower heavy mineral fraction and a lower proportion of the heaviest minerals such as garnet, which is the dominant heavy mineral. This reflects the preferential sorting of lighter minerals by wind. The light mineral fraction is dominated by quartz, and shows slightly lower amounts of feldspar in the main B-A palaeosoil, which is probably caused by weathering. Overall, the mineralogy of the dune sands indicate that there are significant local variations, even at the decameter scale, and that the Holocene sediments more closely reflect the mineralogical signature of the fluvial source material. This is probably due to the input of new, less weathered material from the Drava River following deglaciation of the Alps.

We conclude that (1) the Pleistocene–Holocene transition in this aeolian sand archive, spanning the period 17–8 ka, is characterised by several phases of sand move-

ment and landscape stability (soil formation), (2) the most striking feature of palaeosoil formation is decalcification rather than the addition/preservation of soil organic matter or other soil formation indicators, and (3) the Holocene aeolian sands witness the input of fresh, less weathered material.

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MIDDLE TRIASSIC SYN-RIFT RHYOLITES AND RHYOLITIC IGNIMBRITES ON THE NORTH-EAST MARGIN OF ADRIA (NE SLOVENIA, NW CROATIA): POSSIBLE SOURCE OF RHYOLITIC TUFFS (*PIETRA VERDE*) IN THE WIDER DINARIDE AREA

SREDNJOTRIJASKI SIN-RIFTNI RIOLITI I RIOLITNI IGNIMBRITI NA SJEVEROISTOČNOM RUBU ADRIE (SI SLOVENIJA, SZ HRVATSKA): MOGUĆI IZVOR RIOLITNIH TUFOVA (*PIETRA VERDE*) U ŠIREM PODRUČJU DINARIDA

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Ključne riječi: *srednji trijas, bazaltno-andezitne stijene, riolit, riolitni tuf (Pietra Verde), Adria*

Srednjotrijaske magmatske i piroklastične stijene u području Adrie, odnosno šireg područja Dinarida i Južnih Alpa su česta pojava. To su uglavnom bazične magmatske stijene: bazalti, andezit-bazalti, rjeđe andeziti te riolitne piroklastične stijene (*Pietra Verde)*. Izvorište riolitnog piroklastičnog detritusa u širem području Dinarida do sada nije jasno određeno.

Trijaske kisele magmatske stijene poznate su samo na SZ rubu Adrie. U okviru projekta GOST istraživane su ove stijene na uzvisini Sv. Junger u SI Sloveniji, koje su determinirane kao rioliti, te na području Margečana na uzvisinama Gradišće, Hamec, Oštra Gorica i Sv. Duh u SZ Hrvatskoj, koje su određene kao riolitni ignimbriti.

Rioliti imaju porfirnu strukturu i homogenu teksturu. Fenokristali su plagioklas i K-feldspat, a osnova je leukokratna, devitrificirana u sitnozrnati kvarc, feldspat i bijeli tinjac. Fenokristali plagioklasa su alterirani u sitnolistićavi bijeli tinjac i minerale glina. K-feldspat je sviježs alteriranim inkluzijama.

Riolitni ignimbriti imaju debljinu veću od 100 m. Izdvajaju se (1) čvrsti laminirani folijativni tok riolitnih ignimbrita i (2) čvrsti masivni riolitni ignimbriti. Folijativne trake su debljine od 1–10 cm. Izmjenjuju se vrlo tanki slojevi vitrofirnog, lapilno vitrofirnog i kristaloklastičnog riolitnog piroklastičnog toka. Lamine vitrofirnog riolitnog piroklastičnog toka izgrađene su od izmijenjenog matriks-potpornog piroklastičnog detritusa manjeg od 2 mm i devitrificirane staklaste osnove. Vitrofirni riolitni lapilni ignimbrit sadržava izmijenjene matriks-potporne do klast-potporne plovučce veće od 2 mm i kristaloklaste u devitrificiranoj staklastoj osnovi. Kristaloklastični riolitni piroklastični tok izgrađen je od kristaloklasta kvarca, albita ($An_{0.0\text{-}4.5}Ab_{95.1\text{-}99.9}Or_{0.1\text{-}0.6}$) i K-feldspata ($An_{0.0\text{-}1.0}Ab_{1.8\text{-}4.2}Or_{95.0\text{-}98.4}$), kao i vrlo rijetkih čestica lapilnog plovučca, dok je matriks izmijenjen u fengit. Masivni čvrsti riolitni lapilni ignimbriti izgrađeni su od klast-potpornih do matriks-potpornih alteriranih lapilnih plovučaca, a

rjeđe od kristaloklasta izmijenjenih feldspata i kvarca u devitrificiranoj staklastoj osnovi. Produkti izmjene u svim varijetetima su sitnozrnati kvarc i listići filosilikata. Alteracijski procesi su dvofazni: tijekom dijagenetskih procesa i postdijagenetskih tektonskih procesa kao što su dinamo-termalne metamorfne promjene, koje se očituju u klivažu uškriljavanja po kojem se razvija folijativni bijeli tinjac. Bijeli tinjac je fengit sa sadržajem 3.4 SiT a.p.f.u.

Izvorište riolitnih tufova (*Pietra Verde*) na području Strahinjščice, Žumberačke gore i šireg područja Dinarida (Lika, Knin, Svilaja i dr.) mogu biti navedene istraživane eksplozivne riolitne vulkanske stijene SI ruba Adrie.

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KVARNERIĆ POLJE AND ZRMANJA PALEORIVER DURING LAST GLACIAL MAXIMUM

KVARNERIĆKO KRŠKO POLJE I PALEOZRMANJA TIJEKOM ZADNJEG GLACIJALNOG MAKSIMUMA

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Keywords: *polje, fluviokarst, sea-level, Pleistocene, NE Adriatic Sea*

The Velebit Channel and its marginal basins and Kvarnerić (the channel zone of NE Adriatic Sea) were analysed in order to reconstruct the geomorphological evolution of this area during the Late Pleistocene and Holocene (MIS 5 to MIS 1) using detailed seabed maps, new data on sea-level changes, and submarine investigation. Submerged parts of the river canyon, paleodeltas, traces of ancient lakes, and a large polje were discovered by analysing these maps (BENAC *et al.*, 2022).

The highly rugged terrestrial and submarine karst relief was formed in relatively resistant carbonate rocks. This relief probably slightly changed during the Late Pleistocene and Holocene. Deep straits or canyons are the link between the depressions within the Velebit Channel, as well as with the marginal basins: the Pag and Ljubač bays and the Novigrad Sea.

While the sea-level fluctuated between –20 m and –50 m below recent sea-level i.e. from 110 to 70 ka B.P. (MIS 5.d – 5.a) the drying up took place in the Novigrad Sea, the Ljubač Bay and in the Pag Bay, but also in the marginal SE part of the Velebit Channel. When the sea-level fluctuated between –50 m and –80 m i.e. 75 – 30 ka B.P. (MIS 4 and MIS 3) the sea gradually retreated from the SE part of the Velebit Channel to the northwest. Marine connection between the central part of this channel and the NE part between Rab Island and the mainland was interrupted. The remaining connection to Kvarnerić basin was possible only through the passage between the Pag and Rab islands. The previously submerged karst elevations emerged and the Kvarnerić basin became much smaller.

When the sea-level dropped to a depth between –100 to –120 m from 30 ka to 20 ka B.P. i.e. during Last Glacial Maximum (LGM) the sea completely withdrew from the Velebit Channel leaving only the Zrmanja paleoriver flow, and Kvarnerić became the largest paleo-polje in the Dinarides with an approximate area of 880 km^2 (Fig. 1). Lakes could have been preserved in the deepest parts. The maximum depth of karstification was recognised –70 m below recent sea-level in wide Kvarner area. These data correspond to paleo marine terrace, which are a reliable indicator of sea-level stagnation.

During LGM, the valley of the Zrmanja paleoriver can be traced along the Velebit Channel at a distance of approximately 140 km. The location of the paleo-riverbed is not visible on the ancient flood plains, unlike in the canyons or straits. As a result, the shape and depth of paleobasins may have changed during the Late Pleistocene. However, there are not enough data on whether the Zrmanja paleoriver during LGM flowed on the surface to the Po paleoriver through straits between Ilovik and Premuda islands or Škarda and Ist islands. The other plausible possibility is that this paleoriver was a sinking river with ponors in the paleo-polje in the present-day

Kvarnerić basin. The sea-level rose very rapidly between 19 ka and 7 ka B.P. and rapidly flooded the Velebit Channel and its marginal basins.

The Velebit channel and Kvarnerić basin are fine examples of drowned karst relief, where zones of unchanged karst paleorelief (fluviokarst canyons) are preserved, along with zones covered with recent/subrecent sediments in downstream part of the Zrmanja paleoriver and the Kvarnerić paleo-polje. The area, especially the rim of this paleo-polje, and canyon flanks are a zone of promising submarine archeologic sites occupied during Upper Palaeolithic and Mesolithic.

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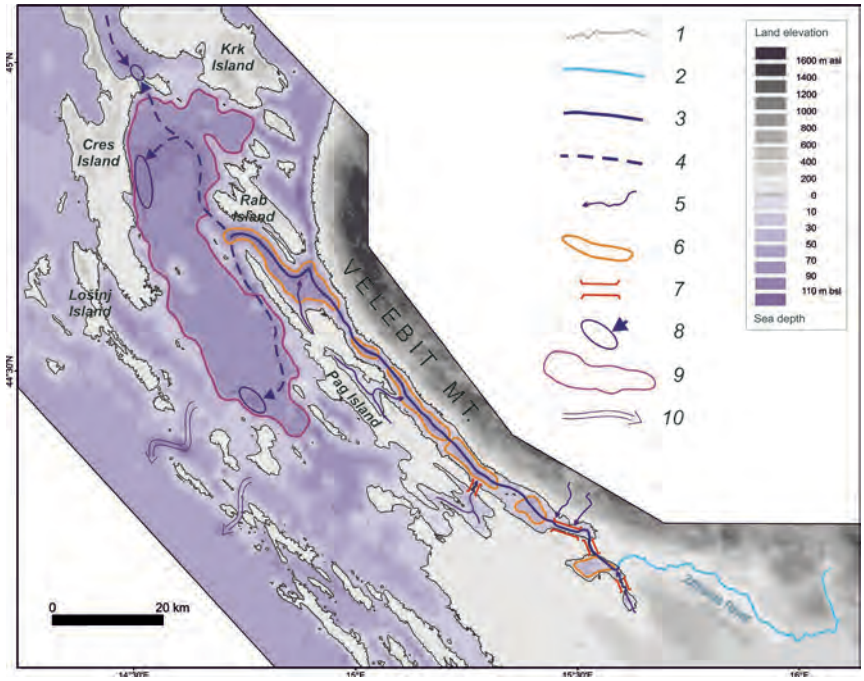

Figure 1: 1. recent shoreline, 2. recent Zrmanja riverbed, 3. the Zrmanja paleoriver valley, 4. possible continuations of the Zrmanja paleoriver, 5. main tributaries, 6. presumed flood plains, 7. submerged canyon, 8. assumed ponor zones, 9. contours of Kvarnerić paleo-polje, 10. possible surface connections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

THE LANDSLIDE SUSCEPTIBILITY ASSESSMENT FOR APPLICATION IN THE SPATIAL PLANNING SYSTEM: FROM NATIONAL TO LOCAL SCALE

PROCJENA PODLOŽNOSTI NA KLIZANJE ZA PRIMJENU U SUSTAVU PROSTORNOG PLANIRANJA: OD DRŽAVNOG DO LOKALNOG MJERILA

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Keywords: *landslides, landslide susceptibility assessment, Croatia*

The main motivation to research the landslide susceptibility assessment for application in land use planning arises from the national landslide risk assessment (BERNAT GAZIBARA *et al.*, 2019) which recognised landslides as a second natural risk in Croatia (CNPDRR, 2019). Furthermore, the preliminary regional landslide susceptibility analysis showed that approx. 20 % of the Republic of Croatia area is potentially prone to sliding. Therefore, landslide susceptibility assessment for national, county and local levels was carried out in the frame of two scientific projects Methodology development for landslide susceptibility assessment for land-use planning based on LiDAR technology (LandSlidePlan, HRZZ IP-2019-04-9900) (BERNAT GAZIBARA *et al.*, 2022) and project Applied landslide research for the development of risk mitigation and prevention measures (PRI-MJER, KK.05.1.1.02.0020). The national landslide susceptibility map at a small scale is created to give a general overview of critical areas for an entire country, and its purpose is to inform policymakers and the general public (MIHALIĆ ARBANAS *et al.*, 2022). County-level landslide susceptibility assessment on a medium scale synthesizes available data and identifies wider areas with landslide problems and can be used to define areas for more detailed research on a local level. The third level is the local-scale landslide mapping and zonation that includes specific areas of local administrative units (municipality or city) or complex critical areas. The results were landslide susceptibility maps for seven study areas: (i) the Republic of Croatia; (ii) City of Zagreb, Karlovac County and Primorje–Gorski Kotar County; and (iii) the study areas in the Zagreb City (BERNAT GAZIBARA *et al.*, 2023), Hrvatsko Zagorje (SINČIĆ *et al.*, 2022a), Karlovac City (SINČIĆ *et al.*, 2022b) and Istria.

Methodology development for landslide susceptibility assessment on national and county scales was carried out using a heuristic approach, i.e. Fuzzy Logic method, and available topographical and geological data. Given that the validation of the final landslide susceptibility map is mandatory, and systematic landslide inventories at the national or county level do not exist, we used the landslide database conducted by the University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering. The database consists of 2,186 landslides with the exact location of the occurrence. All landslide susceptibility maps showed high accuracy and were classified into three susceptibility zones, considering The Area Under the Receiver Operating Characteristic Curve (AUC_{ROC}).

Methodology development for landslide susceptibility assessment on a local scale was carried out using different mapping units and statistical methods (e.g. Information Value method, Weights of Evidence method, Logistic Regression and Discriminant Analysis, and machine learning methods, including Support Vector Machine, Artificial Neural Network and Random Forest). Moreover, landslide susceptibility models were computed using different scenarios of high-resolution input data, i.e. geometrical types of LiDAR-based inventory and variations of causal factors. Finally, all landslide susceptibility models were evaluated based on model fitting performance, model prediction performance, and model uncertainty. The purpose of comparing landslide susceptibility models is to define the most suitable maps for application in spatial planning at national, regional, and local levels. The research was based on innovative technologies, limitations related to the availability of spatial data in Croatia (limited amount of geological data), and urgent needs for efficient solutions applicable in the Croatian spatial planning system in line with European and global requirements related to sustainable development, human and environmental protection.

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PETROGRAPHIC, MINERALOGICAL AND CHEMICAL CHARACTERISTICS OF BAUXITE FROM POSUŠJE DEPOSITS, BOSNIA AND HERZEGOVINA – AGEMERA PROJECT RESEARCH

PETROGRAFSKE, MINERALOŠKE I KEMIJSKE KARAKTERISTIKE BOKSITA IZ LEŽIŠTA U POSUŠJU, BOSNA I HERCEGOVINA – AGEMERA PROJEKT ISTRAŽIVANJA

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Keywords: *bauxite deposit, karst bauxite, Posušje, petrography, AGEMERA*

The exploitation of bauxite in the wider area of Posušje in Bosnia and Herzegovina has been known since the first half of the 20th century, and to date more than 1100 deposits or occurrences of various sizes and structures have been discovered. Bauxite deposits of Posušje represent typical karst bauxites, formed during the emersion phase between Upper Cretaceous rudist limestones in the footwall and various carbonate and clastic rocks of Paleocene/Eocene and Oligocene ages in the hanging wall. The most intensive mineralogical and geochemical bauxite research in these areas was carried out during the 70s and 80s. Afterwards, despite numerous newly discovered deposits, no petrographic, mineralogical and geochemical analysis on the bauxites has been published. The present study is focused on recently discovered bauxite deposits in Posušje and their petrographic and mineralogical description. The bauxites show ooidic to pelitomorphic, but in places also clastic textures. Micro-ooids and spheroids are mostly smaller than 0.1 mm, and in places fragments of the former ooid can be found. In some bauxites, pebbles of resedimented bauxite prevail, mostly larger than 2 mm but sometimes larger than 1 cm, which define their conglomerate texture. Gibbsite and boehmite are the main Al-bearing minerals of the bauxites, and diaspore has not been observed. The ratio of gibbsite to boehmite varies between deposits, and in some deposits boehmite is the only aluminium phase present. Where present, the gibbsite is developed into relatively large hypidiomorphic crystals larger than 0.25 mm, with clearly defined polysynthetic lamellae. Hematite is the dominant Fe-phase in all deposits. Although rarely, goethite-rich bauxites can be found in the form of isolated layers, with just traces or no hematite. Zircon, apatite and calcite are minor and ac-

cessory minerals, and X-ray analysis indicated significant amounts of anatase and rutile. Kaolinite was detected in only one sample. Chemical analyses indicate a negative correlation of Al and Fe content. The Al_2O_3 content ranges from 53.4 to 63.9 wt.%, and Fe_2O_3 from 22.5 to 35.2 wt.%. The SiO_2 and TiO_2 content varies from 1.6 to 5.6 wt.% and 3.5 to 4.6 wt.%, respectively. The chemical composition of the analysed samples defines them as ferrous bauxites. A change in the chemical composition was observed in relation to the footwall distance. The relatively high content of Zn (up to 627 ppm) gradually decreases towards host carbonates of the footwall, and a similar trend is observed in the Fe, Cr and Zr content, while Al, P, Ca and Ti, on the other hand, increase closer to the footwall. Mineralogical, petrological and chemical studies of the recently opened bauxite mines in Posušje revels heterogenic properties and indicate a complex genesis of the deposits, with possibly diverse source material.

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SEA WATER IMPACT ON THE COASTAL KARSTIC AQUIFER BOKANJAC-POLIČNIK
UTJECAJ MORA NA PRIOBALNI KRŠKI VODONOSNIK BOKANJAC-POLIČNIK

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Ključne riječi: *utjecaj mora, priobalni krški vodonosnik, Bokanjac-Poličnik, Zadar*

Izvori i kopani bunari u zaleđu grada Zadra od velikog su značaja za vodoopskrbu grada Zadra jer su dugi niz godina bili jedini izvori vodoopskrbe za potrebe grada, a i danas se koriste za vodoopskrbu uz dovod vode s rijeke Zrmanje. Na slivnom području nalazi se više vodnih objekata uključenih u vodoopskrbni sustav grada Zadra. To su: Bokanjac, Boljkovac, Golubinka, Jezerce i Oko.

Tijekom dugih sušnih razdoblja, dio tih vodoopskrbnih objekata je povremeno pod utjecajem mora, iako su neki od njih udaljeni i nekoliko kilometara od morske obale. To ukazuje na duboke prodore zaslanjene morske vode u slatkovodni vodonosnik, odnosno na postojanje slane vode ispod slatkovodnog sustava i konusno izdizanje slane vode zbog prekomjernog crpljenja.

Golubinka je priobalni krški izvor koji ima problema sa zaslanjivanjem tijekom svakog ljetnog sušnog razdoblja u potpuno prirodnim uvjetima te se za vodoopskrbu koristi samo izvan tih razdoblja. Ostali vodoopskrbni objekti u slivu su kopani bunari, od kojih Boljkovac i Jezerce imaju povremeni problem zaslanjivanja, dok je kod Bokanjca to najmanje izraženo. Vodocrpilište Oko se trenutno ne koristi za potrebe vodoopskrbe, ali na njemu nije zabilježeno zaslanjenje.

Za potrebe Plana upravljanja vodnim područjima 2016. – 2021. (NN br. 66, 2016) sliv je proglašen tijelom podzemne vode na kojem su u skladu s nacionalnom metodologijom za ocjenu kemijskog stanja podzemnih voda krških vodonosnika, provedena klasifikacijska ispitivanja. Klasifikacijskim ispitivanjima ovo tijelo podzemne vode ocijenjeno je „u lošem stanju" i „u riziku" te su propisane mjere i operativni monitoring (BIONDIĆ *et al.*, 2016).

Operativni monitoring je započeo krajem 2017. godine izvođenjem četiri duboke bušotine i postavljanjem automatskih senzora električne vodljivosti, temperature i razine podzemne vode po dubini bušotina. U svaku bušotinu postavljeni su automatski senzori na svakih 10 m dubine koji su mjerili razinu podzemnih voda, temperaturu i električnu vodljivost svakih 10 minuta. Monitoring je završio krajem 2019. godine čime je cijeli vodonosnik praćen po dubini kroz dvije hidrološke godine, odnosno dva sušna kritična razdoblja. Tijekom toga razdoblja, zdenci vodocrpilišta Bokanjac nisu zaslanjivali, ali se vrijednost električne vodljivosti kretala u rasponu od 0,590 do 0,985 mS/cm što je malo povišena vrijednost u odnosu na prosječnu u tom vodonosniku. Na vodocrpilištu Jezerce, koje je bliže moru od vodocrpilišta Bokanjac, električna vodljivost se kretala u rasponu od 0,850 do 1,084 mS/cm. Na vodocrpilištu Boljkovac električna vodljivost se tijekom kišnog kretala oko 3,5 mS/cm, tijekom sušnih razdoblja se spuštala na oko 1 mS/cm, dok su u proljetnom razdoblju 2019. godine izmjerena dva maksimuma 5,27 mS/cm (6. 2. 2019.) i 4,89 mS/cm (16. 4. 2019.). Od studenoga 2018. do lipnja 2019. godine crpilište nije bilo aktivno (BIONDIĆ *et al.*, 2019).

Monitoring je nastavljen kroz provođenje projekta: Upravljanje krškim vodonosnicima ugroženima klimatskim promjenama (UKV) (KK.05.1.1.02.0022) od svibnja

2020. do početka 2023. godine (BIONDIĆ, 2023) tijekom kojih je zabilježeno vrlo slično ponašanje ovog priobalnog krškog vodonosnika, kao i u prethodnom razdoblju.

Na navedenom vodonosniku provedena su istraživanja koja su pokazala potrebu sustavnog kontinuiranog provođenja takvih istraživanja i na drugim priobalnim vodonosnicima u Republici Hrvatskoj. Iako svaki vodonosnik ima svoje specifičnosti, dio istraživanja i metodološki pristup je vrlo sličan, ali prilagođen posebnostima pojedinih vodonosnika. Na svakom od predloženih priobalnih i otočnih vodonosnika potrebno je provesti detaljna hidrogeološka istraživanja sa svrhom definiranja točaka monitoringa (postojećih bušotina), izvođenja potrebnih novih bušotina te određivanja dubina na kojima je potrebno postaviti senzore za automatsko mjerenje saliniteta (električne vodljivosti). Postepeno, kako istraživanja napreduju, sve monitoringe je potrebno uključivati u jedinstvenu mrežu monitoringa.

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PETROLEUM GEOCHEMISTRY SUMMARY OF THE HUNGARIAN PART OF THE DRAVA DEPRESSION

NAFTNO GEOKEMIJSKI SAŽETAK MAĐARSKOG DIJELA DRAVSKE DEPRESIJE

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Keywords: *source potential, maturity, biomarkers, stable carbon isotopes, Dráva block*

Source potential evaluation and fluid characterisation of the Dráva exploration block and surrounding NW and SE area included investigation of various sets of geochemical data from 40 wells.

L. Pannonian SRs could be identified in the lowermost intervals of Endrőd formation These SRs were found all over the Dráva block, with maturity distribution depending on the tectonics (subsidence/uplift regime). The best quality SRs (kerogen type II and mixed II/III) and the least mature are present in N part of the Dráva block, in the central part on the most uplifted Vízvár-Görgeteg-Babócsa high and in E part. Early to late mature samples with type III kerogen were found in S border, in the Barcs Ny area, with poor to good generative potential, depleted also due to high maturity.

Badenian SRs could be identified in sedimentary sequence which is present all over the SE part of Dráva block and to the far SE Zaláta-Dravica area. Central to E Szulok-Darány area has Badenian SRs of the best quality, mostly mid mature oil prone (kerogen type II), with good and very good generative potential. Potony and Zaláta-Dravica area have mid to late mature oil and gas prone SRs containing mixed kerogen II/II and type III in oil window, with generative potential partially depleted due to high maturity.

Maturity assessment relied on Tmax measurements and measured vitrinite reflectance (VR) data from Pre-Miocene basement (Precambrian, Paleozoic) through the Miocene sedimentary sequence. The top of oil window (VR 0.6 % Ro) in this part of the Dráva basin can be estimated at depth about 2200 m, and the top of gas/condensate window (1.3 % Ro) at ~3400 m.

Characterization of oils, condensates and SR bitumens (extracts) relied mainly on measurements from wells on Vízvár-Görgeteg-Babócsa high and Zaláta-Dravica area. Main and specific parameters for oils and condensates

(Thompson's parameters, biomarkers and stable carbon isotopes) were available L. Pannonian, Mid Miocene and Paleozoic-basement RES. SR bitumens for the SR-SR, and SR-oil correlations were available from L. Pannonian and Badenian SRs.

Fluids of the Dráva block vary from marginally mature on the N part, to highly mature oils and condensates in the central Vízvár-Görgeteg-Babócsa high and SE Potony area. Lighter, "more mature" oils in shallower intervals of the same wells show the effect of mostly secondary migration where the lighter HCs migrate more easily to shallower RESs. Additionally, GB and Heresznye oils are mostly affected by evaporitic fractionation and degradational processes, while on the E part of the block oils are non-altered, indicating good sealing properties of the traps.

Carbon stable isotopes, isoprenoid to n-alkane ratios, hopane and sterane biomarker parameters of the biomass origin and deposition environment indicate that oils of the Dráva block originate from SRs containing mixed marine and terrigenous type of OM (type II/III) deposited in suboxic, deltaic to open marine environment, from L. Badenian to L. Pannonian shales, claymarls and (calcareous) marls. Most of the Dráva oils can be related to open marine environment and generally with Badenian SR extracts. Some Heresznye and Potony oils originate from shallow marine environment with more clay content, higher oxicity, and bacterial reworking of OM, which is generally characteristic of L. Pannonian SR extracts. Locally, deposition environment can vary significantly, like in Potony area with evidence of increased salinity both in Badenian and L. Pannonian SRs.

Sterane maturity parameters show that oils in Dráva block mostly originated from SRs in early to peak maturity and are in consistence with Thompson's parameters. L. Pannonian SRs are early to mid mature (0.6–0.7 % Ro) and Badenian SRs are mid to late mature (~0.65–0.8 % Ro), which is in consistence with measured VR and maturity calculated from Tmax data.

Characterization of HC gases relied on compositional and carbon isotope data from wells in mainly NW part of the Dráva block (Vízvár É and Vízvár area), from L. Pannonian and Mid Miocene RESs, indicating mainly wet thermogenic gases, mixed with small portions of (immature) biogenic gas. Overmature dry gases are present in the deepest parts of the Dráva basin on the far SE Zaláta-Dravica area. Wide maturity range of Dráva gases indicates origin from different SRs, deposited in the basin areas of deeper burial and/or migration through faults connected to the more mature basement sources.

WHAT IS THE AGE OF BARAĆ CAVE SYSTEM?
KOLIKO SU STARE BARAĆEVE ŠPILJE?

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Ključne riječi: *speleologija, datiranje sigovine, krš, Baraćeve špilje*

Baraćeve špilje nalaze se kod Nove Kršlje u općini Rakovica. Radi se o četiri špilje koje su razvijene na različitim visinama: Gornja (duljine 520 m), Donja (565 m) i Nova Baraćeva špilja (94,5 m) te izvor-špilja Baraćevac (KOVAČEVIĆ, 2003). Špilje se pružaju kroz donjokredne karbonatne stijene, pretežno vapnence i vapnenačke breče (VELIĆ & VLAHOVIĆ, 2009). Špiljski kanali najvjerojatnije su se razvijali u epifreatskim uvjetima. Uslijed tektonskog izdizanja i okršavanja nastajali su kanali na manjim nadmorskim visinama dok su oni na većima postali hidrogeološki neaktivni (CZUPPON *et al.*, 2018). Kanali izvor špilje Baraćevac imaju i danas aktivan vodeni tok dok su ostale tri špilje hidrološki neaktivne i ukazuju na razine nekadašnjih podzemnih tokova. Gornja Baraćeva špilja turistički je uređena. Jedno od pitanja koje se nameće pri turističkom vođenju je i pitanje starosti špilje.

Kako bi probali prikupiti više informacija o starosti špilje datirane su sige iz njenog glavnog kanala. Za uzimanje uzoraka odabrani su sigasti stupovi koji su se po svojoj morfologiji i debljini činili kao potencijalno najstariji. Uzorkovanje je izvršeno na tri mjesta pomoću električne bušilice i krune promjera 4 cm. Ukupno su izbušene tri jezgre duljine 70, 80 i 100 cm. Uzorci iz jedne jezgre procijenjeni su kao nepovoljni za datiranje zbog velike

poroznosti i naoko vidljivih detritalnih primjesa koji bi kompromitirali rezultate U-Th datiranja. Po jedan uzorak iz najstarijih dijelova preostale dvije jezgre je izdvojen za datiranje. Uzorci karbonata datirani su U-Th metodom koristeći Neptune Plus MC-ICP-MS na Johannes Gutenberg Sveučilištu u Mainzu.

Rezultati datiranja dva odabrana uzorka pokazuju njihovu starost od 129,5 (+/– 0,61) ka BP odnosno čak 644,1 (+93,2/ –53,1) ka BP. Ovi rezultati pokazuju da je glavni kanal Gornje Baraćeve špilje vrlo vjerojatno stariji od 644 ka BP, ali rezultate treba uzeti s oprezom s obzirom da su na samoj granici datiranja U-Th metodom. S obzirom da prilikom uzorkovanja nije mogao biti dosegnut najniži (najstariji) dio sigastog stupa te da postoji mogućnost da ovo i nije najstarija siga, starost ovog kanala vjerojatno je i veća. To ukazuje da je podzemno otjecanje tamo bilo razvijeno već na prijelazu iz ranog u srednji pleistocen. S obzirom na položaj datiranih siga u kanalu, s velikom vjerojatnošću se može pretpostaviti da je u vrijeme njihovog nastanka kanal već bio potpuno neaktivan. To znači da je tijekom srednjeg pleistocena voda već tekla kroz niže provodnike, vjerojatno današnju Donju Baraćevu špilju. Dobiveni rezultati trenutno predstavljaju podatke o najstarijoj datiranoj sigi u kršu Hrvatske.

CZUPPON, G., BOČIĆ, N., BUZJAK, N., ÓVÁRI, M., MOLNÁR, M. (2018): Monitoring in the Barać and Lower Cerovačka caves (Croatia) as a basis for the characterization of the climatological and hydrological processes that control speleothem formation. Quaternary International, 494, 52–65. DOI: 10.1016/j.quaint.2018.02.003.

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CEEPUS NETWORK CIII-RS-0038: RECOGNITION OF CHALLENGES IN GEOLOGICAL EDUCATION IN SOUTH-EASTERN EUROPE AND PROMPT RESPONDS

CEEPUS MREŽA CIII-RS-0038: PREPOZNAVANJE IZAZOVA U OBRAZOVANJU GEOLOŠKIH STRUKA U JUGOISTOČNOG EUROPI I MOGUĆA RJEŠENJA

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Keywords: *CEEPUS, geological education, South-Eastern Europe*

Geological education at South-Eastern European universities is developed under the CEEPUS CIII-RS-0038 network (Earth-Science Studies in Central and South-Eastern Europe – EURO Geo-Sci), which includes participating unites from eleven countries: Albania, Austria, Bosnia and Herzegovina, Croatia, Czech Republic, Hungary, Poland, Romania, Serbia, Slovakia and Slovenia. For long 24 years, EURO Geo-Sci continuously promotes sharing of knowledge and know-how via multilevel activities: student mobility, engagement of visiting peer-experts, joint supervision Master and PhD thesis, reinforcing geosciences educational infrastructure of the participating institutions. The network covers wide spectrum of geological disciplines including both fundamental (regional geology, mineralogy, crystallography, geochemistry, petrology, paleontology, structural geology etc) and applied disciplines (e.g. mineral resources, engineering geology, hydrogeology and geophysics). In the past 24 years more than 1500 individuals used the network through student and teacher mobilities, joint supervision master and PhD projects (successfully defended more than 20) as well as field excursions.

During such a long period, the network is also continuously facing with many internal and external challenges. Internal challenges are related to low-funded, classical and sometimes outdated curricula of some programmes, lack of innovative content and teaching diversity brought by visiting experts and hands-on practical experience for peer academicians as well as for the students. External challenges are related to declining demographic trends and regional brain drain leading to decreasing in number of students, pandemic, unstable political situation (wars) as well as negative public perception of the geology (and mining) sector due to environmental and political activism. Thanks to flexibility of the network and dedicated engagement of the local coordinators, the network responds appropriately to the challenges involving new

courses, networking with current scientific projects, cooperation with industry and serving the society in solving problems concerning pollution, water resources, land sliding, earthquakes, mineral deposits and many others.

For more details about EURO Geo-Sci the following publications are recommended: ŠARIĆ (2022), ŠARIĆ *et al.* (2022), ŠARIĆ & IONESCU (2018), as well as the network's website: https://ceepus.rgf.bg.ac.rs/, facebook page: Ceepus.RS0038 and instagram page: ceepus.rs0038.euro_geosci.

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DEEPWATER-CE: DEVELOPMENT OF AN INTEGRATED IMPLEMENTATION FRAMEWORK FOR MANAGED AQUIFER RECHARGE SOLUTIONS TO FACILITATE THE PROTECTION OF CENTRAL EUROPEAN WATER RESOURCES ENDANGERED BY CLIMATE CHANGE AND USER CONFLICT

DEEPWATER-CE: RAZVOJ INTEGRIRANOG OKVIRA ZA PROVEDBU KONCEPTA UMJETNOG PRIHRANJIVANJA VODONOSNIKA SA CILJEM ZAŠTITE RESURSA PITKE VODE UGROŽENIH KLIMATSKIM PROMJENAMA I SUKOBIMA KORISNIKA U SREDNJOJ EUROPI

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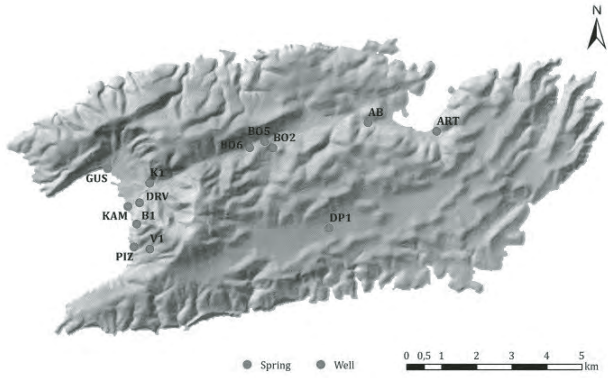
Ključne riječi: *umjetno prihranjivanje vodonosnika, otočki krški vodonosnik, Vis, Hrvatska*

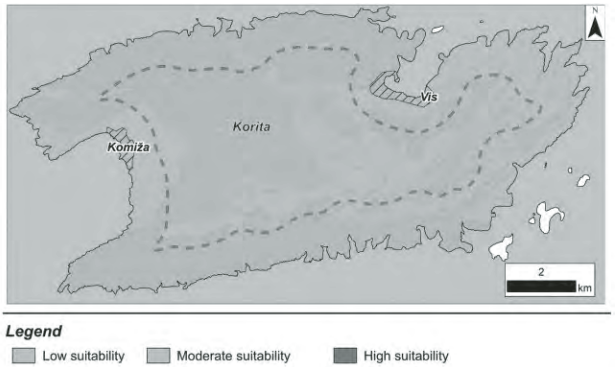
Projekt DEEPWATER-CE provodio se u razdoblju od svibnja 2019. do travnja 2022. sa ciljem razvoja integriranog okvira za provedbu umjetnog prihranjivanja vodonosnika (eng. managed aquifer recharge – MAR). MAR je važan mehanizam održivog upravljanja vodnim resursima, posebice u područjima gdje je kakvoća ili dostupnost vode ugrožena, a temelji se na prikupljanju oborinskih i površinskih voda tijekom vlažnih perioda, njihovom skladištenju (npr. akumulacije) te umjetnom prihranjivanju (npr. utisni zdenci ili infiltracijske zone) u vodonosnik. Projekt je bio sufinanciran iz programa transnacionalne suradnje Interreg Srednja Europa 2014. – 2020., a uključivao je sedam projektnih partnera iz Mađarske, Njemačke, Poljske, Slovačke i Hrvatske.

U sklopu projekta provedena su interdisciplinarna istraživanja sa ciljem lociranja područja i vodonosnika pogodnih za primjenu metoda umjetnog prihranjivanja. Hrvatsko područje istraživanja bio je otok Vis, koji je, zahvaljujući kvalitetnim krškim vodonosnicima, samodostatan po pitanju vodoopskrbe.

Terenska istraživanja na otoku Visu uključivala su kontinuirana i periodička opažanja, te laboratorijska i raznovrsna terenska istraživanja. Kontinuirano su automatskim mjeračima opažani razina podzemnih voda, temperature i elektrolitičke vodljivosti. Periodička mjesečna opažanja obuhvaćala su razine podzemnih voda i *in*



Slika 1. Lokacije uzorkovanja voda na otoku Visu



Slika 2. Karta prikladnosti za primjenu sustava umjetnog prihranjivanja (MAR) na otoku Visu

situ mjerenja (T, pH, EC, O_2) te uzorkovanja za hidrokemijske laboratorijske analize glavnih aniona i kationa, metala te stabilnih i radioaktivnih izotopa. Lokacije ovih mjerenja i uzorkovanja prikazane su na slici 1. Od terenskih su istraživanja provedena još i geofizička istraživanja metodama seizmičke refrakcije, električne tomografije i magnetotelurike te strukturno-geološka istraživanja.

Najvažniji je ishod projekta razvoj metodologije za istraživanje primjenjivosti sustava umjetnog prihranjivanja vodonosnika u geološki različitim okolišima (slika 2). Rezultati projektnih aktivnosti u Hrvatskoj prezentirani su kroz stručne i znanstvene radove (Bonacci *et al.*, 2021; Bašić & Patekar, 2022; Patekar *et al.*, 2022), a u pripremi je i doktorska disertacija kolege Matka Patekara na temelju rezultata istraživanja.

Prikazana istraživanja provedena su u sklopu projekta DEEP-WATER-CE kojeg je sufinancirala Europska komisija kroz program Interreg CE (CE1464).

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MULTIDISCIPLINARY APPROACH TO CONCEPTUAL MODELLING OF HYDROTHERMAL SYSTEMS

MULTIDISCIPLINARNI PRISTUP IZRADI KONCEPTUALNIH MODELA HIDROTERMALNIH SUSTAVA

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Ključne riječi: *hidrotermalni sustavi, multidisciplinarna istraživanja, Hrvatska*

Panonski dio Hrvatske ima povoljne geotermalne karakteristike, a prirodni izvori termalne vode temperatura do 65 °C pojavljuju se na dvadesetak lokacija. Te vode se koriste tisućljećima, a u proteklih pedeset godina predstavljaju ključni resurs turističkih i lječilišnih centara. Povećanje potražnje za termalnom vodom s vremenom

je potaknulo crpljenje većih količina. Međutim, termalna izvorišta su dio hidrotermalnih sustava koji uključuju: područja prihranjivanja u planinskim zaleđima izvora; geotermalne vodonosnike (uglavnom mezozojske karbonatne stijene) u kojima se voda zadržava i zagrijava zbog toplinskog toka iz Zemljine unutrašnjosti; i područja istjecanja na mjestima povoljnih struktura veće propusnosti. Kontinuirano funkcioniranje takvih sustava zavisi od osjetljive ravnoteže između brzine toka podzemne vode, procesa taloženja / otapanja i tektonskih pokreta. Kako bi se ta ravnoteža očuvala i termalna izvorišta koristila na održiv način, potrebno je razumijevanje na razini sustava te su istraživanja predložena s tim ciljem.

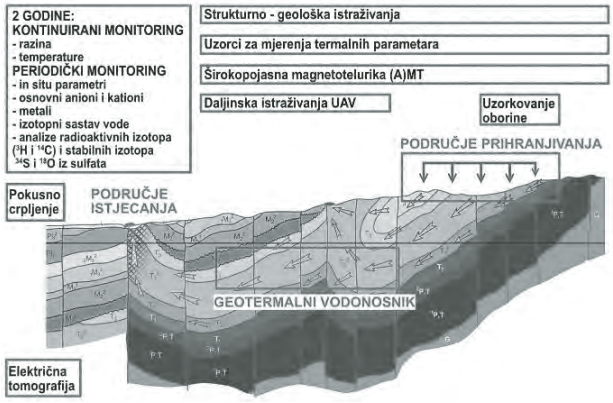
Slika 1. Karta termalnih izvorišta na tri pilot područja u sklopu projekta HyTheC (Daruvar, Hrvatsko zagorje i Topusko)

Rezultati multidisciplinarnih istraživanja (strukturno-geološka, hidrogeološka, geotermijska, hidrogeokemijska, geofizička i daljinska istraživanja) koriste se za izradu konceptualnih modela hidrotermalnih sustava, 3D geološku rekonstrukciju, hidrogeološku i termalnu parametrizaciju jedinica i provedbu numeričkih simulacija funkcioniranja sustava u neporemećenim uvjetima i s različitim scenarijima crpljenja. Metodologija se testira na tri pokusna područja u Hrvatskoj gdje se koristi termalna voda.

Istraživanja se provode u sklopu petogodišnjeg uspostavnog istraživačkog projekta HyTheC. Tijekom dosadašnjih triju godina provedbe formirana je istraživačka grupa, nabavljeni su potrebna oprema i usluge te su provedena sva predviđena terenska istraživanja u trima pokusnim područjima (slika 1). Raspored pojedinih metoda istraživanja prema dijelovima hidrotermalnih sustava prikazan je na slici 2.

Do sada su izrađeni 3D geološki modeli dvaju hidrotermalnih sustava (Daruvara i Topuskog), dok je jedan i parametriziran (Daruvar) te su u tijeku numeričke simulacije funkcioniranja sustava korištenjem komercijalnih programskih paketima i programa otvorenog koda.

Kvalitetni konceptualni i numerički modeli koji će biti izrađeni u sklopu projekta omogućit će ocrtavanje i zaštitu područja prihranjivanja i određivanje održivih crpnih količina, što je preduvjet za dugoročno održivo korištenje hidrotermalnih sustava, a trenutno nije adekvatno regulirano u hrvatskom zakonodavnom okviru.



Slika 2. Pozicioniranje pojedinih vrsta istraživanja u različitim dijelovima hidrotermalnih sustava.

Povećano korištenje termalne vode predviđeno je mnogim europskim i hrvatskim strateškim dokumentima iz područja energetike, turizama i zaštite okoliša. Stoga HGI-CGS uspostavlja multidisciplinarnu grupu za istraživanje hidrotermalnih sustava koja će doprinijeti odgovornom razvoju geotermalnih lokaliteta u našoj državi, te biti znanstveno produktivna i konkurentna u prijavama na natječaje različitih mehanizama financiranja.

Prikazana istraživanja provode se u sklopu uspostavnoga istraživačkog projekta HyTheC kojeg financira Hrvatska zaklada za znanost (UIP-2019-04-1218).

NEW FINDS OF MIOCENE FOSSILS FROM THE BUKOVA GLAVA LOCALITY (NEXE D.D., NAŠICE, CROATIA)

NOVI NALAZI MIOCENSKIH FOSILA S LOKALITETA BUKOVA GLAVA (NEXE D.D., NAŠICE, HRVATSKA)

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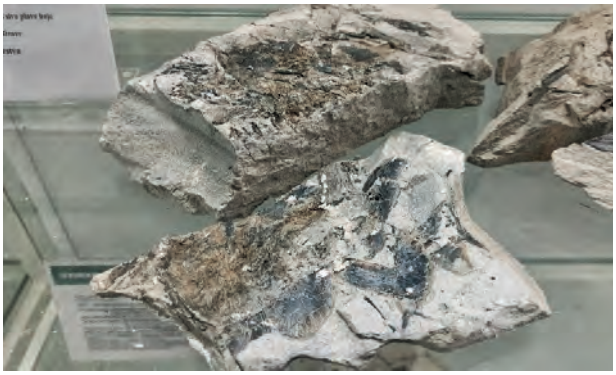
*dopisni autor: zeljko.bortek@os.ht.hr

Ključne riječi: *srednji miocen, makrofosili (ribe), Bukova glava*

Lokalitet Bukova glava se nalazi u ležištu mineralne sirovine za cementnu industriju u koncesiji tvrtke „NEXE“ d.d., (slika 1). Na geološkom profilu naslaga baden–sarmatske starosti dužine 2,5 km i 97 m visine, kontinuirano se tijekom svake godine otkrivaju nove površine dostupne geološkim istraživanjima. Lapori badenske starosti su iznimno fosiliferni, dobro uslojeni, često fino laminirani kao „kamena knjiga“ i sadrže visoki udio organske tvari. U njima je pronađena brojna makrofosilna flora i fauna (PAVELIĆ *et al.*, 2003). Osobito su česti nalazi fosilnih riba, ježinaca, školjki i puževa. Pronađeni su dobro očuvani cjeloviti fosilizirani skeleti riba i fragmenti ribljih ostataka (slika 2) iz porodice papaline, sardine, skuše i tune (VRSALJKO *et al.*, 2018). Uzorci fosila su izloženi u okviru Muzeja školjaka i vodenog svijeta u Osijeku (stalni postav) i Hrvatskom prirodoslovnom muzeju u Zagrebu.

Slika 1. Lokalitet Bukova glava



Slika 2. Ostatci ribe? (U tijeku istraživanja)

PAVELIĆ, D., KOVAČIĆ, M., MIKNIĆ, M., AVANIĆ, R., VRSALJKO, D., BAKRAČ, K., TIŠLJAR, J., GALOVIĆ, I., BORTEK, Ž. (2003): The evolution of the Miocene environments in the Slavonian Mts. area (northern Croatia). 22nd IAS Meeting of Sedimentology, 173–181.

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GENERATING LOG-MODELS OF GEOPHYSICAL PARAMETERS USING MACHINE LEARNING METHODS (GOLA FIELD)

GENERIRANJE BUŠOTINSKIH MODELA GEOFIZIČKIH PARAMETARA UPORABOM STROJNOG UČENJA (POLJE GOLA)

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Keywords: *Geophysics, Well logging data, Machine Learning, Regression, Predictions*

In the area of the Gola field, the Upper Miocene deposits of the western part of the Drava depression represent a sequence of sediments consisting of sandstone, siltstone, marl and their transitional lithofacies. The sandstone deposits, i.e., the main reservoir rocks, mostly occur in lenticular forms (KRPAN *et al.*, 2018), which makes it difficult to spatially correlate. These deposits were formed in a brackish lake environment in the zone of the lake littoral and part of the sublittoral and represent sediments of channel fills and underwater fans deposited from turbidites (TADEJ, 2011).

In order to improve the interpretation of well logging data in the research area, different machine learning models were tested. In this study, regression analysis was used for acoustic log and porosity predictions. The regression belongs to supervised learning models, which means that the learning is based on already known values of the required variables.

Algorithmic processing of a large amount of data is only possible if the matrix of input data is not singular, i.e. its determinant is not zero. The problem with data preparation is the fact that most logging data sets are in the form of a singular matrix, that is, most wells are missing a certain number of values at certain depth intervals (MCDONALD, 2021). For this reason, the missing values were added to existing well depth intervals after predictive modelling by machine learning.

Various statistical methods used to analyse data, including correlation and regression, assume that the data have normal distribution. Most algorithms are also based on the assumption that the variables are around zero to one and that they are comparable to each other. For this reason,

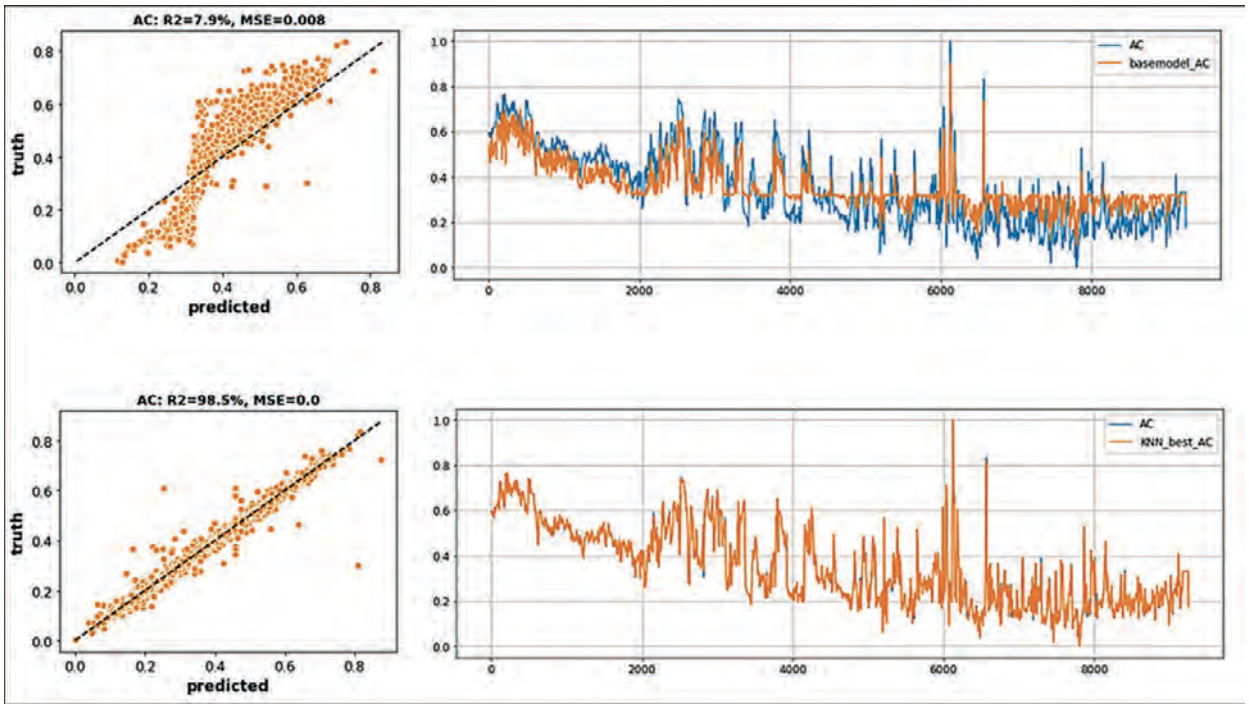

Figure 1. Acoustic log predictions of a Support Vector Regression (SVR) base model (upper images) and K-Nearest Neighbors (KNN) model as the best result (lower images)

prior to testing the algorithms, the data were standardized, normalized, or transformed depending on the algorithms used (SEMENIKHIN & BELOZEROV, 2019).

Based on the correlation matrix, 14 variables (logs) were determined for the calculation of the forecast model. A total of six regression models were used to predict the acoustic logs and porosity values. The base model was calculated using the Support Vector Regression (SVR) algorithm (Fig. 1), as the goal was to determine the boundaries of acceptable predictions.

The measure of accuracy for regression models, amongst others, is the coefficient of determination R^2, which indicates how well the predicted and measured values correlate. For the base model, at the shallower depths the predicted values follow the trend of the measured ones but at the greater depths the predictions fall out of the trend, which makes the results unreliable. The most accurate model was generated using the K-Nearest Neighbour (KNN) algorithm, where the coefficient of determination was over 0.9 (Fig. 1).

The greatest advantages of predicting the values using trained models are the ability to fill in missing logging data and the short time required to get the initial image of the subsurface. Based on the predicted values, the further processing and interpretation methods are determined more quickly.

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DETERMINING THE FORMATION OF KAOLINITE MINERALIZATION USING MINERALOGICAL ANALYSES IN MOTAJICA GRANITE COMPLEX, BOSNIA AND HERZEGOVINA

UTVRĐIVANJE MEHANIZMA NASTANKA KAOLINITA KORIŠTENJEM MINERALOŠKIH ANALIZA U MOTAJIČKOM GRANITNOM KOMPLEKSU, BOSNA I HERCEGOVINA

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Keywords: *kaolinitisation, hydrothermal alteration, XRD, FTIR*

The aim of this abstract is to present the formation mechanism of the kaolinite and kaolin deposits in the Motajica Mt. Although several projects and investments are currently being carried out in the Motajica Mt. area, the development and formation of kaolinite mineralisation is still relatively poorly known. Kaolinite deposits are associated with the Motajica granite pluton, which is characterised by syncollisional granite of Eocene age (JURKOVIĆ, 2004). Numerous papers have been published on the Motajica kaolinites (STANGAČILOVIĆ, 1956; JURKOVIĆ & ŠINKOVEC, 1960; VARIĆAK, 1966; TRUBELJA & BARIĆ, 1979), with different authors proposing different formation mechanisms for the kaolinites. Some authors believed that kaolinitisation occurred during Tertiary marine transgression, others suggested that kaolinitisation occurred through superficial weathering, while in some cases it was considered to be the result of hydrothermal solutions.

The focus of this work is mineralogical analysis of the kaolinitised granites in the Motajica area aiming at determination of clay minerals and definition of the kaolinite deposits origin. The following analyses were performed on the samples: macroscopic determination of mineral composition, X-ray diffraction analysis on original samples, samples treatment with ethylene glycol, heating at 350 °C and 550 °C and treatment with dimethyl sulphoxide (DMSO), Fourier transformed infrared spectroscopy (FTIR) and geochemical analysis on three samples.

The semi-quantitative mineral composition of the kaolinitised granites of the original samples revealed typi-

cal granite mineralisation, including quartz, K-feldspars, plagioclase and mica minerals. Diffractograms obtained after treating the samples with different treatment methods show a relatively strong diffraction peak of illite at 10 Å and a diffraction peak of kaolinite at 7 Å in all samples (Fig. 1). In addition, some samples indicate chlorite, possibly due to alteration of biotite granite. Faint indicative peaks of topaz and dickite were also noted. The presence of these minerals suggests that hydrothermal activity in the temperature range 100–350 °C played an important role in the formation of the kaolinite mineralisation. FTIR spectrum indicates characteristic absorption bands of kaolinite between 3500 and 3700 cm-1. When four characteristic bands (approx. 3700, 3670, 3650 and 3620 cm-1) are well defined, the structure of kaolinite is considered to be ordered (TIRONI *et al.*, 2012). Kaolinitised samples exhibit slightly higher Al contents than the locally occurring various granite types. Based on TiO2/Zr and Cr+Nb/Ti+Fe ratios, two samples are consistent with purely hydrothermal kaolinitisation, while one sample shows signs of mixed type of formation (DILL *et al.*, 1997).

This hypothesis is consistent with the geochemical analysis of quartz veins occurring in the Bosanski Kobaš kaolin deposit in the north-eastern part of Motajica. Elevated contents of bismuth (Bi) in locally occurring quartz veins, similar to the results of RAMOVIĆ *et al.* (1982),

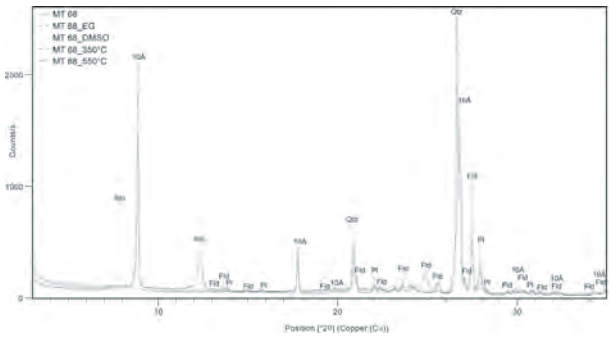

Figure 1. X-ray diffractogram of one Motajica sample with sample treatments

indicate strong hydrothermal activity in this area. The presence of hydrothermal veins in the samples studied clearly indicates a hydrothermal phase that played an important role in the formation of the kaolinites studied. Furthermore, several studies (FLEURENCE & NICOLAS, 1964; ESTÉOULE-CHOUX, 1981; SHOVAL *et al.* 1999) confirmed that hydrothermal kaolinites tend to have higher crystallinity when compared to supergene kaolinites. The presence of a supergene phase of kaolinisation cannot be completely ruled out because the deposits are at the surface, but it can be safely assumed that there was initial hydrothermal kaolinitisation.

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GEOLOGY FOR BLIND AND VISUALLY IMPAIRED
GEOLOGIJA ZA SLIJEPE I SLABOVIDNE

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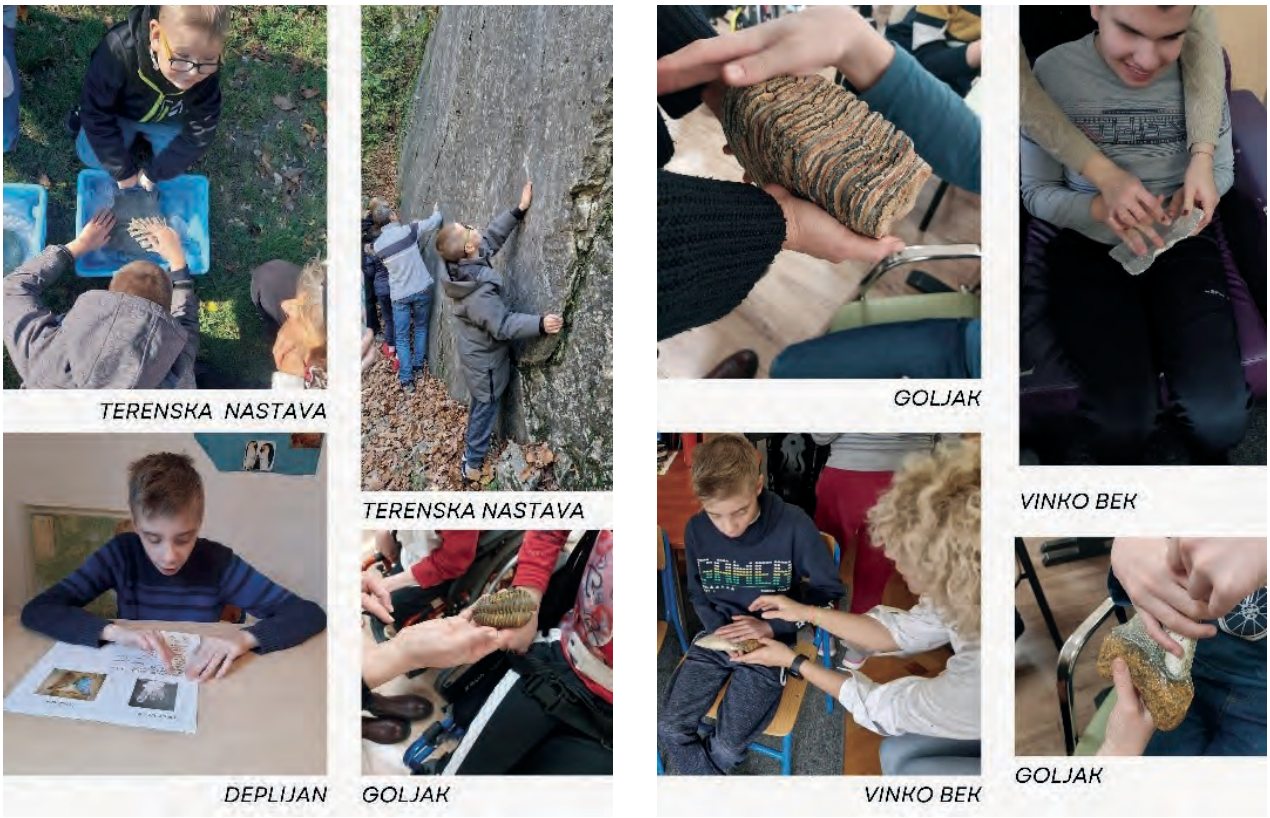
Ključne riječi: *geologija, slijepi, slabovidni, muzej*

Geologija je vizualna znanost pa se može činiti apstraktna slijepim ili slabovidnim osobama jer je kao takva ponekad izazovna i studentima s dobrim vidom. Ipak, sve je veća želja da i slijepe i slabovidne osobe steknu geološka znanja. Uobičajeni vizualni zadaci u geologiji uključuju istraživanje terena, pronalaženje i tumačenje fosila, minerala, stijena te izradu geoloških karata radi upoznavanja unutarnje strukture Zemlje i razvoja života na njoj. Sve više geoloških fakulteta, a i prirodoslovnih muzeja imaju implementirane alate kojima se omogućava i tim osobama učenje geologije. Hrvatski prirodoslovni muzej ima programe za slijepe i slabovidne, ali samo za geologiju. Jedina prilagodba slijepim osobama bili su audiovodiči i taktilni pano na Brailleovom pismu u Mineraloško-petrografskom postavu.

Program za slijepe i slabovidne osobe započeo je 2000. godine uz izložbu „Dinosauri u povorci života – život kroz milijardu godina". Od tada se sustavno radi na prilagodbama približavanju geologije ovoj ciljnoj skupini uz primjenu fosila i minerala određenih karakteristika. Uzorci koji se koriste u radu jednostavnih su oblika, teksturalno izraženi i stoga pogodni za učenje dodirom, jer slijepe osobe mogu dodirom razviti dublje, snažnije razumijevanje predstavljenih uzoraka.

S vremenom se suradnja s ovom ciljnom skupinom povećavala, zbog čega se i pristup učenju geologije za tu ciljnu skupinu razvijao pri čemu smo i mi naša znanja o radu sa slijepim i slabovidnim osobama proširili kroz suradnju sa specijaliziranim ustanovama, Centrom za odgoj i obrazovanje „Vinko Bek", Poliklinikom za rehabilitaciju slušanja i govora SUVAG te posebno Tiflološkim muzejom.

Rad sa slijepim učenicima proširio se i na izvan muzejske aktivnosti, u prirodu, na teren. Tako je slijepim i slabovidnim osobama postala dostupna i „terenska" geologija, odnosno omogućeno im je da neka znanja stečena na radionicama primjene i uživo, u prirodi. Učenici su iskoristili



Radionice i terenska nastava u sklopu programa „Geologija za slijepe i slabovidne"

svoja istančana osjetila kako bi što kvalitetnije iznijeli svoja zapažanja, pa čak i neka koja možda studenti geologije s dobrim vidom često mogu zanemariti (kao što je korištenje ravnina kalanja umjesto boje za ispravnu identifikaciju minerala). Rad s ovom grupacijom i nama je pokazao neke nove načine rada i primjenu ovog koncepta.

Svim aktivnostima i korištenim materijalima uspješno su ispunjavani ciljevi koji uključuju prepoznavanje oblika te njihovo opisivanje i tumačenje.

U prošlosti nije bilo razumijevanja za rješavanje pitanja geologije za slijepe i slabovidne, no danas, u vrijeme kada želimo biti inkluzivni, i geologija treba postati dostupna svima, osobito učenicima s ovim oblikom invaliditeta. Izrada materijala za slijepe, tekstovi na brajici ili na audiozapisima dosta su skupi, a i zahtjevni za izradu, pa je to možda i razlog izostanka publikacija i tekstova o geologiji za slijepe i slabovidne. Hrvatski prirodoslovni muzej ima tek letak i 20 kartica s taktilnim slikama muzejske geološke građe. S obzirom na to da postoji interes za učenje geologije kod slijepih i slabovidnih osoba primjer dobre prakse su ove muzejske radionice kojima naš muzej daje određeni doprinos. Naša nastojanja uključuju skoro formiranje edukativne geološke zbirke za slijepe i slabovidne posjetitelje.

Novi muzejski postav bit će u cijelosti prilagođen slijepim i slabovidnim osobama, posebno njegov geološki dio te će tako i naš muzej biti primjer inkluzivnog muzeja, čija će građa biti dostupna svima pa tako i slijepim i slabovidnim osobama. U muzeju se nastavlja i unapređuje rad s ovom ciljnom skupinom stvaranjem repozitorija taktilne grafike.

VOLCANIC SOURCES AND SINKS OF THE ALPINE-MEDITERRANEAN REGION: A WINDOW INTO SILICIC VOLCANISM AND PALEOENVIRONMENTS DURING EARLY–MIDDLE MIOCENE

VULKANSKA IZVORIŠTA I TALOŽNI SUSTAVI ALPSKO-MEDITERANSKE REGIJE: UVID U SILICIJSKI VULKANIZAM I PALEOOKOLIŠE TIJEKOM RANOG DO SREDNJEG MIOCENA

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Keywords: *Silicic volcanism, Karst bauxites, Multi-proxy, Miocene, Alpine-Mediterranean region*

The Alpine-Mediterranean region (AMR) hosted numerous volcanic centres during the Eocene to Quaternary, many of which recorded voluminous explosive activity (e.g., Rhodopes during the Oligocene, Sardinia during the Early Miocene, Anatolia during the Late Miocene–Pliocene, and Italian and Aegean arc during the Quaternary). Individual silicic eruptions in the Carpathian-Pannonian Region (CPR), part of an ignimbrite flare-up, reportedly

affected the AMR during Early and Middle Miocene. The CPR presumably caldera-forming eruptions, each potentially expelling 10s to 100s of km^3 of pyroclastic material (tephra), produced widely spread ignimbrites, best exposed in northern and southwestern Pannonian Basin. These eruption products were also likely distributed by tropospheric easterly trade winds towards the southwest, and were finally deposited as ash fallouts in various distal sedimentary archives. These basinal settings ranged from terrestrial to marine, depending on the evolution of discrete basins within the CPR, as well as in the Alps, the Appenines, the Dinarides and the Aegean-Balkan regions. These volcaniclastic deposits could represent synchronous event marker horizons, and therefore represent potentially powerful tools for constraining the space-time evolution of the region. Furthermore, karstic environments such as the Dinarides could have been distal sinks for fallout tephra sourced from voluminous AMR silicic eruptions during Cenozoic. Under specific paleoenviromental and paleoclimatic conditions, these volcanic materials may have served as the main part of the protolith for karst bauxite formation, and therefore the spatio-temporal distribution of these volcaniclastic rocks has significant bearing on understanding continental paleoclimate for the region.

To address outstanding questions regarding regional Early–Middle Miocene silicic volcanism and bauxitization, we examined volcaniclastic deposits, including ignimbrites and fallout tuffs, and karst bauxites, scattered across the AMR. In order to best capture the full potential dispersion of these volcanic events, sampling included localities within the CPR, as well as distal localities in the Dinaride Lake System, the North Alpine Foreland Basin, and northern Appenines. We utilized volcanological, mineralogical and petrological screening, *in situ* and high-precision U-Pb zircon geochronology, zircon chemistry and Lu-Hf isotopic composition, as well as volcanic glass major and trace elemental and isotopic compositions. Our goals are: 1) to define the ages and temporal relationships of Lower and Middle Miocene volcaniclastic horizons; 2) to reliably evaluate the provenance and correlativity of eruption products and their potential origin from individual widespread silicic eruptions, contributing to regional tephrostratigraphic and volcanological reconstructions; 3) to gain insight into petrogenesis for CPR silicic magmas with time; 4) to constrain the timing, origin, provenance and paleoclimatic implications of karst bauxites underlying the Dinaride Lake System.

IMPLEMENTATION OF A TI(III) REDUCTION METHOD FOR THE DETERMINATION OF NITROGEN (δ15N) AND OXYGEN (δ18O) ISOTOPIC COMPOSITION OF NITRATE

IMPLEMENTACIJA TI(III) REDUKCIJSKE METODE U SVRHU ODREĐIVANJA IZOTOPNOG SASTAVA DUŠIKA (δ^{15}N) I KISIKA (δ^{18}O) IZ NITRATA

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Keywords: *nitrogen and oxygen isotopes in nitrate, titanium method, laser spectrometry*

Pollution of surface and groundwater by nitrate (NO3–) is one of the most serious environmental problems worldwide. The crucial isotopes for the sources and dynamics of nitrogen (N) in the aquatic environment are the nitrogen and oxygen isotope data of NO3-. The stable isotope of nitrogen (δ15N) in dissolved nitrate has been most commonly used to estimate NO3- sources in groundwater. However, measurement of the stable nitrogen isotope alone does not provide a definitive determination of NO3– origin, so the stable oxygen isotope (δ18O) must be used, i.e., a dual isotope approach. The analysis of NO3- for both δ15N and δ18O has been made possible by the development of various laboratory methods for sample preparation, each with its own advantages and disadvantages. Current methods such as the cadmium reduction method (Azide method) or the bacterial denitrification method require toxic chemicals or anaerobic bacterial cultures for NO3- reduction to N2O gas. In 2019, a new sample preparation method was developed (ALTABET *et al.*, 2019), which is a simple one-step conversion method that utilizes Titanium(III) chloride reagent to reduce NO3– to N2O within septum sample vials:

$$2NO_{3^-(aq)} + 8Ti^{+3} + 10H^+ \rightarrow N_2O_{(g)} + 8Ti^{+4} + 5H_2O$$

A single sample preparation takes only a few minutes, followed by a 24-h reaction that generates N_2O headspace gas for δ^{15}N and δ^{18}O analysis by IRMS or laser spectrometer. Briefly, Ti(III) chloride is preconditioned with zinc metal powder about 30 minutes before sample prepara-

tion to ensure efficiency by removing Ti(IV). The volume ratio of sample to reagent for groundwater samples is 10:1, 20:1, or 40:1. We found that higher amounts of Ti(III) reagent (10:1 and 20:1 ratios) gave slightly more accurate $\delta^{18}O$ values. The $\delta^{15}N$ values were most inaccurate at ratios of 10:1 and 40:1, but were more accurate at a 20:1 ratio of sample to reagent. Therefore, a 20:1 ratio is considered practical for further measurements. To ensure consistent N_2O yields and ^{15}N and ^{18}O results, the N concentrations in each vial must be identical for all samples, laboratory controls, and standards. This is achieved by adding an appropriate volume of sample, degassed deionized water, 10% hydrochloric acid, and the preconditioned Ti(III) chloride reagent. The $\delta^{15}N$ and $\delta^{18}O$ isotope analyses were performed using the Isotopic N_2O Laser Analyzer (GLA451-N2OI3), which was acquired as part of the CRO7002 project "Using Nitrogen and Oxygen Stable Isotopes in the Determination of Nitrate Origin in the Unsaturated and Saturated Zone of the Velika Gorica Wellfield", funded by the International Atomic Energy Agency (IAEA). The described method is very competitive (simple, faster and more cost-effective) compared to the existing methods currently used in most laboratories worldwide, and its implementation at the Faculty of Mining, Geology and Petroleum Engineering (University of Zagreb) enabled the development of new research on the estimation of the origin of nitrate in groundwater.

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CONTROL VARIABLES OF THE WATER GEOCHEMISTRY IN THE RULL CAVE, ALICANTE, SPAIN KONTROLNE

VARIJABLE U GEOKEMIJI VODE U ŠPILJI RULL, ALICANTE, ŠPANJOLSKA

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Keywords: *karst, water, geochemistry, Rull Cave, Spain*

The geochemistry of the water stored in underground karstic caves is the product of a complex interaction between climate, soil, unsaturated zone, and the cave inner atmosphere. This geochemical evolution, that begins with rainfall, has a fundamental role in soil configuration, formation of karstic secondary porosity, and the development of caves and speleothems, which constitute key tools for the study of paleoclimate.

The aim of our research is to estimate the controlling factors on cave water chemistry, and to infer some of the processes acting through the infiltration from soil to cave. The studied area is the Rull Cave (SE Spain), developed in marls and limestones under a semi-arid climate. The cave has an average air temperature of 16.2 °C and undergoes annual ventilation cycles, associated with the air density differences between outdoor and indoor atmospheres. During summer, cave air remains stagnant, with higher CO2 concentrations (over 3000 ppm). During winter, through advective gaseous flux, CO2 drops to 478 ppm (PLA *et al.*, 2023). The water inside the cave can be found as drippings, or as gours (cave pools) in chemical equilibrium with the inner atmosphere and its gaseous composition.

To approach the aim of this study, the parameters and elements measured in the water sampled from the largest gour (hereinafter "cave water") were compared with those of the water that has passed through the soil (hereinafter "soil water"). The comparison was made for April and June 2022, considered representative of the wet and dry seasons, respectively.

Soil water was obtained by carrying out two leaching experiments in the laboratory, inserting rainfall-like water (pH 5.5, electric conductivity≈40 μS/cm) into a column of 600 g of soil sampled above the cave, and collecting the water below. We recreated the soil conditions at the selected months. During April (spring of 2022), heavy rains occurred on a soil that is at 8 °C and has held a high volumetric water content throughout the winter (VWC > 25 m^3/m^3). During June (summer of 2022), the scarce rainfalls occurred on dry soil (VWC < 5 m^3/m^3), at 25 °C.

In April then, the soil water would have a pH of 7.3 and an electric conductivity (EC) of 952 µS/cm. Cave water has a significantly lower EC and a pH of 8, indicating water-rock-cave air interaction processes. While soil water has higher concentrations of Ca^{+2}, Mg^{+2}, Cl^{-} and trace elements, the cave water is comparatively enriched in HCO_3^{-}. The calcite and aragonite saturation indices (SI) shift from an undersaturated to a slightly supersaturated state. The CO_2 measured within the cave is half the field measured soil CO_2 (993 and 2298 ppm, respectively).

In June, the pH of the soil water would be nearly the same as the cave water pH (7.8), but the EC is still significantly higher. Compared to the soil water recreated for April, there is a significantly higher amount of trace elements such as B, Al, and Fe, but less Si and Sr. Calcite and aragonite SI are similar in soil and cave water, both slightly supersaturated. The CO_2 measured within the cave is slightly higher than the CO_2 concentration measured in the soil (3000 and 2744 ppm, respectively).

It is then observed that during the cold-humid months, the soil water has carbonates SI below zero, which indicates possible mineral dissolution processes taking place in the vadose zone. Dilution processes are also feasible, associated with the water reservoir overlying the cave, which sustains the various dripping sites. The similarity in the SI of soil and cave water in June shows that, likely, there is calcite saturation throughout the entire profile, which could indicate an attenuation of the carbonates dissolution and mobilization processes during summer.

In summary, cave ventilation cycles have a marked influence on the cave water chemistry since it is in chemical equilibrium with the air. As suggested by the laboratory experiment, the processes taking place in the system are also conditioned by the original chemistry of the water in the vadose zone after passing through the soil. Likewise, soil water chemistry is conditioned by soil itself, but also by the conditions determined by the climate.

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SUBAERIAL EXPOSURE SURFACE WITHIN CARBONATE DEPOSITS AT ZLATNI RT CAPE, ROVINJ, ISTRIA – A RECORD OF A LATE JURASSIC EMERGENCE OF THE ADRIATIC CARBONATE PLATFORM

POVRŠINA SUBAERSKOG IZLAGANJA KARBONATNIH NASLAGA ZLATNOG RTA, ROVINJ, ISTRA – ZAPIS EMERZIJE TIJEKOM MLAĐE JURE NA JADRANSKOJ KARBONATNOJ PLATFORMI

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Keywords: *Subaerial exposure surface, Late Jurassic, Adriatic Carbonate Platform, Istria*

Middle and Upper Jurassic carbonates comprise the first large-scale sequence deposits in Istria, ending with the deposition of the Oxfordian to lowermost Kimmeridgian Muča unit. This succession is overlain by the second large-scale sequence (Upper Tithonian–Lower/Upper Aptian) which begins with the deposition of the upper Tithonian Kirmenjak unit. These two large-scale sequences are separated by important discontinuity characterized by stratigraphic hiatus of different duration, reflecting a compressional tectonic event caused by ophiolite obduction along the NE Adria Microplate margin. The beginning of this subaerial exposure phase is marked by the Rovinj breccias formed during the regression that preceded the emergence. These breccias display a gradual transition from Muča and Lim units and are composed of fragments belonging to both units. This regionally recognized subaerial exposure phase is locally marked by bauxites that filled paleo-depressions within the Lim and Muča unit limestones and the Rovinj breccias. In other places subaerial exposure is mostly recorded by palaeo-

sols, and one of the best examples can be found at Zlatni rt locality in Rovinj.

The palaeosol marks the contact between Muča and Kirmenjak units. The Muča unit consists of two lithofacies (LF) types, representing high to moderate energy marine environments: LF 1 – bioclastic-peloidal grainstone to rudstone characterized by common to abundant peloids and benthic foraminifera, rare ooids, algae, fragments of echinoderms, hydrozoans, coated fragments of *Cladocoropsis*, stromatoporids, bivalves, Rivulariacean-like (*Cayeuxia*) cyanobacteria, corals and *Lithocodium*; and LF 2 – bioclastic-peloidal packstone with common to abundant peloids, benthic foraminifera and fragments of echinoderms. The beginning of regression was marked by Rovinj breccias, which form lenses atop of Muča unit. The palaeosol forms a decimetre-thick horizon of grey clay, which is also present as infills in karstified channels and fissures of the Muča unit and Rovinj breccia. Among other minerals, the palaeosol contains glauconite that formed during the incipient flooding of the carbonate terrain. As the transgression progressed, the palaeosol was covered by a decimeter-thick layer of transgressive breccia, containing fragments of Muča unit and upper Tithonian black pebbles. The formation of black pebbles under vadose conditions is evidenced by the presence of *Microcodium*-like structure, alveolar-septal fabric (in voids of fenestral origin?) and other features indicating subaerial exposure. In the area of Zlatni rt the Kirmenjak unit, which covers the palaeosol and the breccia, begins with a bioclastic (algal)-peloidal grainstone to rudstone abundant in bioclasts of *Campbelliella striata*, *Clypeina sulcata*, *Salpingoporella annulata* and *Favreina* faecal pellets. The rest of the Kirmenjak unit is composed of a cyclic alternation of mudstones, peloidal to bioclastic packstones to grainstones and black pebble breccias with subaerial exposure surfaces.

A very well preserved palaeosol level at the Zlatni rt locality documents one of unique terrestrial palaeoenvironments that existed during the early Kimmeridgian to late Tithonian in the northern part of the Adriatic Carbonate platform.

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GAMMA REY SPECTROMETRY ANALYSIS OF PRE-NEOGENE BASEMENT ROCKS AND ITS IMPLICATIONS ON THE RADIOGENIC HEAT GENERATION POTENTIAL

ANALIZA REZULTATA POVRŠINSKE GAMMA SPEKTROMETRIJE NA STIJENAMA PODLOGE NEOGENA I UTJECAJ NA MOGUĆNOST GENERIRANJA RADIOGENE TOPLINE

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Keywords: *heat flow, thermogenic potential, Neogene basement, basin modelling*

Temperature distribution in the subsurface depends on several factors, including regional heat flow, thermal conductivity of rocks, their radiogenic potential, and local factors that can lead to higher temperatures at shallower depths, such as active migration pathways. In this work, the potential for thermogenic heat generation in the pre-Neogene basement rocks was investigated based on their content of uranium, thorium, and potassium (ABDEL HAFEEZ *et al.*, 2019; ADABANIJA *et al.*, 2020; SANJURJO-SÁNCHEZ *et al.*, 2022). For this purpose, a Gamma Surveyor Vario field gamma-ray spectrometer (Fig. 1) was used to measure the concentrations of the above elements at outcrops on the margins of the Drava sub-basin.

At least three measurements were made at each outcrop, which were later averaged. In total, more than one hundred observation points were measured. The general lithology was summarized in six categories (Table 1): Triassic dolomites, effusive rocks (basalt), granitoid, schist, gneiss, and Miocene effusive rocks. In most cases, the measurements yielded higher values for radioelements than the catalogue values in the Schlumberger PetroMod lithology editor (SCHLUMBERGER PETROMOD, 2022), suggesting a higher potential for radiogenic heat generation. This is a crucial parameter in basin modelling that will help to better estimate the geoenergy potential of the subsurface in the eastern part of the Drava sub-basin.

This work has been supported in part by Croatian Science Foundation under the project GEOlogical characterization of the Eastern part of the Drava depression subsurface intended for the evaluation of Energy Potentials GEODEP (UIP-2019-04-3846)

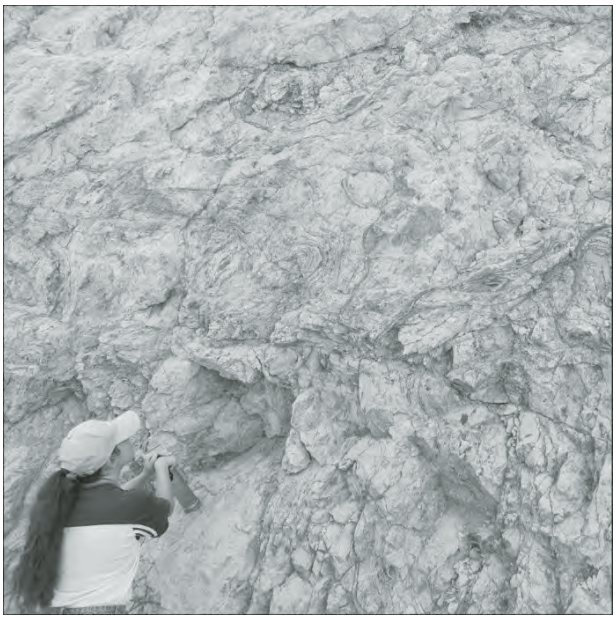

Figure 1. Field measurements with gamma Surveyor Vario

Table 1. Uranium, thorium and potassium values in reference to their radiogenic heat potential

	Dolomite Triassic				Effusive (Basalt)				Andesite Miocene			
Lithology	typical		local		typical		local		typical		local	
U [ppm]	0.8		2.65		0.9		1.42		1.35		11.78	
Th [ppm]	0.6		2.15		2.7		3.51		2.5		24.82	
K [%]	0.4		0.51		0.8		1.01		1.4		4.13	
Porosity [%]	0	10	0	10	0	10	0	10	0	10	0	10
Bulk Value [μW/m³]	0.29	0.26	0.91	0.82	0.52	0.47	0.75	0.67	0.64	0.58	5.04	4.53
	Granitoide				**Schist PNg**				**Gneiss PNg**			
Lithology	typical		local		typical		local		typical		local	
U [ppm]	6.5		4.63		2.1		3.53		5		5.73	
Th [ppm]	17		13.3		9.7		10.33		13		13.67	
K [%]	5.7		4.23		2.2		2.9		3		4.39	
Porosity [%]	0	10	0	10	0	10	0	10	0	10	0	10
Bulk Value [μW/m³]	3.32	2.99	2.46	2.21	1.44	1.29	1.92	1.73	2.5	2.25	2.87	2.58

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BOARD GAME: JOURNEY THROUGH THE EARTH'S PAST
DRUŠTVENA IGRA: PUTOVANJE KROZ ZEMLJINU PROŠLOST

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Ključne riječi: *društvena igra, geologija, paleontologija, povijest Zemlje, škola*

Društvene igre (eng. board games) su jedan od oblika zabave i socijalne interakcije, kako mlađih tako i starijih uzrasta. One mogu biti i koristan obrazovni alat ako kombiniraju razonodu, kompetitivnost i znanje. Igra „Priča iz davnina" (slika 1) je osmišljena na principu igre „Snakes and Ladders", ali s geološko-paleontološkom tematikom u kojoj igrači mogu saznati i naučiti ponešto o značajnim događajima iz geološke prošlosti Zemlje.

Igra je namijenjena starijoj vrtićkoj dobi i osnovnoškolskom uzrastu. Sudjeluju dva do četiri igrača kojima je cilj stići od polja „Start", koje označava nastajanje Zemlje, do polja „Kraj", odnosno današnjice, na igraćoj ploči. Polja su podijeljena prema geokronološkim jedinicama – vremenskim razdobljima (eon, era, period, epoha) Zemljine prošlosti, te svako polje predstavlja neki bitan događaj iz tog razdoblja, npr. „Pojava kisika", „2. Veliko izumiranje", „Raspad Pangeae" itd. Uz polja koja služe za kretanje, postoje i polja na kojima se aktivira „efekt". Primjerice, ako igrač stane na „Ledeno doba" mora propustiti jedno bacanje, ili ako stane na primjer na „1. Veliko izumiranje" vraća se dva koraka unazad. Interaktivni karakter igre postignut je upotrebom fosilnog sadržaja iz kolekcije Geološko-paleontološkog zavoda Prirodoslovno-matematičkog fakulteta Sveučilišta u Zagrebu. Fosili služe kako bi se igrači pobliže upoznali s organizmima iz geološke prošlosti, odnosno sa znanstvenom granom koja se zove paleontologija. Kada stanu na polje označeno zvjezdicom („Upoznaj fosil") i točno prepoznaju navedeni okamenjeni organizam, za nagradu se pomiču korak naprijed.

Igra je prezentirana javnosti na Festivalu znanosti održanom u Tehničkom muzeju Nikola Tesla u Zagrebu (27. 04. 2023.) i manifestaciji „Dan i noć na PMF-u" na Geološkom odsjeku (05. 05. 2023.). U igri je sudjelovalo više od 100 igrača, čiji profili znanja iz geologije idu od predškolskog uzrasta pa sve do docentskog radnog mjesta na Geološkom odsjeku. Inicijalne reakcije su i više nego pozitivne te je bilo višestrukih upita o mogućnosti nabave.

Vrtićima i školama ova bi igra zasigurno bila vrlo korisna jer predstavlja pristupačniji i zabavniji način prenošenja osnovnih znanja iz geologije i paleontologije što bi također pozitivno utjecalo na popularizaciju geologije i znanosti općenito.

Slika 1. Društvena igra „Priča iz davnina"

CHARACTERISTICS OF TRANSITIONAL DEPOSITIONAL ENVIRONMENTS ALONG EASTERN ADRIATIC COAST (SOLINE BAY, KRK ISLAND AND QUEEN'S BEACH, NIN)

KARAKTERISTIKE PRIJELAZNIH TALOŽNIH OKOLIŠA NA ISTOČNOJ OBALI JADRANA (UVALA SOLINE, OTOK KRK I KRALJIČINA PLAŽA, NIN)

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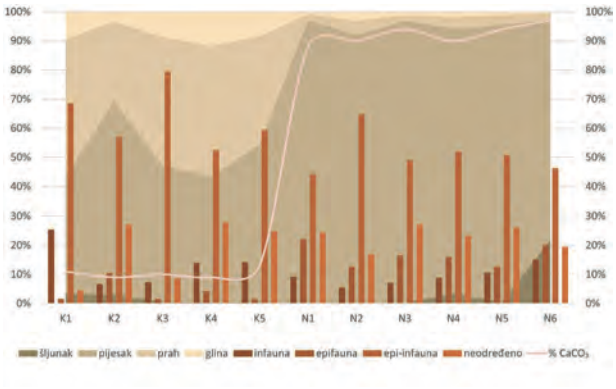
Ključne riječi: *slana močvara, plimna ravnica, granulometrija, kalcijev karbonat, foraminifere*

Na području uvale Soline i Ninskog zaljeva (sjeveroistočni dio Jadrana) nalaze se prijelazni morski okoliši (slane močvare i plimne ravnice) specifičnih sedimentoloških i mikropaleontoloških karakteristika. Cilj ovog istraživanja bio je usporediti naizgled slične tipove taložnih okoliša razvijenih na krškoj karbonatnoj obali na temelju granulometrijskog sastava sedimenta i udjela karbonatne komponente, te sastava i raznolikosti zajednice bentičkih foraminifera. Uzorkovanje je provedeno tehnikom plitkog jezgrovanja, a za potrebe istraživanja analizirani su površinska 2 cm sedimenta, na pet lokacija u području slane močvare i plimne ravnice uvale Soline, te na šest lokacija u slanoj močvari, plimnoj ravnici i plaži u Ninskom zaljevu. Granulometrijskom analizom utvrđena je podjednaka zastupljenost muljevite i pjeskovite komponente u svim površinskim uzorcima sedimenta prijelaznih okoliša uvale Soline te ekstremno slaba sortiranost sedimenta, za razliku od sedimenta u prijelaznim okolišima Ninskog zaljeva koji je klasificiran kao pijesak i koji pokazuje umjerenu do slabu sortiranost. Sedimenti s lokacije Soline sadrže nizak udio karbonatne komponente, u rasponu od 9 do 13 %, dok su sedimenti prijelaznih okoliša Ninskog zaljeva imali značajno viši udio karbonata, u rasponu od 88 do 97 % (ČANČAR *et al.*, 2023). Klaster analiza na temelju najzastupljenijih vrsta foraminifera (zastupljenih s više od 2,5 %) pokazala je grupiranje uzoraka u dvije foraminiferske asocijacije koje se većim dijelom podudaraju s prevladavajućim tipom sedimenta na mjestima uzorkovanja: Ammonia beccarii – Ammonia ex gr. tepida asocijacija u pjeskovitom sedimentu Ninskog zaljeva i Ammonia ex gr. tepida – Porosononion granosum asocijacija u muljevito-pjeskovitom sedimentu uvale Soline. Iako slični, istraživani okoliši pokazuju razlike u granulometrijskim karakteristikama sedimenta i foraminiferskoj zajednici, no najznačajnija razlika je u udjelu karbonatne komponente u sedimentu, što je posljedica različite geološke građe okolnog područja. Sitnozrnatiji sedimenti slane močvare i plimne ravnice uvale Soline imaju veću brojnost infaunalnih jedinki i niži udio karbonata (slika 1). U prijelaznim okolišima Ninskog zaljeva viši udio karbonata povezujemo s većim udjelom biogene i litogene karbonatne pjeskovite frakcije što se podudara s dominacijom epifaunalnih jedinki u foraminiferskoj zajednici.



Slika 1. Dijagram odnosa između funkcionalnih skupina (prema načinu života) bentičkih foraminifera, granulometrijskog sastava i sadržaja karbonata u sedimentu na svim točkama uzorkovanja

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MINERALOGICAL AND GEOCHEMICAL CHARACTERISTICS OF BAUXITES FROM KOŠUTE AND GLJEV, SINJ REGION

MINERALOŠKA I GEOKEMIJSKA OBILJEŽJA BOKSITA IZ KOŠUTA I GLJEVA, OKOLICA SINJA

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Keywords: *bauxite ore, rare earth elements, mineralogical composition, X-ray powder diffraction*

Bauxite is an aluminium ore, but it may also be examined as potential source of rare earth elements, group of chemical elements that represent a critical commodity in modern industry and are essential in many modern technologies. Thus, the bauxite samples from two deposits in south Croatia were collected on the surface of abandoned pits and subjected to mineralogical and chemical analysis to determine the composition of bauxite, REEs amounts and its origin.

The bauxite deposits Košute and Gljev are located in Dalmatian inland near the city of Sinj. Košute deposit is located 9 km south of Sinj and Gljev deposit around 12 km northeast of the city. Both deposits lie on the Upper Cretaceous limestones and are covered by the Upper Eocene Promina beds (MARKOVIĆ, 2002).

Bauxite ore in the Gljev deposit is compact, dark red to yellowish red, while ore from the Košute deposit is dark red and loose.

X-ray powder diffraction (XRPD) results of the Gljev deposit sample (Fig. 1) show presence of mainly gibbsite and böhmite as well as goethite, and minor amounts of hematite, kaolinite and anatase. Goethite is the probable cause of yellowish tint of the samples. The XRPD pattern does not show any böhmite, but indicates solely gibbsite, and more hematite and kaolinite in the Košute deposit.

The ternary diagram $SiO_2 - Al_2O_3 - Fe_2O_3$ (Fig. 2) shows the Gljev deposit samples to be mostly ferritic bauxite to bauxite, which is in a good agreement with XRPD analyses, and moderate to strong lateritization can be assumed. The Košute deposit samples are mostly bauxite with assumed moderate lateritization.

TiO_2 is present in the form of anatase (Fig. 1), which is usually formed syngenetically with bauxite (BÁRDOSSY, 1982).

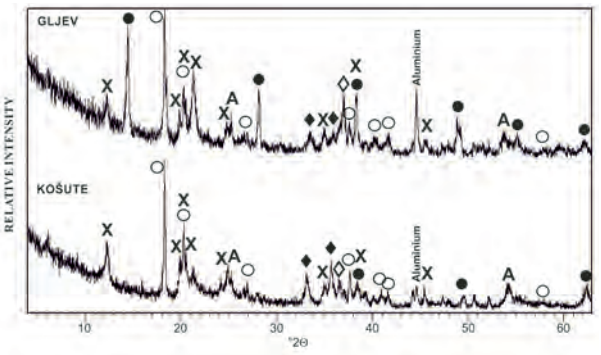

Figure 1. Representative difractograms of the Gljev and Košute bauxite deposits (o – gibbsite; •– böhmite; • – hematite; – goethite; X– kaolinite; A – anatase; Aluminium – aluminium sample holder)

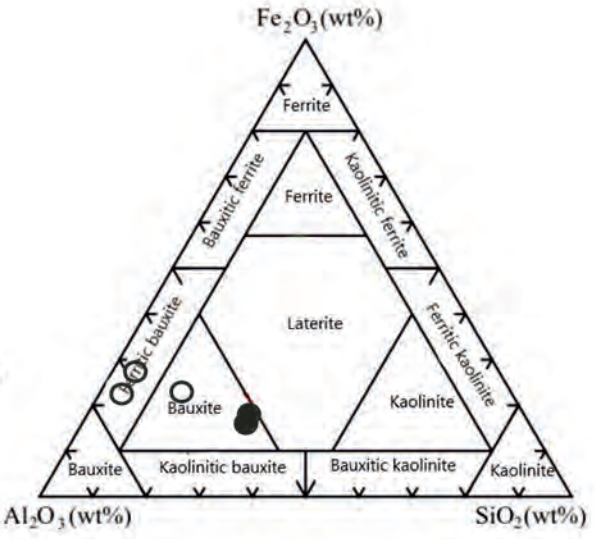

Figure 2. Ternary diagram SiO2 – Al2O3 – Fe2O3 after ALEVA (1994) presenting mineralogical classification of the Gljev (o) and Košute (•) deposits

Both deposits are enriched in REE, with Gljev deposit having up to more than 1500 ppm on average, and Košute 515 ppm average. The Gljev samples, having the highest REE abundances and showing the lowest LREE/HREE ratios (1.4–2.3), indicate relative enrichment in HREE which is in direct relation to high yttrium abundances (~390 ppm). La/Y ratios, which are in the range 0.6–0.9, indicate acidic conditions (La/Y < 1) during weathering, being a possible cause of slight HREE enrichment. Acidic conditions cause pronounced dissolution and prevent formation of common fluorocarbonate phases like bastnäsite-(Ce) or parasite-(Ce) (TOMAŠIĆ *et al.*, 2021) which are common carriers of LREE. On the other hand, La/Y ratios for Košute (2.3–2.4) indicate alkaline conditions favourable for carbonate phases enriched in LREE that is further supported by LREE/HREE ratios of 5.2–5.4. Such high abundances can trigger autigenic REE mineralization.

In order to define in which mineral species REE are contained, further investigation are necessary.

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GEOLOGICAL DEPOSITS IN THE KAPTOL AREA (ZAGREB CATHEDRAL)
GEOLOŠKI ODNOSI I NASLAGE NA PODRUČJU KAPTOLA (ZAGREBAČKA KATEDRALA)

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Ključne riječi: *inženjerskogeološko istraživanje, zagrebački potres, zagrebačka katedrala*

Za obnavljanje Zagrebačke katedrale od posljedica potresa, koji se dogodio 22. ožujka 2020.godine bilo je potrebno angažirati interdisciplinarni skup stručnjaka (GEOTEHNIČKI STUDIO D.O.O., 2022). U tom potresu oštećeno je 16 555 stambenih, javnih i spomeničkih objekata (MARKUŠIĆ *et al.*, 2020). Ozbiljnu štetu u potresu pretrpjela je i zagrebačka katedrala, a njezin južni toranj je pomaknut i morao se ukloniti kako bi se obnovio.

Potres je nastao uslijed interakcije Europske ploče i subdukcije Jadranske mikro ploče. Katedrala se nalazi južno od Medvednice. Vertikalni pomak tla duž rasjedne zone Žumberak–Medvednica–Kalnik jugoistočnog je smjera i otvara se rasjedna zona koja se širila duž potisaka prema sjeverozapadu (MARKUŠIĆ *et al.*, 2020). Epicentralno područje je uzdignuto za 3 cm, a površina koju zauzima uzdignuto područje je površine oko 20 km2, taj rasjed predstavlja seizmički izvor potresa (MARKUŠIĆ *et al.*, 2020).

Nakon potresa pristupilo se istraživanju i prikupljanju podataka za sanaciju katedrale. Tom prilikom izvršeno je geološko rekognosciranje terena i izbušene su četiri istražne geološke bušotine dubine do 35 m. Kao dopuna ovih geoloških radova korištene su i geotehničke istražne bušotine, izbušeno je šest istražnih bušotina dubine do 15 m.

Također su izvršena i geofizička istraživanja, korištena je MASW metoda i *downhole* metoda istraživanja. Cilj istraživanja je bio dobiti promjene brzine S-valova s dubinom kako bi odredili model brzina širenja S-valova te tip tla prema vrijednosti brzine transverzalnih valova u prvih 30 metara dubine (v_{S30}), u skladu s Eurokodom-8 te procijeniti dinamičke module smicanja i elastičnosti u zoni istraživanja. Dosadašnja istraživanja šireg područja katedrale odredila su ove naslage u C tip naslaga prema Eurokodu 8, a detaljnim mikrozoniranjem tla za katedralu kategorizirano je tlo u B tip naslaga prema Eurokodu 8.

Načinjena su četiri prognozna inženjerskogeološka profila oko katedrale. Orijentacija katedrale je istok-zapad tako da su dva inženjerskogeološka profila paralelna geološkoj strukturi Medvednice, a dva profila su okomiti na strukturu. Okomiti geološki profili na strukturu Medvednice prikazuju da šljunčani sloj postaje sve deblji pre-

Tablica 1. Fizikalna svojstva materijala tla

Dubina (m)	Geol. oznaka	Litologija		Wl (%)	Wp (%)	Ip (%)	Ic (%)
0,00–3,70	Pokrovne naslage	Nasip, prahovi, gline	150–270	**41** (37,78–46,04)	**21,5** (20,14–22,36)	**21** (17,64–25,47)	1,21
3,70–16,30	Bistra Q_1	GM Šljunak prahovit	435–460	**53** (43,61–63,99)	**20,5** (19,78–22,29)	**31** (21.79–41,75)	1,01
16,30–26,00	Gornji pont	SM, CH, Cl, GC, Ml, MH Pijesak, glina, šljunak	510–515	**50,5** (43,61–58,72)	**21,5** (20,76–23,62)	**32** (20,07–44,53)	1,01
26,00–35,00	$_2M_7$	CH, Cl, Ml, ML Gline, prahovi		**56,5** (44,37–69,86)	**21,5** (20,69-23,42)	**33,5** (20,99–47,37)	1,01

ma jugu i doseže preko 12 m. Inženjerskogeološki profili paralelni strukturi Medvednice pokazuju da šljunčani sloj prema zapadu i jugozapadu prelazi u debljine od 12 m, a prema istoku debljina šljunčanog sloja je do 4 m.

Plato Kaptola prekriven je nasipom. Ovaj nasipani materijal prema jugozapadu terena je 0,30 m debeo, a prema sjeveru i istoku debljina nasipa je od 1,45 do 2,00 m tako da zalježe do dubine od 2,90 m do 3,70 m. Podlogu čine gline koje se prema sjeveroistoku transformiraju u prah, naslage dosižu dubinu od 2,70 do 3,40 m. Za ove glinovito-prahovite naslage Wl je od 37,78 % do 46,04 %, Wp od 20,14 % do 23,64 %, indeks plastičnosti za ove naslage je od 17,64 % do 24,14 %, a indeks konzistencije je oko 1,20 % (tablica 1).

Nakon ovih naslaga slijedi znatan šljunčani sloj, koji prema jugu zadebljava sve do dubine od 12,00 do 16,30 m. Šljunčani sloj je vodonosan. Taj sloj zalježe na jugu do 16,30 m, prema sjeveru naslage su sve tanje tako da su do dubine od 5,00 m. U tim naslagama prevladava šljunak od 76,40 % do 37,70 %, te sadrži proslojke glinovito prahovitih naslaga. Za visokih voda kada se podzemlje saturira vodom glavnina podzemne vode odlazi prema Trgu bana J. Jelačića, a višak vode se preljeva na povremenim izvorima u blizini parka Ribnjak. Završni *recipient* nadzemnih tokova vode u parku Ribnjak je gradska kanalizacija.

Podlogu šljunčanih naslaga čine nepropusni, sitnozrni, sedimenti gornjeg ponta. Osim dobro graduiranih prahovitih pijesaka, podlogu čine i prahovi srednje do visoke plastičnosti. Općenito prema mineralnom sastavu ove naslage čine mješavinu karbonatnih stijena, kvarca, muskovita, feldspata te minerala glina. Unutar glina i prahovitih glina gornjeg ponta pojavljuju se šljunčane leće fosilnih potoka koji donose vode iz podnožja Medvednice. Na dubini od 17,40 do 20,00 m zabilježena je prva leća, druga leća je na dubini od 21,80 do 23,40 m, a posljednji fosilni trag potoka zabilježen je na dubini od 26,70 m. Gline, visoko plastične gline i prahovite gline ponta pojavljuju se do dubine od 35 m, i prekrivaju šire područje istraživanja. Glinene naslage u podlozi su ujednačenije vlažnosti od 21,62 % do 24,68 %, iznimno kad proslojci praha dominiraju u profilu vlaga poraste na 27,71 %. S dubinom se povećava i brzina S-valova što upućuje na povećanje mehaničkih svojstava materijala.

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POTENTIAL FOR IRRIGATION USING GROUNDWATER IN THE AREA OF THE LOWER COURSE OF THE DRAVA AND DANUBE IN THE REPUBLIC OF CROATIA

POTENCIJAL ZA NAVODNJAVANJE KORIŠTENJEM PODZEMNIH VODA U PODRUČJU DONJEG TOKA DRAVE I DUNAVA U REPUBLICI HRVATSKOJ

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Ključne riječi: *vodonosnik, izdašnost, zdenci, ArcGIS, ArcGIS Online*

Cilj ovog rada je ukazati na mogućnost zahvaćanja podzemne vode iz kvartarnih vodonosnih slojeva Dravskoga vodonosnika u donjem toku Drave i Dunava, u svrhu navodnjavanja poljoprivrednih površina. Za potrebe procjene mogućnosti navodnjavanja načinjena je analiza prigorskih vodonosnika u miocenskim klastičnim i karbonatnim naslagama manjeg značaja za regionalnu vodoopskrbu te važnijih kvartarnih aluvijalnih vodonosnika ravničarskih krajeva. S tim u vezi pomoću računalne aplikacije *ArcGIS Pro* prikazana su perspektivna područja za zahvaćanje podzemne vode s procijenjenim izdašnostima pojedinih zdenaca i sukladno tome vodonosnika na istraživanom području.

Za određivanje područja s potencijalom za zahvaćanje podzemnih voda analizirane su geološke i hidrogeološke značajke vodonosnika (geološka građa, hidrogeološki parametri i debljina vodonosnika) kao i karakteristike zdenaca

na postojećim crpilištima javne vodoopskrbe. Prikupljanjem povijesnih podataka, digitalizacijom karata u *ArcGIS Pro* aplikaciji (hidrogeološkog zemljovida područja, zemljovida izolinija transmisivnosti zahvaćenog dijela kvartarnog vodonosnika, zemljovida hidroizohipsi podzemnih voda te uzdužnog profila Dravskog vodonosnika) te njihovim preklapanjem kreirana je glavna karta, Zemljovid perspektivnosti zahvata podzemne vode, mjerila 1:200 000 (PAVLIN, 2022). Na zemljovidu su istaknute i zone unutar kojih je zahvaćanje podzemne vode ograničeno. Kako bi informacije o preporučenoj dubini zahvata i izdašnosti zdenaca na istraživanom području bile dostupne svakom korisniku, zemljovid je objavljen na internetskoj platformi WEBGIS (*ArcGIS Online*).

Analizom svih podataka i kreiranih podloga istraživano područje pokazuje veliki vodni potencijal i perspektivu za korištenje podzemnih voda. U tom smislu najvažniji i najproduktivniji su vodonosnici građeni od vrlo propusnih šljunkovito-pjeskovitih kvartarnih naslaga koji se dominantno nalaze u zapadnom dijelu istraživanog područja, te od propusnih pjeskovitih naslaga u istočnom dijelu Dravskog vodonosnika.

Analizom profila Dravskog vodonosnika te na temelju objedinjenih podataka iz brojne literature zaključuje se da od zapada prema istoku šljunci facijalno prelaze u pijeske, povećava se broj i debljina prašinasto-glinovitih proslojaka koji uvjetuju formiranje plitkih vodonosnih slojeva malih debljina, potencijalno značajnih za navodnjavanje manjih poljoprivrednih površina. Iako generalno gledajući navedene promjene dovode do smanjenja hidrauličke vodljivosti i smanjenja debljina vodonosnih slojeva, što za posljedicu ima smanjivanje transmisivnosti i izdašnosti zdenaca od zapada prema istoku, vodonosnici su i dalje perspektivni za zahvaćanje podzemne vode i korištenje za navodnjavanje (DUIĆ & HLEVNJAK, 2013).

Prema Zemljovidu perspektivnosti zahvata podzemne vode najveće izdašnosti zdenaca, do 80 l/s, mogu se očekivati u srednjoj Podravini, dok u njezinom južnijem dijelu se smanjuju na 30 l/s. U donjoj Podravini očekuju se izdašnosti do 40 l/s, a na području đakovačkog prapornog ravnjaka do 30 l/s. Južno od Osijeka, izdašnost se lokalno smanjuje na mogućih 20 l/s, kao i na području Bijelog brda, a budući da je Erdutsko brdo uglavnom bezvodno nema zabilježenih izdašnosti. Na području vukovarskog prapornog ravnjaka očekuju se izdašnosti do 20 l/s, a u njegovom južnijem dijelu i do 30 l/s. U Baranji, očekivane vrijednosti izdašnosti zdenaca iznose do 15 l/s, na manjem području u sjevernom dijelu Baranje izostaju vodonosne naslage. U njezinom istočnom dijelu izdašnost je do 30 l/s. Budući da markantni vodonosnici izostaju u južnom dijelu središnje Podravine za njih nisu dane preporuke o zahvatima. Prema izloženom, ravničarski vodonosnici od većeg su značaja za regionalnu vodoopskrbu od prigorskih vodonosnika. Nadalje, na određenim mjestima moguće je zahvaćanje plitkih vodonosnih slojeva na dubinama od 10 do 15 m, 10 do 30 m i 10 do 25 m. Ipak, za njih nisu prikazane moguće izdašnosti jer stvarna izdašnost vodonosnika ovisi o hidrološkim prilikama, odnosno u izrazito sušnim razdobljima oni su odvodnjeni i relativno suhi. Stoga je njihovo iskorištavanje za vodoopskrbu mjestimice upitno i nepouzdano.

Istraživanja su pokazala da na prihranjivanje dubljih dijelova Dravskog vodonosnika i na snižavanje razina podzemnih voda utječe smanjenje godišnje količine oborina uzrokovano klimatskim promjenama i višegodišnje snižavanje vodostaja rijeke Drave uzrokovano izgradnjom hidrotehničkih objekata.

Preporučene dubine zahvata podzemne vode i moguće izdašnosti zdenaca prilagođene su mjerilu istraživanja i nemaju apsolutnu pouzdanost zbog izražene heterogenosti vodonosnika, ali korisniku mogu ukazati na mogućnost zahvaćanja podzemne vode za potrebe navodnjavanja. Za određivanje preciznijih vrijednosti podataka potrebno je napraviti hidrogeološku interpretaciju s dokazom izdašnosti i mogućnosti korištenja podzemne vode.

Imajući na umu da je područje donjeg toka Drave i Dunava bogato plodnim tlima, uz preporuke o kontroliranoj i održivoj eksploataciji podzemnih voda, može se očekivati razvoj hrvatske poljoprivrede, a samim time i ekonomije.

Kao rezultat svih analiza kreiran je Zemljovid perspektivnosti zahvata podzemne vode dostupan svakom korisniku putem URL adrese:

https://rgnf.maps.arcgis.com/apps/mapviewer/index.html?webmap=0e17753d1a62477eaa0b4fea56b56822

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THE ORIGINE AND SHAPES OF TIDAL NOTCHES IN THE KVARNER AREA (CROATIA)
PODRIJETLO I OBLICI PLIMSKIH POTKAPINA NA KVARNERU (HRVATSKA)

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Keywords: *tidal notches, bioerosion, sea level, Holocene regional tectonics, Croatia*

Tidal notches are characteristic erosional forms that develop on relatively sheltered carbonate rocky coasts with small tidal ranges (NEUMAN, 1968; TRENHAILE, 2014). Bioerosion rates are generally highest near the mean sea level (MSL) and gradually decrease toward the upper and lower limits of the tidal range. As a result, erosional, groove-like, features develop with a typical U or V shaped form (PIRAZZOLI, 1986). When found above or below the present MSL they are considered one of the best geomorphological indicators of local sea level changes, with a reliability of up to one decimeter. The inward depth of a tidal notch profile provides information about the duration of relative sea level stability. In addition, profile provides information on the rate of coastal emergence or submergence (PIRAZZOLI, 1986). The Kvarner area is a semi-enclosed channel part of the Adriatic Sea, located between the Istrian peninsula and the Vinodol–Velebit coast. It consists of tectonically deformed and karstified Mesozoic to Cenozoic predominantly carbonate rocks (PIKELJ & JURAČIĆ, 2013). Like the rest of the eastern Adriatic coast, it has typical morphological features associated with chemical dissolution of carbonates, inherited from the karstification processes (JURAČIĆ *et al.*, 2009). The relative sea level changes of the late Pleistocene–Holocene along the eastern Adriatic coast are still not fully understood, mainly due to the intensive and complicated regional and local neotectonics (SURIĆ, 2009). In the Kvarner area, tidal notches occur deeper than 0.5 m below present MSL (Fig. 1; BENAC *et al.*, 2004; BENAC, 2008). Therefore, their detection and measurement are challenging. The varying depths of tidal notches here is a consequence of recent tectonic movements in the Kvarner area, which is seismotectonically very active.

Currently, a comprehensive survey of the coasts of the Krk, Prvić, Plavnik and Cres islands is being conducted as part of ongoing research. The study is focused on the analysis the geometry of tidal notches using the methodology of PIRAZOLLI (1986) and BENAC *et al.* (2004). To ensure accuracy, the biological mean sea level is used as the reference value for the measurement, based on the biological zonation in the intertidal zone. Morphological and curvature analyses are being performed for each photo-documented tidal notch. These analyses will be conducted on individual profiles as well as through a statistical analysis of all profiles to identify patterns and trends not apparent from individual analyses. In light of recent tectonic activity, some previously measured sites will be reanalysed. This should provide a more comprehensive understanding of relative sea level changes and recent tectonic processes.

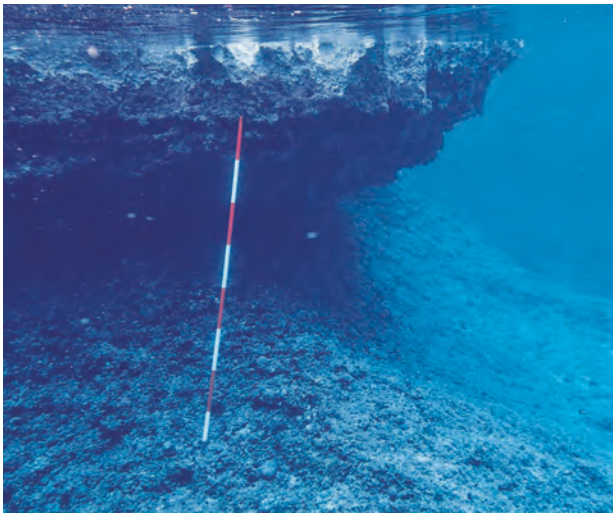

Figure 1. Submerged tidal notch on the Prvić Island

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AMMONOID AND CONODONT BIOSTRATIGRAPHY OF AN ENIGMATIC LATE ANISIAN TO LADINIAN RED LIMESTONE SUCCESSION WITH MASS TRANSPORT DEPOSITS IN NORTHERN MONTENEGRO (KOVČEZI LOCALITY, DURMITOR MTS.)

BIOSTRATIGRAFIJA AMONITA I KONODONATA ZAGONETNIH KASNOANIZIČKIH DO LADINIČKIH VAPNENACA IZMIJEŠANIH S TALOŽINAMA MASENOG TRANSPORTA U SJEVERNOJ CRNOJ GORI (LOKALITET KOVČEZI, DURMITOR)

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Keywords: *Ammonoids, Conodonts, Anisian, Ladinian, Durmitor*

Middle Triassic cephalopod faunas play an important role in biostratigraphic age dating of Middle Triassic red nodular limestone successions (mainly assigned to the Bulog Formation) in Montenegro. One enigmatic red, and in parts nodular limestone succession with intercalated Mass Transport Deposits (MTDs) and condensed ammonoid-bearing horizons appear in northern Montenegro, in the Durmitor Mt. (Kovčezi section near Crvena Greda), overlain first by red and later by grey siliceous limestones with intercalated turbidites consisting of shallow-water debris. The roughly 80 m thick deep-water carbonate succession was deposited above andesites and volcanic sandstones. The whole red limestone part should have a Late Anisian to Ladinian age according to ammonoid faunas (SLADIĆ-TRIFUNOVIĆ & LJUBOVIĆ, 1975; LJUBOVIĆ, 1976). Directly above the andesites follow a series of sandstones made of reworked volcanics and volcanic ash layers, overlain by reddish to grey micritic deeper-marine limestones with polymictic breccias (~40 m thick), predominantly in the upper part. Above the series with MTDs typical red nodular limestones (~8 m thick) were deposited with two condensed horizons containing ammonoids, the first at the base and the second on the top. Upsection follow first red dm-bedded (~10 m thick) and later grey dm-bedded siliceous limestones with intercalated turbidites (< 25 m thick) which consists of shallow-water components, topped by coarse-grained fore-reefal float- and rudstones of the prograding Wetterstein Carbonate Platform.

In the polymictic carbonate breccias (equivalent to the Komarani Formation of the Bulog Group – SUDAR & GAWLICK, 2022) in a red micritic crinoid- and filament-bearing wackestone matrix, dated by conodonts (*P. excelsa*, *P. trammeri*, *P. praetrammeri*, *G. tethydis*) as Late Illyrian occur beside shallow-water carbonate clasts with dasycladalean algae various red nodular limestone clasts, some of them with ammonoids: *Acrochordiceras carolinae* MOJSISOVICS, *Acrochordiceras* sp., *Proarcestes* cf. *pannonicus* (MOJSISOVICS), and *Aristoptychites* sp. indicating a Late Pelsonian age. In addition, some red limestone clasts contain the Late Pelsonian to earliest Illyrian conodont species *P. bifurcata*. Above the series of polymictic MTDs the red nodular limestones with condensed ammonoid-rich layers (Fossillagerstätten) were formed, in the first (lower) horizon with following diverse ammonoid fauna: *Ptychites rugifer* (OPPEL), *Flexoptychites flexuosus* (MOJSISOVICS), *Lanceoptychites indistinctus* (MOJSISOVICS), *Metadinarites decrescens* (HAUER), *Proarcestes subtridentinus* (MOJSISOVICS), *Joannites tridentinus* (MOJSISOVICS), *Parakellnerites rothpletzi* (SALOMON), *Tropigastrites lahontanus* SMITH, *Norites gondola* (MOJSISOVICS), *Megaphyllites obolus* MOJSISOVICS, *Megaphyllites* cf. *sandalinus* (MOJSISOVICS), *Beyrichites reuttensis* (BEYRICH), *Monophyllites wengensis* (KLIPSTEIN), *Leiophyllites* cf. *taramellii* (MARTELLI),

Epigymnites cf. *ecki* (MOJSISOVICS), *Proteusites* cf. *robustus* HAUER, *Longobardites* cf. *zsigmondyi* (BÖCKH), *Kellnerites* sp., *Celtites* sp., and *Sturia* sp. This fauna contains mostly species with a relatively long age range or species for which the available database about their exact biostratigraphic age is currently scarce, but the presence of *Parakellnerites rothpletzi* (SALOMON) indicate the Avisianum subzone of the Reitzi zone i.e. Late Illyrian.

From the second (higher) condensed ammonoid-bearing horizon only material from rockfalls could be collected. As these ammonoids differ in preservation from the other levels, they can be easily attributed to this horizon. Following ammonoids could be determined: *Monophyllites wengensis* (KLIPSTEIN), *Flexoptychites flexuosus* (MOJSISOVICS), *Flexoptychites angustoumbilicatus* (BÖCKH), *Gymnites incultus* (BEYRICH), *Discoptychites megalodiscus* (BEYRICH), *Discoptychites* ? sp., *Joannites* ? *batyolcus* (BÖCKH), *Proarcestes* cf. *pannonicus* (MOJSISOVICS), *Sturia* cf. *sansovinii* (MOJSISOVICS), *Celtites* sp., *Beyrichites* ? sp., and *Arcestes* ? sp. indicating a topmost Illyrian age (Secedensis zone).

This is confirmed also by the conodont faunas from this level of red nodular limestones, mainly consisting of *G. tethydis*, *P. excelsa*, and *P. trammeri*. The base of the Ladinian starts most likely with the onset of deposition of the siliceous and radiolarian-rich red dm-bedded limestones, but a marker conodont species of the genus *Budurovignathus* is missing. Only few meters higher one bed contain *P. excelsa*, *P. trammeri*, *P.* cf. *fueloepi*, *P. inclinata*, and *G. tethydis* i.e. a mixed fauna from the Late Fassanian to Early Longobardian. This indicates very low depositional rates throughout the Ladinian.

The overlying thin-bedded grey siliceous limestones with turbidites consist of shallow-water debris from the prograding Wetterstein Carbonate Platform are Early Carnian in age, as proven by the co-occurrence of *P. polygnathiformis* and *G. tethydis*.

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COMPARISON OF XRD AND FTIR ANALYSES FOR DETERMINING MINERAL PHASES IN UROLITHIASIS CROSS-SECTIONS

USPOREDBA XRD I FTIR ANALIZA KOD ODREĐIVANJA MINERALNIH FAZA U POPREČNIM PRESJECIMA UROLITIJAZE

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Keywords: *Kidney stones, Urolithiasis, FTIR, XRD, cross-section*

Kidney stones (urolithiasis) are an area of scientific study that overlaps between medicine and geology. In medicine, the focus is on the treatment and prevention of a patient's condition, while in geology, specifically medical geology, the focus is on the stone itself. Problems with urolithiasis are observed in more than 12 % of the world's population at some stage in their lifetime, and the trend is increasing (ALELING & PETROS, 2018). It is believed that this increase is associated with modern lifestyle factors such as insufficient physical activity, diet, and even global warming. From a medical point of view, information about the type of urolithiasis leads to a better understanding of the formation of the stone and consequently leads to better prevention. Additionally, it can provide information used to direct medications and treatments.

Urolithiasis differs in size, shape, chemical composition, and phases (minerals). Traditionally, there are four main types of kidney stones: calcium oxalate, uric acid, struvite, and cystine stones, with an additional fifth type,

drug-induced stones (RADHAKRISHNA, 2021). Stones can be monomineralic or polymineralic, of uniform composition from the core to the edge (homogenic), or of different composition (heterogenic).

To define the type of stone, it is necessary to carry out analyses, and X-ray diffraction analysis (XRD) is a standard technique for phase analysis based on crystal structure. As such, it would be an ideal technique for these purposes, but its high price and time consumption are drawbacks. On the other hand, Fourier transform infrared spectroscopy (FTIR) is a method of lower price, shorter time, and smaller amount of sample required for analysis (KHAN *et al.*, 2018) To observe changes in the composition of the stone cross-section, it is necessary to analyze very small segments of the stone itself, where the availability of material for analysis is limited. This is precisely why FTIR is the analytical method of choice in urolithiasis. Mineral phases in the cross-section were identified in 49 samples of urolithiasis by FTIR, and additionally by XRD on selected samples, to determine if there were phase differences in the core and outer parts of the stone, and to assess whether XRD could be used for this purpose. 63 % of all samples were defined as monomineralic, and in 37 % the mineral composition was defined as polymineralic (Fig. 1). A larger number of samples did not show differences in composition and mineral phases in their cross-section (61 %), but in 39 % of samples a difference was determined. Such a determination was possible with FTIR analysis due to the smaller amount of sample required, while XRD was not suitable.

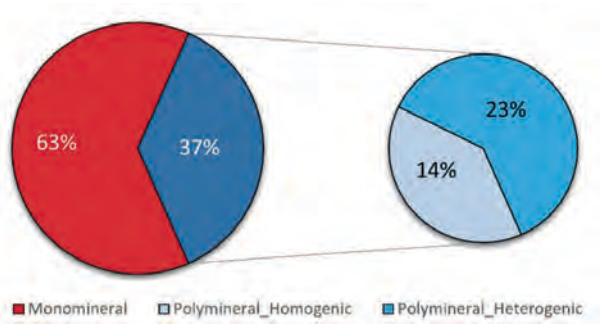

Fig. 1. Urolithiasis distribution regarding homogeneity/heterogeneity of the core and the outer part

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GEOLOGY IN THE 4TH GRADE OF SCIENCE GYMNASIUMS

GEOLOGIJA U 4. RAZREDU PRIRODOSLOVNIH GIMNAZIJA

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Keywords: *: geology, school subject, science gymnasium, textbook*

During the first half of the 20th century, until the middle 1950's, geology was, as one of the fundamental sciences, present as a subject in Croatian secondary schools. It was taught mainly following the textbooks by HOCHSTETTER & BISCHING (1882), BABIĆ (1922) and TUĆAN (1923), which all had several editions. After the middle 1950's geology was taught only in few schools, as, for example, for geological technicians. Since that time, children in Croatian schools have been learning about geology through geography, biology, chemistry and physics, not always aware that gained knowledge partly belongs also to geology, or geosciences in general. Even though there were earlier attempts, the change started in 2020 when a Curriculum for the subject Geology in the fourth grade of Science Gymnasiums was prepared and brought by the Ministry of Science and Education in 2021 (URL 1). This change resulted in Geography being taught during the first three years, and Geology in the fourth year in Science Gymnasiums. The introduction of this less familiar subject represented a new challenge for the geography teachers who now probably have to teach

geology as well. Due to the lack of textbook and geological samples in high schools, some teachers contacted the geological departments of the University of Zagreb for help, which was gladly and readily provided. University employees visited several schools and donated relevant literature, as well as samples of rocks, fossils and minerals for practical work, while the Croatian Geological Survey donated geological maps. To help both the teachers and their pupils, several scientists from the Department of Geology of the Faculty of Science recognized the need and prepared a textbook in Croatian, which follows the Curriculum and offers all the basic information needed for the subject. The textbook comprises six chapters: 1. Earth's origin and structure, 2. Earth's internal dynamics, 3. Earth's external dynamics, 4. Structural elements of the lithosphere, 5. Applied Geology, 6. Geology of Croatia. It is prepared in collaboration with the publisher Školska knjiga, and will be available and used as from the school year 2023/2024 (FIO FIRI *et al.*, 2023).

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SIMULTANEOUS TRACING TEST WITH THREE DIFFERENT TRACERS IN THE PLITVICE LAKES NATIONAL PARK, CROATIA

SIMULTANO TRASIRANJE TRIMA TRASERIMA U NACIONALNOM PARKU „PLITVIČKA JEZERA"

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Keywords: *karst hydrogeology, tracing test, groundwater flow*

A tracing test with the use of three different tracers was done on the karstified hydrogeological aquifer of the Plitvice Lakes National Park in Croatia. Although several researches have been done in the past, the delineation of specific springs' catchment areas is still not clear enough. Therefore, it was decided to inject three different tracers: sodium naphthionate, fluorescein sodium, and rhodamine WT.

Since the catchments of Plitvice Lakes and their main springs belong to highly tectonized and karstified terrain, mainly composed of limestones and dolomites typical for the Dinaric karst, there are few surface water flows. After the bulk hydrogeological reconnaissance, three karst features were chosen for the dye injection: two sinkholes and one abandoned borehole (Fig. 1). All three tracers were injected in a period of 22. – 23. 3. 2023, during high water conditions caused by recent rainfall and snowmelt. All three tracers were injected with additional water supplied by fire trucks.

Following springs were observed by taking water samples: Andrijanin, Bijela rijeka, Crna rijeka, Klanac, Koreničk a rijeka, Koreničko vrelo, Krbavica, Ljeskovac, Majerovo vrilo, Mlinac, Plitvički Ljeskovac, Pećina, Suvaja, Ševerova pećina, Tonkovića vrelo, Vukmirović. Water samples were analysed on a Perkin-Elmer LS55 spectrofluorometer. Additionally, field fluorimeters were used in Bijela Rijeka, Crna Rijeka, Ljeskovac, Koreničko vrelo and Tonkovića vrelo.

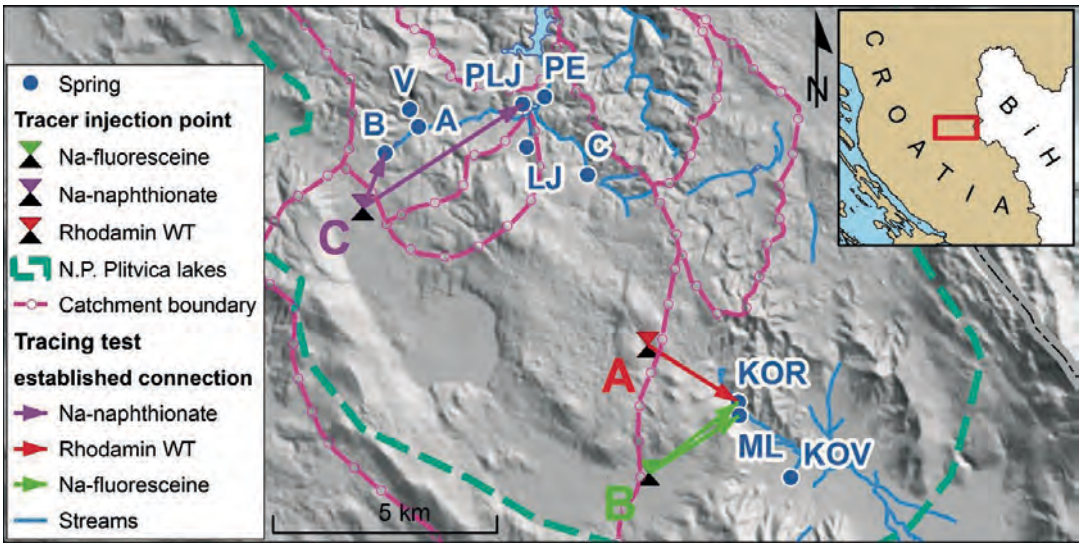

Figure 1. Position of tracing test locations with established connections and previous catchment boundaries (MEAŠKI, 2011). Springs are: A – Andrijanin; B – Bijela Rijeka; C – Crna Rijeka; LJ – Ljeskovac; KOR – Korenička rijeka; KOV – Koreničko vrelo; ML – Mlinac; PE – Pećina; PLJ – Plitvički Ljeskovac; V – Vukmirović

The results of all tracing tests showed that gradient was the main determining factor in the groundwater flow direction. That is in contradiction with the previous results from a tracing test done in 1982, on the approximate location of sinkhole "C". On that occasion, tracer was discovered in the Crna Rijeka spring (DEŠKOVIĆ *et al.*, 1984). Despite similar hydrological conditions, a recent tracing test showed a clear connection only with the Bijela Rijeka spring. Tracer recovered in the Plitvički Ljeskovac spring came through the Bijela Rijeka stream.

Sinkhole "A" showed a connection only to the Korenička Rijeka spring, and only after rainfall, so the apparent velocity was low (Table 1).

There was unreliable oral information about a tracer test done in the borehole "B", which showed a connection with the Gacka springs. This tracing test proved a strong connection with Korenička Rijeka spring. After heavy rainfall, tracer from location "B" also briefly showed in the Mlinac spring.

Conducted tracing tests gave a better insight into groundwater flow directions and catchment boundaries. They also proved the necessity for repeating tracing tests done in past times, with unreliable equipment and insufficient documentation for evaluating their results.

Table 1. Groundwater connections proven by the tracing test with the main parameters

Connection	Distance (km)	Height difference (m)	Time to first occurrence (hours)	Maximal apparent velocity (cm/s)	Maximal concentration (ppb)
A – KOR	2.4	145	615.60	0.11	44.27
B – KOR	2.5	94	97.80	0.71	155.15
B – ML	2.4	96	1321.80	0.05	1.54
C – B	1.3	46	34.25	1.05	791.41
C – PLJ	4.2	115	49.33	2.36	47.22

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NEW CLASSIFICATION OF DISCONTINUITIES ACCORDING TO THE DEGREE OF SPELEOGENESIS

NOVA KLASIFIKACIJA DISKONTINUITETA PREMA STUPNJU SPELEOGENEZE

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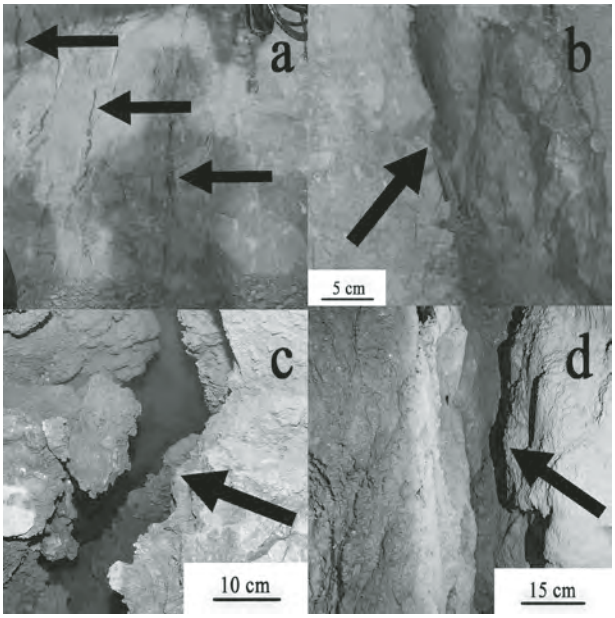
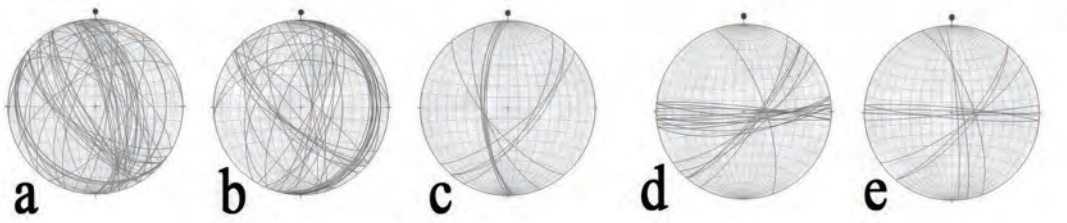
Ključne riječi: *Klasifikacija, diskontinuiteti, speleogeneza, geotehnika, kršs*

Diskontinuiteti su opisani u mnogim radovima s obzirom da predstavljaju glavne čimbenike u pojavi anizotropije stijenske mase. Možemo ih promatrati kao ravnine koje čine značajnu promjenu u fizičkim i/ili kemijskim karakteristikama stijena. U kršu su to stratifikacija, pukotine, prsline i rasjedi. Podaci o diskontinuitetima jedan su od glavnih parametara koji se koriste u suvremenoj tunelogradnji u krškim terenima. Smjer i kut nagiba diskontinuiteta, dužina, zijev, ispuna, stupanj trošenosti itd., koriste se u mnogim klasifikacijama stijenske mase kao što su: Rock Quality Designation – RQD (DEERE *et al*., 1967), Rock Mass Rating – RMR (BIENIAWSKI, 1989), Rock Mass Quality – Q (BARTON, 1988), Geological Strength Index – GSI (MARINOS *et al*., 2007). Međutim, niti jedna od postojećih podjela ne odnosi se na stupanj speleogeneze, odnosno skup procesa stvaranja speleoloških objekata. Jedan od najvećih izazova s kojima se inženjeri suočavaju pri radu u kršu je pojava kaverni, to jest speleoloških objekata bez prirodnih ulaza na površini terena (GARAŠIĆ, M., 2021). Kaverne predstavljaju problem zbog svoje veličine, morfologije, hidrogeološke funkcije i upitne stabilnosti. Postojanje kaverni unutar stijenske mase, osobito ako se nalaze na većim dubinama, gotovo je nemoguće predvidjeti. Da bi se problem pojave kaverni tijekom izgradnje tunela mogao eliminirati, bilo bi potrebno znati njihov točan položaj u stijenskoj masi i izbjegavati prolazak kroz njih u fazi planiranja. Suvremena tehnologija još nije dovoljno razvijena da bi nam pružila takve informacije. Možemo se osloniti samo na pretpostavke temeljene na statističkoj analizi podataka prikupljenih na terenu, geološkim spoznajama i interpretacijama geofizičkih mjerenja. Prilikom izgradnje brojnih cestovnih tunela u hrvatskom kršu uočena je korelacija između morfologije otkrivenih kaverni i svojstava specifičnih za određene diskontinuitete iz iste stijenske mase. Radi se o diskontinuitetima dužim od 10 metara, širine zijeva veće od 30 cm, s glinovitom, boksitnom ili kalcitnom ispunom, povremeno uz prisustvo vode. Iz navedenog zapažanja rodila se ideja o stvaranju nove klasifikacije diskontinuiteta prema stupnju speleogeneze (GARAŠIĆ, D., 2021). Diskontinuiteti su svrstani u četiri kategorije (slika 1). Kategorija 1 predstavlja diskontinuitete bez tragova speleogeneze. Radi se od inicijalnim pukotinama ili prslinama dužine do 10 m, zijeva do 1 cm i bez ispune. Kategorija 2 predstavlja diskontinuitete u inicijalnoj fazi speleogeneze. To su diskontinuiteti dužine veće od 10 m, zijeva od 1 do 10 cm, bez ispune, povremeno uz prisustvo vode. Kategorija 3 predstavlja diskontinuitete u glavnoj fazi speleogeneze, dužine veće od 10 m, zijeva od 10 do 30 cm, s prisustvom vode, ponekad s glinovitom ili kalcitnom ispunom. Kategorija 4 predstavlja diskontinuitete u zreloj fazi speleogeneze, odnosno duže od 10 m, zijeva šireg od 30 cm, s glinovitom, kalcitnom ili boksitnom ispunom, ponegdje uz prisustvo vode. Klasifikacija je primijenjena na podacima o diskontinuitetima prikupljenim prilikom izgradnje 10 tunela u Hrvatskom kršu, te su dobiveni parametri uspoređeni s podacima o istraženim kavernama pronađenim u istoj stijenskoj masi. Rezultati su potvrdili direktnu vezu između orijentacije diskontinuiteta kategorije 4 (slika 2d) i speleogeneze, odnosno morfologije kaverni (slika 2e) pronađenih u istoj stijenskoj masi, što je vidljivo na stereografskim projekcijama diskontinuiteta iz tunela Brinje (slika 2).



Slika 1. Kategorije diskontinuiteta: a – bez tragova speleogeneze, b – inicijalna faza speleogeneze, c – glavna faza speleogeneze, d – zrela faza speleogeneze



Slika 2. Stereografske projekcije diskontinuiteta iz tunela Brinje; a – kategorija 1, b – kategorija 2, c – kategorija 3, d – kategorija 4, e – glavni diskontinuiteti u kavernama

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POSSIBILE OCCURENCE OF HYPOGENE KARST AND CAVES IN CROATIA
MOGUĆE POJAVE HIPOGENOG KRŠA I SPELEOLOŠKIH OBJEKATA U HRVATSKOJ

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Ključne riječi: *hipogeni, krš, speleologija, Hrvatska, speleogeneza*

U posljednjih dvadesetak godina u svijetu se intenzivno istražuju krška područja čija se geneza vezuje uz tzv. hipogeni krš (KLIMCHOUK, 2007, 2009), pa tako i u Hrvatskoj. Do sada o pojavi hipogenog krša u Hrvatskoj nema objavljenih radova. Međutim, postoje dokazi o istovremenom djelovanju slatke i slane vode tokom speleogeneze što bi se moglo povezati s hipogenim kršem u Hrvatskoj. Faktori koji su potrebni za stvaranje hipogenog krša mogu biti različiti i vremenom se spoznaja o njima proširuje. Primjerice PALMER (2000) definira hipogene speleološke objekte kao one koji su nastali agresivnošću vode u podzemlju, ali bez utjecaja s površine ili CO_2 iz tla ili nekih drugih izvora kiselosti s površine terena. To je tzv. geokemijska definicija, koja je kasnijim istraživanjima hipogenog krša proširena u tzv. hidrogeološku definiciju koju iznosi KLIMCHOUK (2007). Najnoviju definiciju hipogene speleogeneze daje KLIMCHOUK (2017). Iz većine objavljenih radova može se zaključiti da je hipogeni krš značajna komponenta litogeneze inducirane fluidima i igra važnu ulogu u razvitku poroznosti i propusnosti u mnogim sedimentim stijenama, a ponegdje i metamorfnim stijenama. Uspoređujući pojedina područja po svijetu s kršem u Hrvatskoj, ipak se može zaključiti da i na ovim prostorima postoji mogućnost pojave hipogenog krša.

1. Uspoređujući pojave hipogenog krša u Austriji s područjem Hrvatskog zagorja i Banovine, moguće je uočiti sličnosti. Dublji rasjedi s mineralnim i termalnim vodama s većim postotkom CO_2 mogli su odigrati ulogu u stvaranju hipogenog krša, što bi se moglo povezati i sa sufozijskim pojavama (urušne ponikve) na Banovini ili s nekim speleološkim objektima na Ivanščici, Ravnoj gori i Strahinjščici.

2. Veliki broj hipogenih spilja u svijetu nađen je uz vodu koja izvire iz speleoloških objekata gdje se uzdiže po dubokim rasjedima iz dubina. Takvih primjera ima u Hrvatskoj na nekoliko mjesta dubljih od 200 metara. Ovdje bismo, zbog morfologije špiljskih kanala, spomenuli mogućnost pojave hipogenog krša u unutrašnjosti izvora rijeke Une u Lici (slike 1 i 2), gdje je ronjenjem dosegnuta dubina od 248 metara (CASATI & GARAŠIĆ, 2016; GARAŠIĆ, 2021).

3. Određeni broj hipogenih speleoloških objekata u Europi nastao je na kontaktu paleozojskih i mezozojskih stijena zbog agresivnosti vode (FARRAT & HARRISON, 2017). Takvi speleološki objekti mogli bi postojati u Hrvatskoj na sjeverozapadnim obroncima planine Velebit i u Gorskom kotaru (Izvor Ličanke, Fužine).

4. U literaturi se spominje znatan broj pojava hipogenog krša na mjestima miješanja slatke i slane (morske) vode. Područje obalnog dijela krša u Hrvatskoj obiluje podmorskim izvorima slatke vode. Poznate su vrulje duboke preko 160 metara ispod masiva Biokova i Omiške Dinare (Dalmacija), te veliki broj dubokih i dugačkih vrulja ispod masiva Velebita (Hrvatsko primorje). Postoje indikacije da su neke od njih formirane hipogenom speleogenezom.

Možemo zaključiti da novija istraživanja u nekim poznatim speleološkim objektima na odabranim područjima Hrvatskoj mogu proširiti spoznaje o pojavi hipogenog krša.

Slika 1. Profil Vrela Une –248m (foto L. Casati)

Slika 2. Ronjenje u Vrelu Une (foto L. Casati)

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OCCURRENCE AND MINERAL CHEMISTRY OF THE TITANIAN CLINOHUMITE FROM MARBLE OF ZOROVAC CREEK, MOSLAVAČKA GORA, CROATIA

POJAVA I MINERALNA KEMIJA TITANSKOG KLINOHUMITA IZ MRAMORA POTOKA ZOROVAC, MOSLAVAČKA GORA, HRVATSKA

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Keywords: *titanian clinohumite, marble, Moslavačka Gora*

Clinohumite is a scarce mineral, but is the most abundant mineral of the humite group which is characterized by a general formula of nM2SiO4x*M1-xTix(OH, F)2-2xO2x, where M stays for octahedrally coordinated Mg, Fe, Mn, Ca and Zn cations in declining order of abundance, x < 1 with n=1, 2, 3, 4 for norbergite, chondrodite, humite and clinohumite (JONES *et al.*, 1969). The occurrence of clinohumite is in the nature limited to only five rock types: kimberlites, Archean ultramafics, Alpine peridotites, carbonatites and marbles. However, despite the rarity of its occurrence, clinohumite is essential in understanding hydration and dehydration processes in the petrogenesis of mantle derived ultramafic bodies found in polymetamorphic Archaean terranes (NISHIO *et al.*, 2019), but also in reconstruction of Ti mobility in the frame of crustal metamorphism linked to the clinohumite formation in forsterite marbles (KARMAKAR, 2021). Recently, the occurrence of humite-bearing marbles has been used for the reconstruction of the plate geometries during Neoproterozoic time, known as "humite epoch", characterized by very water-rich, fluorinated fluid activity coeval with the waning stages of Pan-African tectono-thermal event (PRADEEPKUMAR & KRISHNANATH, 2000; FERNANDES & CHAVES, 2014).

Clinohumite occurs in Croatia only in the grey marbles of Zorovac creek in the Moslavačka Gora and was described by BARIĆ (1972), GARAŠIĆ (1993) and BALEN *et al.* (2000). The Moslavačka gora is crystalline complex located in the SW part of the Pannonian Basin, in Croatia. It comprises metamorphic rocks of high-to medium-grade, predominately migmatites and gneisses and of medium grade, mostly metapelites and amphibolites, which intermittently surround granitoids of different kind (PAMIĆ, 1990). The Moslavačka Gora belongs to Sava zone (SCHMID *et al.*, 2008), located between Laurasia and Gondwana, and was recognised as high-heat flow zone causing Cretaceous igneous and metamorphic events (BALEN & PETRINEC, 2011). Zircon dating of two mica-granite gave Cretaceous age and Early Ordovician age for metagranite (the most of the metamorphic complex), whereas the Cretaceous age of low pressure-high temperature (LP/HT) metapelite was obtained by monazite dating (STARIJAŠ *et al.*, 2010).

The studied marbles occur as interlayers up to 50 cm thick in cordierite and diopside-amphibole schists. Mineral assemblages in marbles indicate three metamorphic events of different metamorphic grade. The highest grade mineral assemblage consists of forsterite+spinel+calcite+pargasite. The most important forsterite+clinohumite+calcite±phlogopite±tremolite assemblage occurred during LP/HT metamorphism, as result of replacement of fosterite by clinohumite. The textural relationships in the lowest grade mineral assemblage consisting of clinohumite+spinel+calcite+chlorite+dolomite suggest that chlorite and dolomite grew at the expense of clinohumite, spinel and calcite (Fig. 1). Also replacement of forsterite by talc and serpentine belongs to this retrograde lowest grade metamorphism.

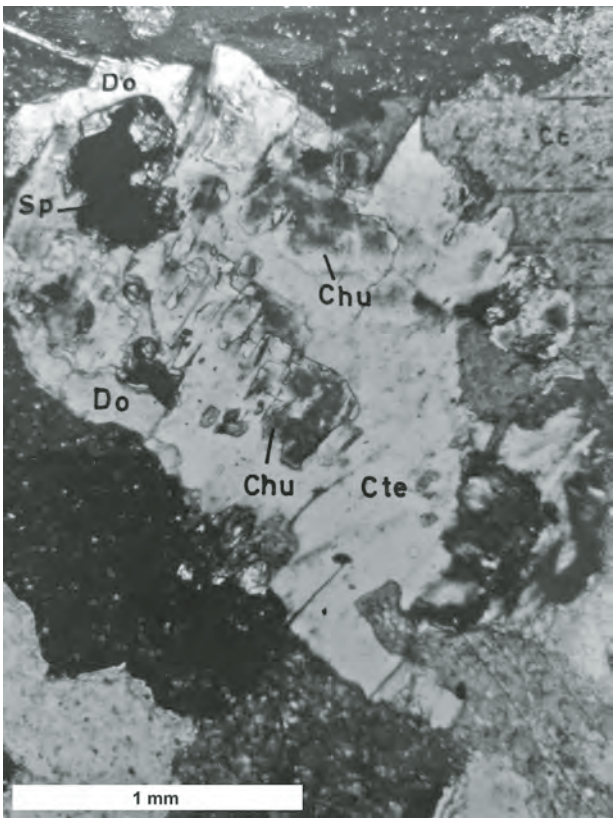

Figure 1. The lowest grade mineral assemblage in marbles of Moslavačka Gora consisting of clinohumite (Chu), spinel (Sp), calcite (Cc), chlorite (Chl) and dolomite (Do)

Microprobe analyses of clinohumite revelead that content of TiO_2 varies between 0.88 (in the mineral parageneses with phlogopite) and 4.04 wt.% (in the mineral parageneses with amphiboles). The fluorine concentration in Ti-clinohumite shows negative correlation with titanium, and ranges from 1.30 to 3.16 wt.%. This is in accordance with expected substitution (Mg,Fe)+2(OH,F) = Ti+2(O). The ratio of F/(F+OH) in clinohumite or $X_{F\text{-}Chu}$ is in the range between 0.32 (in the parageneses with amphiboles) and 0.57 (in the parageneses with phlogopite). Content of H_2O varies from 2.16 to 2.66 wt.%. The concentrations of MgO reach the values from 51.87 to 55.63 wt.% depending on the content of titanium and iron oxides, whereas FeO content ranges from 1.64 to 4.79 wt.%. The SiO_2 content shows slight variation (37.07 and 37.63 wt.%). Other cations in Ti-clinohumite are present in negligible amounts.

Textural relationships and microprobe analyses reveal that Ti-clinohumite grew at the expense of forsterite caused by infiltration of titanian and fluorinated H_2O-rich fluids. Such rare clinohumite marbles with remarkably similar mineral assemblages, textures and P-T-fluid metamorphic conditions and multiphase evolution are widespread in the dispersed Gondwana fragments (PRADEEPKUMAR & KRISHNANATH, 2000). Although the Cretaceous age of LP/HT metapelite was determinated in the Moslavačka Gora, because marbles are more sensitive than other rocks to the changes in fluid composition (FERRY, 1992), the LP/HT metamorphism in marbles is not necessarily comparable to the LP/HT metamorphism in the metapelites.

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AWARENESS OF MINERAL RESOURCES POTENTIALITY IN THE REPUBLIC OF CROATIA AS INCENTIVE FOR THE GENERAL ECONOMIC GROWTH

POZNAVANJE POTENCIJALA MINERALNIH RESURSA REPUBLIKE HRVATSKE KAO POTICAJA OPĆEM GOSPODARSKOM RASTU

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Keywords: *mineral resources, economic growth, geological data, mining, sustainability*

Exploration and exploitation of mineral resources are part of the comprehensive economic activity of the Republic of Croatia. The relevant and studied are mineral resources for industrial processing and the production of building materials, ornamental stone, and metal mineral resources. Such mineral resources are strongly related to the construction industry, infrastructure projects, processing industry, and general economic trends. Continuous implementation of the "Map of Mineral Resources of the Republic of Croatia" program at the Croatian Geological Survey (HGI-CGS) systematizes data on primary and secondary deposits and occurrences of mineral resources. Within this program, new deposits and occurrences are also explored using existing legacy geological maps in small scales, geochemical and geophysical data. The database on mineral resources formed in this way serves as a spatial basis for creating a unique information system of mineral resources, and it aims to be adapted to the INSPIRE directive of the European Commission. Based on these data, maps of the potential of mineral resources are created at the national level, which serve as a basis for spatial planning. Online data from the Unified Information System of Mineral Raw Materials (JISMS) of the Ministry of Economy and Sustainable Development are included as an integral part of these maps. JISMS includes a register of exploration and exploitation fields, a list of mining companies, a record of all demands for exploration and exploitation fields, as well as a balance sheet of mineral reserves. The combination of the above databases at the level of the Republic of Croatia assists many sectors such as mining and industry by providing them with a vast geoscientific knowledge. At the level of Eastern and Southeastern European countries (ESEE) through the RESEERVE project (2018-2021), supported by the European Institute of Innovation and Technology Raw Materials (EIT RM), HGI-CGS was included in mapping the mineral resources and mining waste in Croatia. The aim of the project was to create a register of primary and secondary mineral resources of the Western Balkans, which is integrated into the online platform European Geological Data Infrastructure (EGDI). In line with EU mineral needs and strategic trends, West Balkan Mineral Register provides publicly available data for interested stakeholders: potential investors, mineral-related companies, research and educational institutions. Through the GeoERA project (Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe; 2018-2022), the European Union has identified security of supply, improvement in environmental management, and resource efficiency as key challenges for the raw materials sector (mainly Mintell4EU project). The results of this project, which relate to the spatial distribution of primary and secondary mineral resources, and in which HGI-CGS was intensively engaged, were integrated into the EGDI. The ambition to create a sustainable geological service for Europe arose from a need for a body whose combined knowledge will be extremely important for the transition from "brown" to "green" economy. The European Commission supported this by funding the Geological Service for Europe (GSEU) project which started in the second half of 2022. The long-term ambition of this project is to provide European institutions, businesses, and citizens with up-to-date, high-quality information, unified at the EU level, about the geology of the Earth´s crust. Project partners will accomplish this by pulling together Europe's fragmented body of geoscientific data, information, and knowledge, as well as people and facilities. All these datasets are important for economic development which requires the preparation of medium and long-term forecasts and analyses of the international and domestic demand for mineral commodities and the identification of their supply sources. Mineral security, which has become one of the biggest challenges of the 21st century, means the access to adequate mineral supply obtained from domestic or external sources. The current knowledge about mineral reserves and resources is constantly changing as a result of conducted research and new discoveries of mineral deposits, introducing of new extractive technologies and new geological theories and models. Expanding geological knowledge on the occur-

rences of mineral deposits is a continuous task of geological surveys carried out in cooperation with other stakeholders. In Croatia, a fundamental role in this process is carried out by the HGI-CGS, operating as the national geological survey under the supervision of the Ministry of Science. It is predicted that the role of national geological institutes will be further regulated through legislation, in terms of creating National Exploration Programmes for the purpose of finding previously unidentified mineral deposits that, among other things, contain critical mineral raw materials crucial for the sustainability of economic growth.

Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE directive)
EGDI: https://www.europe-geology.eu/
GeoERA: https://geoera.eu/
GSEU: https://www.geologicalservice.eu/
JISMS: https://jisms.gospodarstvo.gov.hr/#/maps
RESEERVE: https://reseerve.eu/results

THE UNITED NATIONS FRAMEWORK CLASSIFICATION EXAMPLES FOR MINERAL RESOURCES IN THE REPUBLIC OF CROATIA

PRIMJERI "OKVIRNE KLASIFIKACIJE UJEDINJENIH NARODA" ZA MINERALNE RESURSE REPUBLIKE HRVATSKE

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Keywords: *UNECE, UNFC, mineral resources, mineral raw material reserves, categorization*

In the Republic of Croatia legislation, geological reserves are categorized into A, B, and C_1 categories, depending on the degree of exploration, overall knowledge of the deposits and the accuracy of the calculation (Ordinance on determination of reserves and exploitation of mineral raw materials, Official Gazette 138/2022). Potential reserves are classified as mineral resources and are not confirmed by the national "Commission" decision. Regarding the possibility of their exploitation, reserves of mineral raw materials are classified as off-balance, balance and exploitation reserves. A similar method was used by regulations that preceded the above, relying on the "Russian Code" of determining reserves. During the 2000s, a need to introduce a new way of classifying mineral reserves arose, since the adoption of the Sustainable Development Goals, managing energy and raw material resources in a sustainable manner has become paramount to all stakeholders. In 2013 United Nations Economic Commission for Europe (UNECE) issued the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 incorporating Specifications for its Application. In 2017, the name changed to United Nations Framework Classification for Resources (UNFC). The classification and instructions for its implementation were additionally updated in 2019 and 2022 (UNECE, 2020, 2022). UNFC is a global classification and management system applicable to minerals, anthropogenic resources, etc. UNFC is a principles-based system in which the products of a resource project are classified on the basis of the three fundamental criteria of environmental-socio-economic viability (E), technical feasibility (F), and degree of confidence in the estimate (G), using a numerical coding system. Combinations of these criteria create a three-dimensional system (Fig. 1). Transition from the existing reserve categorization system to the UNFC classification, which is certain to be demanded by the European Commission in the future, requires creating a whole series of accompanying instructions for all participants in the process. We have used two examples to show the requirements necessary for the transition from one system to another, and we have categorized the reserves of mineral resources in accordance with the UNFC classification. The first example is the active exploitation field of brick clay "Rečica" in Karlovac, and the second is the inactive exploitation field of gypsum "Vranjkovići" in the area of the town of Vrlika. Exploitation of brick clay in the area of the exploitation field "Rečica" began in 1954, and continues today. The wider area of the deposit, i.e. the area of the Crna Mlaka basin, is built mainly of Quaternary clayey deposits in which interlayers and lenses of sands and fine-grained conglomerates are embedded, and of younger Neogene sands. Geological works were carried

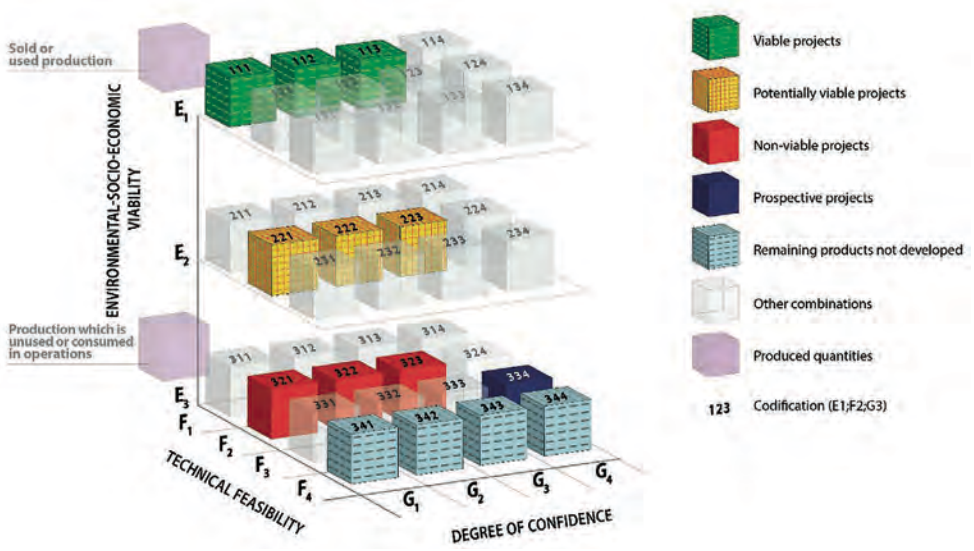

Figure 1. UNFC Categories and examples of classes

out during 1986, 1996, 2003, 2007, 2010 and 2020, with a total drilling length of 561.3 meters in 52 borehols. Numerous tests of the quality of the mineral raw material, either on individual or on composite samples, were done, corresponding studies on reserves and mining projects were produced, and environmental impact assessment procedures were also carried out. The last valid decision confirming the quantity and quality of mineral raw material reserves dates from 2021, and brick clay reserves were divided into A, B and C_1 categories. Applying the UNFC methodology, we classified this project as a viable project with the numerical code E1 F1.1 G1. No mining activity is currently carried out inside the inactive gypsum exploitation field "Vranjkovići", but previous surveys took place several times in the period from 1973 to 2020. Drilling was performed in 1998 and 2000, and boreholes were mapped and sampled. A total of 403 meters were drilled. The area of the gypsum exploitation field "Vranjkovići" was 15.75 ha, and the exploitation ended without the complete determined gypsum reserves being exhausted. Considering the amount of exploration and the fact that gypsum was at one time exploited here, we placed the field into the G2 category, while due to the lack of data on technical feasibility as well as environmental-social-economic conditions into the E2 and F2 categories. According to the UNFC, this would belong to the class of potentially viable projects, with the numerical code E2 F2.2 G2. The methodology for transformation from the national system to UNFC has been demonstrated, and the next step is the creation of bridging documents, which is currently being worked on.

Project supported by ESA Network of Resources Initiative.

Data provided by the European Space Agency.

1. Ordinance on determination of reserves and exploitation of mineral raw materials (Official Gazette, 138/2022).
2. United Nations Economic Commission for Europe (2020): United Nations Framework Classification for Resources–Update 2019.
3. United Nations Economic Commission for Europe (2022): UNFC GUIDANCE EUROPE: Guidance for the Application of the United Nations Framework Classification for Resources (UNFC) for Mineral and Anthropogenic Resources in Europe.

GEOLOGICAL ANALYSIS OF HISTORICAL AERIAL IMAGERY: BRIBIRSKE MOSTINE AREA, CROATIA

GEOLOŠKA ANALIZA POVIJESNIH SNIMAKA IZ ZRAKA: PODRUČJE BRIBIRSKIH MOSTINA, HRVATSKA

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Keywords: *remote sensing, geological mapping, historical data reinterpretation, mapped data improvement, geographic information system (GIS)*

Geological maps are thematic maps on which usually rock units are differentiated and presented along with their stratigraphic and structural features (PLUMMER *et al.*, 2022). As geological maps differ in scale, purpose and extent, there are many variations (MALTMAN, 2012). The process of map development evolved through time as different techniques and technologies developed (MACEACHREN, 1979), but still field measurements and observations with remote mapping techniques, along with subsequent data analysis are the most important in this process (PAIN & KISER, 2012; GUPTA, 2018; PLUMMER *et al.*, 2022). Geological maps can be updated with time as changes in the mapped area takes place, new technologies are developed and new data becomes available. This process has become much more effective with development of geographic information systems (GIS) and remote sensing techniques and methods. Herein a short preview of ongoing research is presented, showcasing a geological assessment of digitally processed historical aerial imagery used for map data improvement for a case study in Croatia. The study area of Bribirske Mostine (detail of area shown on Fig. 1a–d) is covered by the Basic Geological Map of Yugoslavia (BGMY), sheet Šibenik, at a scale of 1:100,000 (MAMUŽIĆ, 1966), Fig. 1a). As the BGMY was developed more than 50 years ago, numerous expert reports and scientific papers indicate that there is room for its improvement in scale and presented data (GIZDAVEC *et al.*, 2022). Linear structural elements, as faults, are analysed and discussed with regards to possible improvements of data, scale and presentation by applying modern day technologies and rein-

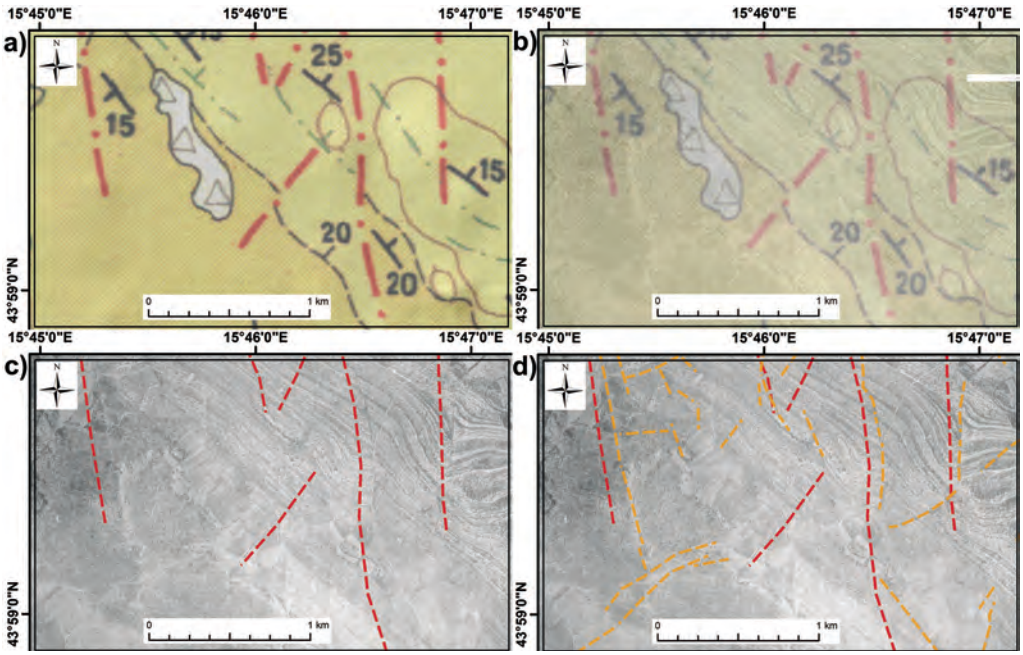

Figure 1. Study area segment shown: a) as historical geological map: BGMY (MAMUŽIĆ, 1966); b) BGMY overlapped with aerial imagery from 1959 used in BGMY development; c) with "original" linear structural elements (faults) digitalized: dashed lines; d) with reinterpreted linear structural elements (faults): dash-dot-dash lines

terpretation. Georeferenced historical geological data is reassessed: map (MAMUŽIĆ, 1966) and aerial imagery from 1959 used in original map development (Fig. 1b). "Original" linear structural elements (faults) were digitalized (Fig. 1c) and reinterpreted (Fig. 1d) with the following conclusions: (i) by digital processing of aerial photographs taken 60+ years ago and through detailed review and analysis more accurate data (spatial positioning) on linear structural elements (faults) can be gained; (ii) at the same time new data were acquired (additional fault lines were interpreted); and (iii) the map scale can be "upgraded" to 1:25,000 for the investigated areas, at least for the fault data (Fig. 1a–d). For Croatia, historical geological data is valuable and often is the "prime source" of geo data for some areas and locations. As this data is mainly available at a scale of 1:100,000 – it is relatively "coarse". By reinterpretation and analysis in GIS and CAD environment, an improvement in "historical" mapped data accuracy (spatial positioning) can be obtained and can lead to map elements upscale with the development of new, additional sets of georeferenced data.

Project supported by ESA Network of Resources Initiative. Data provided by the European Space Agency.

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CALCICLASTIC MASS-TRANSPORT DEPOSITS (MTDs) IN A SHALLOW-MARINE SUCCESSION OF THE DINARIC FORELAND BASIN (NORTHERN DALMATIA, CROATIA)

PRODUKTI RESEDIMENTACIJE KARBONATNIH KLASTITA U PLITKOMORSKIM NASLAGAMA DINARSKOG PREDGORSKOG BAZENA (SJEVERNA DALMACIJA, HRVATSKA)

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Keywords: *blocky-flow deposits, debrites, Eocene, Promina Beds, slumps*

Mass-transport deposits (MTDs) are products of gravity-driven en masse sediment redistribution processes and are known from passive and active tectonic settings, both ancient and recent. This study documents several types of MTDs that are interbedded with intensely bioturbated offshore and offshore-transition strata of the Middle to Late Eocene, deposited in a thrust-top (piggyback) basin of the Dinaric Foreland Basin (BABIĆ & ZUPANIČ, 2012; ĆOSOVIĆ *et al.*, 2018). The ~600 m thick sedimentary succession is located in the vicinity of Novigrad in northern Dalmatia. Five types of MTDs, ranging in thickness from 13 to 600 cm, have been identified: (1) calcilutite and calcarenite slumps with evidence of sediment torsion and deformation; (2) "dough-like" slumpdebrites comprising contorted matrix-supported conglomerates; (3) blocky-flow deposits (sensu MUTTI *et al.*, 2006), bearing outsized blocks of beachface and shoreface deposits; (4) rockfall deposits comprising scattered blocks of beachface conglomerates and shoreface calcarenites; and (5) "classical" matrix-supported debrites. Calciturbidites oc-

cur rarely in the studied succession, comprise mainly Ta and Tb divisions, but are not regarded as MTDs because they are generated by flows whose motion is supported by turbulence. The studied succession shows several transgressive–regressive cycles and progressive deepening of the sedimentary basin, with an accompanying increase in the occurrence of blocky-flow deposits and debrites. Slump-debrites are mostly found in association with offshoretransition deposits, suggesting that mass flows were triggered in fairly shallow water above the storm wave base. It is suggested that they were most likely mobilised due to a combined effect of strong earthquakes related to the basin tectonic development, sediment destabilisation due to pore water overpressure during forced regressions, and storm-wave loading affecting the shallow seabed. Progressive basin deepening likely favoured massflow transformations, although the overall paucity of turbidites suggests relatively short mass-flow transport distance and turbidity current bypass to deeper realms. Multiple erosional phases and resedimentation processes from the Cretaceous to the Late Eocene contributed to the diverse suite of both intraformational and extraformational clasts in the MTDs studied. The study results show that MTDs may be triggered and emplaced in shallow-marine settings mainly during regressive stages of basin development. Some of their peculiar sedimentary features and occurrence within shallow-marine calciclastic deposits render these MTDs rather unique. Therefore, they are suitable to re-assess the preservation potential of sedimentary features in wave-worked nearshore environments, as well as the nature and evolutionary continuum of processes involved in subaqueous sediment mass transport.

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PARTICLE COMPOSITION AND DEPOSITIONAL ENVIRONMENT OF THE KOŠNA CONGLOMERATES (VELEBIT MT., CROATIA)

SASTAV ČESTICA I TALOŽNI OKOLIŠ KOŠNA KONGLOMERATA (VELEBIT, HRVATSKA)

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Keywords: *sandstones, carbonates, shallow-marine environment, Early Permian*

Carboniferous and Permian carbonate and clastic rocks crop out in the Brušane area of the Velebit Mt., Croatia. Within them, the Košna conglomerates from the 'Košna voda' spring (SALOPEK, 1942) are quite distinct due to their multicoloured gravel-size clasts and red matrix. The conglomerates are clast- to matrix-supported, poorly sorted, and often normally graded. Imbricated gravel clasts of different size and composition occur locally and are surrounded by a sandy stratified matrix. Several types of clasts are present: sandstone, limestone, chert, as well as monomineral and polymineral quartz of pebble and cobble size. Sandstone clasts are classified as lithic arenites, subarkoses and arkoses. Limestone clasts are represented by shallow-marine wackestones to packstones with foraminifera, ostracods, echinoid, and bryozoan fragments. *Microcodium* and calcispherae are also present in the clasts. Particle composition suggests different sediment sources and possibly multiple resedimentation phases, while normal grading and imbrication indicate tractive particle transport. Fragments of fusulinid foraminifera found in the matrix suggest deposition in a marine environment.

Based on field observations and conducted paleontological, petrographic, ore microscopy and X-ray diffraction analyses, the Košna conglomerates are defined as Early Permian polymict conglomerates derived from

the uplifted Hercynian Mountains and deposited and reworked in a coastal part of the Paleo-Tethys. Due to their structural and textural features, the Košna conglomerates are comparable with Late Paleozoic conglomerates from other areas in the Dinarides, Eastern and Southern Alps.

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FROM REEF TO BASIN – PROGRADATION OF THE SHALLOW WATER CARBONATES OVER THE MIDDLE TRIASSIC NORTHWESTERN CROATIAN RIFT RELATED BASIN (IVANŠČICA MT., NW CROATIA)

OD GREBENA DO BAZENA – PROGRADACIJA PLITKOVODNIH KARBONATA PREKO SREDNJETRIJASKOG RIFTNOG BAZENA SJEVEROZAPADNE HRVATSKE (IVANŠČICA, SZ HRVATSKA)

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Keywords: *Middle Triassic, volcano-sedimentary succession, reef, NW Croatia*

The NW part of Croatia represents a tectonically complex area at the junction of the Dinarides and the Southern Alps. In Očura Quarry on Ivanščica Mt. there is 34 m thick section composed of volcanic, volcaniclastic and carbonate rocks that can be divided into three parts. The lower interval (7 m) is composed of dominantly basaltic rocks (SiO_2 = 43–51 wt%). In the basal part glomeroporpyric basalt is followed by basaltic autoclastic breccia. The second interval (7–19 m) is composed of cm–dm irregularly and wavy bedded calcarenites, occasionally coarsening upward, with lithoclasts varying in size from fine sand up to fine breccia. Carbonate lithoclasts are mostly micritic limestones – biomicrite, pelmicrite, pelsparite, intrasparite, also bioclasts of bivalves, crinoids, ammonoids, brachiopods, and gastropods. Two types of basaltic lithoclasts are present in the dominantly calcarenite interval, one with the porphyric to glomeroporphyric texture, similar to the basalts of the lower part; and the other type completely hyaline. Lithoclasts are cemented by sparry calcite. In the coarser varieties lithoclasts are the same, with the only difference in the matrix found between the clasts, that is composed of fine calcarenites with basaltic lithoclasts. Calcarenites are interlayered by thin layers of biomicrites with filaments and radiolarians, and thin layers of fine to coarse ash vitriclastic tuffs. In the middle of this interval around 1.5 m thick matrix supported breccia occurs with limestone and basaltic lithoclasts. Third interval of the section (19–34 m) is composed of extremely unsorted breccia with slump texture. Clasts of limestones, calcarenites, and subordinary basalts are supported by fine grained matrix of carbonate and basaltic particles. Abundant framestone clasts are present in the breccia, containing complex reef community, dominating of sponge *Celyphia zoldana*, with other microorganisms of uncertain taxonomy *Plexoramea cerebriformis* and *Olangocoelia otti*, and others. Generally in this interval carbonate material is predominant over basaltic lithoclasts.

The investigated section represents sedimentation in the deeper marine environment near the steep edge of the carbonate platform and reef. Basalts found at the base of the section present effusions in the marine areas, and their fragmentation and reworking. A thick interval of calcarenites with basaltic lithoclasts is formed by shedding of the carbonate material from the nearby platform to the pelagic/basinal areas, indicated by the pelagic limestone interlayers. Chaotic breccia with meter sized fragments of reefal limestones indicates a more proximal position to the shallow marine area from which these clasts were derived. Slump texture emphasizes gravitational processes. The general trend of coarsening upward, as well as the predominance of the framestone clasts in the breccias

imply the progradation of the platform over the basinal areas. Therefore, indicating a relatively rapid closure of the basinal/pelagic areas and cessation of the extensional tectonics related to the Neotethyan rifting. One sample (OD-15A) bears conodonts *Gladigondolella tethydis* (Huckriede), *Paragondolella trammeri* (Kozur), that indicate Illyrian to Lower Longobardian age of this section. That age is in the accordance with the regional cessation of the volcanic activity in the Ladinian, and progradation of the platforms over the basinal areas that were filled with various clastic, volcaniclastic, silicious and pelagic sediments.

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SARMATIAN SEDIMENTS OF THE SOUTHWESTERN PART OF THE HRVATSKO ZAGORJE BASIN (HZB), CROATIA

SARMATSKI SEDIMENTI JUGOZAPADNOG DIJELA HRVATSKO ZAGORJE BAZENA (HZB), HRVATSKA

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Keywords: *depositional environment, mineralogical characteristics, provenance, Sarmatian volcanism*

A number of lithostratigraphic columns within the Sarmatian deposits were documented during the geological mapping of the area of the southwestern part of the Hrvatsko Zagorje Basin (HZB) resulting in thorough measurements and sedimentological description. It is well known that at the end of the Badenian, the isolation of the Pannonian Basin System started, which at the beginning of the Sarmatian resulted in the establishment of marine environment characterized by reduced salinity (AVANIĆ *et al.*, 2018). Two distinct depositional environments gave rise to the deposition of Sarmatian sediments in the southwestern part of the Hrvatsko Zagorje Basin – nearshore deposits made of conglomerate, sandstone, biocalcirudite, biocalcarenite and marl, and offshore deposits with a local input of clastic material represented by marl and silt with sand intercalations. A bentonite clay layer is documented near the Sutla River in the border region with Slovenia. Bentonite mineralogy accounts dominantly for montmorillonite (60–70 %) and in lesser content opal-CT, calcite and quartz. Marls predominantly consist of calcite and clay minerals, while quartz and feldspars are less abundant. The calcite content varies from 20 to 80 %. Clay fraction is made of smectite, illite, chlorite and kaolinite. The mineral association of garnet, dolomite, glauconite, tourmaline, zircon, and rutile in the sand and silts indicate a local origin of the material. Abundant fossil assemblage served as a tool for biostratigraphical correlation and interpretation of the depositional environment. The bentonite clay likely originated as an alteration product of distant tephra sourced from the north-eastern part of the Carpathian–Pannonian Region (GRIZELJ *et al.*, 2023). Furthermore, the development of the Sarmatian deposits from the southwestern part of the Hrvatsko Zagorje Basin is consistent with the development in other parts of the Central Paratethys.

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LANDSLIDE DENSITY FOR NORTH AND EAST CROATIA BASED ON DATA FROM HISTORICAL GEOLOGICAL MAPS

GUSTOĆA KLIZIŠTA SJEVERNE I ISTOČNE HRVATSKE DERIVIRANA TEMELJEM PODATAKA POVIJESNIH GEOLOŠKIH KARATA

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Keywords: *landslide inventory, landslide density, historical geological maps, Croatia*

Landslides present the landforms that result from the downslope movement of rock, soil, and organic materials under the influence of gravity (HIGHLAND & BOBROWSKY, 2008). In order to reduce potential losses and damages that landslides can cause, it is necessary to develop sustainable landslide risk management, for which one of the key elements is terrain zonation according to the degree of susceptibility, hazard or risk.

For such assessments, the initial step is to prepare the landslide inventory maps (GUZETTI *et al.*, 2012). They primarily record the landslide location, and when known, the type of landslide and the date of occurrence. The inventories can be created from various data sources at different scales (MALAMUD *et al.*, 2004). Complete small-scale national landslide inventories are rare in reality, as they require the systematic collection of landslide data over wide areas. That activity mostly implies collecting historical landslide information and analysis of aerial photographs combined with field prospection. In that sense, this work presents the analysis of landslide data from historical geological maps, as one-step towards creating a comprehensive national landslide inventory in Croatia, which by far does not exist yet.

The study area presents the entire northern and eastern continental part of Croatia, covering 29,785.51 km^2. It mostly belongs to the Pannonian Basin System covered with numerous geological units, which are spatially differently distributed. Pre-Neogene basement rocks are locally exposed at the slopes or cores of the mountains located within the study area. Neogene and Quaternary deposits, in which most of the landslides occur, are predominantly exposed on the surface. Their composition varies from marls and carbonate rocks, to various clastic sediments, all of which are deposited solo or as sediment complexes.

The landslide inventory used in this study synthesizes landslide locations (presented as points) in northern and eastern Croatia, gathered from historical geological maps: Engineering Geological Map at a scale of 1:500,000, sheets of Basic Geological Map at a scale of 1:100,000, and draft field geological maps at a scale of 1:25,000. Based on the 861 landslide point data, the landslide density map was derived (Fig. 1). The map was created using

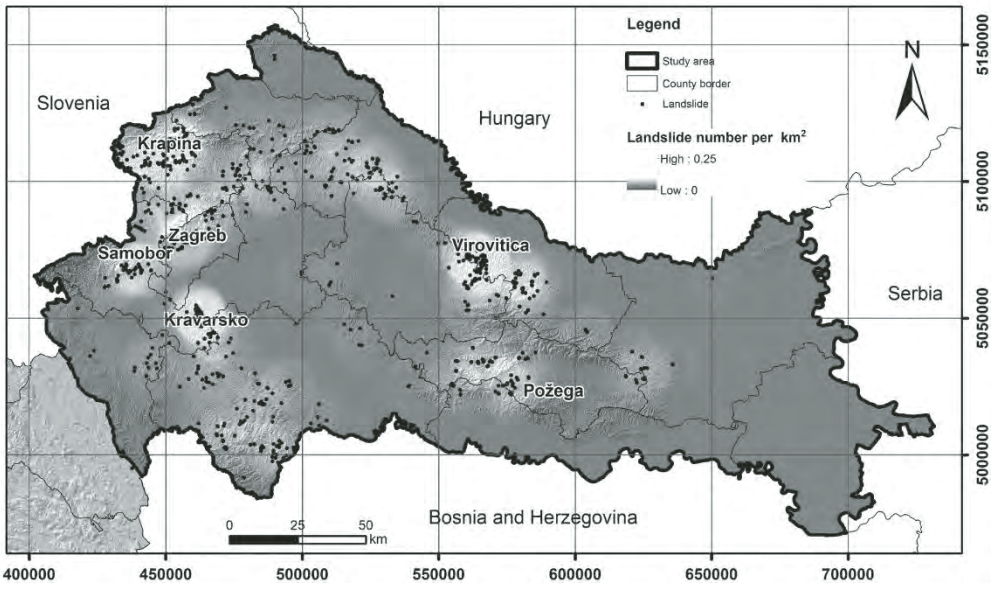

Figure 1. The landslide density map of northern and eastern Croatia

ArcGIS Point density tool with a circular shape option of the neighbourhood area, with a circle radius of 10,000 m. The cell size of the final grid was set to 500×500 m. All landslides from the combined inventory were included in the analysis as equally important with no weighting factors assigned.

The landslide density ranges from 0 to 0.25 landslides per km^2 (Fig. 1). Light zones on the map generally correctly highlight the regions which are known to have problems with landslides. Some exceptions are probably the result of unequal criteria for landslide identification by different authors/geologists, various landslide activity due to different meteorological conditions during mapping campaigns, and small scale of input data. Despite that fact, this landslide density map harmonizes historical landslide records on the national level and allows a quantitative measure of landslide spatial distribution which enables direct comparison of different regions. According to the analyses the zones with the highest landslide density are distinguished in areas around the cities of Virovitica, Krapina, Kravarsko, Zagreb, Samobor, and Požega.

Still, it is important to point out that this map cannot provide estimates of landslide occurrences in the future. Therefore, this inventory and landslide density will be further used to estimate the geological units most susceptible to landslides and assess their geomorphological characteristics, which strongly influence landslide occurrence.

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SEDIMENTOLOGICAL CHARACTERISTICS OF THE APTIAN–ALBIAN DEPOSITS OF THE KANFANAR QUARRY, ISTRIA

SEDIMENTOLOŠKE ZNAČAJKE APTSKO–ALBSKIH NASLAGA KAMENOLOMA KANFANAR, ISTRA

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Ključne riječi: *taložni okoliši, mikrofacijesi, mikrofosilne zajednice, apt, alb, emerzijske površine, kamenolom Kanfanar*

U kamenolomu Kanfanar, u blizini istoimenog mjesta u zapadnom dijelu središnje Istre, izvrsno je otkriven istraženi dio aptsko–albskih naslaga s nekoliko emerzijskih površina, tj. diskordancija. Najznačajnija diskordancija predstavlja regionalnu emerziju i granicu između 2. i 3. megasekvencije naslaga Istre (TIŠLJAR *et al.*, 2002).

U okviru terenskog rada i istraživanja na području kamenoloma Kanfanar snimljen je, uzorkovan i opisan slijed naslaga debljine 20,85 m (slika 1). Na temelju mikroskopskih litoloških značajki i fosilnog sadržaja određena su četiri mikrofacijesa (MF1–MF4). Mikrofacijes MF1 obuhvaća mikritne vapnence (vekstone-pekstone) s bačinelama, dekastronemama, bentičkim foraminiferama, bioklastima, onkoidima i fragmentima školjkaša (većinom rudista) te ukazuje na okoliš potplimne zone niske energije vode. Na temelju prisutnosti navedenih fosila uzorci s prevladavajućim udjelom bačinela, onkoida i bioklasta čine podtip MF1a dok uzorci u kojima većinom prevladavaju bentičke foraminifere, dekastroneme, fragmenti ljuštura školjkaša i dazikladalne alge čine podtip MF1b. Mikrofacijes MF2 obuhvaća sitnozrnastije mikritne vapnence (većinom madstone do pekstone) s intraklastima, bioklastima, peloidima, bentičkim foraminiferama te ljušturama školjkaša čime ukazuje na okoliš potplimne zone povišene energije vode. Na temelju navedenih elemenata razliku-

jemo podtipove MF2a, u kojem prevladavaju intraklasti, bioklasti kao i bentičke foraminifere dok peloidne čestice, bentičke foraminifere te u manjoj mjeri bioklasti prevladavaju u podtipu MF2b. Mikrofacijes MF3 obuhvaća zrnastije tipove vapnenaca (većinom vekstone–pekstone uz neke grejnstone) s litoklastima, bioklastima, peloidima, bentičkim foraminiferama (miliolidama), dekastronemama i dazikladalnim algama čime ukazuje na okoliš plimne zone. Na temelju prisutnosti navedenih fosila u uzorcima izdvojen je podtip MF3a u kojem dominiraju litoklastične i bioklastične komponente; u MF3b prevladava prisutnost bentičkih foraminifera i peloida. Mikrofacijes MF4 predstavlja prijelaz iz morskog okoliša (plimne zone) u slatkovodni okoliš pa razlikujemo fenestralne vapnence (MF4a) s fragmentima ljuštura ostrakoda, fenestralnim šupljinama, bioturbacijama i foraminiferama; te haroficejske vapnence (MF4b) s dominantnom pojavom slatkovodnih haroficeja i ostrakoda.

Mikrofosilna zajednica s vrstama *Palorbitolina lenticularis*, *Praechrysalidina infracretacea*, *Voloshinoides murgensis, Pseudolituonella conica*, *Archaealveolina reicheli* ukazuje na stariju aptsku starost donjeg dijela slijeda. Na oko 10 m slijeda nalazi se trošniji horizont karakteriziran brečiranim i okršenim vapnencima s udubljenjima ispunjenim glinovitim matriksom. Mikrofosilna zajednica u uzorcima neposredno ispod te emerzijske površine je mlađeaptske (npr. *Salpingoporella dinarica, Protochrysalidina elongata, Rumanoloculina minima*), a iznad mlađealbske starosti (npr. *Pseudonummoloculina heimi, Sigmoilina*? sp., *Novalesia* cf. *Angulosa, Vercorsella* cf. *immaturata Cuneolina parva, Nezzazatinella picardi*), ukazujući da je to

Slika 1. Slijed naslaga u kamenolomu Kanfanar (foto. M. Martinuš)

glavna aptsko–albska diskordancija. Emerzijske površine sličnih značajki nalaze se i na oko 14 m te 16,5 m slijeda mlađeg alba.

Istraživani slijed naslaga ukazuje na relativno oplićavanje taložnih okoliša tijekom apta i uspostavljanje kopnenih uvjeta i nastanka paleotla na prijelazu apt–alb. Slijed alba u krovini paleotla karakteriziran je oscilirajućom transgresijom na koju ukazuju brojne emerzijske površine.

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PALAEOENVIRONMENTAL CHANGES IN THE EARLY MIOCENE OF THE PAPUK MOUNTAIN
RANOMIOCENSKE PALEOOKOLIŠNE PROMJENE NA PAPUKU

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Keywords: *Papuk Mountain, Lower Miocene deposits, Miocene Climate Optimum, 40Ar/39Ar chronology, Biostratigraphy*

An integrated stratigraphic study has been performed of the Lower Miocene deposits from the southwestern slopes of Papuk Mountain, coupled with $^{40}Ar/^{39}Ar$ dating, geochemical and mineralogical study of tuffitic and silty sand beds.

The sedimentary basin formation in Papuk Mountain's area started in the Early Miocene. Lithologically different deposits in the Lower Miocene of the North

Croatian Basin (NCB) at Papuk Mountain, called the Poljanska unit, are represented by predominantly well-bedded dolomites, pelite layers, sandstones, tuffs, and tuffites with analcime and deposited in a salina-type lake (ŠĆAVNIČAR *et al.*, 1983; KOVAČIĆ *et al.*, 2017; PAVELIĆ & KOVAČIĆ, 2018; PAVELIĆ *et al.*, 2022). This informal unit is exposed only on the southwestern slopes of Papuk Mountain, and the most representative outcrop is situated in the active quarry.

Investigated Poljanska and the Mala sections are located close to the active quarry. The sedimentary records evidence deposition influenced by volcaniclastic input. The presence of marine, brackish, and non-marine microfossils indicate complex palaeoenvironment, palaeoecology, and palaeobiogeography. Several new stratigraphic, palaeoclimatic, and palaeoenvironmental data essential for the Central Paratethys have emerged from this work (HAJEK-TADESSE *et al.*, 2023):

- The $^{40}Ar/^{39}Ar$ age of 22.2 ± 1.9 Ma of volcanic glass from tuffitic sediment of the lowest part of the Poljanska section indicates older volcanic activity in the NCB *pro tempore*.
- The oldest marine fauna and flora in NCB determined from the marine deposits of Unit M1 (the Mala section) is the latest Early Miocene (Karpatian; Zone NN4) in age and connected with the TB 2.2.
- The fish remains in the Poljanska section represent the first finding of the lowermost Miocene mugilid *Liza gaudanti* Reichenbacher and Cappetta and the gobiid *Gobius* (n.) sp. in the NCB.
- Most of the sediments of the Poljanska section were deposited in time of the Miocene Climate Optimum (~17–14.7 Ma) under humid subtropical and tropical conditions. The joint finding of crocodile tooth and pollen of mangrove cf. *Avicennia* implies higher temperature and may coincide with the known temperature maximum event in the Central Paratethys. One interruption with lower temperatures characteristic for higher latitudes was presumed, which could be a consequence of the known cooling event in the Central Paratethys.
- The beginning of salina-type lake sedimentation in the Poljanska section is detected.
- Mineralogical analyses revealed that the deposits are of a hybrid origin, pyroclastic, and terrigenous. The pyroclastic material is mainly and slightly altered into smectite and clinoptilolite heulandite type of zeolites. A gradual increase in aridity and salinity probably caused the occurrence of clinoptilolite/heulandite-type zeolites.

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GEOLOGICAL MAPPING OF THE CROATIAN ADRIATIC SEAFLOOR WITHIN THE FRAME OF EMODNET GEOLOGY INITIATIVE

GEOLOŠKO KARTIRANJE PODMORJA HRVATSKOG DIJELA JADRANA U SKLOPU PROJEKTA EMODNET GEOLOGIJA

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Keywords: *seafloor mapping, seabed substrates, coastal behaviour, submerged landscapes*

The European Marine Observation and Data Network (EMODnet) is an initiative that brings together over 120 organizations to process marine data and make it freely available. This approach of collecting data once and using it multiple times benefits a wide range of users, including policymakers, scientists, private industry, and the general public.

Among the seven broad disciplinary thematic lots that deal with bathymetry, physics, chemistry, biology, seabed habitats, and human activities, is also geology. EMODnet Geology provides harmonized information on marine geology for the entire European seas. During the past five phases, lasting from 2009 until the present, it grew to a project spanning over nine Work Projects whose data products are available on the web portal. Those products comprise Seabed Substrates and Sedimentation rates; Sea-floor Geology: Pre-Quaternary geology, Quaternary geology and geomorphology; Coastal Behavior; Geological Events and Probabilities (e.g., earthquakes, submarine landslides, volcanoes, and Quaternary tectonics, landslide susceptibility); Marine minerals (e.g., aggregates, hydrocarbons, gas hydrates, marine placers, polymetallic nodules); Submerged landscapes; Entity indexes (borehole and grab samples, Seismic and multibeam survey data). The high-quality data products are continually harmonized and updated, making more detailed data and maps available with each new phase.

Within the initiative, the first digital seabed substrate map of the Adriatic was created with the most recent available data. The collected data were later incorporated into the harmonized "Seabed substrate of the Adriatic sub-region" (Fig. 1). Based on 53 exploration wells located in the Croatian part of the Adriatic Sea and selected seismic profiles from more than 80 000 km of 2D seismic data, an attempt was made to develop the first digital pre-quaternary sea-floor geology map of the Croatian part of the Adriatic Sea (Fig. 1). A new Coastal Behavior and Coastal Type maps for the whole Croatian

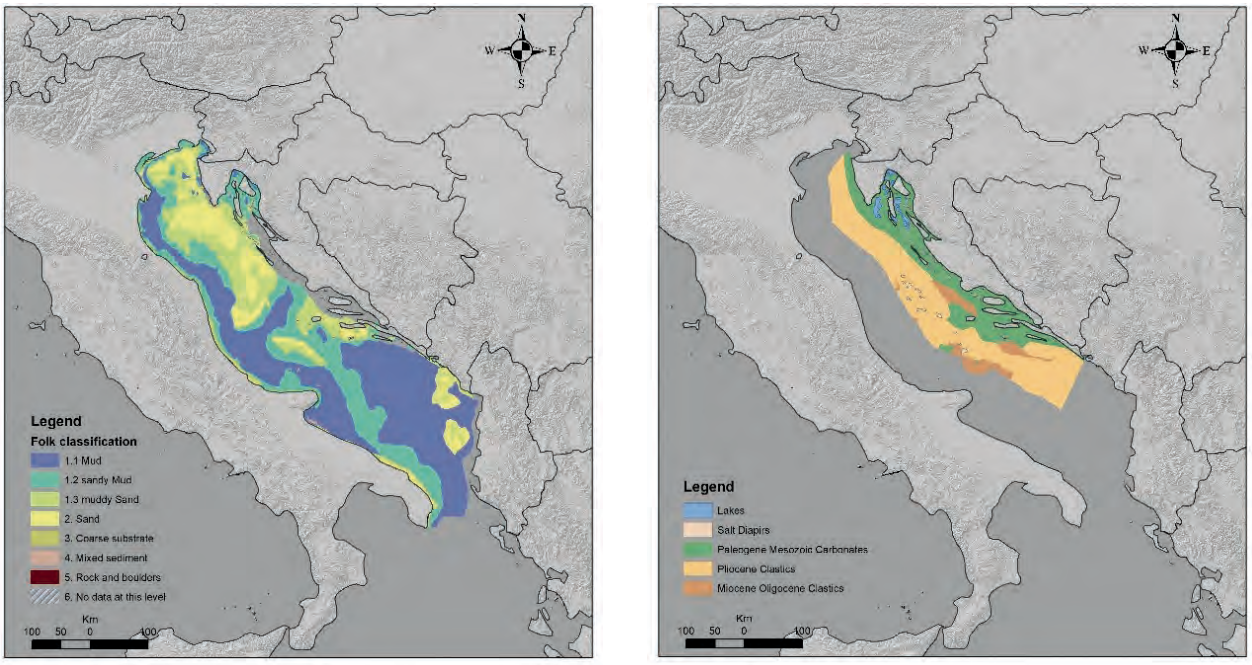

Figure 1. Harmonized sea-bed substrate map of the Adriatic Sea (left) and geological map of the Croatian Adriatic seafloor (right)

part of the Adriatic Sea were created based on lithology data from the Geological map of Croatia (M 1:100 000) and published papers. Geological units were reclassified into EROSION morpho-sedimentological coastal type units to finally derive 13 EUROSION classes. Data on Submerged Landscapes is continuously updated based on current research on the subject, including submerged coastal landforms, deltas, estuaries, lakes, channels, as well as recent sea-level index points.

Although the available marine geology data is the most interesting for geologists, a large interest is also shown by the marine managers, habitat mappers, and archaeologists. The Initiative forms a foundation for delivering the EU Green Deal and the digital transition. The dynamic and active portal is available at https://emodnet.ec.europa.eu/en/geology.

The European Marine Observation and Data Network (EMODnet) is a network of organizations supported by the EU's integrated maritime policy and managed by the Directorate-General for Maritime Affairs and Fisheries (DG MARE).

CUMULATIVE AND COSEISMIC DISPLACEMENTS DERIVED FROM TECTONIC GEOMORPHOLOGY AND GEODESY ANALYSIS ON THE RUPTURED PETRINJA–POKUPSKO FAULT (MW 6.4, 2020, CROATIA)

KUMULATIVNI I KOSEZMIČKI POMACI DOBIVENI TEKTONSKO GEOMORFOLOŠKOM I GEODETSKOM ANALIZOM AKTIVIRANOG SEGMENTA PETRINJSKO-POKUPSKE RASJEDNE ZONE (MW 6.4, 2020, HRVATSKA)

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Keywords: *Active faults, earthquake, surface rupture, geodesy, source modelling, fault slip-rate*

The Mw 6.4 Petrinja earthquake that hit Croatia in 2020 is one of the largest magnitude intracontinental earthquakes to occur in Europe in recent decades. Such moderate magnitude earthquakes are rare in slowly deforming contexts. Thus, their study can improve our knowledge of the spatial and temporal strain accommodation that is critical to better assess the regional seismic hazard. To better constrain the seismic cycle of intraplate fault system we then use the Petrinja case by comparing the long-term along-strike offsets accumulated on Petrinja–Pokupsko fault with the coseismic slip distribution from the 2020 rupture.

We analyze the fault zone geomorphology from field observations and high-resolution topographic data to provide constraints on the surface fault geometry and associated long-term cumulative offsets along-strike. Our mapping shows a clear NW-SE-trending 10-km-long strand between Donja Budičina and Cepeliš, and a 1–4-km-long right-stepping segment to the north with evidence of significant uplift. The fault appears very discontinuous with the deformation absorbed by a series of small fault sections rather than on a single fault strand. Offset geomor-

phic markers (incised streams and terrace risers) along-strike record cumulative displacements ranging from 5 to ~20 m, and potentially up to 200 m. Several sites on the southern strand are used to estimate fault slip-rates from precise quantification of cumulative displacements and cosmogenic nuclide exposure and radiocarbon datings of the corresponding displaced markers.

Based on fast-static geodetic measurements, continuous GNSS time-series, optical image correlation and coseismic interferograms, we also refine the 2020 ruptured fault trace and evaluate the slip distribution of the earthquake at depth. The *elastic inversion of the* coseismic slip shows a shallow seismic source (< 7 km) with surface ruptures on the northern portion of the fault with dextral displacement reaching > 1.2 m, as well as a potential sub-parallel secondary fault on the foothill SW of Petrinja. Nevertheless, comparing the geodetic displacements with the coseismic offsets measured on the field indicates that > 70 % of the slip is likely distributed at the surface.

The comparisons of the long-term and coseismic strain localization also suggests a transpressive setting in which the deformation is not absorbed by a single fault strand. The segmented long-term fault trace and the discontinuous 2020 rupture are consistent with an immature fault system. Assessing the seismic hazard and the role of the Petrinja-Pokupsko fault in the regional Adria–Europe convergence will be the focus of future work.

PLEISTOCENE FORAMINIFERAL ASSEMBLAGE FROM THE NORTH ADRIATIC, CROATIA
PLEISTOCENSKA ZAJEDNICA FORAMINIFERA SJEVERNOG JADRANA, HRVATSKA

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Keywords: *foraminifera, Pleistocene, North Adriatic*

Pleistocene sediments of the North Adriatic Sea contain a fossil assemblage consisting of numerous and well-preserved benthic and planktonic foraminifera. The biostratigraphical, lithological and palaeoecological results were obtained from drill cuttings collected from two exploration wells. The wells are situated southwest of the Istrian Peninsula. Petrographic analyses were made on a total of 40 samples. Micropaleontological analyses were performed on 37 samples prepared using a standard washing procedure (sieve fractions – 0.63; 0.25; 0.16; 0.125; 0.063 mm). The biostratigraphic interpretation was based on IACCARINO *et al.*, 2011; TURCO *et al*, 2011, 2016; WADE *et al.*, 2011; LIRER *et al.*, 2019.

The lower Pleistocene deposits consist of pelitic sediments (claystones and marls) and contain diversified and very well-preserved foraminiferal association (planktonic foraminifera – *Neogloboquadrina pachyderma*, *Orbulina universa*, *Globigerinoides ruber*, *Globoconella inflata*, *Globigerinoides conglobatus*; benthic foraminifera – *Hyalinea balthica, Bulimina marginata*, *Melonis padanus*, *Uvigerina peregrina*, *Trifarina angulosa*, *Cibicides floridanus*, *Quinqueloculina padana* etc.). Index fossils *Neogloboquadrina pachyderma* and *Hyalinea balthica* are cool water indicators. The predominance of planktonic foraminifera implies a deeper (outer shelf) and cooler marine environment.

The lower to middle Pleistocene sediments are represented by pelitic sediments as well (claystones, marls, rarely mudstones and siltstones). In relatively diverse foraminiferal associations, specimens of planktonic and benthic foraminifera are equally represented. Foraminiferal assemblage is composed of the following representatives: *Neogloboquadrina pachyderma*, *Neogloboquadrina incompta*, *Globoconella inflata*, *Globigerina bulloides*, *Orbulina universa* and *Turborotalita quinqueloba*, *Planulina ariminensis*, *Trifarina angulosa*, *Melonis padanus*, *Bulimina marginata*, *Bulimina inflata*, *Uvigerina peregrina*, *Paracassidulina neocarinata*, *Ammonia beccarii*, *Elphidium crispum*. In comparison to lower Pleistocene deposits, sedimentation took place in a somewhat shallower marine environment (shelf), but with the influence of the open sea.

Sedimentation of pelitic deposits continued in the middle Pleistocene. Sediments are represented by clays and marls, rarely muds, silts and sands. Occurrences of coal were observed as well. The Middle Pleistocene interval is characterized by foraminiferal assemblage with benthic foraminifera predominance (Ammonia beccarii, Elphidium crispum, Paracassidulina neocarinata, Quinqueloculina padana, Quinqueloculina sp. etc.). Specimens of planktonic foraminifera are very rare. Species Ammonia beccarii and Elphidium crispum are characteristic for shallow marine environments, depth up to 50 m (MURRAY, 2006; BALDANZA *et al.*, 2011). The sediments of this interval were deposited in a shallow marine, delta-influenced environment with significant material supply from the land.

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TESTING THE METHODOLOGY: THE SEVEN-STEP SEQUENTIAL EXTRACTION ANALYSIS OF STREAM SEDIMENTS AFFECTED BY SEDIMENT-HOSTED Cu DEPOSITS

TESTIRANJE METODOLOGIJE: SEDMOSTUPANJSKA SEKVENCIJSKA EKSTRAKCIJSKA ANALIZA VODOTOČNIH SEDIMENATA POD UTJECAJEM Cu LEŽIŠTA U SEDIMENTIMA

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Keywords: *the mobility and bioavailability of metals and metaloids, stream sediments, sequential extraction, ICP-MS analysis Cu mineralization*

The Paleoproterozoic Greenstone Belts of Fennoscandia are metamorphosed and deformed volcano-sedimentary basins that host various types of Cu deposits. The Alta-Kvænangen Tectonic Window (AKTW), an exposed fragment of the Fennoscandian Shield beneath the Caledonides in northern Norway, is characterized by abundant Cu deposits. Copper mineralization occurs as epigenetic quartz-carbonate veins that crosscut the Storkviknes formation and the underlying Kvenvik formation. The main ore minerals are chalcopyrite, bornite and digenite. In addition, small amounts of galena, covellite, molybdenite and wulfenite are found. Due to the high latitude, the area is exposed to the weathering characteristic for the Arctic climatic conditions.

The aim of this study is to determine the distribution of metals and metaloids in the major mineral phases accumulated in stream sediments affected by Cu mineralization. A total of 44 stream sediments were collected, freeze-dried and sieved through a 0.063 mm sieve. The bulk composition of this fraction shows Na, K, Ca, Mg, Fe, P and S as major elements, in addition to which Cu, Pb, Zn, Ni, Mn, As, U and V show a significant enrichment. Scandium, Co, and Ti are enriched in the Kvenvik formation, and Au, Se, Bi and Hg in Storkviknes formation.

The sequential extraction analysis applied in this study is based on the methodology proposed by TORRES & AULEDA (2013), with modified 7th step. The analysis targets the following mineral fractions: 1) water-soluble; 2) exchangeable; 3) phases bound to low crystalline Fe(I-II)-oxyhydroxides; 4) crystalline Fe(III)-oxides; 5) organic fraction; and 6) sulfides. The 7th step represents total digestion of residual material from step six, using the methodology proposed by FIKET *et al.* (2016). The extracts were analyzed for 27 elements (Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Ni, Rb, Sb, Sc, Se, Sn, Sr, Ti, U, V, Y and Zn) using ICP-MS.

With concentrations of up to 270 and 95 mg/kg respectively, K and Mg represent the prevailing elements bounded to the water-soluble fraction. Calcium (195–8770 mg/kg) and Mg (20–1200 mg/kg) dominate the exchangeable fraction. In addition, this fraction is enriched in other car-

bonate-bounded elements such as Ca, Ba, Cd, Cu, Mn, Sr, U and Zn. The low crystalline Fe(III)-oxyhydroxides and crystalline Fe(III)-oxides predominantly consist of Fe and Mn and are enriched in Al and a range of chalcophile (As, Cu, Mo, Sb, Zn) and siderophile elements (Co, Ni). The organic fraction is an important carrier for Se (up to 1.5 mg/kg Se, i.e. 25 % of total Se). The sulfide fraction is enriched in chalcophile elements, but the analysis also revealed increased concentrations of several lithophile elements (up to 6000 mg/kg Al, 53500 mg/kg Ca, 1100 mg/kg K, 19000 mg/kg Mg, 155 mg/kg Rb, 9 mg/kg Li). The great majority of elements, with an exception of As, Cu, Mn and Mo, have at least half an order of magnitude higher concentrations in the residual phase comparing to other extracted fractions.

The tested modified sequential extraction analysis provides a good chemical resolution in studying the mobility and bioavailability of metals in the stream sediments affected by weathering of Cu deposits. Anyhow, the unexpected leaching of lithophile elements in the 6th step (targeting the primary sulfide fraction) may reflect that 8 mol/l HNO_3 used in this step could have partly affected crystal lattices of clay minerals. Therefore, the additional clay mineral characterisation will be performed at aliquots of selected samples prior and after this step.

The research has been conducted within the MinExTarget (Enhanced Use of Heavy Mineral Chemistry in Exploration Targeting) project and has received funding from European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation.

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GEOCHEMICAL RECORDS IN CROATIAN KARST BAUXITES – TECTONIC AND CLIMATIC EVENT MARKERS AT REGIONAL UNCONFORMITIES

GEOKEMIJSKI ZAPIS U HRVATSKIM KRŠKIM BOKSITIMA – TEKTONSKI I KLIMATSKI MARKERI REGIONALNIH DISKONTINUITETA

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Keywords: *bauxite geochemistry, compositional data, discriminant function model, Adriatic-Dinaric carbonate platform, Croatia*

Croatian bauxites have long been known for their chemical and physical diversity arisen from their characteristic origin and emplacement within the area of the Adriatic–Dinaric carbonate platform (ADCP). Formed on subaerially exposed platform paleoenvironments they comprise eight horizons bridging the period between the Upper Triassic (Carnian) and the Miocene. However, until lately, the issues of their genesis, interaction with the adjacent karst palaeo-environment and associated tectonostratigraphic constraints, have been largely underestimated. In earlier investigations they were studied in the context of paleoclimate related geochemical and mineralogical processes and of local tectonics. Only recently, they again became the focus of interest owing to the newly constructed models of orogenic evolution of the ADCP region that had underscored the importance of a number of hiatuses of variable duration marked by bauxite deposits. Recognizing bauxites as tectonic and climatic event markers at regional unconformities, new investigations called for additional correlative studies within and across different stratigraphic horizons, particularly concerning their genesis. In this sense their geochemical and mineralogical composition was understood as a unique signature of tectonostratigraphic evolution of the different parts of the Croatian Karst, including specific tectonostratigraphic features such as, for example, the forebulge unconformity typical for the Istrian area. In this study, explanation of the typical patterns of bauxite formation is based on the construction of a discriminant function mod-

el (DFM) resulting from the compositional data (CoDa) analysis of bauxite geochemical data. It included a total of 219 samples (215 bauxite + four terra rossa samples) collected from the Croatian karst region and analyzed at the Bureau Veritas laboratory (former ACME Analytical Laboratories Ltd.) in Vancouver, Canada, applying the Lithogeochemical Whole Rock Major and Trace Element analytical method). The model shows that the greatest part of the variation contained in the analysed bauxite data is associated with regular alteration of geochemical composition in time (the first discriminant function, DF1), emphasizing characteristic decrease in base loss and gradual enrichment in heavy metals from oldest (Upper Triassic) to the youngest (Miocene). In the general scheme, particular bauxite horizons represent standalone groups (Upper Triassic) while others form clusters showing increase and/or decrease of a particular set of elements signalling the changes in environmental conditions during the considered geological history of ADCP. In this case, the time arrow (DF1) is also accompanied with characteristic shift from felsic to ultramafic rocks as potential bauxite parent material as seen in systematic increase of chromium values towards younger horizons (with except of the youngest, Miocene, bauxites) and corroborated by ternary Zr-Cr-Ga diagram. Residual variation also contributes to the all-inclusive distinction between the eight a priori defined bauxite groups discriminated by the characteristic set of geochemical variables where DF2 typically refers to the process of desilication, while DF3 to that of deferralitization.

IN SEARCH OF THE MOST EFFICIENT METHODS IN "LIBERATING" PLANKTONIC FORAMINIFERA FROM INDURATED LIMESTONES: A CASE STUDY OF EOCENE TRANSITIONAL BEDS (VINODOL VALLEY, CROATIA)

U POTRAZI ZA NAJEFIKASNIJOM METODOM OSLOBAĐANJA FORAMINIFERSKIH KUĆICA IZ VAPNENACA: PRIMJER EOCENSKIH PRIJELAZNIH NASLAGA (VINODOLSKA KOTLINA, HRVATSKA)

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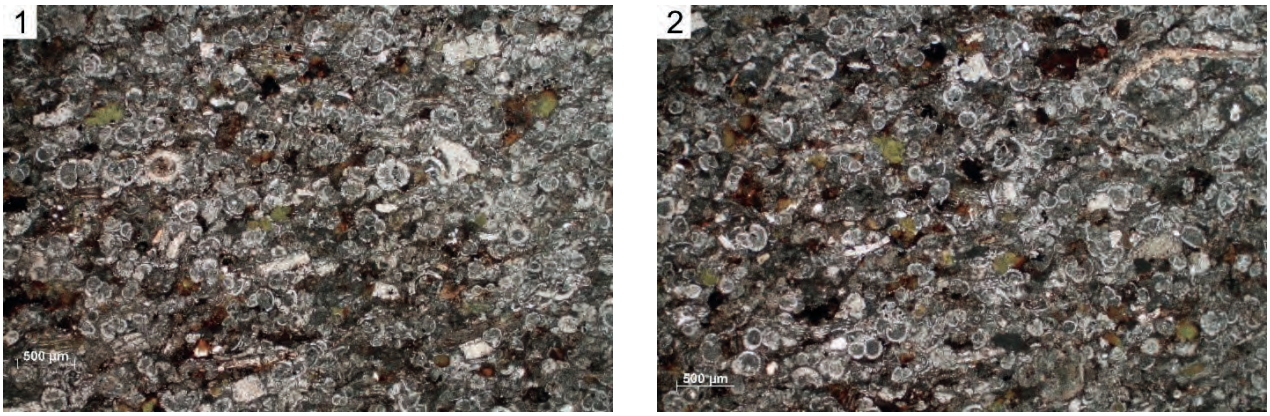
Ključne riječi: *octena kiselina, eocen, Prijelazne naslage, planktonske foraminifere*

Planktonske foraminifere izvrsni su provodni fosili. Lako prepoznatljiva kućica jednostavne je građe (bez unutarnjih strukturnih elemenata) i baš zbog toga za identifikaciju vrsta trebamo izolirane jedinke. Odvajanje jedinki iz sedimenta je jednostavno, ali kad su kućice „zarobljene" u konsolidiranoj karbonatnoj stijeni nastaje problem. Najstarija metoda, poznata gotovo sto godina (HANNA & CHURCH, 1928), je opetovano grijanje i hlađenje. Danas se, u dobro opremljenim laboratorijima, koristi tekući dušik (RENIM *et al.*, 2012). Druga metoda je otapanje, isprva u otopini vodikovog peroksida (WICK, 1947), a od 60-ih godina prošlog stoljeća (BOURDON, 1956) u otopini octene kiseline (koncentracije 10–15%). Nakon niza testiranja, LIRER (2000) je postavio protokol za primjenu metode otapanja u octenoj kiselini (koncentracije 50 % do 80 %).

Istraživanja su obuhvatila uzorkovanje i interpretaciju eocenskih Prijelaznih naslaga. To su vapnenci istaloženi u okolišima gornjeg batijala (paleodubine > 200 m), a kućice planktonskih foraminifera su brojne (slike 1, 2). Metoda otapanja bila je jedina opcija zbog opremljenosti laboratorija Geološko-paleontološkog zavoda (laboratorija s najdužom tradicijom rada u mikropaleontologiji u zemlji, u kojemu su profesori Vanda Kochansky-Devidé, Donata Nedela-Devidé, Milan Herak pripremali uzorke s koralinacejama, fuzulinidama, globotrunkama i dazikladacejama).

Ista količina mehanički usitnjenog (veličina zrna od 2 do 5 mm u promjeru) uzorka iste stijene (eocenske naslage iz Vinodolske kotline) izložena je otapanju u različitim koncentracijama octene kiseline od 50 %, 60 %, 70 % i 80 % za vrijeme od 5 ili 15 sati. Uspoređena je efikasnost i kvaliteta (sačuvanost ključnih osobina kućice) taloga zaostalog nakon otapanja (IŠTUK *et al.*, 2023). Cost/



Slike 1, 2. Fotomikrografije Prijelaznih naslaga, presjeci kućica planktonskih foraminifera

benefit analiza otkrila je kako reakcija uzorka s 60 % i 70 % koncentriranom kiselinom kroz pet sati daje najbolje rezultate. Oslobodilo se najviše kućica planktonskih foraminifera i kućice su nosile tek neznatne tragove otapanja. Veći udio fragmentiranih kućica, znatan broj sačuvanih „kamenih jezgara" (otopljena stijenka, sačuvana ispuna), te veći udio kućica kojima je otopljena stijenka najmlađe klijetke, nađeno je u talogu nakon što su uzorci 15 sati bili otopljeni u 80 % kiselini. Najmanja koncentracija kiseline (50 %) i najkraće vrijeme djelovanja (5 sati) „oslobodilo" je relativno mali broj kućica. Nedoumica da li otapati pet sati uzorke s 60 % ili 70 % kiselinom, razriješena je usporedbom kvalitativnih i kvantitativnih osobina kućice taloga u korist primjene 60 % octene kiseline. Naime, brojnost „oslobođenih" kućica koje su dobro sačuvane najveća je upravo u tako procesuiranim uzorcima.

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HOLOCENE STABLE ISOTOPE RECORD IN LAKE SEDIMENTS AND OSTRACODS FROM LAKE VELO BLATO ON THE ISLAND OF PAG (DALMATIA, CROATIA)

HOLOCENSKI ZAPIS STABILNIH IZOTOPA U JEZERSKOM SEDIMENTU I OSTRAKODIMA U JEZERU VELO BLATO NA OTOKU PAGU (DALMACIJA, HRVATSKA)

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Keywords: *Holocene, stable isotopes, lake sediments, ostracods, karst lake*

Lake Velo Blato is a shallow (up to 3 m deep) coastal karst lake situated in the southern part of the Island of Pag on the Eastern Adriatic Coast (Croatia). A 568 cm long sediment core (VB-2) was drilled in the central part of the lake and subsequently analysed by multiproxy approach (ILIJANIĆ *et al.*, 2022). The lake was formed in the early Middle Holocene (at ca. 8100 cal yr BP) due to rising groundwater levels driven by the Holocene sea-level rise (ILIJANIĆ *et al.*, 2022). This contribution is a continuation of the cited research and is focused on the stable isotope data obtained by isotope-ratio mass spectrometry: the stable isotope analysis of calcite (δ18Ocalcite and δ13Ccalcite), ostracod shells measured on two different ostracod species: Cyprideis torosa (δ18OC. torosa, δ13CC. torosa) and Candona angulata (δ18OC. angulata, δ13CC. angulata), and carbon isotope composition of organic matter (δ13Corg). The lake has no visible surface inlets or outlets and is responsive to changes in precipitation. Measurements of physical and chemical properties of lake water samples (temperature, conductivity, dissolved oxygen, pH, anions, cations) revealed slightly brackish (oligohaline) conditions in modern lake with well-mixed water column, while stable isotope composition (δ18O and δ2H) suggest hydrologically closed (endorheic) basin where water loss occurs predominantly through evaporation.

Oxygen isotope record of lake carbonate (δ18Ocalcite) displays a clear trend from relatively lower values (–3.86 ± 0.5 ‰) during the early Middle Holocene (8100–6800 cal yr BP) to relatively higher values (–2.8 ± 0.3 ‰) in the Late Holocene (6800–800 cal yr BP), followed again by decreased values (–3.1 ± 0.4 ‰) in the last 800 cal yr BP. Carbon isotope record (δ13Ccalcite) shows similar trend throughout the Holocene, with a significant shift to lower values occurring in the last ca. 200 cal yr BP. High positive correlation between δ18Ocalcite and δ13Ccalcite (r=0.7) suggest similar controls on the behaviour of the two isotopes in hydrologically closed basin. In contrast to average stable isotope values in endogenic carbonates (bulk values recorded in 1-cm sample resolution), stable isotope composition of ostracod shells provides a "snapshot" of water conditions at the time of calcification (ROBERTS *et al.*, 2020). Stable isotope composition of ostracod shells in Velo Blato sediment core displays a great variability compared to the "averaged" stable isotope composition of endogenic carbonates. Nevertheless, an upward trend can be seen in both species, which is similar to the trend in isotopic signal derived from lake carbonate. Carbon isotope record of sediment organic matter (δ13Corg) varies between –17.1‰ in the lower part of the core and –26.2‰ in the upper part of the core, which could reflect changes in lake productivity.

Stable isotope record of Holocene lake sediments from lake Velo Blato will be further interpreted in context of Holocene climate change on the Eastern Adriatic Coast.

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GEOMORPHOLOGICAL SETTINGS AND TYPES OF LANDSLIDES IN THE CITY OF BUZET IDENTIFIED USING LIDAR DIGITAL TERRAIN MODEL

GEOMORFOLOŠKI OKOLIŠI I TIPOVI KLIZIŠTA NA PODRUČJU GRADA BUZETA IDENTIFICIRANI PRIMJENOM LIDAR DIGITALNOGA MODELA RELJEFA

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Keywords: *visual interpretation of LiDAR DTM, landslide inventory map, geomorphological settings of landslides, landslides in gullies, Buzet*

This study presents the results of landslide detection and mapping at a large scale, performed in the area of the city of Buzet in central Istria. The research was conducted within the frame of scientific research project "Methodology development for landslide susceptibility assessment for land-use planning based on LiDAR technology" (LandSlidePlan, HRZZ IP-2019-04-9900). The study area (20 km^2) consists of Eocene flysch sediments, composed of a rhythmical alternation of marl and carbonate sediments in the lower part of the complex, and thinly bedded carbonate-siliciclastic turbidite sediments in the upper part (BERGANT *et al.*, 2003).

For the first time, the detailed geomorphological landslide inventory map (GUZZETTI *et al.*, 2012) is created for the area in the flysch environment in central Istria, using innovative remote sensing technology that proved to be effective in mapping landslides (GÖRÜM, 2019; JAGODNIK *et al.*, 2020a). Identification and mapping of landslides was carried out based on the visual interpretation of topographic datasets derived from the bare-earth LiDAR (Light Detection and Ranging) Digital Terrain Model (DTM) at a 0.3 m spatial resolution. Airborne laser scanning was performed in March 2020, with an average point density of 16 points per m^2.

In the study area, more than 1,160 landslides are identified and delineated with high geographical accuracy and thematic certainty due to the clear visibility of landslide features on LiDAR DTM derivatives. However, it was quite a challenge to identify and map individual landslides in areas of gully erosion and badlands, which represent the typical geomorphological phenomena in the flysch environment of central Istria (GULAM *et al.*, 2014). Landslide density is 58 landslides per km^2. Most of the landslides are debris slides, and debris slide-debris flows (HUNGR *et al.*, 2014), which are the main types of landslides in flysch deposits (JAGODNIK *et al.*, 2020b). Landslides are predominantly small and shallow. Their sizes are in the range between only 4 m^2 to 8 ha.

Generally, there are three typical geomorphological settings of landslides in the study area: (i) complex gullies; (ii) agricultural fields; and (iii) artificial slopes along the roads. Gullies are the predominant environment for the occurrence of landslides, with approximately 65 % of identified landslides being situated in gullies. Such specific geomorphological setting of landslide phenomena confirmed that there is a significant interplay between mass movements and fluvial processes in the investigated area. Therefore, in the future research, the results of this study will be used for testing the relevance of gully and badland phenomena as conditioning factors in landslide susceptibility modelling at a large scale.

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IDENTIFYING GEOMORPHOLOGICAL UNITS BASED ON LITHOLOGICAL AND GEOMORPHOLOGICAL MAPPING USING LIDAR DIGITAL TERRAIN MODEL: EXAMPLE FROM THE VINODOL VALLEY

IDENTIFIKACIJA GEOMORFOLOŠKIH JEDINICA NA TEMELJU LITOLOŠKOG I GEOMORFOLOŠKOG KARTIRANJA PRIMJENOM LIDAR DIGITALNOGA MODELA RELJEFA: PRIMJER VINODOLSKE UDOLINE

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Keywords: *LiDAR DTM, geomorphological unit, lithological mapping, landform, Vinodol Valley*

This study presents the procedure of identification of geomorphological units in the complex geological environment of the Vinodol Valley (area of 65 km^2), situated in the north-western coastal part of Croatia, using 1 x 1 m bare-earth LiDAR (Light Detection and Ranging) Digital Terrain Model (DTM). Steep valley flanks are composed of Upper Cretaceous and Paleogene carbonates, while the hypsometrically lower parts of the valley are built of Paleogene flysch sediments (BLAŠKOVIĆ, 1999). Flysch bedrock is almost entirely covered by Quaternary superficial deposits, formed by geomorphological processes active both in the carbonate and flysch rock mass (ĐOMLIJA, 2018).

According to general definition (COOKE & DOORNKAMP, 1990), geomorphological unit is a unit of the Earth's surface determined by specific topography, forming geomorphological processes, and forming material. Therefore, each relief unit is closely related to the geological features of an area, i.e., lithology and, in principle, hydrological conditions. The criteria for the identification of geomorphological units in the study area are (HASKINS *et al.*, 1998): (i) landforms, (ii) landform lithology; (ii) geomorphological processes; and (iv) morphometry. Additionally, the criterion of the size for the smallest area of an individual landform or lithological body to be included in the geomorphological unit is adopted to be 1 hectare (ĐOMLIJA, 2018).

First, the lithological mapping was carried out based on the visual interpretation of topographic datasets derived from the LiDAR DTM (JAGODNIK *et al.*, 2020a), coupled with field reconnaissance mapping. Lithological mapping was conducted with the attribute of homogeneity of identified lithologies corresponding to engineering formations (DEARMAN, 1991). Most of the landforms were actually identified and delineated already during lithological mapping. To each delineated lithology the forming geomorphological process was assigned during the mapping. For example, recent talus sheet formed by gravitational mass movements was identified and mapped by delineating recent scree deposits. Gully erosion and landslide phenomena, representing active geomorphological processes in the study area, are also identified and mapped (ĐOMLIJA *et al.*, 2019; JAGODNIK *et al.*, 2020a, 2020b). The morphometric landform features are determined based on the morphometric analysis of the elevation map, the slope map, and the curvature map derived from the LiDAR DTM.

There are 11 geomorphological units identified in the Vinodol Valley, based on the lithological and geomorphological mapping: (i) carbonate plateau; (ii) carbonate rock slopes; (iii) carbonate cliffs; (iv) breccia rock slopes; (v) recent colluvial sheet; (vi) older colluvial sheet; (vii) proluvial sheet; (viii) denudational slope; (ix) denudational hollow; (x) accumulational footslope; and (xi) alluvial plain. Symbols are proposed for each geomorphological unit. The map of geomorphological units was prepared according to GAMS *et al.* (1985). Data on hydrological conditions and anthropogenic elements are manually digitized based on the visual interpretation of LiDAR DTM and official state Topographic Base Map at a scale 1:5,000, and are also presented on the geomorphological unit map.

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DENTAL REMAINS OF THE EXTINCT SHARK *PTYCHODUS* (ELASMOBRANCHII, PTYCHODONTIDAE) FROM THE UPPER CRETACEOUS OF CROATIA

DENTALNI OSTATCI IZUMRLOG MORSKOG PSA *PTYCHODUS* (ELASMOBRANCHII, PTYCHODONTIDAE) IZ NASLAGA GORNJE KREDE HRVATSKE

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Keywords: *Fossils, Dental plate, Durophagy, Ontogeny, Dalmatia*

Ptychodus is an extinct elasmobranch shark from the Albian-Campanian of North America, Europe, Africa, and Asia (CAPPETTA, 2012). The fossil record of this group predominantly comprises isolated teeth (CAPPETTA, 2012; AMADORI *et al.*, 2023). In addition, articulated dental plates and mineralized cartilaginous elements have been rarely reported up to now (SHIMADA *et al.*, 2009). In Ptychodus, the general tooth shapes combined with occlusal dental ornamentations provide the most important characters for species identification (CAPPETTA, 2012; AMADORI *et al.*, 2023). Nevertheless, the taxonomy and systematics of this enigmatic elasmobranch group are still debated (CAPPETTA, 2012). In Ptychodus, molariform teeth suitable to crush shelled prey (durophagy) were arranged in massive tooth plates placed in both lower and upper jaw (SHIMADA *et al.*, 2009; CAPPETTA, 2012). Different species were characterized by flat, bulgy or cuspidate teeth, which probably allowed them to feed on a wide range of prey and reach considerable sizes (SHIMADA *et al.*, 2009, 2010; CAPPETTA, 2012). Indeed, some species of these voracious predators could probably exceed ten meters in total length (SHIMADA *et al.*, 2010; JAMBURA & KRIWET, 2020).

So far, findings assigned to the genus *Ptychodus* from Croatia were mentioned only briefly in the literature (BARDACK & RADOVČIĆ, 1973; RADOVČIĆ, 1975). Three new specimens of *Ptychodus* are presented here for the first time. The specimens were collected during a field-work in 1972 with the collaboration of Ivan Crnolatac (Geological and Paleontological Museum, Zagreb) and Jakov Radovčić (Institute for Palaeontology and Quaternary Geology of the Yugoslav Academy of Sciences and Arts, Zagreb).

Among the new findings, an exceptionally well-preserved dental plate (CNHM 9350) from Prapatnica (15 km NNW of the city of Trogir, Dalmatia) is characterized by un-cuspidate teeth representing the first known articulated tooth set of Ptychodus from Croatia and the most complete lower dentition of P. decurrens discovered so far. This articulated plate is embedded in wackestone/packstone limestones, which are indicative of a paleoenvironment within the inner carbonate platform, possibly the inner slope, with significant exchanges with off-reef areas and possibly of Campanian age (RADOVČIĆ *et al.*, 1983). Micropaleontological analysis is currently in progress for a more precise dating of CNHM 9350. If the Campanian age of the specimen is confirmed, the plate from Croatia would represent the stratigraphically youngest known record of P. decurrens, as this species is only reported from the Albian to Turonian (AMADORI *et al.*, 2023).

The comparison between the articulated dental plate from Croatia and the articulated tooth sets from southern England (WOODWARD, 1904, 1912) allow the interpretative reconstruction of the complete dentition of *P. decurrens* (upper and lower plates). Moreover, the compared dentitions from the Cenomanian of southern England have different size and probably represent different ontogenetic stages. In addition, the symphyseal teeth of the largest plate from England exhibit transversally elongated tooth crowns, while more squared symphyseal teeth characterize the smallest articulated specimens from the same age and provenance. The dentition from Croatia herein presented has size and shape very similar to the smallest specimens from England, suggesting that it belonged to a juvenile individual of *P. decurrens*.

The second specimen of *Ptychodus* herein reported for the first time from the Upper Cretaceous of Croatia includes more than 50 teeth of *P. decurrens* scattered on a limestone plate (CNHM KRR 26) from an unknown locality. The largest teeth probably belong to the symphyseal row of a lower dental plate.

The third specimen of *Ptychodus* from the Upper Cretaceous of Croatia is an isolated tooth (CNHM 9148) found on the northeastern slope of Kozjak Mt. (15 km northeast of Split, Dalmatia). Ammonites belonging to *Vascoceras* and *Acanthoceras*, together with the bivalves *Inoceramus*, discovered from the same locality suggest a Turonian age (RADOVČIĆ, 1975). This tooth is the only one with an occlusal cusp known from Croatia so far and therefore represents the first evidence of a cuspidate *Ptychodus* species from this area.

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PATHOLOGICAL CHANGES ON THE FOSSIL WHALES VERTEBRAE
PATOLOŠKE PROMJENE NA KRALJEŠCIMA FOSILNIH KITOVA

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Ključne riječi: *patologija, kralješci, kitovi, srednji miocen*

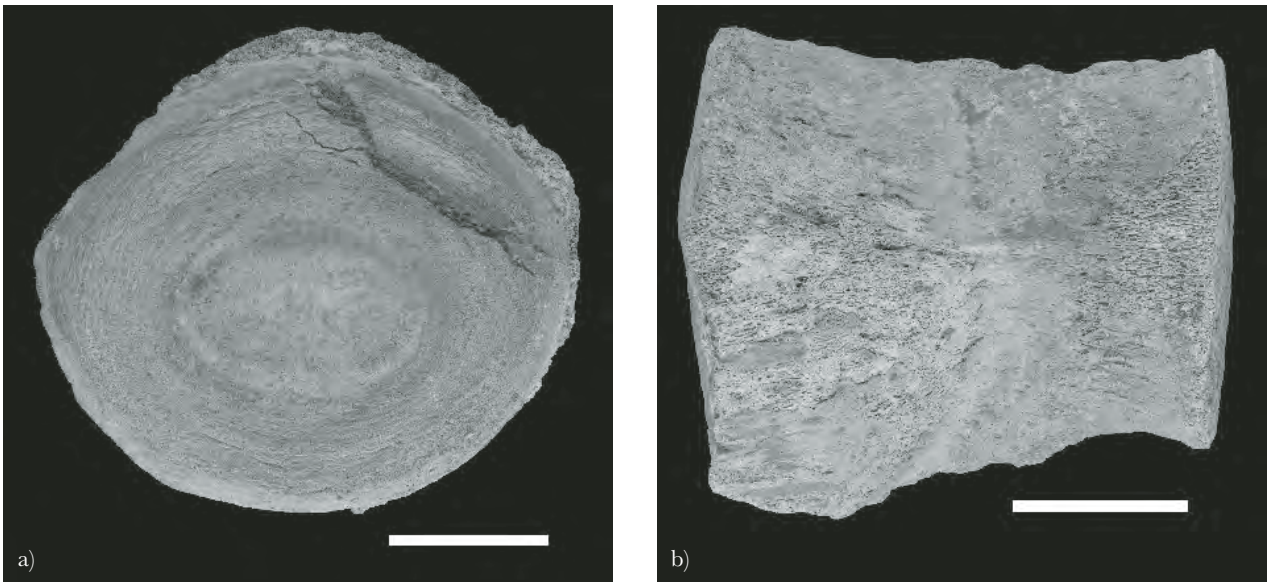
U zbirci Muzeja Brodskog Posavlja čuvaju se kralješci fosilnih kitova s više lokaliteta u Bosni i Hercegovini (BiH). MALEZ (1971) i MALEZ i SLIŠKOVIĆ (1989) opisuju nalaze s lokaliteta Kalenderovci. PAUNOVIĆ (1993) daje pregled svih lokaliteta u BiH s ostacima fosilnih kitova koje pripisuje vrsti *Mesocetus* aff. *agrami*. Vjerojatno su primjerci iz Muzeja Brodskog Posavlja upravo kralješci koji se opisuju u navedenoj literaturi iako neki od njih nedostaju. Iz iste literature moguće je zaključiti da je starost fosila srednjomiocenska, najvjerojatnije badenska. Prema navedenoj literaturi i usporedbom s primjercima iz zbirki Hrvatskoga prirodoslovnog muzeja, većina primjeraka iz Muzeja Brodskog Posavlja može se pripisati kitovima iz podreda Mysticeti.

Analizirano je ukupno 18 kralježaka fosilnih kitova. Petnaest kralježaka potječe s četiri lokaliteta u Bosni i Hercegovini (Dažnica, Kalenderovci, Knežica i Bosanski Lužani), dok su tri kralješka s nepoznatih lokaliteta. Na temelju usporedbe s recentnim kralješcima dviju vrsta kitova zubana (podred: Odontoceti), dobrim dupinom (Tursiops truncatus) i glavatim dupinom (Grampus griseus), određen je položaj kralježaka u kralježnici o čemu je načinjena stručna studija (ĐURAS *et al.*, 2022).

Na tri kralješka: MBP 16173 (DAŽ-9-91); MBP 16177 (KAL-17-91) i 16179 (KAL-16-91); MBP 16178 (KAL-12-91) makroskopski su uočene patološke promjene te su ovi kralješci snimljeni pomoću CT uređaja SOMATOM go.Now (Siemens AG, Njemačka) u Zavodu za rendgenologiju, ultrazvučnu dijagnostiku i fizikalnu terapiju Veterinarskog fakulteta Sveučilišta u Zagrebu.

Makroskopska analiza i CT nalaz patoloških kralježaka je sljedeći:

MBP 16173 (DAŽ-9-91): srednji slabinsko-križni kralježak, lokalitet Dažnica. Tijelo kralješka kita. Nedostaju luk kralješka, izdanci i lijevi dorzalni dio kranijalne epifize. Očuvan je kaudalni spoj nožica luka s tijelom. Poprečni izdanci su erodirani. Lijevo i ventralno na kaudalnoj epifizi vidljiva je linija loma (slika 1a), a lijevo i kaudalno na tijelu se vidi koštano bujanje (slika 1b), vjerojatno kao posljedica stvaranja kalusa nakon prijeloma. Ovaj kalus seže kranijalno do polovice tijela, a zahvaća i njegov desni ventro-kaudalni dio. Prijelom je nastao zaživotno što je potvrđeno na CT snimkama.



Slika 1. Patološke promjene na kralješku MBP16173 (DAŽ-9-91): a. linija loma na kaudalnoj epifizi (mjerilo=5 cm); b. koštano bujanje na tijelu kralješka (mjerilo=5 cm)

MBP 16177 (KAL-17-91) i 16179 (KAL-16-91): kaudalni slabinsko-križni kralježak, lokalitet Kalenderovci. Dva fragmenta tijela kralješka kita za koje je tijekom determinacije utvrđeno da pripadaju istom kralješku zbog poklapanja krugova na epifizama (kranijalno i kaudalno) i plohe duž loma na tijelu kralješka. Nedostaju kralješni otvor i izdanci. Spoj poprečnih izdanaka i tijela je na sredini lateralne površine tijela. Uz kranijalni spoj lijevog poprečnog izdanka sačuvan je mali usjek. Kaudalno od spoja luka je dobro izražena horizontalna površina koja se proteže do kaudalne epifize. Kaudalno, ventralno i lijevo uz kaudalnu epifizu je koštano bujanje koje se proteže kranijalno i ventralno tako da se teško raspoznaje ventralni greben. Kranijalni, ventralni i lijevi dio tijela nedostaje, no nazire se bujanje ventralno i desno uz kranijalnu epifizu. Lijevo i ventralno na tijelu vidi se otisak žila/živaca usmjeren kaudalno uz spoj tijela s poprečnim izdankom koji se usmjerava kraniodorzalno po površini između luka i poprečnog izdanka. Na desnoj strani taj žlijeb nije vidljiv što ide u prilog pretpostavci o koštanom bujanju na ovom dijelu kralješka.

MBP 16178 (KAL-12-91): kaudalni prsni kralježak, lokalitet Kalenderovci. Tijelo kralješka kita, nedostaju luk i poprečni izdanci i lijeva strana tijela. Spoj tijela s nožicama luka dobro je očuvan i jasno se vidi duža površina od spoja nožica do kaudalne epifize. Površina između spoja tijela s lukom i s poprečnim izdancima je manja od one u slabinsko-križnih kralježaka. Desno, dorzalno i kaudalno uz spoj desnih nožica luka je udubina ispunjena mineralnim sadržajem. Takvu udubinu imaju prsni kralješki glavatog dupina. Koštana bujanja vide se duž desne strane kranijalne i kaudalne epifize.

S obzirom na vrlo rijetke zapise o paleopatološkim promjenama na kitovima (HAMPE *et al.* 2014; GODFREY & BEATTY, 2022) ovi nalazi će zasigurno doprinijeti boljem poznavanju načina života kitova i paleookoliša u kojem su živjeli. Sličan opis zacijeljenog prijeloma na kralješku kita iz miocenskih naslaga lokaliteta Calvert Cliffs (SAD) autori pripisuju napadu velikog predatora (morskog psa) ili manje vjerojatno, kao posljedicu napadaja zbog štetnog cvjetanja algi i posljedične toksičnosti domoične kiseline (GODFREY & BEATTY, 2022).

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SEISMOSTRATIGRAPHY AND TECTONIC STRUCTURE OF THE KVARNER OFFSHORE RESEARCH AREA

SEIZMOSTRATIGRAFIJA I TEKTONSKI SKLOP ISTRAŽIVANOG PODRUČJA KVARNERSKOG ODOBALJA

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Keywords: *Northern Adriatic, 3D reflection seismic data, Adriatic carbonate basin, tectonic structure, Kvarner fault*

This research (KAMENSKI & KORBAR, 2023) is focused on the Kvarner offshore covered by 3D seismic block Aiza which is situated within the common but diachronous Adriatic foreland of the northern External Dinarides and the Northern Apennines (Fig. 1a). The main goal is to characterize the structural-tectonic setting of the research area, in particular to investigate the possible continuation of the transversal structures recognized onshore and between the islands, that could be connected

to the still insufficiently defined transversal Kvarner fault zone. We also re-investigated "compressional structures" pointed out by previous papers. One of the focuses was the evolution of the Adriatic carbonate platform and its margin.

The investigated research area of Aiza covers 652.15 km^2 of the northeastern part of the Adriatic offshore (Fig. 1a). The research included the correlation of geological data from the surrounding wells (Susak more-1 and Alessandra-1) and high-resolution 3D seismic reflection data from the research area (Aiza exploration block). A number of seismic attributes were extracted in order to perform a detailed interpretation. The construction of maps in time and depth scale was crucial for a clearer definition of the geological structures along the Mesozoic Adriatic carbonate platform to the Adriatic basin transition, which is covered by younger sediments within the Adriatic foreland. However, the emphasis was on the tectonic structures, in particular on the identification of possible faults with Plio-Quaternary activity that favour or are conducive to possible reactivation and accompanying seismic hazard.

The distribution of four main seismostratigraphical horizons: Base of carbonate platform (BCP), Top of carbonate platform (TCP), Messinian erosional surface (MES), and Plio-Quaternary horizon (PQ), as well as six dominant faults, were interpreted. The results of the interpretation of geophysical data enabled the creation of subsurface geological maps and the subsequent development of a 3D model that depicts the geological setting and evolution of the research area (Fig. 1b).

The main transversal faults striking NNE–SSW are probably related to the Kvarner fault zone that dissects the frontal thrusts of the External Dinarides. The Kvarner faults appear to have been active during late Miocene (Messinian?) since do not dissect the NW-SE striking Pliocene normal faults that were probably re(activated) during re-tilting of the distal foreland of the Northern Apennines.

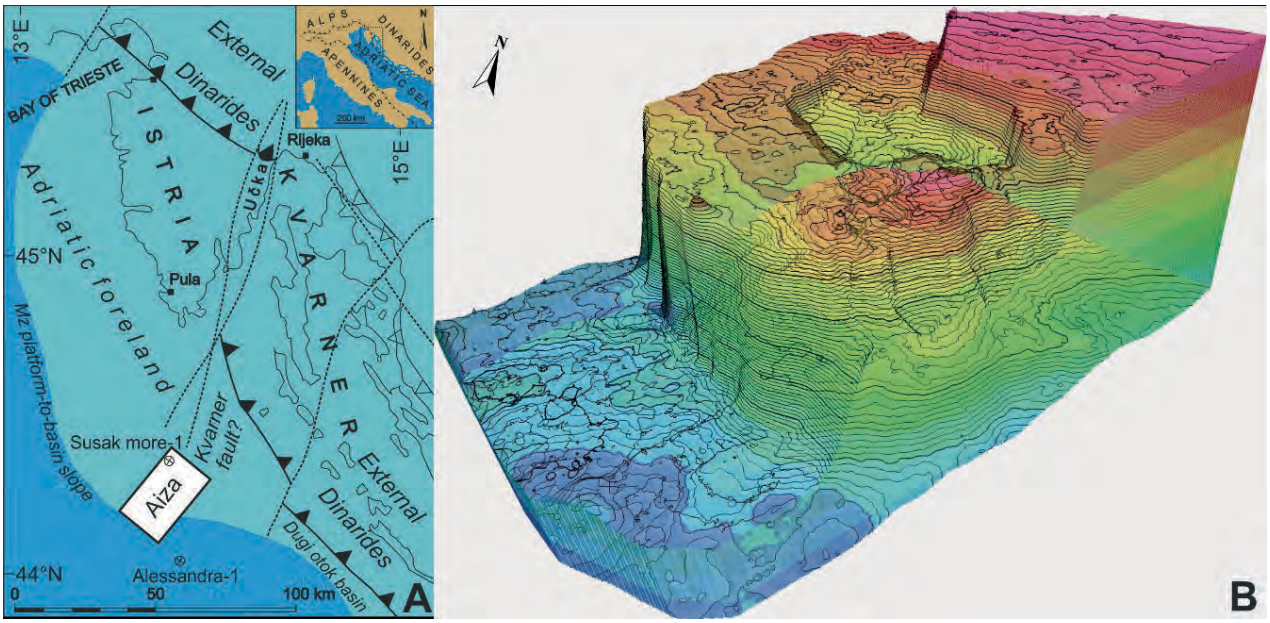

Figure 1. a. Location, palaeoenvironmental and tectonic map of the study area showing the position of the Aiza research area and the two wells (Susak more-1 and Alessandra-1), offshore Kvarner and southern Istria (contours are the shorelines of the mainland and the Kvarner islands). Inset shows location of the map in the Northern Adriatic area and the thrust fronts of the surrounding orogens. b. Oblique-imaged (panorama) model in elevation time domain that represents top of carbonate platform (TCP) within the Aiza exploration block. Z-scale has a fivefold vertical exaggeration. The depth variation interval is 2839.60 ms.

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THE ROLE OF THE GRAVEL PIT LAKES IN REDUCING GROUNDWATER CONTAMINATION WITH NITRATES

ULOGA ŠLJUNČARA U SMANJENJU ONEČIŠĆENJA PODZEMNIH VODA NITRATIMA

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Keywords: *nitrate, gravel pit lakes, groundwater, modelling*

The alluvial aquifer in the Varaždin region has experienced high nitrate concentrations in groundwater during the last decades, which is mainly related to use of fertilizers in agricultural production (MARKOVIĆ *et al.*, 2022). Since the groundwater presents the only source of drinking water for the inhabitants of this area, the research of nitrate attenuation processes has become essential for sustainable groundwater utilization. Denitrification is considered as the dominant mechanism for nitrate removal in groundwater, but certain conditions must be met for the reaction to take place, e.g. low dissolved oxygen, presence of denitrifying bacteria, electron donor etc. (RIVETT *et al.*, 2008). The aim of this research is to investigate gravel pits as possible locations for nitrate attenuation. Although gravel pits are potentially hazardous for contaminants entry into groundwater, there are other impacts on groundwater quality. The differences between studied gravel pits and the surrounding groundwater were investigated using in-situ, hydrochemical, isotopic parameters (δ18O-H2O, δ2H-H2O, δ15N-NO3 and δ18O-NO3) and groundwater modelling. The analyses indicate that nitrate attenuation processes take place in gravel pits, with expressed seasonality and differences depending on the activity of the gravel pit. The groundwater flow and nitrate transport model was developed to simulate denitrification in gravel pits and to predict possible remediation scenarios, i.e. the impact of denitrification in gravel pits on future groundwater quality.

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SPATHIAN (LOWER TRIASSIC) CONODONTS FROM THE TULCEA VECHE QUARRY (NORTH DOBROGEA, ROMANIA)

SPATIJSKI (DONJI TRIJAS) KONODONTI IZ TULCEA VECHE (SJEVERNA DOBRUDŽA, RUMUNJSKA)

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Keywords: *Biostratigraphy, Olenekian, North Dobrogea Orogen, Romania*

The richly fossiliferous Triassic strata of North Dobrogea, Romania are well known for its Tethyan-type facies (ARTHABER, 1906; KITTL, 1908; SIMIONESCU, 1908, 1927; GRĂDINARU, 2000). North Dobrogea, which lies south of the Danube Delta, is a fold-and-thrust belt called the North Dobrogean Orogen and it represents the westernmost segment of the Paleotethys-issued Cimmeride orogenic system (SĂNDOLESCU, 1995).

The focus of our study was the documentation of a conodont fauna originating from a short stratigraphic interval of the Tulcea Veche Quarry and its correlation within the Spathian conodont zonation (Fig. 1). Fully marine deposition started with a basinal carbonate sequence attributed to the Tulcea Veche Limestone (BALTREŞ, 2003). It consists of thin-bedded dark greyish mudstone interbedded with dark, bituminous marly shale, occasionally with thin beds of fine-grained grainstone. The Spathian age of the Tulcea Veche Limestone (SIMIONESCU, 1908, 1927) is also documented by a recently collected ammonoid fauna comprising *Tirolites cassianus* (Quenstedt), *T. haueri* Mojsisovics, and bivalves *Leptochondria alberti* (Goldfuss), *Eumorphotis venetiana* (Hauer), and *Crittendenia decidens* (Bittner). The ammonoid fauna is indicative of the base Spathian *Tirolites cassianus* Zone. The fossil content also includes a new coelacanth taxon, *Dobrogeria aegyssensis* Cavin & Grădinaru and its good state of preservation indicates that the anoxic/dysoxic environment precluded destruction of the bones by scavengers (CAVIN & GRĂDINARU, 2014).

The composition of the recovered conodont associations of all 23 examined samples is very similar, and they are marked by the dominant representation of species of the genera *Novispathodus* and *Triassospathodus*. The list of identified conodont elements includes the following taxa:

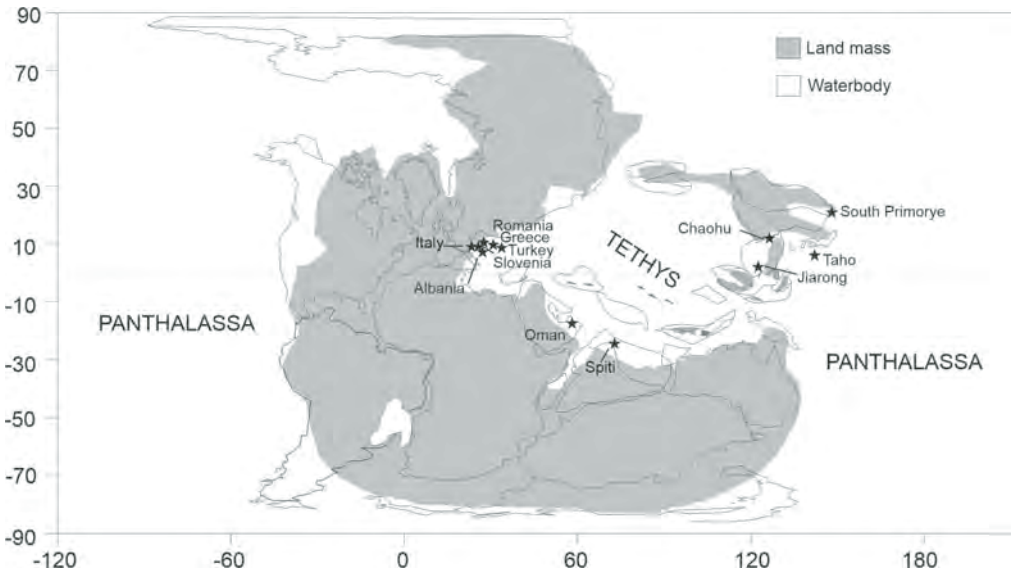

Figure 1. Paleogeography of the Olenekian world with marked important localities containing conodonts (modified after PÉRON *et al.*, 2005)

Icriospathodus crassatus (Orchard), *Neospathodus robustispinus* Zhao & Orchard, *Novispathodus abruptus* (Orchard), *Nv. brochus* (Orchard), *Nv.* aff. *brochus* (Orchard), *Triassospathodus* ex gr. *homeri* (Bender), *Tr. hungaricus* (Kozur & Mostler), *Tr.* ex gr. *hungaricus* (Kozur & Mostler), *Tr. symmetricus* (Orchard), *Tr.* aff. *symmetricus* (Orchard), and *Triassospathodus* sp. Based on the dominant occurrence of the species *Tr. symmetricus*, the recovered fauna is attributed to the *Tr. symmetricus* Zone. The absence of some stratigraphically important Tethyan taxa is noted, such as *Icriospathodus collinsoni*, *Nv. waageni*, and *Nv. pingdingshanensis,* which are missing in the Tulcea Veche Quarry, as well as in the Dinarides and Albanides.

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SALTECTA – SALT DIAPIRS AND ACTIVE TECTONICS IN THE CENTRAL ADRIATIC

SALTECTA – SOLNI DIJAPIRI I AKTIVNA TEKTONIKA SREDNJEG JADRANA

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Ključne riječi: *Jadransko predgorje, solna tektonika, dijapiri, kvartarne naslage, potresi*

Srednji Jadran je predgorje dvaju orogenih sustava – Dinarida na sjeveroistoku i Apenina na jugozapadu. Osim velike debljine naslaga, to područje obilježava i specifična predgorska tektonika te brojne solne strukture. Te halokinetske strukture različito su prikazivane na objavljenim preglednim kartama i ilustracijama geoloških profila, a tek sporadično na interpretiranim seizmičkim profilima. Solni dijapiri čine impozantne potpovršinske strukture koje mjestimice izbijaju na površinu i tako utječu na morfologiju (batimetriju) tog područja. Solne strukture srednjeg Jadrana su znanstveno nedovoljno istražene, a nije istraživana niti uzročno-posljedična veza halokinetike i umjerene seizmičke aktivnosti koja obilježava to područje. Pretpostavlja se da je izdizanje soli vezano uz neotektonsku reaktivaciju mezozojskih rasjeda, od kojih su neki vjerojatno i danas aktivni. Projektom se namjerav-

Slika 1. Pregledna geotektonska karta s označenim područjem planiranih istraživanja (crveni okvir)

aju interpretirati najnoviji 2D seizmički profili odobreni od strane Agencije za ugljikovodike (AZU), reinterpretirati gravimetrijski podatci, definirati glavni rasjedi te 3D modelirati geometrija odabranih solnih struktura. Strukturno-tektonski sklop (re)definirat će se na pučinskim otocima srednjeg Jadrana (slika 1). Uspoređivanjem prostornog rasporeda epicentara i hipocentara zabilježenih potresa s interpretiranim geološkim strukturama, pokušat će se razjasniti povezanost aktivne tektonike sa solnim strukturama. Istraživanjem i datiranjem najmlađih (kvartarnih) naslaga pokušat će se definirati neotektonska aktivnost solnih dijapira. Istraživanjem odabranih markantnih (sub)recentnih erozijskih oblika nastojat će se procijeniti prošla i buduća seizmotektonska aktivnost i seizmogeohazardi.

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DEVELOPMENT OF A GEOLOGICAL MODEL OF THE THERMAL SPRING AREA IN DARUVAR USING GEOPHYSICAL RESEARCH

IZRADA GEOLOŠKOG MODELA TERMALNOG IZVORIŠTA U DARUVARU KORIŠTENJEM GEOFIZIČKIH ISTRAŽIVANJA

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Keywords: *ERT, Daruvar hydrothermal system, fault architecture, carbonate complex*

Geothermal energy is one of the renewable energy sources foreseen in the European Union's plans for the green energy transition. Its sustainable utilisation mostly depends on the characteristics of the geothermal resource from which it is extracted. Among others, detailed geological modelling and reconstruction of the subsurface is a key factor for estimating the potential of a geothermal resource. In particular, it is crucial to determine the geometry of faults and fractures since the associated highly permeable damage zones represent a preferential pathway for the circulation of thermal fluids and their uprising (BENSE *et al.*, 2013; FAULDS *et al.*, 2013).

This research focuses on the modelling and reconstruction of the geological and structural settings in the Daruvar thermal spring area using surface geophysical techniques. Electrical resistivity tomography (ERT) was employed to delineate the geometry of resistivity layers in the subsurface. The ERT results were combined with an integrated approach based on the passive Horizontal to Vertical Spectral Ratio (HVSR) method and the active Multichannel Analysis of Surface Waves (MASW) method to map the thickness of the Quaternary cover. The geophysical data were constrained using the stratigraphic logs of wells in the spring area and its surroundings obtaining a 3D reconstruction of the geological setting.

The spatial distribution of resistivity shows relatively low values from 10 to 150 Ωm (Fig. 1). Based on ERT results and the stratigraphic logs of the wells, three resistivity layers/geological units were identified (Fig. 1): (1) the Quaternary alluvial cover with resistivity ranging between 30 and 50 Ωm (layer 1); (2) the Neogene sediments with

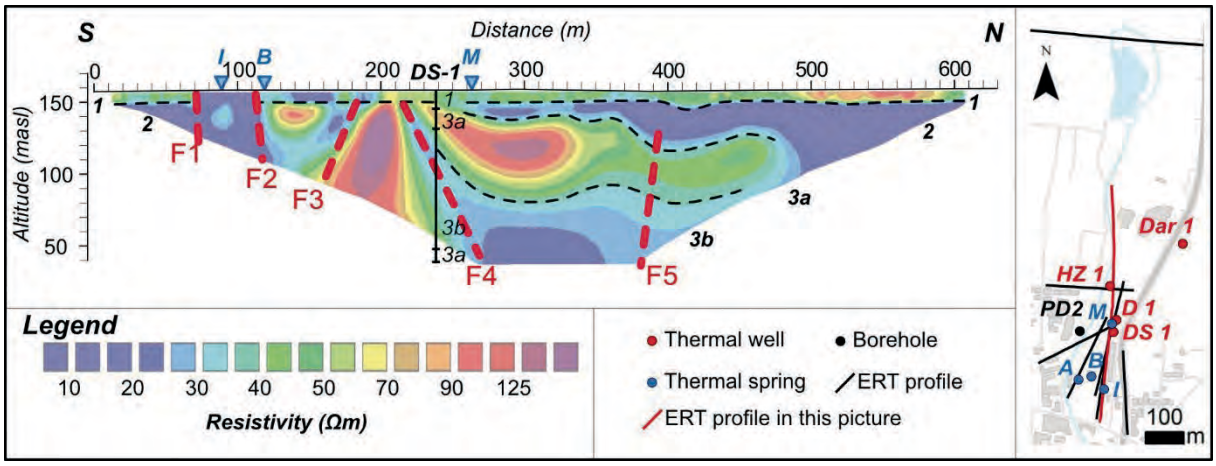

Figure 1. Inverse resistivity model of ERT profile conducted with 10 m spacing between electrodes. The ERT profile shows a general overview of the resistivity distribution in the Daruvar spring area. Dashed red lines (F1-F5) indicate fault zones characterised by low resistivities. The map shows the traces of ERT profiles (lines) conducted in the study area and the locations of springs and boreholes (dots) used for geological reconstruction. The ERT profile shown in this picture is marked by the red line.

resistivity values of 10–30 Ωm (layer 2); and (3) the Triassic dolomites that were divided in a compact layer with resistivity ranging from 70 to 150 Ωm (layer 3a) and a fractured layer characterised by resistivity values of 20–30 Ωm (layer 3b). Furthermore, sharp lateral variations in the resistivity distributions were observed. They were generally marked by low resistivity anomalies that were interpreted as the fracture zones along the faults (F1 to F5; Fig. 1). The high secondary porosity of the fault zones and the occurrence of thermal waters decrease the bulk resistivity of the rock mass.

The obtained results allowed us to reconstruct the geological setting of the Daruvar thermal spring area. The Quaternary cover has a 5 to 15 m thickness, increasing northward and eastward. Its thickness and geometry were confirmed by seismic investigations. Neogene deposits are generally found below the alluvial cover, except for the central part of the study area where the Carbonate complex, i.e., Triassic dolomites are found. Local scale faults and their fracture zones enhance the upwelling of thermal waters resulting in the occurrence of thermal springs with temperatures up to 48 °C (BOROVIĆ *et al.*, 2019). Two main faults border southward and eastward of the thermal spring area juxtaposing the highly permeable Triassic dolomites with the low permeable Neogene deposits. This lateral contrast fosters the rising of the thermal waters forming a shallow thermal resource in the Daruvar area.

Presented research has been conducted in the scope of the project "Multidisciplinary approach to hydrothermal system modelling" (HyTheC) funded by the Croatian Science Foundation under grant number UIP-2019-04-1218.

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SOIL WATER ISOTOPIC SIGNATURE IN SLOPED VINEYARD, ZAGREB, CROATIA
IZOTOPNI SASTAV VODE U TLU NAGNUTOG VINOGRADA, ZAGREB, HRVATSKA

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Keywords: *soil water, isotopic signature, sloped vineyard, experimental field Jazbina, SUPREHILL project*

Investigation of the hydrological processes that take place in the hillslope soils can be very challenging. The focus of this research is related to the examination of soil water isotopic signature at four different depths in the agricultural sloped area located in the City of Zagreb, within the experimental field Jazbina. It is a vineyard with rows separated by grassed inter-row area which are 2 m wide. According to the World Reference Base classification system the soil is classified as Dystric Luvic Stagnosol, while according to the United States Department of Agriculture soil classification system soils have been classified as silt loam or silty clay loam. The hillslope is separated into the three segments: hilltop, backslope, and footslope. Soil water has been collected at a total of 24 locations from depths of 20 cm (self-constructed instrument for collection of surface water runoff), 40 cm (passive wick lysimeters), 60 cm (self-constructed instrument for collection of subsurface runoff), and 100 cm (suction probes). Instruments installed at 20, 40 and 60 cm depth mostly collect gravitationally induced mobile water flow, while suction probes installed at 100 cm depth can additionally collect non-mobile water due to low applied suction used during sampling. Stable isotopes of hydrogen and oxygen from soil water and precipitation ($\delta^{2}H$ and $\delta^{18}O$) have been determined at the Laboratory for Spectroscopy of the Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, using laser absorption spectroscopy (LWIA-45-EP, Los Gatos Research). All results are presented in permil notation (‰) with respect to VSMOW (Vienna Standard Mean Ocean Water). Monthly sampling of soil water and precipitation has started in February 2021, while within this research all available data from one hydrological year has been examined, i.e., from October 2021 to September 2022, including a total of 138 soil water and 12 precipitation samples. It must be emphasized that sampling of soil water in summer months was not possible in most cases due to extremely dry conditions. Results show that most of the soil water isotopic signature fall on the Local Meteoric Water Line, but also that great variability is present with respect to the depth of the observation and location in the sloped vineyard. The exception is related to the isotopic signature of soil water from 100 cm depth which shows much less variability, especially in the hilltop and backslope area. All results suggest the existence of different infiltration patterns in the study area, while most of the precipitation infiltration and mixing with soil water occurs in the first 100 cm depth. Although soil water isotopic composition varies much less at 100 cm depth, it is not clear what is the origin of that water, i.e., whether the captured soil water presents older precipitation which was non-mobile in the observed period, or bulk water. From that perspective, except for the development of flow and transport models, future research should also focus on the evaluation of the influence of different sampling devices on the isotopic signature of soil water and the characterization of the isotopic difference between mobile, non-mobile, and bulk soil water.

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CASCADING EFFECTS OF HAZARDS AND THEIR IMPACT ON CRITICAL INFRASTRUCTURE IN THE CROSS-BORDER AREA

KASKADNI EFEKTI HAZARDA I NJIHOV UTJECAJ NA KRITIČNU INFRASTRUKTURU U PREKOGRANIČNOM PODRUČJU

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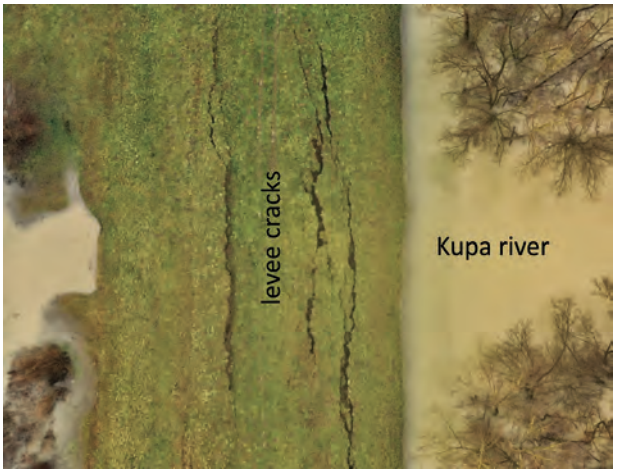
Keywords: *cascading hazards, critical infrastructure, risk assessment, civil protection*

Earthquakes and floods are natural hazards influencing large areas and causing a chain of cascading effects. Recent natural hazards in Croatia have emphasized the necessity to address the challenges of hazards' impact on critical civil engineering infrastructure in more comprehensive manner, especially considering the omnipresence of climate change effects and Croatia's earthquake-prone territory. For example, the 2014 Sava River flood (SCHWARZ, 2016) was the largest flood in Croatia's recorded history, resulting in 62 fatalities and lots of damage to infrastructure and land, while the recent earthquake events in 2020 resulted in eight fatalities and devastating consequences for buildings and infrastructure (BAČIĆ *et al.*, 2021; POLLAK *et al.*, 2021). One of the main consequences of the Petrinja 2020 earthquake was the lateral spreading caused by liquefaction of saturated and loose sands, which occurred on the flood embankments of the river Sava and on natural riverbanks of the Kupa and Petrinjčica rivers (Fig. 1a). If during this period river levels rose to normal highs the impact of flooding to the already heavily damaged cities of Petrinja and Sisak would be completely devastating. This event has shown an urgent need for the assessment of multi-hazard cascading scenarios.

Both Slovenia and Croatia are particularly vulnerable to earthquakes due to their position in the seismically active area (the juncture of three geotectonic units: the Alps in the north and west, the Dinarides in the southern, south-western and central part, the Pannonian Basin in the northeast). If an earthquake of higher magnitude occurred near the border with neighbouring Slovenia, where the Posavje region is one the highest earthquake hazard areas (Fig. 1b), the impacts would be not only cross-border but also cause cascading failures of a range of critical infrastructure, including a dam, bridges, levees, energy supply etc. In the same time, being near major European river systems, the cross-border area of Croatia and Slovenia has history of extreme floods and is marked as an area with mutual interest for flood protection.

To deal with the challenges of the multi-hazard cascading effects in the Croatian-Slovenian region along the Sava River basin, the project CROSScade (Cross-border cascading risk management for critical infrastructure in the Sava River Basin), financed through the EU Civil Protection Mechanism, focuses on the development of cross-border risk assessment methodology and action plans to increase the resilience of critical infrastructure exposed to potential combined hazards caused by earthquakes and flooding. Specifically, project analyses the vulnerability of flood protection system, hydropower plant dams and



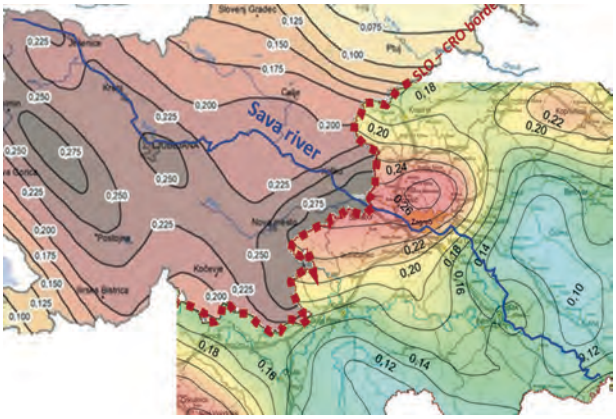


Figure 1. a. One of the many results of the Petrinja 2020 earthquake – levee transversal cracks, b. overlapped seismic hazard maps for Croatia, seizkarta.gfz.hr, and for Slovenia, arso.gov.si/potresi/

transport infrastructure, vital for Critical Infrastructure Managers (CIM) and Civil Protection Agencies (CPA, i.e. first responders) and for disaster relief operations.

The project is organized in several work packages (WPs) that carry out the planned work streams. WP 'Identification of cross-border risk management gaps and needs' identifies the gaps and needs within the national and cross-border risk management practices. 'Development of cross-border hazard scenarios' WP maps the critical infrastructure in cross-border area and develops a cascading hazard event chain representing the series of adverse hazard events generated by triggering event. It also analyses significant cross-border hazard scenarios, on which the subsequent risk assessment methodology builds upon. Further 'Cross – border cascading risk assessment' WP develops a risk methodology for the identified cascading hazard scenario, which will assess the cascading effects of critical assets' failures in cross-border area. WP on 'Cross – border action plans for cascading risks' finally develops the Action Plan for CIMs on strengthening the structural resilience of their assets to cascading hazards, as well the Action Plan for enhanced cross-border communication between the CIMs and CPAs during and after the cascading hazard events, on protocols for reducing the crisis scale up.

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THE RARE EARTH ELEMENT (REE) POTENTIAL OF CROATIAN KARST BAUXITES

GEOLOŠKI POTENCIJAL HRVATSKIH KRŠKIH BOKSITA ZA ELEMENTE RIJETKIH ZEMALJA (REE)

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Keywords: *REE, bauxite geochemistry, Croatia*

With development of modern technologies, an increasingly large range of raw materials are utilised by society. There is a growing global concern over their long-term secure and adequate supply. Raw materials of increasing economic importance and indispensability for a wide set of strategic sectors, but for which there is a high risk of supply disruption (including political and economic reasons), have been termed Critical Raw Materials (CRM). Since 2011 the European Commission has assessed every three years the list of CRMs for the European Union (EU) economy. While the demand for CRMs is projected to increase drastically, EU relies almost exclusively on imports, often from quasi-monopolistic third country suppliers. In March 2023, the severity of the situation has prompted the Commission to propose the Critical Raw Materials Act with the aim of establishing a framework for ensuring a secure, diversified and sustainable supply of critical raw materials.

The rare earth elements (REE) represent a group of 17 chemically similar elements (lanthanides, with scandium and yttrium included) and are typically divided into light (LREE) and heavy (HREE). Several members of this group are integral components in modern technology, such as magnets used in wind turbines, engines in electric cars, smartphone screens and batteries. Recycling is unlikely to be able to meet the ever-increasing demand, and thus mining of natural deposits is expected to continue as the major source for REE. Almost 90 % of all REE entering the global market is produced in China while the EU has to import all of its REE, either as raw materials or as final products (GOODENOUGH *et al.*, 2016). The European Commission has identified the REE, particularly HREE, as critical materials and research for new resources with substantial levels of REEs has become a priority in the scientific field of the world, particularly in the EU, including alternative mineral resources, in which REE can be exploited as by-products.

Bauxite deposits in EU occur potentially as genuine resource and supplier of REE for industrial and other needs of the Old Continent. Karst bauxites are formed as residual or/and detrital deposits, in the process of alteration and chemical weathering of alumosilicate-rich parent rocks in humid tropical to sub-tropical climates on subaerially exposed paleoenvironments – karstified zones of carbonate rocks. Bauxites can concentrate REEs (and other CRM) to economic levels, although the REE abundances are affected by the palaeogeographic setting, parent rock, climate, drainage, soil pH, and redox conditions (MONGELLI *et al.*, 2021). Typical values of REEs in bauxites range from < 100 ppm to ~500 ppm (DEADY *et al.*, 2014). In Croatia, karst bauxites are located in the area of Croatian Karst Dinarides. They include eight horizons spanning the period between the Upper Triassic (Carnian) and the Miocene (ILIJANIĆ *et al.*, 2023). Mining of bauxite for aluminium industry in Croatia commenced in the 16th century, and was continuous from 1914 till 1990. It has been evaluated that roughly 27.5 million tonnes of bauxite had been recovered in this period. Currently, there are only two active exploitation fields for use in processing industry. Proven reserves of bauxite in 2012 were approximately 6 million tonnes. Besides these, the database of mineral resources in Croatia contains data on locations of more than 1000 bauxite deposits and occurrences. REEs have never attracted due attention during the long history of bauxite exploration and exploitation in Croatia. Only lately, and mostly at the edge of other studies such as geochemical mapping of the Croatian karst terrains, once more they were brought into focus of interest thanks to their geochemical distinctiveness and affinity with modern terra rossa soils.

To that effect 215 bauxite samples from different horizons and locations were collected and whole rock chemical analyses of major, minor and trace elements (including REE) of the bauxite samples were carried out. The Upper Eocene karst bauxites, especially in the Obrovac area and in the areas of towns Sinj and Imotski have higher than average contents of REEs – some samples contained REE in quantities up to a several thousands mg/kg. However, exploitable potential depends on the future development of REE extraction technologies from bauxites and the total available bauxite resources. Further investigations are needed in order to clarify the future destiny of REE production in Croatia.

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MIOCENE FACIES CHARACTERIZATION AND DISTRIBUTION, DRAVA-02, PANNONIAN BASIN, CROATIA

KARAKTERIZACIJA I DISTRIBUCIJA MIOCENSKIH FACIJESA, DRAVA-02, PANONSKI BAZEN; HRVATSKA

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Keywords: *Miocene, Drava Depression, facies, organic facies, GDE maps*

Based on standard analyses of drill cuttings and core macroscopic analyses, structural and lithological characteristics, detailed biostratigraphic, petrographic and geochemical analyses from numerous wells, biofacies, lithofacies and organic facies (in palynological and geochemical sense) have been interpreted. The obtained information correlated with available seismic and wireline logs is crucial for sedimentological model characterization

(definition of time-constrained paleoenvironment with the entire suite of the associated facies) and creation of the Gross Depositional Environment (GDE) maps as sketches of facies types and their supposed distribution in the area.

The Drava-02 (DR-02) exploration area occupies the western part of the Drava Depression. It is located in the southern edge of the Pannonian Basin System (PBS), which is characterized by the presence of two separate basins, the Hrvatsko Zagorje Basin (HZB) and the North Croatian Basin (NCB), differing in their depositional settings during the Early Miocene (PAVELIĆ & KOVAČIĆ, 2018). The HZB is characterized by the prevailing marine depositional environments lasting from Egerian to Sarmatian. Neogene sedimentation in the NCB started during Ottnangian when, after a period of a long-lasting emersion, syn-rift rock- fall, alluvial and lake sediments were deposited on a weathered and tectonized Paleozoic-Mesozoic paleorelief. Although the Lower Miocene marine deposits (Egerian to Karpatian) have been found in the north-western part of the Drava Depression and in the Bjelovar Subdepression, due to a limited overflow and extension of marine sedimentation over the Legrad high, the first marine transgression (ĆORIĆ *et al.*, 2009; PAVELIĆ & KOVAČIĆ, 2018) in the Drava basin generally occurred in the Middle Badenian. Starting from the Middle Miocene, the evolution of the HZB and the NCB shared the same path.

In the largest part of the DR-02, the Neogene sedimentation began with deposition of the Ottnangian, Karpatian and Lower Badenian syn-rift continental (alluvial and lacustrine) deposits. Subsequently, from the Middle until the uppermost Badenian, the Central Paratethys marine transgression(s) covered the entire area. Besides carbonate and clastic deposits, volcanic rocks were also recorded. Towards the end of the Badenian and throughout the Sarmatian, the gradual regression took place. In the Sarmatian, the Central Paratethys became isolated from the world seas. The environments drastically changed, causing the extinction of certain organisms (foraminifera) and endemism in communities of ostracods, molluscs and dinoflagellates. Due to ecological changes, all stenohaline species gradually disappeared and euryhaline organisms prevailed. In the palynoassociation, prasinophycean algae (an exceptional precursor for quality source rocks) took over. The stratigraphic correlation of the Upper Miocene deposits is difficult due to impossibility of using the standard biostratigraphic methods which rely on established stratigraphic ranges and biozonations, caused by expansion and prevalence of the endemic species in the rock record. In addition, the prograding mechanism of sedimentation causing the shift of facies through space and time complicates the situation.

The Upper Miocene (Pannonian) deposits usually have a consistent vertical and lateral sediment succession. In the shallower environments, the deposition began with calcite-rich marls, argillaceous limestones and locally sourced coarse clastics, followed by basin marls, slope toe sandstones from subaquatic fans and turbidites of the deeper and open lake settings. Afterwards, the deposition of slope pelites, shelf and delta sediments occurred. The succession ends with deposition of alluvial and marsh deposits.

The prograding clinoforms of the slope are most easily visible on seismic logs, allowing us to acquire information concerning the depth, extension of the depositional area and the thickness of each part of the succession. The prograding mechanism of sedimentation caused the advancement of the facies in space and time, thus promoting the biostratigraphy (based on dinoflagellates and molluscs) as highly relevant for the interpretation.

The geochemical parameters, the recorded types of organic facies, source rock distribution as well as the hydrocarbon potential are causally connected to the established DR-02 sedimentological model. The source rock facies are related to the Badenian marine (shallow and deep-water) and Pannonian lacustrine (brackish) environments. The summarized data reflect either organic matter type or thermal maturity of the area. In the Pliocene, clays, gravelly sands and coals were deposited in lake and fluvial settings, often covered by Quaternary sediments deposited in continental environments.

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CONTINUOUS MONITORING OF THE KOSTANJEK LANDSLIDE AND A TOOL FOR AN EARLY WARNING SYSTEM

KONTINUIRANO PRAĆENJE KLIZIŠTA KOSTANJEK I APLIKACIJA ZA SUSTAV RANOG UPOZORAVANJA

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Keywords: *Kostanjek landslide, monitoring, early warning tool*

Landslide movements pose a substantial risk to people and infrastructure (e.g. PETLEY, 2012; HAQUE *et al.*, 2016). Sometimes, in complex or large-volume landslides, monitoring and prediction are the only reliable and cost-efficient methods for mitigating landside risk (KRKAČ *et al.*, 2019). This paper presents ten years (2013–2023) of monitoring data series observed by the Kostanjek Landslide Observatory (Zagreb, Croatia) and data application in civil protection.

The Kostanjek landslide is the largest in the Republic of Croatia. It is a reactivated deep-seated translational landslide located in the urbanised area of the City of Zagreb at the base of the southwestern slopes of Medvednica Mt. The total landslide area is approximately 1 km2. Since its activation in 1963, the Kostanjek landslide has caused substantial damage to buildings and infrastructure in the residential and industrial zones (KRKAČ *et al.*, 2020). The landslide was caused by anthropogenic factors, mainly by excavations in a marl quarry placed at the toe of the landslide (STANIĆ & NONVEILLER, 1996). Despite extremely slow to slow landslide movements over 60 years, the risk in the area is high for residents and for material properties (approx. 300 single-family houses and infrastructure networks are placed on the moving landslide mass).

In the framework of the scientific Japanese–Croatian bilateral SATREPS FY2008 project 'Risk Identification and Land-Use Planning for Disaster Mitigation of Landslides and Floods in Croatia', a Kostanjek landslide monitoring system was established with the primary objective of landslide mitigation through the development of an early-warning system (MIHALIĆ ARBANAS *et al.*, 2013). In the period 2011–2014, multiple sensor networks were set up for continuous observations of external triggers, hydrological properties and displacements (KRKAČ *et al.*, 2019).

During the period 2013–2023, the Kostanjek landslide experienced multiple reactivations, with displacements of 720 mm at the central part of the landslide. All reactivations are consequences of high groundwater levels. During the monitoring period, the groundwater level changed from 19 to 10.5 m. The cumulative precipitations that caused groundwater levels to rise ranged from 21 mm to 180 mm, depending on the initial groundwater level.

In the frame of European Structural and Investment Funds under the project "Applied landslide research for the development of risk mitigation and prevention measures" (KK.05.1.1.02.0020), a tool for an Early Warning System for Kostanjek landslide was developed. The tool consists of an application which provides a unique interface for monitoring data and information related to early warning. The application aims to provide useful information to civil protection in case of increased amounts of precipitation, high groundwater levels and increased landslide velocities.

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THE EGERIAN-EGGENBURGIAN VOLCANICLASTIC DEPOSITS IN THE SUBSURFACE OF NW CROATIA – NEW INSIGHT INTO SEDIMENTARY BASIN EVOLUTION OF MURA HYDROCARBON PROVINCE (MHCP)

EGERSKE I EGENBURSKE VULKANOKLASIČNE NASLAGE U PODZEMLJU SZ HRVATSKE – NOVI UVID U EVOLUCIJU SEDIMENTACIJSKOG BAZENA MURSKE NAFTNO-PLINSKE PROVINCIJE

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Keywords: *Egerian–Eggenburgian volcaniclastics, Zircon dating, Mura hydrocarbon province*

From the exploration point of view, the Mura hydrocarbon province (MHCP) occupies NW Croatia – the area bounded by Slovenian and Hungarian state borders on NW, N and NE, by Mts. Strahinjščica, Ivanščica and Kalnik on the S, and by the Legrad subsurface high on the SE. The oldest Oligocene–Miocene deposits outcropping in its westernmost part are of the Egerian and Eggenburgian age and were studied by many geologists. The remaining surface area, covered mostly by the Badenian and younger sediments, has been the subject of subsurface exploration for hydrocarbons over past decades.

Currently, exploration block SZH-01 is undergoing a new cycle of exploration activities that have included zircon dating on selected volcanic rocks from deep wells within the area of the new 3D seismic coverage.

The results of geochronological analysis using U–Pb LA-ICP-MS on zircons revealed that the time of intensive volcanism in central and southern MHCP took place between 24.6 and 21.23 Ma (Uppermost Oligocene, Egerian and Eggenburgian; MATOŠEVIĆ *et al.*, 2023) The relevant volcaniclastic section of predominantly andesitic and pyroclastic rocks, with thicknesses exceeding 2000 m in some places, indicate an active sin-sedimentary volcanism associated with the major fault system (southern MHCP boundary), which is the eastern continuation of Periadriatic Lineament (PAL) formed due to Adriatic and European foreland collision during the Oligocene and Miocene (TOMLJENOVIĆ & CSONTOS; 2001). Deposition in the wide Egerian-Eggenburgian basin accommodated on carbonate paleo-topography in the E part (N of Mt. Kalnik) had presumably taken place in paralic to marine environments (?). In the W part, investigated in detail on outcrops (AVANIĆ *et al.*, 2021), coastal and deltaic marine environments were determined. Structural interpretation of the new 3D seismic data in the E part of the MHCP reveals the existence of broad grabens and intra-basinal highs of WSW–ENE trend and heavily faulted section by normal NW–SE faults dipping predominantly to NE. The latter agrees with FODOR *et al.* (2021) who stated that the onset of graben formation and major phase of extension is diachronous across the Pannonian Basin System and had started already at 25–23 Ma in its S and W part.

Hiatus between Egerian and Eggenburgian was observed on outcrops by the detailed study of Eggenburgian sediments and volcaniclastics (tuff) in the W part of MHCP (AVANIĆ *et al.*, 2021). K–Ar dating performed on three glauconite samples from this section resulted in ages of 22.4, 23.1 and 22.6 Ma, which, as the author concluded, imply the recycling of detrital glauconite from older sedimentary rocks – presumably Egerian. Accordingly, 3D seismic data on the E part reveal that emersion took place over most of the MHCP for a long time, particularly in the central and S part. A major uplift in the central part resulted in the inverted Mihovljani anticline, which contains the oldest volcaniclastics in its core (poor Zr extraction, though).

The top of Egerian–Eggenburgian sequence is marked by clear angular unconformity on the 3D seismic data and superimposed by the transgressive younger Miocene sequence. Thick volcanoclastic deposits with no evidence of source rock intervals were buried bellow 2500 m of predominantly Pannonian sediments due to the later tectonic history in the SE part of the MHCP.

The main Miocene source rock bearing siliciclastic basin (without volcaniclastics) was predominantly developed in the NW and NE part of the MHCP with marine sedimentation since the Lower Miocene. Sin-sedimentary active half-grabens which had originated on pre-existing trends of WSW–ENE and E–W faults, hosted sedimentary columns of Lower and Middle Miocene deposits significant in thickness to the NW and NE (up to 2225 m). The same grabens were later inverted by Pliocene compressive phase (e.g., Ormož-Selnica structure). On the other hand, uplifted Egerian–Egenburgian deposits in the central and S part were covered by shallow marine sea only in Upper

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EARLY NEOTETHYAN HISTORY ARCHIVED IN THE OPHIOLITIC MÉLANGE OF NW CROATIA

RANA POVIJEST NEOTETISA ZABILJEŽENA U OFIOLITNOM MELANŽU SJEVEROZAPANDE HRVATSKE

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Keywords: *ophiolitic mélange, Neotethys, radiolarians, E-MORB, Ivanščica Mt.*

Ophiolite sequences as sections of Earth's oceanic lithosphere offer unique insights into the evolution of ancient oceans. While ophiolites may be preserved as large thrust sheets of relatively undisturbed lithostratigraphy, often the original sequences occur as dismembered blocks within chaotic units referred to as ophiolitic mélanges. They are formed in trench-like basins in front of advancing nappe stack during subduction and accretion, their formation being controlled by tectonic and sedimentary processes. Ophiolitic mélanges typically comprise cm- to km-sized blocks of different lithologies and ages originating from both colliding tectonic plates embedded within a fine-grained matrix. Biostratigraphy, commonly based on radiolarians, accompanied by petrological and geochemical information, plays a key role in studying ophiolites and reconstructing history of vanished oceans.

Ophiolitic mélanges are a common feature of the Dinaric orogen. The Dinarides, together with the Hellenides, were formed by continental collision and closure of the Neotethys Ocean (sensu SCHMID *et al.*, 2008), that existed between Adria and Eurasia during the Mesozoic. The main stages of the geodynamic evolution of the Neotethys included: 1) intracontinental rifting leading to the oceanization in the Late Anisian (Maliac–Meliata Ocean); 2) onset of intraoceanic subduction of Adria beneath Eurasia in the Middle Jurassic and formation of suprasubduction crust (Vardar Ocean); 3) Middle to Late Jurassic convergence with mélange formation and obduction of ophiolites on the Adria margin; 4) deposition of synorogenic deposits from the latest Jurassic to the Late Cretaceous; 5) continental collision from the Late Cretaceous to Eocene. The majority of ophiolite occurrences in the Dinarides are remnants of the Jurassic suprasubduction lithosphere. The Triassic oceanic lithosphere is almost exclusively preserved within mélanges, with the exception of two ophiolite units in Albania and Greece where radiolarites associated with mostly MOR basalts yielded Middle to Late Triassic age (FERRIER *et al.*, 2016 with therein).

The occurrences of ophiolitic mélange on Mts. Medvednica, Samoborska Gora, Kalnik and Ivanščica in NW Croatia represent the northwesternmost exposures of the Dinaridic ophiolites. These units are interpreted as formed as a part of the Repno Oceanic Domain (BABIĆ

et al., 2002), which we consider to be a part of the Neotethys. Several types of Triassic and Jurassic basaltic rocks described from these units testify about the long-lasting evolution of the ROD (SLOVENEC *et al.*, 2011).

The newly documented outcrop on Ivanščica Mt. consists of several up to hm-sized blocks of basalts and radiolarites in a pelitic matrix. The large blocks of radiolarites show clear stratification with individual beds up to 15 cm thick. The analysed samples yielded rare and poorly preserved radiolarians. Occurrences of characteristic detached spines of Oertlispongidae enabled more precise age determination of one of the samples. Co-occurrence of *Paroertlispongus multispinosus* Kozur and Mostler and *Oertlispongus inaequispinosus* Dumitrica indicates Late Anisian to Early Ladinian age. Radiolarites are found in stratigraphic contact with basalts, although that contact is slightly tectonized in one place.

The effusive basic rocks represent chemographically uniform subalkaline high-Ti massive tholeiitic basalts characterized by an enriched composition typical of E-MORB. The analysed basalts are consistent with partial melting of an enriched mantle source. Such enriched oceanic crust formed during the Early Ladinian magmatic stage in non-subduction geotectonic setting E-MORB-type. The ophiolite basalts originating from this enriched magma reflect the initial succession of oceanic protocrust formation and the onset of an ocean spreading ridge formation.

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GROUNDWATER VULNERABILITY ASSESSMENT IN THE VICINITY OF COAL ASH LANDFILLS IN ŠTRMAC (ISTRIA) AND PLAŠKI (LIKA)

PROCJENA PRIRODNE RANJIVOSTI PODZEMNIH VODA U BLIZINI ODLAGALIŠTA UGLJENOG PEPELA U ŠTRMCU (ISTRA) I PLAŠKOM (LIKA)

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Keywords: *coal ash, landfill, contamination, groundwater vulnerability assessment*

The vulnerability of an aquifer near a coal ash landfill can pose a serious threat to groundwater quality and public health. Namely, as a byproduct of coal combustion, coal ash contains various metals and other contaminants that can have numerous environmental impacts (MEDUNIĆ *et al.*, 2016; FIKET *et al.*, 2020). For this reason, it is important to conduct a complex analysis of the natural characteristics of the aquifer system and its response to anthropogenic influences to determine the degree of natural protection of the aquifer. In this regard, aquifers in carbonate rocks require a special approach to management and protection due to their characteristic features, such as a thin soil layer with discontinuous distribution at the surface and a large number of interconnected fractures that allow water to penetrate rapidly into the subsurface.

In this study, the vulnerability of the aquifer in the area of two coal ash landfills was investigated. The first landfill is located in Štrmac, a village on the Istrian peninsula, the westernmost part of Croatia, and is situated on well-drained foraminiferous limestones covered with brown soils belonging to the Chromic Cambisol class

(ŠIKIĆ *et al.*, 1969; MIKO *et al.*, 2003). The landfill consists of coal bottom ash and slag disposed of by a local foundry in the 1960s. The second landfill is located in Plaški, a village in the Lika region in central Croatia. The landfill is located on well-permeable Cretaceous deposits and medium-to-poorly permeable Jurassic dolomite rock complex (VELIĆ & SOKAČ, 1982). The landfill consists of fly and bottom ash from the former sulfate pulp factory, which was in operation from 1965 to 1991.

The COP method (C – runoff concentration, O – overlying layers, and P – precipitation) was used to assess the intinsic vulnerability of groundwater (VIAS *et al.*, 2006). Factor C is a factor describing the potential for surface runoff generation. Factor O is the factor of overlying layers, it indicates the possibility that the layer of the unsaturated zone of the aquifer retains or dilutes pollution. The third factor is the factor P, which describes the influence of precipitation. It takes into account the ability of water (in this case precipitation) to transport contaminants from the surface through the unsaturated zone to the water surface. The analysis was supported by the ESRI ArcGis software.

The results of the analysis showed that the studied sites differed in terms of their vulnerability classes, with the landfill in Štrmac having a higher vulnerability to pollution compared to the landfill in Plaški (Fig. 1a–b).

In conclusion, the study highlights the potential risks associated with coal ash landfills to groundwater quality and public health, particularly in aquifers located in carbonate rocks. It underscores the importance of conducting a comprehensive analysis of the natural characteristics of aquifer systems and their response to anthropogenic impacts to determine the level of protection needed.

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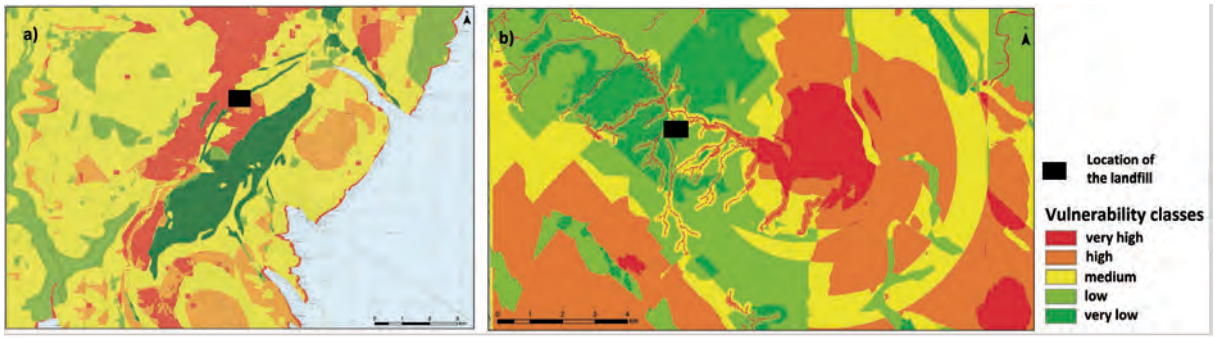

Figure 1. Vulnerability map for the wider area of the landfill in a. Štrmac and b. Plaški

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SEISMOSTRATIGRAPHIC CHARACTERIZATION OF THE SYN RIFT HALF-GRABEN INFILL, EASTERN PART OF DRAVA DEPRESSION, MIKLEUŠ AREA

SEIZMOSTRATIGRAFSKA KARAKTERIZACIJA ISPUNE POLUGRABA SIN-RIFTNE FAZE RAZVOJA BAZENA, ISTOČNI DIO DRAVSKE DEPRESIJE, MIKLEUŠ

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Keywords: *Seismostratigraphic characterization, half-graben, Drava depression*

Mikleuš area is located on the southwestern edge of the eastern part of the Drava depression, representing the southwestern margin of the Pannonian Basin System (PBS). Development started in Early Miocene with syn-rift phase of basin evolution, marked by extensional tectonic and formation of half-grabens, while the post-rift phase was characterized by basin subsidence (e.g., PAVELIĆ *et al.*, 1998; PAVELIĆ, 2001; PAVELIĆ & KOVAČIĆ, 2018). Newly recorded 3D seismic data enabled interpretation of tectono-stratigraphic evolution and defined seismic facies of half graben infill. The tectonic-sedimentary architecture of half-grabens is controlled by interaction between footwall, hanging wall and axial-derived depositional system. Hanging-wall half-grabens as main depocenters recorded extensive coarse-grained deposits intercalated sporadically with syn-rift volcanoclastic while during the early post-rift phase carbonate shallow marine production was started. To explore the hydrocarbon potential of Mikleuš area, sedimentological model was created to define the lateral and vertical distribution of reservoir and seal deposits.

A seismic facies unit with different seismic signatures can be defined as a sedimentary unit (e.g., XU & HAQ, 2022). Within half graben infill four distinct seismic facies units were defined. Defined seismic facies are: 1. discontinuous, low amplitude, chaotic reflection unit representing base of Neogene crystalline basement; 2. semi-discontinuous, low to medium amplitude reflection unit represents syn-rift coarse clastic deposition (Lower to Middle Miocene); 3. subparallel, medium amplitude reflection unit represent syn-rift Middle Miocene siliciclastic; 4. Parallel, medium to high amplitude, continuous reflection belongs to early Post-rift Middle Miocene biocalcarenites and transgressional marls. Once seismic facies units have been identified and integrated with stratigraphic and tectonic-sedimentary architecture, it is possible to translate them into paleogeographic maps illustrating the distribution of depositional environments (POSAMENTIER *et al.*, 2022).

Based on regional knowledge, seismic interpretation, seismic facies analysis, well and outcrop data, sedimentology model was made. The Lower Miocene and part of the Middle Miocene represents the earliest phase of rifting. The findings reveal that deposition during this phase occurred in continental/lake sedimentary environments within the hanging wall half-graben basin with the predominant sedimentary deposits consisting of coarse-grained materials such as rock-fall, talus breccias, conglomerates, and sandstones. Furthermore, the study indicates that during the later Middle Miocene, the extensional tectonic activity significantly slowed down and basin inversion can be observed. Due to the sea-level rise and Middle Miocene inversion, wide areas of Central Parathetys are covered with shallow seas with carbonate building organism. Inherited hanging-wall basins are quickly being filled with carbonate/siliciclastic sediments.

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BADENIAN MACROFOSSIL ASSEMBLAGES FROM THE CEPELIŠ LOCALITY (BANOVINA, CROATIA)

BADENSKA MAKROFOSILNA ZAJEDNICA NA LOKALITETU CEPELIŠ (BANOVINA, HRVATSKA)

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Keywords: *Miocene, Badenian, Banovina, paleoecology, Paratethys*

The Banovina region is located in the southwestern Pannonian Basin and the North Croatian Basin, respectively. The first paleontological studies on this region go back to PILAR (1873). Lately, MARTINUŠ *et al.* (2013) provided a biostratigraphic dating and paleoenvironmental reconstruction of the Badenian carbonate deposits from Zrin locality based on its microfauna. Currently, a corresponding macrofaunal analysis is missing.

The locality Cepeliš is situated 5 km southwest from the town of Petrinja. It shows a Badenian marine carbonate succession overlaying the nonfossiliferous Paleogene clastic deposits (PIKIJA, 1987) and crops out along a ~800-m-long road. The succession was studied from base to top in four partial sections, CEP-I, CEP-II, CEP-III and CEP-IV, intermitted by covered intervals. Altogether, 88 specimens of bivalves, corals, echinoids, gastropods and crustaceans, preserved mainly as internal molds and calcite skeletal fragments were collected for the present study.

In the first section (CEP-I), after transgression, coral assemblage of Tarbellastraea reussiana (Milne-Edwards & Haime) is recorded, associated with Balanus sp., Creusia darwiniana Prochazka and boring bivalves Lithophaga coralliophila Kleeman. Shallow marine epibenthic bivalves, such as Hyotissa hyotis (Linnaeus) and Talochlamys multistriata (Poli), are common in some intervals of this section. The assemblage resembles the middle Badenian Hyotissa and coralline algae facies of Leitha limestones in the Vienna Basin (WIEDL *et al.*, 2013) and represents a shallow subtidal environment.

The next section (CEP-II) documents the first occurrence of irregular echinoids and gastropods, whereas the corals became absent. Besides, the assemblage comprises shallow infaunal glycymerids and venerids, as well as several epibenthic pectinid species, i.e. *Manupecten fasciculatus* (Millet), *Flabellipecten besseri* (Andrzejowski), and *Talochlamys brussonii* (Serres). Dominance of shallow burrowing species indicates a shallow subtidal environment for the section. Detritivorous echinoids point to an increased organic matter of the sea bottom sediment.

Section CEP-III is marked by the increased abundance of shallow burrowing, seagrass associated, chemosymbiotic bivalve *Codakia leonina* (Basterot). The shallow burrowing bivalves dominated by *Glycymeris deshayesi* (Mayer) are most abundant in the assemblage, indicating altogether a shallow subtidal environment rich in organic matter apparently contributed by the seagrass meadows.

Finally, the section CEP-IV shows a dominance of epibenthic, cementing suspension feeders. The most abundant are corals *T. reussiana*, *Solenastrea* sp., *Porites* sp. and *Parascolymia* sp., representing a typical Badenian coral assemblage forming bioherms and biostromes (RIEGL & PILLER, 2000). The latter were inhabited by the byssally attached epibenthic bivalve *T. multistriata*.

In summary, all the macrofaunal assemblages detected at Cepeliš indicate a shallow subtidal environment. The shift from the *Hyotissa*, *Lithophaga* and coral-dominated fauna of CEP-I to the *Codakia*-rich assemblage of CEP-III indicates a moderate deepening upwards trend associated with transition from a sandy to organic rich muddy substrate, allowing the colonization of detritivorous echinoids in CEP-II, followed by the establishment of seagrass associated chemosymbiotic bivalves in CEP-III. In contrast, the coral recovery and occurrence of byssate pectinids suggest the return to relatively shallower conditions in CEP-IV.

This study was supported by Erasmus+ traineeship 2022 (2022-1-HR01-KA131-HED-000060894) and Croatian Science Foundation Project – SEDBAS, IP-2019-04-7042.

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IMPORTANCE OF DOUBLE-DEGREE MASTER PROGRAMME AT UNIZG-RGNF – EUROPEAN INSTITUTE OF INNOVATION & TECHNOLOGY (EIT) LABELLED INNOVATIVE MINERAL EXPLORATION STUDY PROGRAMME

VAŽNOST IZVOĐENJA DIPLOMSKOG STUDIJSKOG PROGRAMA INOVATIVNOG ISTRAŽIVANJA MINERALNIH SIROVINA NA UNIZG-RGNF S OZNAKOM KVALITETE EUROPSKOG INSTITUTA ZA INOVACIJE I TEHNOLOGIJU (EIT)

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Keywords: *TIMREX, EIT Label, Mineral Exploration, double-degree programme*

The University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, participates in the European Institute of Innovation & Technology (EIT) labelled double-degree master programme "TIMREX – T-Shaped Master Programme for Innovative Mineral Resource Exploration", financed by the EIT RawMaterials consortium. Beside University of Zagreb, the University of Miskolc, the University of Technology in Luleå and the University of Science and Technology in Wroclaw also participate in the mention master programme.

What is the main goal of the TIMREX double-degree programme?

Through the joint master's degree programme in mineral exploration a new generation of experts in the field of geosciences, focused on the research of mineral deposits using innovative methods with add-on entrepreneurship skills will be educated. Establishment of study program will influence the increase in the number of qualified experts for mineral deposits research in the EU, especially in the two main prospecting and mining geographic centres – Scandinavia and Eastern and Southeastern Europe.

What is the EIT-label and why is labelling important for the programme?

EIT Label is a certificate of quality that is granted only to excellent educational programmes at the master's and doctoral level. Since exploration of primary recourses is returning to Europe it is important to complement Education portfolio of EIT RawMaterials with new MSc programme in Mineral Exploration Geology. In such programme students will develop innovative mineral exploration technologies, have field based practical training, participate in international internship, partake in student research work, social and community internships, mentoring programme and have EIT chapter in the thesis work.

What will be the main students' competencies after graduating from the TIMREX?

The TIMREX students will be experts in mineral raw materials and their competencies will be developed through cooperation with other professions and industry partners. Students will acquire skills on innovative techniques of mineral raw materials prospecting complemented with field and laboratory methods, including underground and underwater environments. In addition, students will learn about environmental and ecological sustainability, social responsibility, and support of the public when exploring mineral resources.

How will the double-degree programme work?

A two-semester mobility is mandatory during the second year to one of the partner universities with the aim of obtaining two diplomas. In addition, after the first academic year of study, students will have different activities oriented to mineral raw material topics.

Who can apply to the TIMREX programme?

Candidates who have a Bachelor's degree with strong earth sciences background like BSc in Geology, Geophysics, Earth Sciences, Earth Sciences Engineering, Geosciences Engineering, Mining Engineering could apply. Students from all parts of the EU are welcome, especially

from Scandinavia and Eastern and Southeastern Europe. Student mobility is planned based on AVSA, ERASMUS+ and CEEPUS sources, but also as self-financing. Enrolment of the first generation of students with the possibility of obtaining a double-degree is planned for the academic year 2023/2024. If you are interested and want to learn more about the master study programs, visit the project website (https://timrexproject.eu/) or social networks (https://twitter.com/TIMREX_Project).

DEPOSITIONAL ENVIRONMENTS IN THE NORTHEASTERN PART OF THE NOVIGRAD PIGGYBACK BASIN DURING THE PALEOGENE (KARIN GORNJI, NORTHERN DALMATIA)

TALOŽNI OKOLIŠI U SJEVEROISTOČNOM DIJELU NOVIGRADSKOG PIGGYBACK BAZENA TIJEKOM PALEOGENA (KARIN GORNJI, SJEVERNA DALMACIJA)

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Ključne riječi: *Dinarski predgorski bazen, karbonatni klastiti, plitkovodne delte, prepletene rijeke*

Razdoblje paleogena na području sjeverne Dalmacije obilježeno je značajnom tektonskom aktivnošću, potaknutom kolizijom Jadranske mikroploče i Euroazijske ploče. Kolizija dviju ploča uzrokovala je izdizanje planinskog pojasa Dinarida, ispred kojeg se istovremeno formirao Dinarski predgorski bazen. Napredovanjem „slijepih" reversnih rasjeda tijekom eocena u proksimalnom dijelu predgorskog bazena razvio se orogenski wedge-top bazen (DECELLES & GILES, 1996), koji je zbog formiranja topografskih antiklinalnih izdignuća podijeljen na više manjih piggyback bazena (ORI & FRIEND, 1984). Navedene tektonske aktivnosti ostavile su svoj trag u slijedu naslaga, koje će nam izvrsno objasniti kako i u kojim uvjetima je došlo do njihovog taloženja.

Istraživane su naslage na području Karina Gornjeg u kanjonu rijeke Bijele, odnosno u proksimalnom dijelu predgorskog bazena, točnije u sjeveroistočnom dijelu Novigradskog *piggyback* bazena. Terenskim radom koji se sastojao od praćenja naslaga vertikalno i lateralno na izdancima i detaljnog snimanja sedimentološkog stupa „sloj po sloj" obuhvaćeno je otprilike 240 metara naslaga, koje čine karbonatni klastiti s različitim teksturama i fosilima. Na temelju sedimentološkog stupa interpretirani su facijesi. Prostorno i genetski povezani facijesi svrstani su u facijesne asocijacije koje predstavljaju specifične taložne sustave (okoliše).

Istraživani slijed naslaga obuhvaća više od 20 ciklusa plitkovodnih delti koji su odvojeni površinama plavljenja. Debljina pojedinog ciklusa iznosi od minimalno 3 do maksimalno 16 metara. Naslage plitkovodnih delti sastoje se od kalklutita, kalkarenita i konglomerata. Kalklutiti ukazuju na taloženje u distalnom dijelu prodelte, gdje je česta pojava slampova nastalih prilikom destabilizacije padine ili velikog donosa sedimenta. U plitkom podvodnom dijelu delte, odnosno čelu delte dolazi do taloženja kalkarenita s humčastom i dolinastom kosom slojevitošću i drugim tipičnim teksturama koje ukazuju na utjecaj valova, dok prisutan trend pokrupnjavanja kalkarenita označava progradaciju delte nastalu djelovanjem fluvijalnih procesa, tj. donosom sedimenta rijekama s izdižućeg orogena. Trend pokrupnjavanja prisutan je mjestimično i kod konglomerata taloženih na području deltne zaravni. Iznad ciklusa plitkovodnih delti nalazi se približno 60 metara fluvijalnih naslaga, odnosno konglomerata taloženih unutar distribucijskih kanala prepletenih rijeka i kalkarenita taloženih na njihovim prudovima i u vankanalskom prostoru.

Ciklusi plitkovodnih delti odvojeni površinama plavljenja impliciraju na česte relativne promjene razine mora koje su stvarale novi akomodacijski prostor za napredovanje delti. Iz toga se može zaključiti da je do čestih promjena razine mora dolazilo uslijed aktivne tektonike unutar Novigradskog bazena. Tijekom kasnog paleogena dolazi do slabljenja tektonske aktivnosti i bazen se ispunjava fluvijalnim sedimentima.

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HISTORICAL OVERVIEW ON HIGH SCHOOL TEXTBOOKS IN GEOLOGY AND MINERALOGY
POVIJESNI PREGLED ŠKOLSKIH UDŽBENIKA IZ GEOLOGIJE I MINERALOGIJE

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Keywords: *geology, mineralogy, textbook, high schools*

For more than 65 years, high school students in Croatia mostly do not know that geology, as one of the fundamental sciences, used to be taught at secondary level of education. Unfortunately, they are also not always aware that there are two Faculties in Zagreb where they can study geology. This may finally change with the reintroduction of geology as a subject to the 4th grade of science gymnasiums in 2021.

There were several high school textbooks, from the end of the 19th century and the first half of the 20th century that covered all the basic knowledge of geology and mineralogy. One of the first used textbooks was in German, written by WALCHNER (1840). The next textbook on mineralogy and geology was written by HOCHSTETTER and BISCHING (1882) and translated into Croatian by Mijo Kišpatić. This textbook was published in five editions and interestingly later editions bear only the names of the first author and the translator (HOCHSTETTER-KIŠPATIĆ, 1905). Bogdan Babić wrote separate textbooks for geology, mineralogy and ore geology which were approved by the Ministry of Education, which also could be used in high schools (BABIĆ, 1922a, 1922b, 1926). In the early 1920s, Fran Tućan wrote the textbook "Mineralogy and Geology" which was also approved for use in high schools (TUĆAN, 1923). In 1938, Fran Tućan wrote a new textbook that conformed to the curriculum and went through a total of seven editions until the 1950s (TUĆAN, 1938). Also available was a textbook "Geology and Mineralogy" by PETKOVIĆ (1931) with several editions. Some editions of Tućan's and Petković's textbooks were available in Latin script and some in Cyrillic script. An attempt was also made to standardise the terminology for Croatian and Serbian high school students. Tućan's textbook was also translated into Slovenian (TUĆAN, 1948).

Since the late 1950s, geology was no longer part of the high school curriculum except for a few schools, such as, for geological technicians. This reduced the need for the previously mentioned textbooks and subsequently led to the termination of their publication.

According to the new curriculum approved by Ministry of Science and Education for the subject Geology in high schools, introduced in 2021 (NN 54/2021), a new textbook "Geology" is published which comprises basic geological knowledge in six chapters: 1. Earth's origin and structure, 2. Earth's internal dynamics, 3. Earth's external dynamics, 4. Structural elements of the lithosphere, 5. Applied Geology, 6. Geology of Croatia (FIO FIRI *et al.*, 2023).

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WALCHNER, F.A. (1840): Handbuch der Mineralogie und Geognofie für alle Stände. Carl Hoffmann, Stuttgart, 868 p.

RECONSTRUCTING THE GROWTH DYNAMICS OF *MYTILUS GALLOPROVINCIALIS* IN THE EASTERN ADRIATIC SEA USING SHELL GEOCHEMISTRY

REKONSTRUKCIJA DINAMIKE RASTA ŠKOLJKAŠA *MYTILUS GALLOPROVINCIALIS* U ISTOČNOM JADRANU KORIŠTENJEM GEOKEMIJE LJUŠTURE

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Keywords: *bivalves, shells, Mytilus galloprovincialis,* $\delta^{18}O$*, shell growth*

Geochemical properties of mollusc shells (made of calcium carbonate) can serve as paleoenvironmental proxies. Stable isotopes of oxygen and carbon from bivalve shells have been widely used as a tool for reconstructing past environmental conditions (SCHÖNE & GILLIKIN, 2013). In particular, oxygen stable isotopes have been used to investigate variations in temperature, salinity and water sources (BUTLER *et al.*, 2014), while carbon stable isotopes have been used to investigate changes in individual metabolism, primary production, respiration and estuarine mixing (MCCONNAUGHEY & GILLIKIN, 2008). The mussel, Mytilus galloprovincialis is a common and commercially important bivalve in the whole Mediterranean region, and is often used as a bioindicator. A recent study validated M. galloprovincialis as a reliable recorder of seasonal seawater temperature fluctuations, supporting the use of this species in paleoenvironmental studies (MILANO *et al.*, 2019).

In this study, we collected *M. galloprovincialis* specimens (Fig. 1a) from two important bivalve aquaculture sites in the eastern Adriatic – Krka River estuary (April 2022) and Mali Ston Bay (March 2023). The first location has variable environmental conditions influenced mostly by the Krka River discharge, resulting in high variation of a temperature and salinity gradient along the estuary. In contrast, Mali Ston Bay is a relatively shallow enclosed bay with more stable conditions representing fully marine conditions. The main objective of this study was to investigate the growth dynamics and potential differences in carbon sources in specimens inhabiting these sites.

Studied shells were of similar size with a mean shell length of 65.5±3.3 mm at Krka and 65.3±1.6 mm at Mali Ston. Samples for oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) stable isotopes were acquired by manual microdrilling cross-sectioned shells. Prior to sampling, the shells were embedded in epoxy resin (Fig. 1b) and cut along the major growth axis (Fig. 1c). Temperature and salinity values were obtained for each locality, through research and monitoring

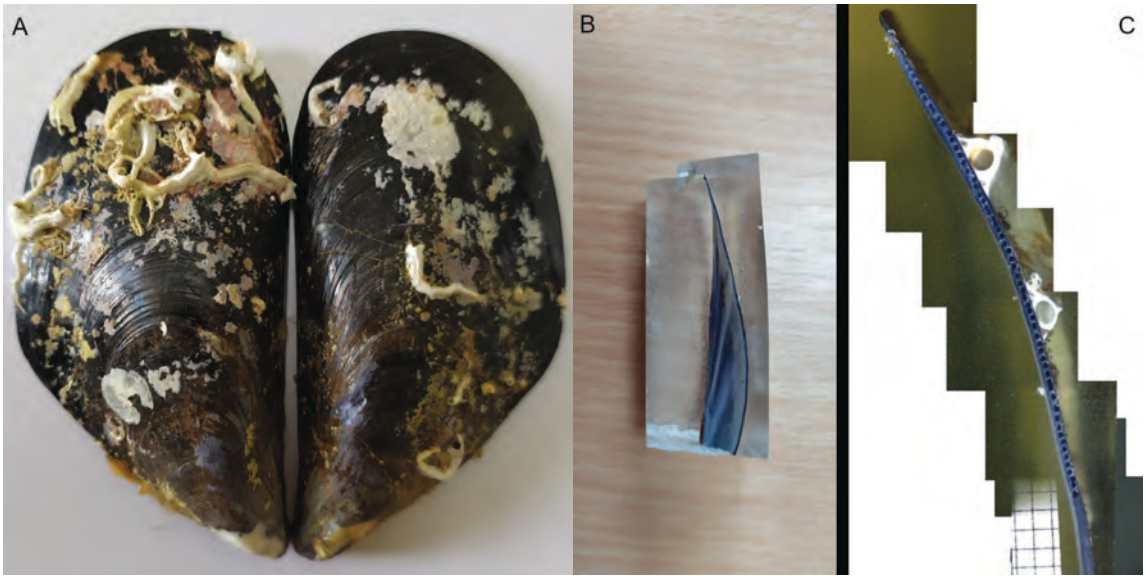

Figure 1. a. Shell of *Mytilus galloprovincialis*; b. Shell embedded in epoxy resin; c. Shell under the stereo microscope with drill holes

projects and used to calculate predicted $\delta^{18}O_{shell}$ values. By aligning the measured $\delta^{18}O_{shell}$ data along the predicted $\delta^{18}O_{shell}$ curve, it was possible to reconstruct the timing and rate of seasonal shell growth.

Preliminary results show variations in $\delta^{18}O_{shell}$ and $\delta^{13}C_{shell}$ data from two sites, with synchronicity among specimens from the same site. Significant positive correlation was found between $\delta^{18}O_{shell}$ and $\delta^{13}C_{shell}$ in specimens from Krka River estuary, while that was not the case for specimens from Mali Ston Bay. Pronounced seasonal $\delta^{18}O_{shell}$ cycles were found in specimens from Mali Ston Bay. These specimens were also characterised by the lower $\delta^{13}C_{shell}$ values than such from Krka River estuary. Preliminary results indicate faster shell growth rate for specimens from Krka River estuary. Considering that shells were deposited near isotopic equilibrium with the surrounding water, data indicate seasonal cycles with a high impact of salinity on shell isotope data. Further analyses are needed to fully understand the seasonal growth dynamics of *M. galloprovincialis*.

Research has been supported by the Croatian Science Foundation under the project BivACME (IP-2019-04-8542). Environmental data including temperature and salinity were acquired from the Interreg ADRION project "Sector Adaptive Virtual Early Warning System for marine pollution" (SEAVIEWS) for Krka River estuary and Interreg IT-HR project "CHANGE WE CARE" for Mali Ston Bay.

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MINERALOGICAL PROPERTIES OF CHERNOZEM AND CHERNOZEM-LIKE SOILS IN EASTERN CROATIA

MINERALOŠKA SVOJSTVA ČERNOZEMA I ČERNOZEMU SLIČNIH TALA U ISTOČNOJ HRVATSKOJ

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Keywords: *Chernozem, Loess-derived soils, Soil mineralogy, Eastern Croatia*

The subject of this study are the soils near the Dalj settlement and Zmajevac settlement (Eastern Croatia). The aim of this work was to determine the mineralogical properties of chernozem and chernozem-like soils in order to observe possible differences between the soils and their parent material and to better understand weathering processes in them. Samples were collected on three soil profiles. Profiles P-3 and P-6 are located on the southern side of the Dalj settlement and represent chernozem soil with developed pedological horizons Ap, A, AC and C. Soil profile P-10 is located near the Zmajevac settlement and represents rendzina with horizons A and C. Each pedological horizon was sampled for pedological analyses, qualitative and semi-quantitative analyses of heavy and light mineral fractions, and qualitative and semi-quantitative mineral analysis of particles < 2 mm and < 2 μm.

The fraction 0.09–0.125 mm was selected for modal analysis because it contains all virtual mineral species in a ratio representative of the bulk sample. The mineral composition of the fractions < 2 mm and < 2 μm was determined by X-ray powder diffraction (XRD) using a PANalytical X' Pert PRO diffractometer. XRD patterns of the clay fraction were obtained on oriented mounts after the different treatments: (a) air drying, (b) ethylene glycol solvation of air-dried samples, (c) K^+ saturation with 4M KCl solution, (d) Mg^{2+} saturation with 4M $MgCl_2$

solution, (e) DMSO solvation of K-saturated samples, (f) ethylene glycol solvation of K-saturated samples, (g) solvation of Mg-saturated samples with ethylene glycol, (h) solvation of Mg-saturated samples with glycerol, (i) heating to 400 °C for 1 h, (j) heating of the saturated samples to 350 °C and (k) heating to 550 °C for 1 h.

Based on the obtained mineralogical composition of the soil profile horizons, a gradual degradation of chernozem was determined, particularly in the form of leaching of carbonates from the surface and their precipitation in deeper horizons. The presence of a degradation process, due to the influence of recent weathering processes, can also be indicated by the presence of a small amount of kaolinite and goethite in the fraction < 2 μm. Slightly lower amounts of vermiculite in the upper part of both profiles could indicate the displacement of the clay fraction by water infiltration and wind erosion or by the possible alteration of a vermiculite clay mineral to kaolinite. Although the parent material of all three profiles is loess sediment, the reason why the soil material from profile P-10 did not develop a chernic horizon is a constant contribution of aeolian material and a short period of exposure to pedogenetic processes.

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

SUBAERIAL EXPOSURE SURFACES MARKING REGIONAL UNCONFORMITY IN THE UPPER CRETACEOUS TO LOWER PALAEOGENE PLATFORM CARBONATES, THE ISLAND OF BRAČ (CROATIA)

POVRŠINE SUBAERSKOG IZLAGANJA KAO REGIONALNA DISKORDANCIJA U GORNJOKREDNO DO DONJOPALEOGENSKIM NASLAGAMA KARBONATNE PLATFORME, OTOK BRAČ (HRVATSKA)

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Keywords: *Subaerial exposure surfaces, Late Cretaceous, Early Palaeogene, Adriatic Carbonate Platform, Brač*

Upper Cretaceous to Lower Palaeogene shallow marine carbonates are the youngest deposits on the Brač Island and contain numerous subaerial exposure surfaces marked by karstification and soil formation. The most prominent emersion surface marks regional unconformity and occurs at the top of the shallow marine Sumartin fm.

Four correlative sections on different parts of the island reveal temporally and spatially differential exhumation of parts of the former shallow Adriatic Carbonate Platform. From west to east the locations are: Cape Gomilica, Likva Cove, Babin Loz Cove and Cape Debelo Čelo. Irregular unconformity in the Cape Gomilica section cuts the upper Maastrichtian part of the Sumartin fm. and is marked with up to 1 m thick transgressive breccia. Overlaying palustrine carbonates (micrites with gastropods including *Stomatopsis* sp., charophyta remains and dasyclad algae) are followed by upper Palaeocene limestones rich in miliolid foraminifera (including *Haymanella* sp.). At Likva Cove unconformity truncates lower Danian part of the Sumartin fm., shows irregular relief and up to 2.5 m thick breccia bed composed of terrestrial carbonate clasts (black pebbles, calcretes, clasts with rhizoliths, *Microcodium* aggregates, alveolar septal fabric) imbedded in clayey calcareous and reddish matrix. The overlaying palustrine carbonates with rare *Kayseriella decastroi* are of late Danian age. At Babin Loz Cove palaeokarst surface is developed in mid–upper Maastrichtian Sumartin fm. and characterized by circular dissolution potholes several metres deep filled with reddish bauxitic material and lithoclasts of terrestrial carbonates. The presence of bauxitic material during this exposure phase indicates its longevity (> 1 Ma) and points to soil formation in subtropical to tropical climate. The overlying foraminiferal limestones are of Eocene age. At Cape Debelo Čelo unconformity truncates the Maastrichtian part of the Sumartin fm. and is overlied by a 10 m thick carbonate breccia (reworked terrestrial carbonates) followed by palustrine limestones, and finally by shallow marine carbonates.

Terrestrial periods recorded in the Upper Cretaceous to Lower Palaeogene Brač carbonates are the re-

sult of a gradual development of a forebulge in front of the emerging Dinaridic orogen. They record a regional change from the Mesozoic semi-isolated Adriatic Carbonate Platform to complex Palaeogene carbonate ramp system as well as change from the warm humid climate to semi-arid conditions.

NEW FINDINGS OF STRAIGHT-TUSKED ELEPHANT (PALAEOLOXODON ANTIQUUS) IN THE AREA OF LOWLAND CROATIA

NOVI NALAZI RAVNOKLJOVOG SLONA (*PALAEOLOXODON ANTIQUUS*) NA PODRUČJU RAVNIČARSKE HRVATSKE

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Ključne riječi: *Ilok, Stari Perkovci, srednji pleistocen, Palaeoloxodon antiquus, paleontologija*

Fosilni ostaci (kutnjaci) ravnokljovih (šumskih) slonova, koji su pohranjeni i inventirani u Muzeju grada Iloka i Muzeju Brodskog Posavlja prikupljeni su s dva lokaliteta na području ravničarske Hrvatske. Na području grada Iloka (lokalitet – ribnjak) prilikom kopanja bunara, na dvadesetak metara dubine iz prapornih naslaga iskopan je kutnjak mlađe jedinke šumskog slona. Naslage lokaliteta zastupljene su alevritskim pijescima i glinama riječno-barsko facijesa, srednjopleistocenske starosti (ČIČULIĆ-TRIFUNOVIĆ & GALOVIĆ, 1984, 1985). Drugi kutnjak izoran je na njivi (*ex situ*) u Starim Perkovcima kod Slavonskog Broda i pripada odrasloj jedinci šumskog slona. Za razliku od mnogobrojnih nalaza koji se odnose na vrste roda *Mammuthus* te se čuvaju se u zbirkama naših muzeja (LENARDIĆ, 1991), nalazi ostataka šumskih slonova rijetki su, ali predstavljaju veliki doprinos boljem razumijevanju distribucije ove vrste kao i rekonstrukciji paleookoliša za vrijeme srednjeg pleistocena na području ravničarske Hrvatske.

Za provedbu analize dentalne morfologije uzoraka korišten je standardni protokol mjerenja i metodologija utemeljena na radu MAGLIO (1973). Na kutnjacima su mjerene sljedeće vrijednosti: P – broj lamela, L – duljina (mm), W – širina (mm), H – visina (mm), LF – frekvencija lamela, ET – debljina cakline (mm), HI – indeks hipsodoncije. Dobivene vrijednosti uspoređivane su s vrijednostima iz literaturnih podataka (DAVIES, 2002) temeljem čega su nalazi determinirani kao: *Palaeoloxodon antiquus* (FALCONER & CAUTLEY, 1847)

MGI – 28918 – gornji desni kutnjak (M1) – Muzej grada Iloka (slika 1)

MBP – 37755 – donji desni kutnjak (m3) – Muzej Brodskog Posavlja (slika 2)

Lubanja šumskog slona ima ravan dorzalni profil i karakterističan vorteks (vrh) s dvostrukom kupolom. Premaksile su lepezaste i izuzetno proširene distalno. Mandibula je kratka sa slabo razvijenim simfiznim rostrumom. Kljove su velike i slabo zakrivljene. Kutnjaci su obično uski i izrazito visoki u usporedbi s vrstama roda *Mammuthus*. Relativna visina krune (indeks hipsodoncije) zadnjih kutnjaka varira od 1,8 do 2,0, a u nekim slučajevima prelazi 2,0. Lamele imaju zakrivljenost u obliku slova „S“ gledano s bočne strane. Laminarna frekvencija varira između 5 i 6. Caklina je debela 2,0 do 3,0 mm, obično je jako naborana te ima jedan do tri oštra nabora (ili sinusa) koji su često prisutni i na prednjoj i na stražnjoj strani (medijalna proširenja) caklinske petlje, tvoreći tako blago romboidnu strukturu (VIRAG, 2014). Početne figure trošenja lamela na okluzalnoj površini često su oblikovane velikom ovalnom središnjom petljom i dvjema malim kružnim bočnim petljama. To je takozvani uzorak točka-crtica-točka ili prsten-petlja-prsten, a koji se kod šumskog slona obično pojavljuje na nekoliko uzastopnih lamela, dok nije tipičan kod vrsta roda *Mammuthus*.

Šumski ili ravnokljovi slon vrsta je izumrlog slona koja je nastanjivala Europu za vrijeme interglacijala u srednjem i gornjem pleistocenu (prije 781.000 – 60.000 godina). Nalazi fosilnog šumskog slona u Hrvatskoj poznati su sa lokaliteta: Krapina, Novigrad u Istri, Sinjsko polje, Dubci, Županja, Stara Gradiška, Donji Vinjani kod Imotskog, Kninsko polje, jama Vrtare Male kod Crikvenice, podmorje kod otoka Raba i Desmerice kod Ogulina (MAUCH LENARDIĆ, 2011). Većina tih nalaza odnosi se na ostatke kutnjaka i fragmente kljova, a manji dio na kranijalne i postkranijalne skeletne elemente. Nalazi s hrvatskih lokaliteta uglavnom se pripisuju interglacijalnom razdoblju kasnog srednjeg pleistocena (prije 250.000 – 130.000 godina).

Slika 1. *Palaeoloxodon antiquus* (FALCONER & CAUTLEY, 1847), gornji desni kutnjak (M1 dext.) – bukalno, MGI – 28918

Slika 2. *Palaeoloxodon antiquus* (FALCONER & CAUTLEY, 1847), donji desni kutnjak (m3 dext.) – lingvalno, MBP – 37755

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AN EXAMPLE OF DIGITAL FIELD GEOLOGY DATA INTEGRATION TO STANDARD DESIGN SOFTWARE

PRIMJER INTEGRACIJE DIGITALNIH TERENSKIH GEOLOŠKIH PODATAKA U STANDARDNE SOFTVERE ZA PROJEKTIRANJE

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Keywords: *smartphone, digital data collection, engineering geology*

Digital data collection and geological mapping with smartphone applications have been used for over a decade and have shown many advantages to classical data gathering with an analogue geological compass (ALLMENDINGER *et al.*, 2017; BRUSH *et al.*, 2019; BUBNIAK *et al.*, 2020; OLIINYK *et al.*, 2020; CHEN & JIANG, 2022). Besides the replacement of the analogue compass device, having a smartphone as a unique field tool also replaces cameras for fieldwork photo-documentation, sheets of impractical maps used on the field and a notebook for field observation and data evaluation.

The freeware mobile application "Field Move Clino" used for this research represents a virtual geological compass and clinometer which can rapidly perform a number of given site structural data measurements (BUBNIAK *et al.*, 2020; OLIINYK *et al.*, 2020). The data obtained this way if compared to the classical analogue compass performance, statistically represent enviable structural site information with the capability of obtaining numerous data in a relatively short time (ALLMENDINGER *et al.*, 2017). In addition, the smartphone application allows for simultaneous photo-documentation linked to the single structural data point as well as customization of the point marks, which enables different types of markings and notes (other than pure structural data) in the same application. Data collection is positioned with smartphone GPS location resulting in an internet-free use of the geological compass application and the ability to perform digital field geology in remote places with no connection (which usually occurs quite often to an average geologist). Regardless of all the aforementioned benefits, inaccuracies in measured data were observed so far due to the smartphone's hardware performance (NOVAKOVA & PAVLIS, 2017, 2019; LEE *et al.*, 2018; WHITMEYER *et al.*, 2019), although these issues can be avoided or minimalised with the pre-evaluation of the used mobile device performance (NOVAKOVA & PAVLIS, 2019).

Once the data collection and mapping process for a given site is finished, the mobile application can export this data in a "mve" format used by the application itself, "kmz" format for Google Earth and GIS presentation and a "csv" format which makes a textual list of all the measurement data obtained.

The integration of such textual data into commonly used designing software such as CAD has proven to be somewhat troublesome due to the large number of measurements and different types of data obtained, as well as the difficulty of properly overlapping the measurements' locations with the design drawings. For an engineering geologist, such integration is crucial and requires fast and feasible performance since most construction designs are fast-paced and rely on the CAD software solution for the design and the presentation of field data.

This paper's research is focused on the example of the use of smartphones for digital field geology followed by relatively simple and user-friendly data manipulation for the purpose of its integration into commonly used engineering software.

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FIRST PALEOSEISMOLOGICAL STUDY IN CROATIA: PRELIMINARY RESULTS AFTER THE 2020 EARTHQUAKE ON THE PETRINJA-POKUPSKO FAULT

PRVA PALEOSEIZMOLOŠKA STUDIJA U HRVATSKOJ: PRELIMINARNI REZULTATI NAKON POTRESA 2020. NA PETRINJSKO-POKUPSKOM RASJEDU

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Keywords: *paleoseismology, 2020 Petrinja earthquake, paleoearthquakes, Petrinja–Pokupsko fault, strike-slip fault*

Paleoseismology on active faults is a well-established methodology to characterize fault activity in terms of kinematics, earthquake timing and size, i.e., to reconstruct the seismic history of faults. The 2020 Petrinja earthquake is the first earthquake for which surface ruptures were fully documented in Croatia (BAIZE *et al.*, 2021) through a coordinated field survey performed by Croatian (HGI-CGS) and international teams (INGV, IRSN, CEREGE, GeoZS). The 2020 surface faulting stimulated collaborative geomorphological, geophysical and paleoseismological studies, the latter for the first trench opening in Croatia, thanks to funding from different projects: Cogito; Seismic Hazard in CROatia: a COllaborative approach -SH-CROCO-; and, "Earthquake Geology Studies in Central Croatia: active faults and seismic potential" (supported by the Embassy of Italy in Zagreb).

In particular, four paleoseismological trenches were excavated at different sites along the Petrinja-Pokupsko fault, exposing and revealing the style of deformation of the fault and the youngest faulted deposits. Analysis of sediments and structures was performed, along with radiocarbon and OSL dating, documenting Holocene ages for the youngest surface rupturing events.

In the trench exposures, both fragile and ductile deformation occurs in a several-meter-wide zone below the fault scarp and shows that the 2020 surface rupture is expressed locally as a diffuse zone of deformation. Fault geometry and deposits deformation depict a positive flower structure characteristic of a persistent strike-slip kinematics of the fault zones. This kinematics is in agreement with the 2020 focal mechanisms and aftershocks distribution as well as the long-term morphotectonic features observed along the fault.

Upward fault terminations, open fissures, tilting and warping were used as evidence for the occurrence of dis-

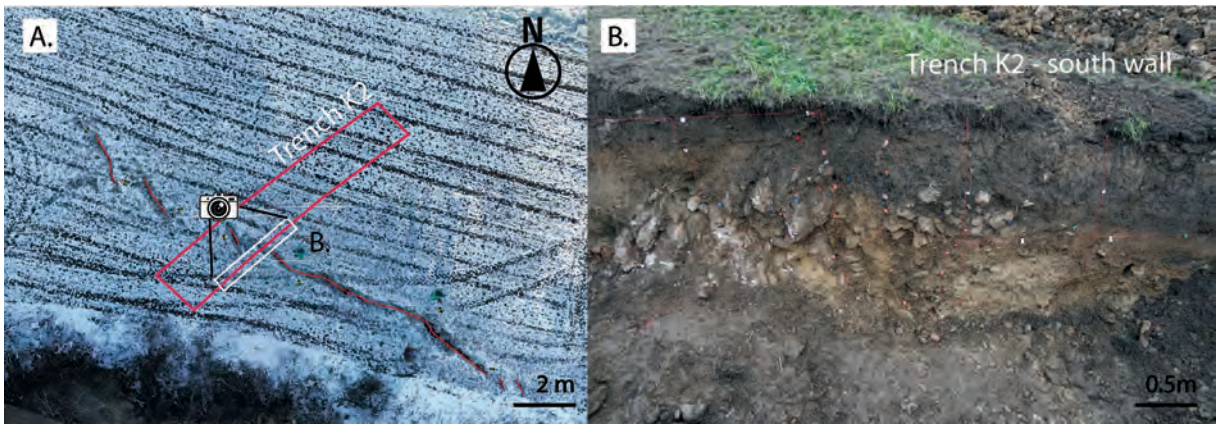

Figure 1. a. Location of the trench on the mapped surface ruptures; b. detailed view of the fault zone on the southern wall

crete paleo-surface ruptures on the central segment of the Petrinja-Pokupsko fault. This set of evidence and the available dating suggest the occurrence of a minimum of four paleoearthquakes (2020 included) in approximately the last 6 ka. This yields a preliminary average recurrence of surface rupture events along this fault of about 2000 years. Further efforts will be dedicated to documenting fault slip rate and better constraining the age of the penultimate event that, based on morphological and stratigraphic evidence at the sites, possibly occurred during Roman times in agreement with archeoseismological study from Sisak (KAZMER & ŠKRGULJA, 2021).

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STRUCTURAL ARCHITECTURE AND KINEMATIC PROPERTIES OF FAULTS IN SOUTHERN DALMATIA

STRUKTURNA GRAĐA I KINEMATSKE ZNAČAJKE RASJEDA JUŽNE DALMACIJE

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Keywords: *Dinarides, fold-thrust belt, High Karst Nappe, Dalmatian Zone, 2D/3D structural modeling, seismogenic potential assessment*

The convergence of the Adria microplate in respect to Eurasian plate and counter-clockwise rotation results in an ongoing seismicity in the area of central and southern Dalmatia, which further extends towards Albania and Greece. The area of southern Dalmatia is considered one of the three tectonically most active regions in Croatia, characterized by moderate to strong seismicity, with recorded earthquakes of Mw ≥ 6, e.g., 1667 Dubrovnik Earthquake, 1996 Ston–Slano Earthquake. Identification of potential seismogenic sources and their detailed segmentation within epicentral areas is of great importance in seismic hazard and risk assessment procedures. Hence, identification of the fault zones, i.e., potential seismogenic fault segments usually convey geological and seismological data overlap.

Here, identification of the fault system and its 2D/3D architecture focused on Dalmatia Zone and its immediate hinterland that is formed mainly from Mesozoic deposits (Upper Triassic to the Upper Cretaceous) built of limestones and dolomites, Paleogene–Neogene carbonate-clastic succession with a thin cover of Quaternary unconsolidated clastic materials. An initial dataset of ten regional geological cross-sections (c. 55 km long, perpendicular to the Dinaridic structures, based on 1:100,000 Basic Geological Maps), was constructed and used for building a conceptual geological three-dimensional model of the study area. For that purpose, the dataset was pre-processed using ArcGIS Pro, ArcGIS 10.1, and Adobe Illustrator software, whereas conceptual 2D/3D model and faults geometrical properties were constructed and computed using Petroleum Expert Move software respectively.

Results show that constructed 3D model incorporate fold-thrust architecture in which fault-bending and propagation systems are dominant, with fault dip angles between 10° and 50° (FRICKI, 2022; MASLAČ, 2022). Structural model with associated spatial relations and faults geometrical properties suggests vertical displacements greater than 3500 m (MASLAČ, 2022). Furthermore, faults geometrical peculiarities suggest a polyphase, complex tectonic history of the Dalmatia area, that is mainly associated with the presence of Paleozoic–Mesozoic decollement surfaces which enabled large scale horizontal movements, i.e., structural shortening and tectonic uplifting. Additionally, the distribution of hypocenters (www.earthquake.usgs.gov) further suggests a complex fault system, i.e., seismogenic source geometries; with highly corrugated surfaces and sub-vertical orientation in the near-surface area, whereas in the deeper sections, mapped fault surfaces convey gentle into listric-shaped geometries (Fig. 1; FRICKI, 2022). Based on fault param-

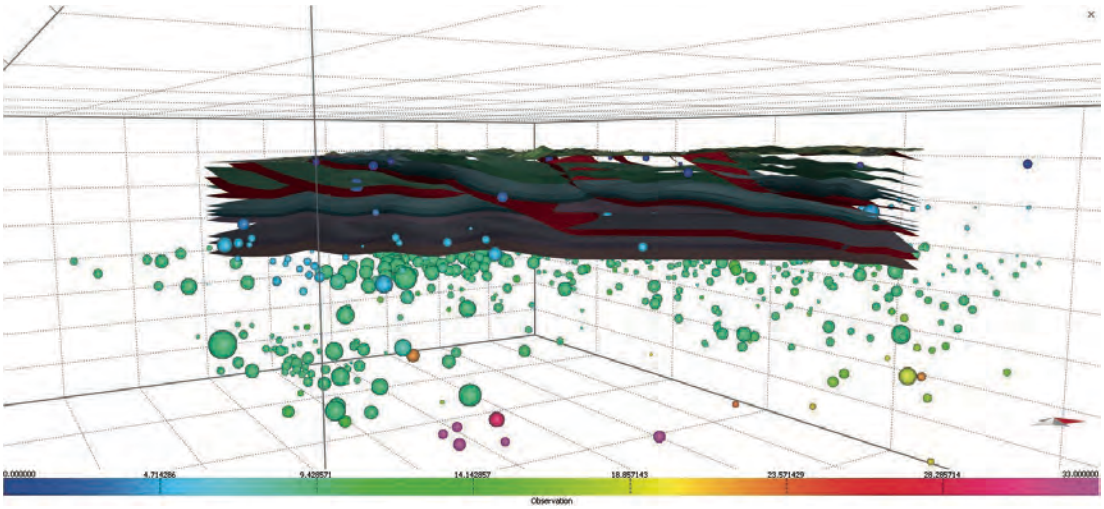

Figure 1. NW part of the 3D conceptual geological model of Southern Dalmatia (see FRICKI, 2022)

eters and empirical computation described in the work of WELLS & COPPERSMITH (1994) and derived properties of modeled fault surfaces of the studied area, the estimated maximal magnitude potential that may occur along mapped fault segments can range from M_w 5.5 to 7.5.

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ANALYSIS OF STRUCTURAL-TEXTURAL PROPERTIES OF CENOZOIC CARBONATE BRECCIA IN AREA OF NP NORTHERN VELEBIT

ANALIZA STRUKTURNO-TEKSTURNIH OBILJEŽJA KENOZOJSKIH KARBONATNIH BREČA NA PODRUČJU NP SJEVERNI VELEBIT

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Keywords: *Mt. Velebit, External Dinarides, fracture and fault system, lithofacies, Cenozoic breccia*

The Velebit Mt., a prominent geomorphological structure on the eastern Adriatic coast, extend from Senjska Draga in the northwest to Zrmanja River in the southeast and cover an area of 2280 km2 (VELIĆ, 2007). With a length of 150 km and 14 km average width, Velebit Mt. represents a fault-related anticline, that is a part of the External Dinarides/Karst-Dinarides, a fold-and-thrust belt extending from the Alps in NW to the Albanides at SE. The Velebit Mt. is built from thick Late Paleozoic-Mesozoic-Oligocene carbonate-clastic succession, largely composed of shallow-marine platform carbonates (≥ 5000 m; see VLAHOVIĆ *et al.*, 2005).

The Velebit Mt. was formed by a complex Eocene–Oligocene thrusting along the NE margin of the Adria Microplate (e.g., TARI & MRINJEK, 1994; TARI, 2002; SCHMID *et al.*, 2008, 2020), resulting in a complex anticline structure, made from NW–SE trending asymmetric anticlines bounded by faults (ŽEBRE *et al.*, 2021 with). Due to Velebit Mt. formation complexity, its tectonic evolution is explained by three scenarios. The first scenario according to BAHUN (1974) and PRELOGOVIĆ *et al.* (1995, 2004) assumes that the tectonic uplift of the Velebit Mt. in a hangingwall of the NE-dipping reverse Velebit fault, which strikes along the Adriatic coastline. The second scenario suggests that the Velebit anticline developed as a positive flower structure along the Cenozoic transpressive dextral-reverse fault (KORBAR, 2009). The third scenario proposed by BALLING *et al.* (2021) suggests formation of the Velebit Mt. monocline that includes a SW-dipping Lika passive backthrust and tectonic uplift of Velebit Mt. in its hangingwall, formed over SW-propagating thrust sheets resembling a triangle structure. These three scenarios are very different and controversial because large areas are covered by Cenozoic carbonate breccias (VLAHOVIĆ *et al.*, 2012) and Quaternary deposits that cover important tectonic contacts and fault zones.

In this study, our principal research objectives were associated with identification of the structural assemblage and structural-textural properties of the Cenozoic carbonate breccia (CCB), known as both Jelar and Velebit breccia (see VLAHOVIĆ, 2012 for details), in the area of NP Northern Velebit. In the National Park area that covers about 115 km^2 of northwestern part of Mt. Velebit, CCB cover 57 % of theterrain. The CCB are massive, non-bedded, clast-supported, poorly sorted and tectonized. They contain clasts of surrounding Jurassic/Cretaceous limestones, mainly ranging in size from less than a millimetre to a couple of centimetres with sporadic cobbles and boulders (see VLAHOVIĆ *et al.*, 2012). In addition, CCB often exhibit multiphase features characterized by the presence of breccia lithofacies which incorporate fragments of previously formed carbonate breccias. The CCB are also multiphase fractured and filled with calcite veins, while locally containing subrounded to rounded clasts indicative of transport through small-scale fluvial systems.

Our study which encompassed geological mapping along nine geological field profiles (covering nearly 60 km) and more than 470 field observed locations indicates that CCB in the NP covers a smaller area (less than 29 %) and includes at least two breccia lithotypes: i) polyphase, polymictic breccia and b) monomictic breccia (Fig. 1). The CCB are characterized by a zonal spatial distribution that gradually extends from polymictic/monomictic breccia to crackle breccia, to tectonized Jurassic/Cretaceous limestone protoliths, and finally to the surrounding homogeneous Jurassic/Cretaceous limestone. The transition between the CCB and the surrounding limestone units is gradual (several meters/tenths of meters wide) and is often associated with both NW–SE striking sub-vertical fracture systems as well as steep SW-dipping fault systems. Similar to the findings of TOMLJENOVIĆ *et al.* (2017), structural analysis of fracture and fault data collected in the Park area suggests N–S, NE–SW and NW–SE extension, while in addition to the general extension, a group of NW, NE-striking subvertical fracture systems/faults with preserved kinematic indicators suggests dextral/sinistral movements as a result of N-S compression. Both kinematic phases can be associated with younger deformation phases (post-Mt.Velebit Eocene–Oligocene formation) that may be associated with Mt. Velebit gravitational collapse relaxation and horizontal movements that probably both enhanced and opened existing/new fracture systems that were eventually filled and tectonized with existing/newly formed breccia material.

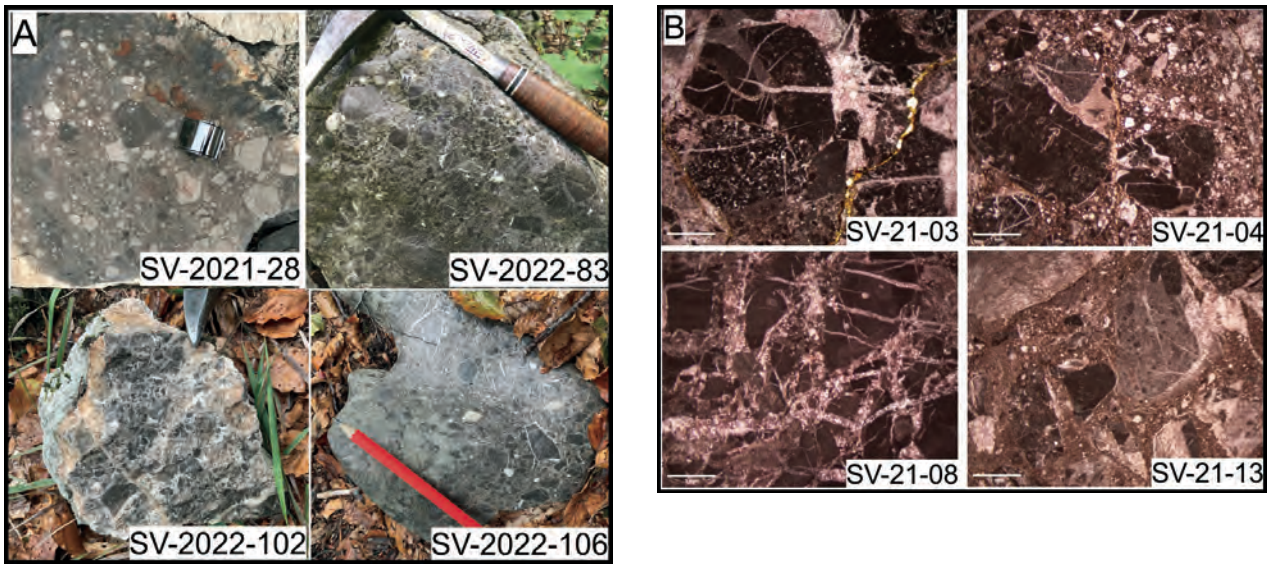

Figure 1. a. Samples of polymictic/monomictic Cenozoic carbonate breccia collected in area of NP Northern Velebit. b. Microphotographs of polymictic/monomictic Cenozoic carbonate breccia collected in area of NP Northern Velebit.

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NEWLY DISCOVERED DINOSAUR TRACKSITE ON THE ISLAND OF VIS (CROATIA)

NOVOOTKRIVENO NALAZIŠTE OTISAKA STOPALA DINOSAURA NA OTOKU VISU (HRVATSKA)

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Keywords: *dinosaur footprints, theropods, Cenomanian, Vis Island*

Although the sediments deposited on the former Adriatic Carbonate Platform (AdCP) crop out along the entire Croatian coast there is a significant difference between the number of dinosaur tracksite found in Istria versus those in Dalmatia (MEZGA, 2010). To date there has been only one tracksite found on Hvar Island, as opposed to twenty found on the Istrian peninsula. Now a new tracksite has been discovered on the island of Vis, at the eastern side of St. George Bay (uvala Sv. Jurja). The outcrop is situated at the seashore and during stormy weather it is in direct contact with sea water. The whole surface of the outcrop is quite eroded due to sea water abrasion, but also due to the human activity.

There are several isolated footprints found on the outcrop. The best preserved one (Fig. 1) is tridactyl, mesaxonic, longer than wide. On the distal end of the digits there are conspicuous V-shaped claw impressions. The footprint is 165 mm long and 125 mm wide, with long

and slender digits and straight digit axes. The middle digit is the largest one (110 mm long and 40 mm wide) while the other two are of similar dimensions. The left digit is somewhat detached from the other two and separated from the middle one by a pronounced bulge which could indicate that this digit is digit II. The digits are widest in their middle part and become narrower proximodistally. The angle that the axis of the left digit closes with the axis of the middle digit is larger than the one between the axis of the middle and the right digit. Total divarication between the outer digits is 37°. Around the footprint there is a pronounced expulsion rim especially between left and middle, as well as on the distal end of the right digit. Inside this rim, there are also visible concentric grooves which probably formed due to cracking under pressure. We interpret the footprint as a true track rather than undertrack although it is relatively shallow when compared to its average size, which means that the sediment consistency was rather solid and firm. The metatarsal impression is visible along the proximal end of the right digit. Regarding the position of digit II, which is represented by a left digit, it is concluded that this print represents the track of the right foot. On the basis of the claw marks or pointed distal end of digital prints, relatively slender digit impressions and generally longer than wide footprint, we conclude that this print belongs to a medium-sized bipedal theropod dinosaur. Beside the above described footprint there are also a couple of faintly visible footprints with similar morphology and dimensions situated on the same trackbearing layer. There are no visible trackways at the outcrop; the footprints are situated randomly with different orientations.

The carbonate succession at the dinosaur tracksite is characterized by predominately mud supported limestones deposited in a peritidal environment with Chondrodonta and rudist shells as most common macrofossil and lamination as structural property. The trackbearing layer is laminated intertidal limestone. According to the data from the basic geological map of Croatia (KORBAR *et al.*, 2012), the age of the footprints is interpreted as Cenomanian.

Figure 1. Theropod footprint found at the Vis tracksite

The Late Cenomanian dinosaur ichnocoenosis from Croatia is constituted of theropod and sauropod footprints found at several localities in Istria. Theropod footprints are the most common. When compared to the other Late Cenomanian theropod footprints in Istria, the footprints from Vis tracksite show close resemblance in terms of morphology and dimensions.

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RECONSTRUCTION OF THE PLEISTOCENE AND HOLOCENE SUBMERGED PALAEOENVIRONMENTS OF THE JADRO RIVER (CENTRAL DALMATIA, CROATIA)

REKONSTRUKCIJA POTOPLJENIH PLEISTOCENSKIH I HOLOCENSKIH PALEOOKOLIŠA RIJEKE JADRO (SREDIŠNJA DALMACIJA, HRVATSKA)

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Keywords: *submerged landscape, paleochannels, Jadro River, sub-bottom profiler*

The submerged landscape studies of interaction between sea and land in the coastal area is an important field for the study on global paleoenvironmental changes. This study focuses on the submerged paleo valley of the Jadro River located within the boundaries of Kaštela Bay (depths up to 50 m) and Splitski Channel (depths between 70 m and 50 m) in central Dalmatia, Croatia. The recent Jadro River is some 4.5 km long and discharges into Kaštela Bay. During the LGM, the length of the Jadro River reached more than 50 km and discharged into the Mid Adriatic Deep through the Šolta Channel (between the islands of V. Drvenik and Šolta) where it probably formed a wide delta. Archaeological studies show that this region was populated during the Palaeolithic (KARAVANIĆ *et al.*, 2022) and Epigravettian (VUKOSAVLJEVIĆ & PERHOČ, 2017) and through the Neolithic to the present. The reconstructions of submerged landscapes and riverine the paleochannels of rivers are therefore of exceptional importance to the archaeology of pre-Holocene periods. The present seafloor surface shows little evidence of the Jadro paleo valley and channels, because of the infill with Holocene marine sediments. The sub-bottom profiling (SBP) geophysical survey within the area allowed the distinction of a wide LGM floodplain valley in the Splitski Channel showing several lateral generations of paleochannels. The Holocene sediment layer is relatively thin and is usually less than 3 m thick in the offshore areas of the Splitski Channel. Accumulations of Holocene sediments with up to 10 m exist only in the deepest parts of Kaštela Bay, mainly covering depressions in the Eocene flysch deposits. In the northern part of the bay, at depths less than 20 m, the Holocene sediment cover is almost absent and the SBP reflectors indicate the morphology of flysch deposits as they are outcropping on land today. The survey also indicates that an Early Holocene estuary was formed in the Jadro River paleochannel along the eastern rim of Kaštela Bay. The thickness of the estuarine sediments is approximately 5 m and at present they are covered with about the same amount of younger Holocene marine sediments (Fig. 1). An important event recorded

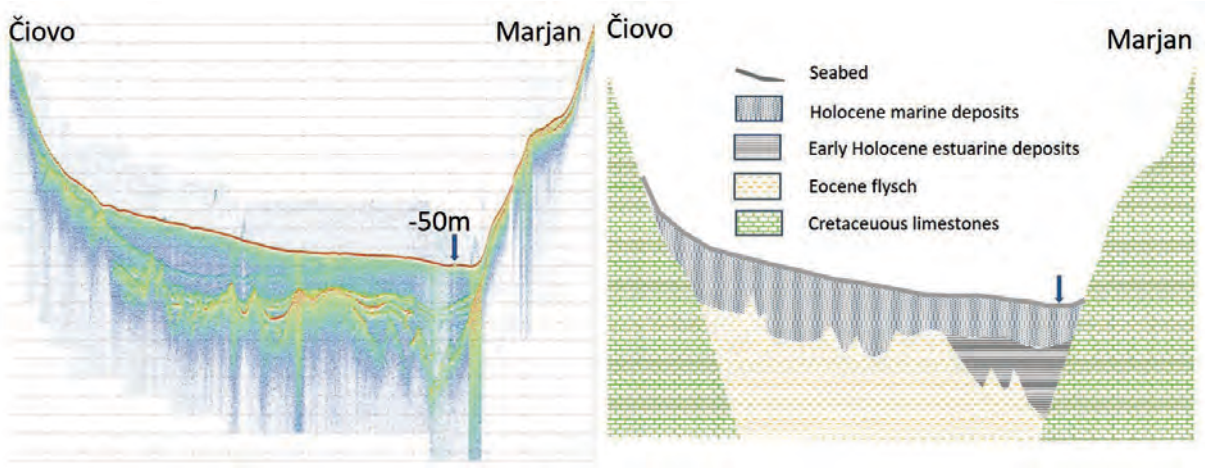

Figure 1. Sub-bottom profile showing the Pleistocene morphology on Eocene flysch deposits, the early Holocene estuarine sediments of the paleo Jadro River and the overlaying Holocene marine sediments. The profile is oriented S–N going from the eastern coast of Čiovo Island to the western tip of the Marjan peninsula.

on the north-western edge of Kaštela Bay is the formation of an alluvial fan (Divulje) dated to 18.8 ky BP, which covers the Eocene flysch deposits. Alluvial fans record climate-driven erosion and sediment-transport processes and therefore indicate that precipitation exerts (or ice melt in the hinterland) was the primary control on fan sedimentation during the Late Glacial. A robust morphologic analysis of shallow buried channel systems in the now submerged valley of the Jadro river has been made based on the interpretation of high-resolution seismic profiles.

The results indicate that the Pleistocene channel systems and floodplain was covered with only a thin Holocene sediment layer in Splitski channel during the period between 50 ky BP and 13 ky BP, when the area was subaerially exposed. It was then drowned and filled during the sea level rise caused by Holocene transgression. This landscape and floodplain hosted both the Neanderthals (KARAVANIĆ *et al.*, 2022), and later the Epigravettian hunter-gatherers. The flooding of Kaštela Bay commenced after the formation of a short-lived early Holocene estuary in the paleochannel of the Jadro River. The study area exhibits the processes from fluvial and estuarine to fully marine.

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DEVELOPMENT OF OPEN EDUCATIONAL RESOURCES ON PERMANENT MAGNETS AND RARE EARTH ELEMENTS

RAZVOJ OTVORENIH EDUKACIJSKIH MATERIJALA O TRAJNIM MAGNETIMA I ELEMENTIMA RIJETKIH ZEMALJA

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Keywords: *Open Educational Resources (OER), Learning Management platform MoD, Digital Academic Archives and Repositories (Dabar), Rare Earth Elements (REE), permanent magnets*

In the frame of the EIT RawMaterials RECO2MAG project (https://reco2mag.rgf.bg.ac.rs/), which focus is on optimizing the manufacturing process of permanent magnet microstructures through novel grain boundary processing to produce resource-efficient sintered NdFeB PMs with lowered Dy content and improved energy products for use in novel electric motor designs, Open Educational Resources -OER (UNESCO, 2022) on permanent magnets and rare earth elements were developed.

Firstly, syllabi for two online courses: (1) "Green Deal and Circular Economy Challenges of Rare Earth-based Permanent Magnets with Technical Aspects", and (2) "Rare Earth Elements Value Chain Gaps and Opportunities in the ADRIA Region" were designed. The courses were aimed primarily at master's and Ph.D. students, but also at researchers, policy-makers and raw material exploration and production experts worldwide, but with emphasis on RIS (Regional Innovation Scheme) countries, i.e. countries and regions in Europe where the pace of innovation is modest or moderate (https://www.eitmanufacturing.eu/what-we-do/regional-innovation-scheme-ris/about-us/). Syllabi included: courses information (title, description, and instructor information); courses objectives, courses outlines (topics to be covered); course agenda; required materials; grading policy; and learning activities.

Following the design of the syllabi, the online courses were successfully implemented in academic year 2022/23. Both courses had a shorter version consisting of six hours of lectures, panel discussions, and quizzes. Panel discussions and lectures were recorded. Successfully completed the long version of the course that included additional 24

hours of teamwork was awarded with one ECTS credit. For each course there were more than 100 applicants from more than 35 countries. Finally, short version of first and second workshop successfully passed 49 and 71 respectively.

To ensure the courses' sustainability, the learning materials and recorded lectures have been adapted as OER. These materials, including text, video, quizzes, and links to other open-source materials on the internet, are placed on the e-learning platform MoD (https://mod.srce.hr/) using course design. MoD is an e-learning system based on the open-source Moodle software system established to support e-learning projects within the academic community. Copies of both e-courses have been placed in the Digital Academic Archives and Repositories (DABAR) of University of Zagreb Faculty of Mining, Geology and Petroleum Engineering (https://repozitorij.rgn.unizg.hr/) under the CC0 license. This type of Creative Commons licence implies that the contents are freely available to the public and can be accessed, reused, repurposed, adapted, and redistributed by anyone without any cost. The developed OER serve as a free and self-sustainable platform for the dissemination of knowledge gained during the project's implementation.

UNESCO (2022): The 2019 UNESCO Recommendation on Open Educational Resources (OER): supporting universal access to information through quality open learning materials. Document code: CI-2022/WS/7 Rev. 16 p. (https://unesdoc.unesco.org/ark:/48223/pf0000383205.locale=en).

STRUCTURAL MODELLING OF WESTERN MARGIN OF MT. PAPUK AND MT. PETROVA GORA: THE CASE STUDIES OF THE DARUVAR AND TOPUSKO HYDROTHERMAL SYSTEMS

STRUKTURNO MODELIRANJE ZAPADNIH OBRONAKA PAPUKA I PETROVE GORE: ISTRAŽIVANJA HIDROTERMALNIH SUSTAVA DARUVARA I TOPUSKOG

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Keywords: *SW Pannonian Basin, 2D/3D structural modelling, thermal aquifer, hydrothermal system, geothermal energy*

In the SW Pannonian Basin area, geothermal gradients and heat flow are higher than the world average (≥3 °C/100 m; JELIĆ *et al.*, 1995). This work presents the results of conducted structural investigations in the Daruvar and Topusko areas (MILEUSNIĆ, 2022; MIŠIĆ, 2022), which are parts of hydrothermal systems in the central part of the Republic of Croatia. Daruvar and Topusko hydrothermal systems are two out of three research areas investigated in the scope of the installation research project "Multidisciplinary approach to hydrothermal system modelling" (HyTheC) funded by the Croatian Science Foundation.

Regionally, Topusko hydrothermal system lies within the area of the Sava Suture Zone, i.e., the contact zone between the Adria microplate and the Tisza-Dacia mega-unit, while Daruvar hydrothermal system belongs to the Tisza-Dacia mega-unit. To understand the recharge and discharge areas of the Daruvar and Topusko hydrothermal systems, we focused on structural modelling of subsurface conditions by defining lithofacies distribution and fault geometry, identifying the predominant fracture systems, potential reservoir rocks, and their hydrogeological parameters. Additionally, the principal objectives were to construct preliminary conceptual 3D models of Mt. Petrova Gora and the western slopes of Mt. Papuk. We conducted extensive structural-geological field observations, which were combined with available geological and geophysical data. Collected structural data of bedding, foliation and fracture system orientations were analyzed using stereographic projection. The principal stress axes and stress field were calculated for the mapped fault planes. At the same time, up to six geological cross sections were created for each preliminary conceptual 3D model of the studied areas. Results show that both Daruvar (Fig. 1a) and Topusko structural models (Fig. 1b), i.e., hydrothermal systems, were hosted by complex,

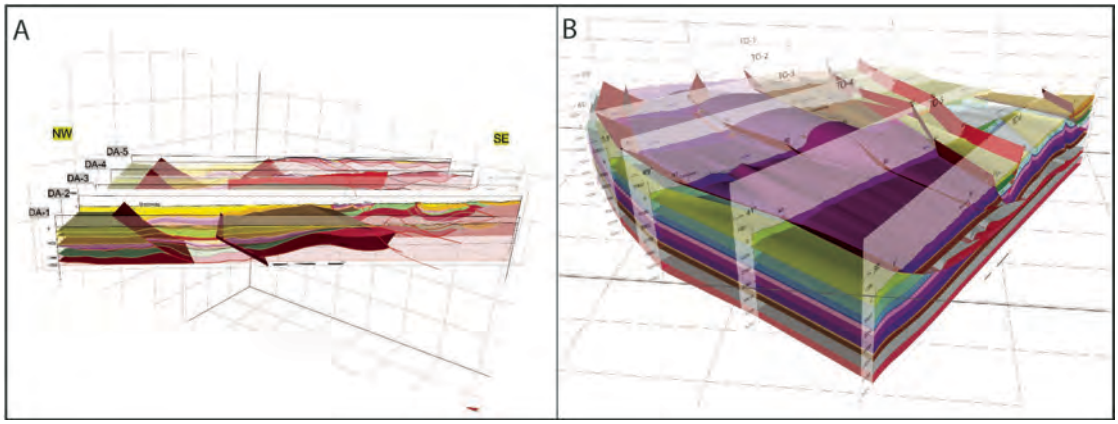

Figure 1. Conceptual 3D structural models: a. Daruvar subsurface model, b. Topusko subsurface model

heavily faulted structural assemblage composed of Mesozoic carbonate-clastic complex (predominantly Triassic carbonates). Its footwall is composed of Paleozoic magmatic and metamorphic rocks, whereas the hanging wall, is covered with Neogene-Quaternary clastic succession. 2D/3D structural models suggest that hydrothermal systems of Daruvar and Topusko are deformed by fault systems, which were tectonically active/reactivated and inverted during Late-Cretaceous-Paleogene and Neogene-Quaternary time, accommodating up to 400 m of vertical movements in Daruvar hydrothermal system and ≥ 2000 m in Topusko hydrothermal system. Both hydrothermal systems are affected by at least three kinematic phases that are associated with Late Cretaceous-Paleogene compression, Neogene extension, and Late Neogene–Quaternary compression/transpression as a result of tectonic inversion of the SW Pannonian Basin. Stress axes are similarly oriented during the identified kinematic phases in both hydrothermal systems. In the study of Topusko area, we preliminary computed the volume of the Triassic aquifer and the volume of water in the aquifer based on the theoretical value of effective porosity.

Considering the tectonic position of the studied areas in relation to the Sava Suture Zone, the nappe systems and inherited underground structures, it can be assumed that the heat flow is transferred to the Triassic hydrothermal aquifer through existing fault systems, which allow heating of groundwater (MILEUSNIĆ, 2022; MIŠIĆ, 2022).

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LITHIUM AND BORON IN EFFUSIVES FROM BÜKKALJA VOLCANIC FIELD
LITIJ I BOR U EFUZIVIMA VULKANSKOG POLJA BÜKKALJA

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Keywords: *Bükkalja, effusives, biotite, boron, lithium*

The aim of this abstract is to analyse the mineralogical and chemical composition of effusive rocks from the Bükkalja Volcanic field and to determine which minerals host lithium and boron. The Bükkalja Volcanic Field, covering an area of 2 km^2, is located in the northern part of Hungary and is part of the Pannonian Basin in the Carpatho-Pannonian region (Fig. 1). The most common volcanic rocks found there are deposits of pyroclastic flows and lapilli-bearing tuffs (HARANGI *et al.*, 2005 and therein), with majority of rocks being of Miocene age (LUKACS *et al.*, 2017). It has been suggested that products of large eruptions that emerged during the Miocene can be found throughout the Pannonian Basin, while in Croatia they can be found in the Kalnik Volcanoclastic Complex, Hrvatsko Zagorje and Sinj Basins, but also elsewhere through Europe (BRLEK *et al.*, 2023). Furthermore, the lithium and boron lacustrine sediments of the Western Balkans are probably related to the Miocene volcanic episode (BOROJEVIĆ ŠOŠTARIĆ & BRENKO, 2022). The samples used for this study are from different Miocene units: Wind-Kalnik Unit, Eger Unit, Mango Unit, Demjén Unit and Harsany Unit, with one sample from Kuchyna Tuff. A total of 12 samples were analysed.

Polarised light microscopy and X-ray diffraction were used to determine the mineral composition of the samples, while X-ray fluorescence was used to determine the bulk chemical composition. One quarter of samples were milled to the size of fine powder, while three quarters of the crushed samples were then sieved through 2 mm, 1 mm, 500 μm, 250 μm and 125 μm sized sieves and separated to extract biotites for further analysis. The separation was done using the magnetic separation for fractions between 125–250 μm and 250–500 μm and hand selection method for fractions between 500 μm–1mm, 1–2 mm and bigger than 2 mm. For each sample, magnetic and non-magnetic fractions were obtained, with the magnetic fraction consisting mainly of biotite. To determine

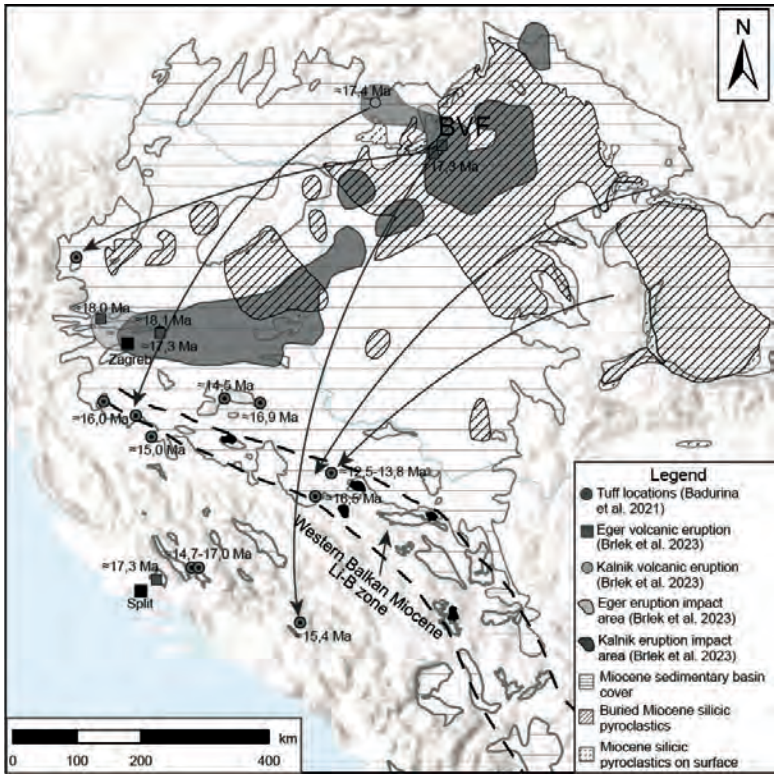

Figure 1. Overview map with Miocene volcanism and tuff in Panonian Basin depicting spatial and temporal distribution according to HENCZ *et al.* (2021); BADURINA *et al.* (2021), BOROJEVIĆ ŠOŠTARIĆ & BRENKO (2023) and BRLEK *et al.* (2023). Abbreviations: BVF – Bükkalja Volcanic Field.

the lithium and boron concentration, individual fractions were subjected to atomic absorption spectroscopy.

According to microscopic analysis, main minerals in all samples are sanidine, plagioclase and quartz, which are in the form of phenocrystals. Biotite is also the main mineral in 11 of 12 samples, comprising between 5 and 15 % of the sample. The biotite varies between fresh and highly altered, and shows a high degree of chloritization and opacification in some samples. Semi-quantitative XRD analysis confirmed presence of feldspar and plagioclase minerals, with contents up to 65 %. Presence of 14 Å peaks, most likely from the smectite group, was detected in 10 analysed samples, with contents up to 25 %. Additionally, analysis of one tuff sample from the Demjén Unit in Hungary revealed the possible presence of apatite mineralization. The matrix is mainly devitrified volcanic glass, which is reflected in high SiO_2 concentrations, ranging from 61 to 73 % according to X-ray fluorescence measurements. The X-ray fluorescence measurements also showed that Al_2O_3 is the next most abundant oxide, with concentrations ranging from 10 to 16 %. FeO content ranges from 1.5 to 4 %, CaO content from 1.7 to 8 %, K_2O content from 1.7 to 6 % and MgO content from below 1 to 2.6 %. The concentrations of MnO, SrO, BaO, TiO_2 and P_2O_5 are below 1 %, except for one sample where the concentration of P_2O_5 is 3.8 %. Atomic absorption spectrometry was performed separately for magnetic and non-magnetic fractions, with the exception of one sample containing no ferromagnesian minerals. In the non-magnetic fraction, the concentrations obtained were mostly below the detection limit and could only be measured in 3 samples. In these samples the lithium concentrations ranged from 4.2 to 21.7 mg/kg, whereas the lithium concentrations in the magnetic fractions ranged from 15.2 to 41.2 mg/kg. The boron concentrations in the non-magnetic fraction range from 835 to 4505 mg/kg, while the boron concentrations in the magnetic fractions range from 3044 to 26 204 mg/kg. Although the lithium concentrations in both fractions are relatively low, the magnetic fractions of all samples show an enrichment of boron and lithium compared to the non-magnetic fractions. It follows that both lithium and boron may be present in the crystal structure of biotite and its alterations, such as chlorite.

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TRACING THE ORIGIN OF LAGO MARE BIOTA: OSTRACODS AND MOLLUSKS FROM THE LATE NEOGENE OF THE SLAVONIAN MOUNTAINS IN THE SOUTHERN PANNONIAN BASIN (NE CROATIA)

PORIJEKLO LAGO MARE BIOTE: KASNONEOGENSKI OSTRAKODI I MEKUŠCI SLAVONSKIH PLANINA JUŽNOG DIJELA PANONSKOG BAZENA (SI HRVATSKA)

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Keywords: *ostracods, mollusks, Lake Pannon, Eastern Paratethys, Messinian Salinity Crisis*

Lake Pannon was a huge central European long-lived endorheic lake settled in the Pannonian Basin System and surrounded by the Alps, Carpathians and Dinarides mountain ranges during the late Neogene (PALCU *et al.*, 2021; HARZHAUSER *et al.*, 2023). The rise of brackish Lake Pannon enabled establishment of specific environmental conditions which triggered a spectacular adaptive radiation of a great number of autochthonous mollusk and ostracod species. The latter species represent excellent regional paleoecological proxies and biostratigraphic markers due to their good preservation-potential and taxonomic richness. Although dominantly endemic to Lake Pannon, some of its taxa managed to migrate into the Eastern Paratethys and have also been reported from the Mediterranean. These species are restricted to the Lago Mare interval, representing the ultimate stage of the Messinian Salinity Crisis, a significant environmental perturbation characterized by massive evaporite deposition. The Lago Mare interval was apparently forced by a drainage of the Eastern Paratethys brackish water into the Mediterranean (STOICA *et al.*, 2016; ANDREETTO *et al.*, 2021). The Bozara section is situated in the southern Pannonian Basin at the southern slopes of Mt. Papuk and carries a well-preserved benthic fauna representative of Lake Pannon. The 27 m thick section consists of alternating pelitic sediments and sand packages divided into four facies: silty marl and calcareous silt (F1), sand (F2), intercalation of sand and sandy silt (F3) and clayey silt (F4). According to the regional stratigraphic division it belongs to the Nova Gradiška Formation. We detected therein 25 ostracod and 17 mollusk taxa allowing an integrated evaluation of the depositional setting, biostratigraphic position and paleogeographic distribution pattern. The paleoecology of Bozara fauna documents a general shallowing upward trend along the section from calm deep-water sublittoral to deltaic high-energy littoral conditions. Based on presence of several biostratigraphic markers, such as the bivalve Rhombocongeria rhomboidea and the ostracod Caspiocypris pontica the stratigraphic position of the Bozara section is constrained to the Portaferrian substage (8.0–4.5 Ma).

From 16 ostracod taxa determined at species level, 10 can be found in the Eastern Paratethys deposits, whereas only three are shared with the Mediterranean Lago Mare. In contrast, among 12 corresponding mollusk taxa, only four are shared with the Eastern Paratethys, while being completely absent from the Lago Mare interval. Such a paleobiogeographic pattern suggests that the Lake Pannon outflow and faunal migration into the Eastern Paratethys, ceased distinctly before the Lago Mare phase and the corresponding migration of Paratethys biota into the Mediterranean basin.

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APPLICATION OF ANALYTICAL METHODS (OM, XRPD, FT-IR, ICP-MS) IN EXAMINATION OF RAW MATERIALS USED FOR POTTERY PRODUCTION

DOPRINOS ANALITIČKIH METODA (OM, XRPD, FT-IR, ICP-MS) U ISTRAŽIVANJU LONČARSKIH SIROVINA KORIŠTENIH U PROIZVODNJI ARHEOLOŠKE KERAMIKE

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Ključne riječi: *lončarska tehnologija, glina, sirovina, analitičke metode*

Ulomci keramičkih posuda jedni su od najučestalijih i najbrojnijih nalaza na arheološkim nalazištima tijekom svih razdoblja ljudske prošlosti. Iako su ponekad stariji i više od nekoliko tisuća godina i dalje sadrže vrijedne dokaze povezane s tehnologijom proizvodnje i izborom sirovina. Ovaj rad predstavlja istraživanje arheološke keramike i potencijalnih glinovitih sirovina prikupljenih u okolici višeperiodnih arheoloških nalazišta u Baranji i Istri. Cilj istraživanja je utvrditi sastav lončarske smjese (glinovita sirovina i primjese) koju su lončari koristili za izradu posuda te utvrditi dostupnost izvornih sirovina i istražiti njihovu prostornu distribuciju. Analitičke metode korištene u istraživanju su optička mikroskopija (OM), rendgenska difrakcija na prahu (XRPD), Fourierева transformacija infracrvena spektroskopija (FT-IR) i geokemijske analize (ICP-ES, ICP-MS). Optička mikroskopija omogućuje određivanje mineraloško-petrografskog sastava uzorka te boje, mikroteksture i dvoloma matriksa. Rendgenska difrakcija na prahu koristi se za određivanje mineralnog sastava glinovitih uzoraka dok FT-IR analiza pruža uvid u sastav i podrijetlo materijala korištenog za ukrašavanje posuda. Pomoću geokemijskih analiza određuje se koncentracija glavnih oksida, elemenata u tragovima te elemenata rijetkih zemalja u keramici i glinovitim uzorcima. Usporedba keramike i glinovitih uzoraka na temelju optičke mikroskopije i geokemijskih analiza ukazuje na nekoliko potencijalnih izvora sirovina najčešće udaljenih nekoliko kilometara od nalazišta. Glinovita sirovina korištena za proizvodnju keramike uglavnom se sastoji od kaolinita i klorita s manjom količinom bubrivih minerala glina. Rezultati istraživanja ukazuju i na korištenje različitih vrsta primjesa (grog, pljeva, litoklasti, grafit, kalcit) koje su u glinu dodavane tijekom pripreme lončarske smjese. Vrsta primjesa na području Baranje karakteristika je pojedine društvene skupine odnosno različitih razdoblja prošlosti dok je za područje Istre karakteristična kontinuirana upotreba kalcita kroz sva razdoblja prošlosti. Analiza materijala za ukrašavanje posuda ukazuje na organsko podrijetlo materijala. Rezultati istraživanja potvrdili su korištenje lokalno dostupnih materijala te istovremeno ukazali kako izbor sirovina (gline i primjesa) značajno varira među istraživanim regijama. Kontinuirana upotreba iste primjese u Istri ukazuje na ograničen izbor resursa koji odgovara ujednačenoj geološkoj građi područja sastavljenoj od karbonatnih stijena (HRVATSKI GEOLOŠKI INSTITUT, 2009). Različite vrste primjesa korištene u Baranji posljedica su geološki raznolikijeg okoliša (HRVATSKI GEOLOŠKI INSTITUT, 2009) koji se sastoji od aluvijalnih i eolskih naslaga uz rjeđu prisutnost magmatskih i sedimentnih stijena.

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ESTIMATION OF THE GEOTHERMAL POTENTIAL IN THE VELIKA GORICA EXPLORATION AREA, SAVA DEPRESSION AND KARLOVAC SUBDEPRESSION, CROATIA

PROCJENA GEOTERMALNOG POTENCIJALA NA PODRUČJU VELIKE GORICE, SAVSKA DEPRESIJA I KARLOVAČKA SUBDEPRESIJA, HRVATSKA

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Keywords: *Geothermal energy, reef-type limestones, Velika Gorica area, Sava Depression, Croatia*

Geothermal energy is a renewable energy source that is stored inside the Earth and can be used sustainably. The Republic of Croatia is geologically divided into two parts: the Pannonian Basin in the north and the Dinarides in the south. The northern part of Croatia represents the south-western margin of the Pannonian Basin, which is characterised by a high geothermal gradient (average 0.05 °C/m).

The Velika Gorica exploration area belongs to the geological region of the Pannonian Basin. The larger part of the studied area belongs to the Sava Depression, the smaller southern part to the Karlovac Subdepression.

The Sava Depression is one of the largest depressions in the Croatian part of the Pannonian Basin. The (neo)tectonic activities that took place from the Miocene onwards had a significant tectonic influence on the development of the depression. In the Early/Middle Miocene, continental rifting occurred (e.g. HORVÁTH & ROYDEN, 1981; TARI, 1994; TARI & PAMIĆ, 1998; LUČIĆ *et al*., 2001; PAVELIĆ, 2001; PAVELIĆ & KOVAČIĆ, 2018), when normal faulting formed elongated half-graben. In the Late Miocene (Pannonian), the Sava Depression undergoes a period of post-rift thermal subsidence, after which inversion and uplift of structures occurs in the Pliocene and Quaternary due to the general stress conditions changing from extensional to compressional (HORVÁTH & ROYDEN, 1981; TARI, 1994; TARI & PAMIĆ, 1998; LUČIĆ *et al*, 2001; PAVELIĆ, 2001; PAVELIĆ & KOVAČIĆ, 2018). As a result of the compression, old faults were reactivated and new ones were created.

The exploration area is covered by geophysical data, 2D seismic, partly 3D seismic and magnetotelluric data. Within the polygon of the Velika Gorica exploration area, either for hydrocarbon or geothermal exploration, seven wells have been drilled.

Geothermal potential was proved in reef-type limestones of Middle Miocene age, which belong to the syn-rift phase of the basin's development. Data from seven exploration wells were analysed and a seismic interpretation of the regional horizons was made. Based on the seismic interpretation and the well data, a conceptual model for the development of the studied area of Velika Gorica was created. The conceptual model fits into the regional framework of the development of the Sava Depression. Maps of the top and bottom of the main geothermal reservoir (reef-type limestones) were produced by integrating all available data and the seismic interpretation of the pre-Pannonian unconformity Rs7. The reef-type limestones extend to a major fault along which a minor half-graben opened in the Middle Miocene. The reef-type limestones were deposited in a shallow sea and their existence was proven in the Lomnica-1, Odra-1, Savica-1, Resnik-2 and KBNZ-1A wells. At the same time, there were no conditions for the deposition of limestones in the half-graben, where marls were deposited as typical sediment of deep-sea environments. This interpretation is confirmed by the sediments drilled in the Kopčevec-1 and Rugvica-2 wells.

Reef-type limestones represent a good geothermal water reservoir with excellent reservoir properties and a total thickness up to 100 m. The expected porosity is between 15 and 18 %. The seal consists of calcareous marls and marls deposited in the post-rift phase. This paper describes a new structural-tectonic framework based on which an area with good reservoir properties has been proposed for the exploration of geothermal potential. Based on the new geological interpretation, a numeric model was created that predicts the dynamics of geothermal water production.

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ZRINSKA GORA: NORTHWESTERN MARGIN OF THE SAVA SUTURE ZONE
ZRINSKA GORA: SJEVEROZAPADNI RUB SAVSKE SUTURNE ZONE

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Keywords: *Zrinska Gora, Sava Suture Zone, low-temperature thermochronology*

Suture zones represent collision zones of intense deformation between two (or more) tectonic units, often formed in different paleogeographic domains. The Dinarides and Helenides orogenic belts host the Sava Suture Zone (SSZ) – a belt of magmatic-metamorphic rocks and sedimentary basin fill created by the Late Cretaceous–Paleogene collision between the Adriatic microplate and the European plate (e.g., USTASZEWSKI *et al.*, 2009). The tectonostratigraphy of the SSZ is relatively unknown, mostly due to the extensive Neogene cover of Pannonian basin in its northern and northwestern part or tectonic reduction between two oceanic domains in its central and southern part. The major constraints on the tectonic development of the SSZ have been obtained from the limited outcrops, especially in northern Bosnia and Herzegovina (e.g., Prosara, Kozara and Motajica), Serbia (Belgrade area, Kopaonik) and North Macedonia (Klepa). In Croatia, rare outcrops of SSZ are exposed on Požeška Gora and Moslavačka Gora, with undefined positions within the SSZ. A relatively unknown area of the SSZ is Zrinska Gora which is a direct northwestern continuation of Kozara Mountain. Along the SSZ, the wider area of Zrinska Gora consists of two sutured geotectonic units – the ophiolitic complex of the Central Dinaridic Ophiolite zone and the Paleozoic-Mesozoic rocks of the Sana-Una unit (Pre-Karst unit; SCHMID *et al.*, 2020).

Zrinska Gora exposes a succession of deposits genetically related to a Cretaceous-Paleogene syntectonic basin formed during the final collision stage of Neotethys Ocean. In a few spots in the southwestern part of Zrinska Gora, transgressive transition to ophiolitic unit is present in the form of basal breccias and breccia-conglomerates with mafic and metamorphic clasts (ŠIKIĆ, 2014). These basal deposits are topped by Campanian pelagic limestones of "scaglia" facies. "Scaglia" limestones show gradual transition to deposition of sandstones in alternation with marls and shales, i.e., turbidites during the Paleocene (BABIĆ & ZUPANIČ, 1976). The Paleocene turbiditic succession displays a distinct thickening and coarsening upward trend which reflects gradual filling of the basin. This led to the replacement of turbiditic deposition with shallow water deposition of coarse-grained clastic rocks and sporadically of Eocene shallow marine foraminiferal limestones (JELASKA *et al.*, 1970; LUŽAR-OBERITER *et al.*, 2019).

The eastern part of Zrinska Gora, near the Una River, exposes a succession related to a different basin. It comprises Upper Cretaceous deep water clastics with turbiditic characteristics and carbonates. The characteristic of this basin is the occurrence of mafic and neutral magmatic rocks and, possibly, tuffs. In the available outcrops, the contact of the magmatic formations with the surrounding sedimentary rocks appears to be primary where different size magmatic bodies are encased within the sedimentary succession.

Zrinska Gora, located between Bosnian Inselbergs (e.g., Kozara, Motajica, Prosara) and Medvednica Mt., represents an important geological terrain among the fragmented exposures of the SSZ and adjoining Dinaric zones, which were involved in the tectonic history of the SW edge of the Pannonian basin. Here, we present research outline and preliminary results of the thermal history reconstruction of the wider area of Zrinska Gora, which involves correlation of new geochemical and thermochronological data with existing data from surrounding areas. Based on vitrinite reflectance, which provides temperature information for each geotectonic unit in the Zrinska Gora area, the Sana–Una unit reached the highest temperature of about 350 °C, the ophiolitic unit around 170 °C, while the youngest unit of the SSZ and

the central part of Zrinska Gora reached temperatures of around 120 °C. All those data suggest that the apatite-based low-temperature thermochronometers, such as U–Th/He with closure temperature at approximately 70 °C, should have experienced total reset and that obtained ages represent cooling ages. The first apatite U–Th/He ages show that the exhumation of the central part of Zrinska Gora took place in middle Miocene times.

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EXPLORING THE OXYGEN ISOTOPE VARIABILITY IN PRECIPITATION AS A PRECONDITION FOR PALAEOCLIMATE INTERPRETATIONS

ISTRAŽIVANJE VARIJABILNOSTI IZOTOPNOG SASTAVA OBORINA KAO PREDUVJET ZA PALEOKLIMATSKE INTERPRETACIJE

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Keywords: *oxygen stable isotopes, precipitation, speleothems, palaeoclimate, Nova Grgosova Cave*

Speleothem oxygen isotope records provide an important information on environmental conditions at the time of their growth, including changes in precipitation, temperature, atmospheric circulation, etc. The captured isotopic signature is a cumulative record of site-specific processes acting in the atmosphere, soil, epikarst and cave air, that preceded the calcite deposition within the cave.

Palaeoclimate interpretations of the stable isotope variability in speleothems, as well as in many other natural archives (e.g. lake sediments) rely on our understanding of modern stable isotope systematics of precipitation at the study location. Oxygen isotopic composition of precipitation is firstly dependent on the isotopic composition of the vapour source, usually ocean surface water. The isotopic composition is then modified by processes associated with phase changes and fractionation, primarily controlled by temperature and relative humidity, but also due to many other factors including the latitude, altitude, air mass trajectories, distance of the studied site with respect to the vapour source etc. To determine which processes and factors are the most dominant at the study site, long term monitoring of precipitation isotopic composition is required.

In this presentation we outline preliminary results of a study performed in the vicinity of the Nova Grgosova cave in NW Croatia. To explore the major drivers of isotopic composition in the precipitation at this site we sampled rainfall samples on daily and monthly resolution, measured the amount of rainfall and air temperature at the site. We compared our results to meteorological data provided by Croatian Meteorological and Hydrological Service and performed back trajectory analysis in order to assess the atmospheric water vapor mass dynamics and the potential modifiers of its isotopic composition. This long-term study will provide additional support that speleothems from this cave are valuable regional palaeoclimate records.

INTERACTIVE EXHIBITION/WORKSHOP "GET TO KNOW THE EARTH – LOOK INTO THE MICROSCOPE " – GEOLOGY AND GEOSCIENCES POPULARIZATION PROGRAM OF THE DEPARTMENT FOR POPULARIZATION OF GEOLOGY AND GEOHERITAGE (CROATIAN GEOLOGICAL SOCIETY)

INTERAKTIVNA IZLOŽBA/RADIONICA „UPOZNAJ ZEMLJU – ZAVIRI U MIKROSKOP!" – PROGRAM POPULARIZACIJE GEOLOGIJE I GEOZNANOSTI U ORGANIZACIJI ODSJEKA ZA POPULARIZACIJU GEOLOGIJE I GEOBAŠTINU HRVATSKOGA GEOLOŠKOG DRUŠTVA

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Ključne riječi: *program popularizacije znanosti, geologija, interaktivna izložba/radionica UZZM*

Interaktivna izložba/radionica „Upoznaj Zemlju – zaviri u mikroskop!" (UZZM) se kao program popularizacije geologije i geoznanosti održava od 2013. godine. Prema početnoj ideji dr. sc. Lidije Galović i dr. sc. Marije Bošnjak, organizira ju i provodi Odsjek za popularizaciju geologije i geobaštinu Hrvatskoga geološkog društva (HGD-a). Već na samom početku održavanja, Agencija za odgoj i obrazovanje dala je pozitivno mišljenje o ovom programu.

Održavanje izložbe/radionice temelji se isključivo na radu volontera – djelatnika iz područja geologije te mnogobrojnih studenata. Uzorci koji se koriste posuđuju se iz raznih institucija koje se bave geologijom. Pojedina izložba/radionica tako uključuje prikaz i stručno tumačenje raznolikih uzoraka stijena, minerala i fosila koje sudionici mogu pregledati i dotaknuti te saznati razne detalje o njima. Korištenjem mikroskopa i binokularnih stolnih lupa sudionici radionice dobivaju pogled i u mikrosvijet te mogu vidjeti kako izgledaju minerali i mikroorganizmi koji čine sastavne dijelove stijena i prirode oko nas. Upoznaje se značaj i primjena geoloških karata te se prikazuje geološka prošlost i razvoj života na Zemlji kroz vremensku lentu. Sudionicima se predstavlja i osnovna geološka oprema za istraživanje i rad na terenu (geološki čekić, geološki kompas, terenska lupa, GPS uređaj). Program uključuje i popularno-znanstvena predavanja raznih tema iz područja geologije te o geološkim značajkama područja gdje se škola ili neka druga javna obrazovno/edukacijska ustanova nalaze, a u kojoj se održava radionica.

Tijekom deset godina provedbe u programu UZZM sudjelovalo je više od 140 geologa i studenata – volontera, a geologija je kao znanost prezentirana u više od 120 škola i drugih javnih obrazovno/edukacijskih ustanova te na različitim manifestacijama popularizacije znanosti (npr. Festival znanosti, Znanstveni piknik, Dan za znanost, Međunarodni dan biološke raznolikosti). Ovisno o sudionicima ili posjetiteljima, provedba programa prilagođava se prema dobnoj skupini. Kako je izložba/radionica u nekoliko navrata održana i u vrtićima, treba istaknuti posebno oduševljenje djece vrtićke dobi te vrlo ugodno i pozitivno iskustvo volontera zahvaljujući velikoj znatiželji i zainteresiranosti djece za sadržajem izložbe/radionice.

Geologija je u osnovnom i srednjoškolskom obrazovanju prisutna najvećim dijelom kroz nastavni predmet geografije, što kod učenika, a i ostalog građanstva otežava percepciju geologije kao zasebne znanosti, odnosno nažalost manje poznatu činjenicu da je geologija jedna od četiri temeljne prirodne znanosti (uz fiziku, biologiju i kemiju). S obzirom na okolnosti koje su zadesile našu zemlju u proteklom razdoblju (npr. serija jakih potresa, otvaranje i/ili aktivacija brojnih klizišta, poplave) sve je značajniji interes cjelokupne javnosti za teme iz područja geologije. Stoga je namjera Odsjeka da daljnjom provedbom programa UZZM-a, ali i dodatnim širenjem aktivnosti što više upoznaje građanstvo s geologijom.

GEOLOGICAL STRUCTURE AND TECTOGENESIS OF THE CENTRAL PART OF THE ĆIĆARIJA MT.
GEOLOŠKA GRAĐA I TEKTOGENEZA SREDIŠNJEGA DIJELA ĆIĆARIJE

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Ključne riječi: *Ćićarija, OGK RH M 1:50.000, litostratigrafske jedinice, geološki profili, ramp and flat geometrija*

Ćićarija sa svojom ljuskavom i navlačnom građom spada u tektonski vrlo kompleksno područje SZ Dinarida. Borano-navlačni sustav Ćićarije pruža se sjeveroistočnim rubom Istarskoga poluotoka te čini morfološki izdignutu strukturu u odnosu na Pazinski flišni bazen na jugozapadu. U sklopu izrade Osnovne geološke karte Republike Hrvatske (OGK RH) M 1:50.000 provedena je geološko-strukturna analiza kojoj su ciljevi bili istraživanje geološke građe, rekonstrukcija tektonskih pokreta te identifikacija kinematike nastanka geoloških struktura ovog dijela SZ Dinarida. Nova OGK M 1:50.000 područja središnjega dijela masiva Ćićarije i rubnoga područja Pazinskog flišnog bazena je ukupne površine veće od 220 km^2 (slika 1). Na njoj je izdvojeno 13 neformalnih litostratigrafskih jedinica, koje su zbog sličnosti nazvane prema tipskim jedinicama definiranim na drugim dijelovima nekadašnje Jadranske karbonatne platforme (JKP). Dobro utvrđeni vertikalni slijed i lateralni razvoj naslaga litostratigrafskih jedinica istraživanoga područja te usporedba s istodobnim jedinicama šireg područja Istre i drugih dijelova nekadašnje JKP, bio je jedan od preduvjeta za interpretaciju tektogeneze.

Rekonstrukcija tektogeneze istraživanog područja obuhvaćala je i konstrukciju 11 geoloških profila poprečnih na pružanje glavnih struktura. Paleogenska ljuskava struktura jugozapadnoga dijela Ćićarije nastala je kao posljedica kompresije i navlačenja neposrednoga sjeveroistočnog zaleđa izgrađenog od kredno–paleogenskih i krednih naslaga. Utvrđeno je da ona predstavlja tzv. *thin-skinned* deformaciju u čijem su nastanku sudjelovale samo paleogenske naslage koje su od svoje kredne podloge odvojene plitkim dekolmanom koji tone prema SI pod vrlo blagim kutom. Najniži dio paketa foraminiferskih vapnenaca paleogena, naslage miliolidnih vapnenaca sadrže bituminoznu komponentu i pogodne su za razvoj smične plohe koja je mogla poslužiti kao navedeni dekolman. Navlačni kontakti kredno–paleogenskih i krednih naslaga su mjestimice vrlo blagoga kuta, a tektonski transport im je u smjeru JZ. U području paleogenske ljuskave strukture ljuskanje paketa paleogenskih naslaga se odvijalo po sustavu *ramp and flat* geometrije, pri čemu su kao dekolmanski horizont poslužile najčešće laporovite prijelazne naslage, a vrlo rijetko i lapori iz početnoga dijela flišnog slijeda.

U sklopu strukturne i kinematske analize kao i rekonstrukcije nastanka pojedinih struktura proračunate

Slika 1. Položajna karta s osjenčanim područjem istraživanja

su orijentacije glavnih osi polja paleonaprezanja. Izmjereni strukturni podaci orijentacija rasjeda i smičnih pukotina te kinematski indikatori ukazuju na najmanje dva tektonska ciklusa u razvoju struktura ovoga područja. Stariji, paleogenski tektonski ciklus je bio karakteriziran kompresijskim poljem naprezanja s P-osi dominantnoga pružanja SI–JZ. Posljedica ovog tektonskog ciklusa je formiranje struktura pružanja SZ–JI (dinaridskoga pružanja). Mlađi, neotektonski ciklus, je započeo najvjerojatnije tijekom mlađega miocena i/ili pliocena, a traje i danas. Očituje se u kompresijsko/transpresijskom polju naprezanja s P-osi pravca pružanja S(-SI)–J(-JZ). Posljedica te tektonike je nastanak novih struktura uglavnom pružanja S(-SI)–J(-JZ), ali i strukturna reaktivacija starijih rasjeda dinaridskoga pružanja s dominantno desnim, a rjeđe i lijevim horizontalnim kretanjem. Navedeni podaci su usporedivi i u korelaciji s opisom tektonskih faza u širem području današnjih SZ Dinarida.

Zaključno, može se pretpostaviti da je postanak ovoga dijela današnjih SZ Dinarida uzrokovan regionalnim sažimanjem prostora uslijed djelovanja naprezanja kompresijskoga tipa polja naprezanja po pravcu SI–JZ. Završno strukturno oblikovanje dogodilo se pod utjecajem neotektonske aktivnosti koja se očituje kroz reaktivaciju starijih dinaridskih rasjednih struktura kao i nastanak novih rasjeda subvertikalne geometrije pružanja SSI–JJZ koji presijecaju starije rasjede dinaridskoga pružanja. Posljedice neotektonske aktivnosti se odražavaju i u vertikalnom izdizanju terena i formiranju današnje morfologije. U istraživanom području nisu utvrđene značajnije strukturne rotacije boranih struktura. Bore su uglavnom zadržale dinaridsko pružanje svojih b osi (SZ–JI), a djelovanje neotektonskoga naprezanja se mjestimice očituje u presijecanju i translataciji osi i krila bora, ali s razmjerno malim subhorizontalnim pomacima.

CHARACTERISTICS OF THE LOFER CYCLICITY IN THE DACHSTENIN DOLOSTONES, HOST OF THE Pb-Zn ORE DEPOSIT ST. JAKOB, MEDVEDNICA MT.

KARAKTERISTIKE LOFERSKE CIKLIČNOSTI FACIJESA U DACHSTEINSKOM DOLOMITU, DOMAĆINU Pb-Zn RUDNOG LEŽIŠTA Sv. JAKOB NA MEDVEDNICI

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Keywords: *Pb-Zn ore deposit, Lofer cyclicity, St. Jakob, Croatia*

The Pb and Zn ore deposit of St. Jakob (ore paragenesis: galena, sphalerite, pyrite) is located on Medvednica Mountain (Croatia) within the Dachstein dolomite, an aerially isolated block overthrusted on the parautochthonous underlying Palaeozoic–Triassic magmatic–sedimentary complex, a unit overprinted by Early Cretaceous middle-grade metamorphism (BELAK *et al.*, 1995; ŠIKIĆ, 1995; TOMLJENOVIĆ *et al.*, 2008). The age of the carbonate host rock is Norian/Rheatian, as determined by megalodonts in the Lofer cyclothems, with A, B, C, D, elements of peritidal-lagoonal cyclicity (Fig. 1) and erosional disconformities. It is a part of Triassic clastics and platform carbonates located several kilometers away SW in Podsused quarry (BELAK *et al.*, 1995). The identification of the ore dolomites as a separate unit suggests that the Triassic carbonate nappe once covered a larger area, most of which is now eroded remaining as a dolomite klippe. The dolomite succession shows typical Loferite cyclicity and petrography.

The St. Jakob ore deposit has been studied in recent decades by mapping, various geochemical methods, stable and radiogenic isotopes, and study of fluid inclusions including destructive and non-destructive methods, Raman spectrometry, organic geochemistry, microtectonics, ore microscopy, and XRD (ŠINKOVEC *et al.*, 2000). Their numerous depositional similarities, placed in the Loferite facies, and the age of the Upper Triassic host rocks suggest a close connection between the Southern Alps and the Dinarides and are a step towards clarifying the evolution of the Neotethys Ocean in its early history in the tectonized Inner and Outer Dinarides.

The aim of present study is to describe the Lofer cyclicity in the Medvednica Mountain.

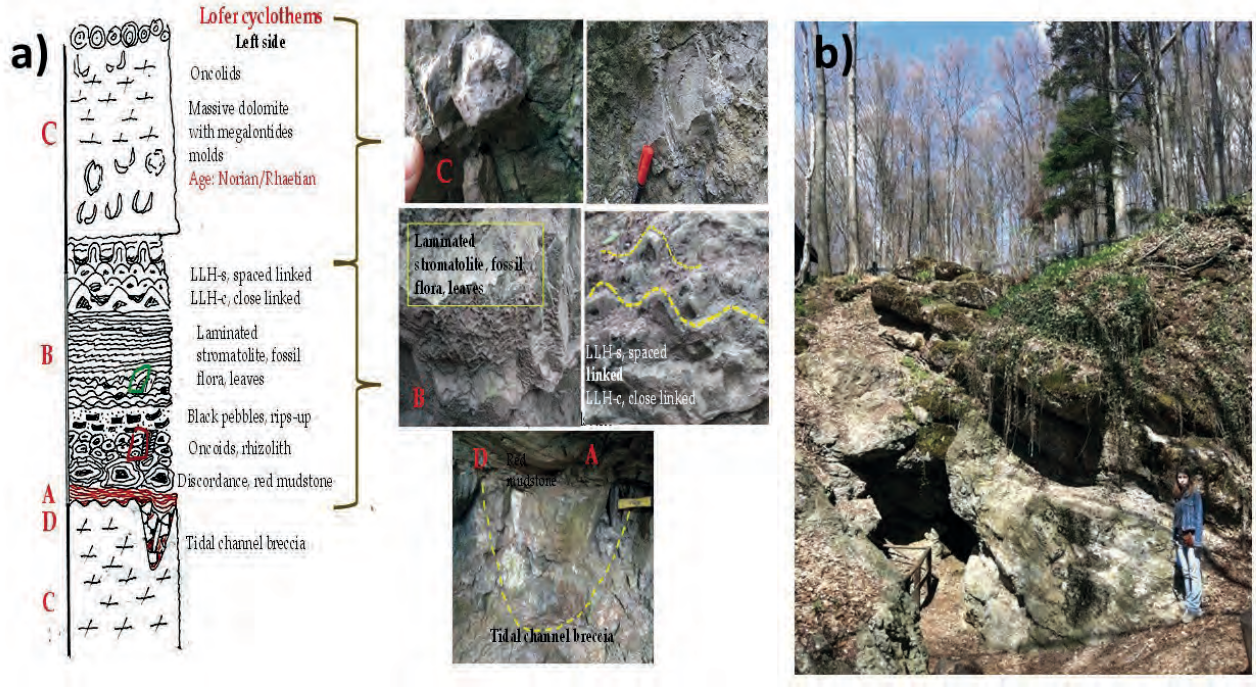

Figure 1. The Lofer cyclothems in the Dachstein dolomite, a. schematic profile, b. in the field

The rhythmic cyclicity is clearly defined as facies A, B, C, D. Facies A corresponds to supratidal-peritidal with characteristic red mudstone. Facies B is lower intertidal (Loferite, *sensu stricto*), with distinctive stromatolites. It hosts the main ore production horizon. Facies C is subtidal and represents the Main dolomite (Haupt dolomit). The thickness of the cycles varies from 0.4 to 2 m, and their number approaches nine. Facieses A, B and C form a rhythmical reappearing cyclothemes, shallowing upward.

Loferitic shallowing upward parasequences compose an Upper Triassic klippe which roots in the Upper Triassic nappe carbonates of the Vrapčanska gora in the west of the Medvednica (FUČEK *et al.*, 1995). It resembles the locus typicus, Loferite cycles, in the Dachstein Plateau, Austrian carbonate Alps.

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RESULTS OF GEOELECTRICAL SOUNDINGS OF LOESS-PALEOSOL SEQUENCE IN ZMAJEVAC, CROATIA

REZULTATI GEOELEKTRIČNOG SONDIRANJA PRAPOR-PALEOTLO SEKVENCE U ZMAJEVCU, HRVATSKA

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Keywords: *Geoelectrical sounding, loess, paleosol, Zmajevac*

As part of the ACCENT project, at the Zmajevac location, Croatia, in February 2022, geophysical measurements using the geoelectrical resistance method were performed. The subject of the research was the loess-paleosol succession of the NE slope of Bansko Brdo. Measurements were made along four parallel profiles, each about 300 meters long. The profiles are positioned from southwest to northeast (Fig. 1). The first profile is located at an average elevation of 140 m, the second at 135 m, the third at 125 m and the fourth at 100 m.

The performed geophysical investigations, with a distance between individual measurements of 50 m and a resolution of the measurement of each individual probe, responded to the project task of interpreting the spatial distribution of the loess-paleosol succession on a relatively larger area of the terrain and a given depth of examination of about 70 meters. It was obtained lower resolution of the vertical distribution of lithological units, but the task of locating exploratory drilling was answered. Smaller distance between sounds (5 m) and denser measurements on each sound (1 m), would provide a better resolution of the detection of lithological units, which could be the goal of further research.

Based on the results of the geoelectrical sounding, the lithological environments, corresponding to the loess and paleosol, can be clearly distinguished. Two loess horizons and two paleosol horizons can be separated. Going from the surface, from an elevation of 140 m ASL, after a thin recent soil, to a depth of about 14.5 m, a lithological environment corresponding to the loess is distinguished. From a depth of about 14.5 m, i.e. an elevation of 125 m and down to 115 m, a paleosol was registered, under which is found a loess layer about 10 meters thick. Beneath the second level of the loess, another paleosol was isolated, at a depth between 105 m and 100 m absolute height (Fig. 2).

Two lithological environments are distinguished below the loess-paleosol sequence, of which the upper unit corresponds to sandy siltstones and has a thickness of about 15 meters, while the lower unit has the characteristics of a sandy aquifer and extends to the end of the geoelectrical sounding measurement at a depth of about 65 meters ASL.

In correlation with the well-explored exposure of Zmajevac (GALOVIĆ, 2014), the matching of some of the geological boundaries between loess and paleosol in terms of the elevation, on the terrain of Bansko Brdo, was noted. That especially applies to the separated lithological unit of the paleosol, located between 125 m and 115 m ASL. Laterally along the profile, in the mentioned interval, the paleosol layer is divided by an intercalated loess layer, and its thickness does not exceed 5 meters.

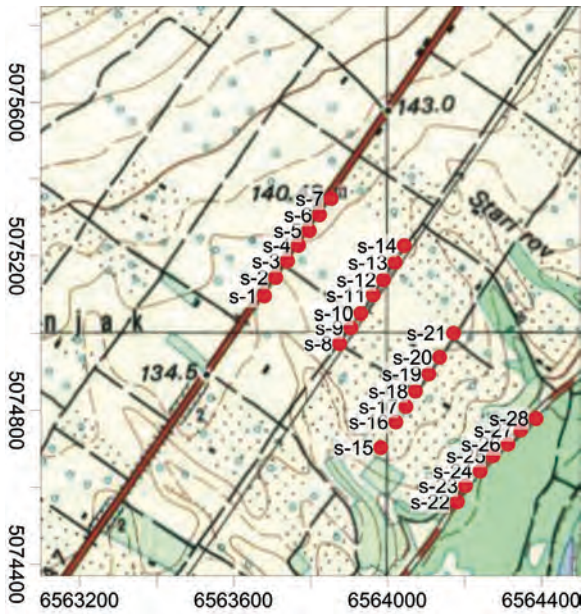

Figure 1. Locations of the geoelectrical sounding sites on topographic map

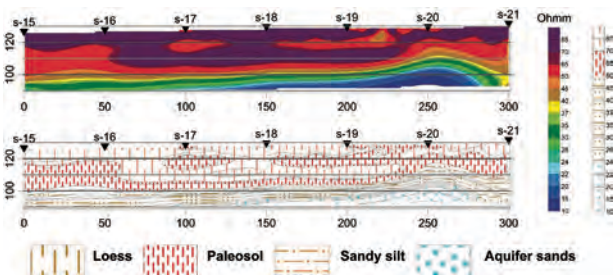

Figure 2. Representative geoelectrical and interpretation profile (sounds: 15 to 21)

The geophysical sounding, which was carried out in the described way, contributed to a better understanding of the depth distribution of the lithological units of the loess-paleosol succession and its underlieing rocks in a wider area. In relation to research carried out by geological profiles mapping and exploratory drilling, geophysical measurements can show lateral changes in the thickness and position of geological units and better understanding of its spatial distribution.

The geophysical measurements that were carried out contributed to determining the location of the exploratory drilling, which was recently carried out to a depth of about 30 meters. Based on the obtained data and the interpretation of the borehole, the correlation of the borehole profile and interpretation geoelectrical profiles will be carried out.

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CHEMICAL COMPOSITION OF GROUNDWATER AS AN INDICATOR OF LITHOLOGICAL AND STRUCTURAL RELATIONSHIPS WITHIN THE RECHARGE AREA OF THE RAKOVAC SPRING (ŽUMBERAK MOUNTAINS)

KEMIJSKI SASTAV PODZEMNE VODE KAO INDIKATOR LITOLOŠKIH I STRUKTURNIH ODNOSA UNUTAR PRILJEVNOG PODRUČJA IZVORA RAKOVAC (ŽUMBERAČKO GORJE)

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Keywords: *groundwater, magnesium, dolomite*

The Rakovac spring is located in the northern part of the Žumberak Mountains and its recharge area covers about 1 km^2. The recharge area of the Rakovac spring comprises highly permeable, intensively tectonized Upper Triassic dolostone deposits, which form the main aquifer. The preferential flow paths of the groundwater are developed, i.e., the aquifer presumably drains through well-developed conduit and fracture system. The spring never dries up, indicating a sufficiently large aquifer with some storage capacity. The fact that the spring's discharge increases rapidly and water becomes muddy after heavy rain periods indicates that, in addition to a fracture porosity, cavern porosity is also present. The rapid response of the spring to rainfall events, i.e., the rapid change in discharge, also indicates a good hydraulic connection between the surface and the aquifer. The ratio of minimum to maximum discharge is 1:520, which is characteristic for typical karst springs. Continuous monitoring and collection of water samples from the Rakovac spring revealed an unexpected chemical composition of the water. The Mg/Ca ratio has significantly lower values than expected compared to other springs in dolomite rocks. During a storm event and extreme discharge of the Rakovac spring, a large amount of pebble- and cobble-sized rock fragments are ejected to the surface within a radius of about one meter around the spring. These rock fragments were collected for detailed micropetrographical determination. Out of 22 collected samples four different lithotypes were determined. Most samples belong to dolostones, both primary and secondary. Primary dolomites have a microcrystalline texture and belong to the dolostromatolites. Secondary dolomites are composed of anhedral to subhedral dolomite crystals with xenotopic structure. The third identified lithotype is presented by limestone breccias. These samples are composed of very angular unsorted clasts. Most clasts belong to the mudstone limestone types, with homogeneous texture. Rare intraclasts are found within the micrite. Some clasts in the breccia are slightly recrystallized. Between the clasts sparry calcite crystalized. The fourth recognized lithotype is a radiolarian chert. Only one sample of this lithotype was determined and it is composed of abundant radiolarians in a very fine crystalline quartz matrix.

The occurrence of limestone breccias and radiolarian cherts are not expected since the entire catchment area of

the Rakovac spring at the surface is composed of dolostones. Looking at wider surroundings of the spring, the catchment area is bordered by two faults delineated on the Basic Geological Map sheet Zagreb (ŠIKIĆ *et al.*, 1977). The fault along the northeastern border is interpreted as a reverse fault bringing Upper Triassic dolostones over Cretaceous strata. The fault along the southwestern border is kinematically undetermined, delineated at the contact between Upper Triassic dolostones and Jurassic limestones. Orientation of strata to the northeast and southwest of this fault suggest that it could be with a reverse and top-SW sense of slip. In the explanatory notes to the Basic Geological Map, sheet Zagreb (ŠIKIĆ *et al.*, 1979), the Jurassic deposits are composed of limestones, limestone breccias and cherts, while the Cretaceous strata consist of breccias, conglomerates, marls, shales, clastics, limestones and cherts. This indicates that the identified lithologies (limestone breccia and radiolarian chert) may belong to one of these two units. During a wet period and a rapid rise of the water table, the depth of groundwater circulation increases, and it is possible that groundwater reaches the underlying lithologies and flings pebble and cobble fragments to the surface. This indicates that the thickness of the Upper Triassic strata is not uniform throughout the Žumberak Mts. and suggests that the Jurassic and Upper Triassic strata are also in reverse fault contact. This interpretation provides a possible explanation for the unusual chemical composition of Rakovac spring water. It suggests that the depletion of magnesium concentration could be attributed to the circulation of groundwater beneath the dolostone and in the limestone or limestone breccias.

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HYDROGEOCHEMICAL AND ENVIRONMENTAL ISOTOPE STUDY OF TOPUSKO THERMAL WATERS, CROATIA

HIDROGEOKEMIJSKO I ISTRAŽIVANJE OKOLIŠNIH IZOTOPA TERMALNIH VODA U TOPUSKOM, HRVATSKA

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Keywords: *hydrothermal system, hydrogeochemical monitoring, thermal spring, stable water isotopes, radiocarbon dating*

Thermal waters in Topusko (Central Croatia), with temperatures of up to 65 °C, have been used for heating, health, and recreational tourism for the past fifty years. A few short-term sampling campaigns of Topusko thermal waters were carried out in the 1980s, but such campaigns are insufficient for investigating sustainable management of the resource. Hydrogeochemical monitoring can provide insights into deeper geological processes and indicate system changes from baseline levels that are not visible from the surface. It helps identify potential anthropogenic impacts (e.g., the response of the aquifer to production stress), as well as natural changes (e.g., climate change and modifications of flow pathways due to earthquakes). Collecting baseline data, long-term monitoring, database management, and scientific studies provide information for the protection of hydrothermal resources (HEASLER *et al.*, 2009). Hydrogeochemical, geothermometrical, and environmental isotope studies of thermal waters in Topusko were conducted to improve the existing conceptual model of the Topusko hydrothermal system, providing a baseline for continuous monitoring of the thermal resource. Measuring thermal water in-situ parameters and conducting monthly thermal water sampling took place from March 2021 until March 2023. Sampling locations included two natural thermal springs, Livadski izvor (53 °C) and Blatne kupelji springs, and the TEB-4 shallow thermal well in the discharge area of the hydrothermal system (Fig. 1). Furthermore, precipitation was sampled in the supposed recharge area. Major anions and cations, stable water isotopes, radioactive isotope analysis of tritium (3H) and 14C, and geothermometers were used to assess the origin of thermal waters in Topusko and

their interaction with the thermal aquifer. A local meteoric water line was constructed and compared with the isotope ratio of the thermal water. The results indicate, according to the stable water isotopes, SO_{42-} isotope composition, and the determined radiocarbon groundwater age of 10–14 kyr, the meteoric origin of thermal water, which was possibly recharged in the colder climatic conditions during the late Pleistocene (POROWSKI, 2014; CLARK, 2015). Ca-HCO_3 hydrochemical facies suggests that carbonate dissolution, as the dominant process driving the solute content, occurs in the aquifer, which is consistent with aquifer lithologies in the stratigraphic logs of wells. Geothermometrical results indicate an equilibrium temperature in the reservoir of 88 °C, according to silica geothermometers, while low tritium activity is consistent with sub-modern waters and recharge before 1955.

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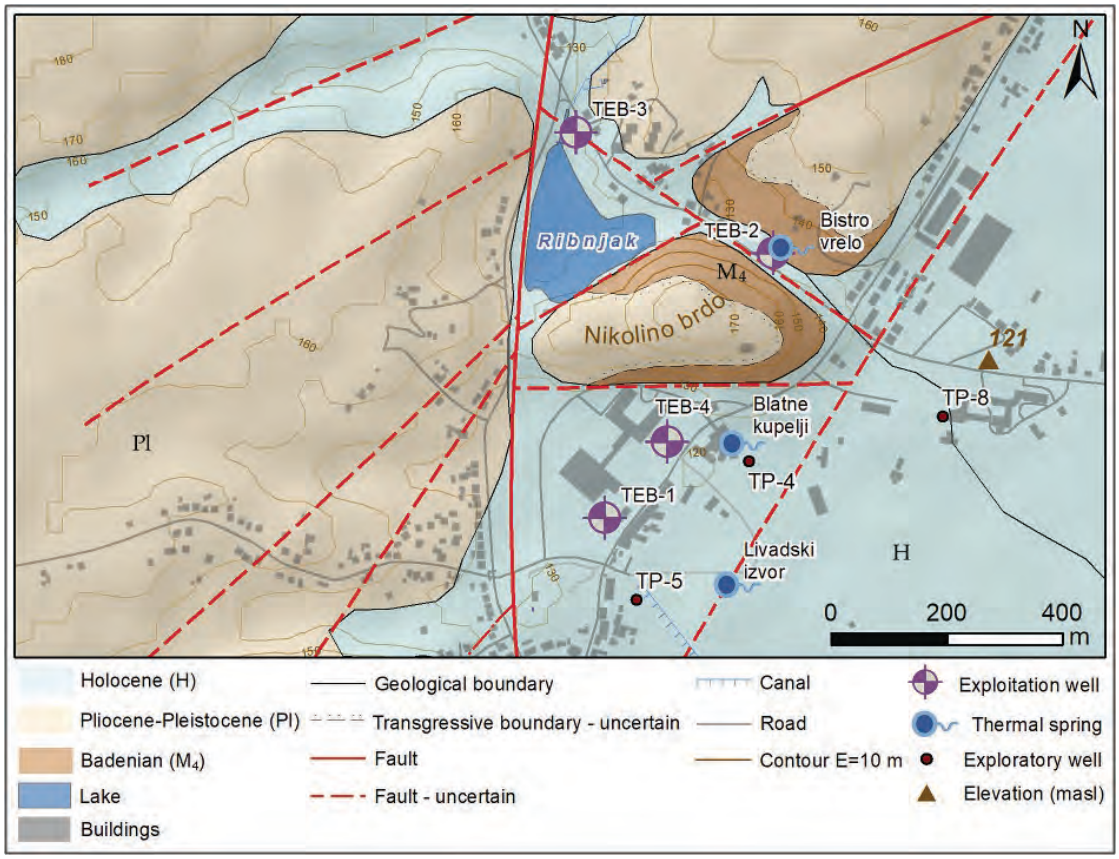

Figure 1. Geological map of study area (modified from KOROLIJA *et al.*, 1980; ŠIMUNIĆ, 2008) with the positions of natural thermal springs and exploitation and exploratory wells in Topusko town (PAVIĆ *et al.*, 2023)

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PRELIMINARY MAGNETIC AND GEOCHEMICAL PROPERTIES OF ZAGREB CITY AREA SOILS

PRELIMINARNA MAGNETSKA I GEOKEMIJSKA SVOJSTVA TALA NA PODRUČJU GRADA ZAGREBA

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Keywords: *Zagreb, magnetic susceptibility, soils, geochemistry*

Magnetic susceptibility (MS) is a degree of magnetization of some material as respond to applied magnetic field. Method of determining of volume magnetic susceptibility is a cheap and fast method and it is possible to use it as an indicator of anthropogenic contamination with some heavy metals. Our study was performed to get the first insight into distribution of the low field volume magnetic susceptibility throughout the largest part of territory of the Zagreb City, since such measurements did not exist before. 125 locations were selected for in-situ field MS measurements. On each selected location, terrain in perimeter of up to 100 m was visually inspected and the most suitable micro-location was selected. Precise geographic coordinates of each location were determined using GPS. The small magnetic susceptibility meter SM-30 was used for MS measurements. Sensor design of SM-30 enables to get 90 % of its signal from the first 20 mm of the measured surface. This feature allows more accurate readings on uneven surfaces. The sensitivity of the instrument is 1×10^{-7} SI UNITS.

Within the 5 m perimeter, 11 measurements on each selected location were performed. Mean value of 11 measurements was used as a result of MS measurement. Since this method of MS determination is fast and cheap, by using it, we created a network of measuring points throughout the research area. By constructing the magnetic susceptibility maps, we determined the 25 most interesting locations (20 % of all locations) for chemical analyses. The sampling for chemical analysis was performed in a following manner – we removed grass or leaves cover until reaching to the bare surface of soil. A square with sides of 25 cm was marked with a spade. On marked surface area, the soil was sampled to a depth of 2 cm. Soil sample was taken with a spade, packed in PVC bags and transported to the laboratory for further investigations.

Geochemical content of selected soil samples was determined using ICP-OES method for 20 elements: Al, As, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, Pb, Sb, Sr and Zn. Determined MS values for Zagreb area are as follows: minimum – 0,054 x 10^{-3} SI UNITS, maximum – 3,027 x 10^{-3} SI UNITS, mean – 0,374 x 10^{-3} SI UNITS and median – 0,245 x 10^{-3} SI UNITS. Maximum MS values were determined at Sljeme peak and its surrounding area, while the lowest MS values were determined at Mikuševa street in the Dubec neighbourhood. Geochemical analysis showed that anomalies of heavy metals mostly appear at the same locations where we found MS anomalies. Further research would be based on the more detailed geostatistical approach and detailed MS measurements to get better insight into element distribution and the correlations between values of magnetic susceptibility and particular chemical elements.

THE USE OF MAGNETIC PARAMETERS IN WILDFIRES RESEARCH – EXAMPLE OF NOVIGRAD 2022. WILDFIRE

UPOTREBA MAGNETSKIH PARAMETARA PRILIKOM PROUČAVANJA POŽARA– PRIMJER POŽARA U NOVIGRADU 2022.

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Keywords: *wildfires, magnetic susceptibility, thermomagnetic curves*

Wildfires became a world concern because of their significant increase in the last few decades. In the recent time, wildfires appear more often, even at some atypical regions such as the boreal forests of Russia, Canada and Norway (e.g., SHVETSOV *et al.*, 2021). Therefore, the necessity to study wildfires nowadays became even bigger. Trough the heating and combustion processes during the wildfire, mineral phases in soils experience thermal transformations. Iron oxides and hydroxides are prone to thermal changes during the wildfire resulting in a consequent change in magnetic susceptibility (MS) of many soil types. Most common reason of change in MS of the soil is the transformation of weakly magnetic minerals such as goethite to the strongly magnetic minerals such as magnetite and maghemite (JORDANOVA *et al.*, 2019). The studied area is in the vicinity of Novigrad town at Istrian Peninsula. It presents a hill slope of burned deciduous forest and low vegetation above the Mirna River Bay. The wildfire occurred in the first week of July 2022. For this study, soil and ash samples were collected from nine different sites across the hill immediately after the fire event. The control soil sample was collected from unburned site about 500 m of airline distance away north-western of the burned area. At the burned sites, ash samples were first collected and soil samples later in order to avoid mixing the two types of materials. The soil sampling depth was 0–5 cm. MS measurements were conducted using magnetic susceptibility meter SM-30 and MFK1-FA Multifunction bridge device for eight burned soil samples and one unburned control soil sample. Magnetic measurements with SM-30 were performed three times, and the mean value was used as a result to assure the highest precision of the data. Using MFK1-FA Multifunction bridge device, for each sample, MS was measured in 3 operating frequencies (976 Hz, 3 904 Hz and 15 616 Hz). Determined MS values for Novigrad soils are as follows: minimum – 0,215 x 10–3 SI UNITS, maximum – 2,557 x 10–3 SI UNITS and mean – 1,349 x 10–3 SI UNITS. By comparing the unburned and burned soil samples regarding the MS values, burned soil samples generally show higher MS values than the unburned (control) soil sample. To observe thermomagnetic behaviour of MS for wildfire samples and get thermomagnetic curves, analyses of temperature variations of low-field magnetic susceptibility were carried out. Using this method, it is possible to make an estimation of the temperature range for the wildfire burning temperature of soil. The heating/cooling experiments were carried out at four different temperatures (275, 400, 525 and 650 °C) for control and burned soil samples. Preliminary results show that Novigrad wildfire did not have uniform burning temperature distribution. There are some parts of the burning area where the temperature was slightly above 250 °C, while at some parts, the burning temperatures were around 600 °C. Most of the burning area was at the temperature range of 400–500 °C. To get more detailed insight for the wildfire temperature range, heating/cooling experiments should be done with a denser targeted temperatures cycles.

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MEASUREMENTS OF RADON AND THORON ACTIVITY CONCENTRATIONS FOR THE PURPOSE OF DETERMINING MIGRATION POTENTIAL ALONG FAULTS IN THE EASTERN PART OF DRAVA SUBBASIN – PRELIMINARY RESULTS

MJERENJA KONCETRACIJA AKTIVNOSTI RADONA I TORONA U SVRHU UTVRĐIVANJA MIGRACIJE PLINOVA PO RASJEDIMA U ISTOČNOM DIJELU DRAVSKE DEPRESIJE – PRELIMINARNI REZULTATI

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Keywords: *radon, thoron, migration, faults*

Radon (222Rn) and thoron (220Rn) are most common of the 39 unstable radon isotopes (NEIDHERR *et al.*, 2009). Half-life of radon equals 3.8 days, and of thoron 55.6 s (JÖNSSON, 1995). While radon is the decay product of radium (226Ra), as part of the decay series of uranium (238U), thoron is formed by the decay of 224Ra in the decay series of thorium (232Th). Measurements of radon concentrations are mainly obtained to assess the radiation risk from this radioactive gas, considering that it causes as much as 50 % of the radiation dose of natural origin (UNSCEAR, 2000).

Monitoring radon and thoron concentrations also plays a role in subsurface investigations. Different authors showed that it is possible to locate faults and unconformities by monitoring radon concentrations (PAPP *et al.*, 2010). These geological structures provide migration pathways for carrier gasses (CO2, N2) and radon (CHIODINI *et al.*, 1998).

Activity concentrations of radon and thoron, along with permeability, temperature and moisture levels, were measured (Fig. 1) at 107 points in the area from Cabuna to Čamagajevac in eastern part of Drava subbasin. Locations of measurement points were set at approximately 2 km distance, and their distribution predominantly follows the position of the seismic sections.

The maximum activity concentration was 137 982 Bq/m3 for radon and 56 970 Bq/m3 for thoron, with minimums of 7865 and 3240 Bq/m3, respectively. Preliminary results show that there is a potential of detecting the faults by an anomaly in the ratio of radon and thoron, as shown on the example in Fig. 2. The same anomaly

Figure 1. Sarad RTM 2200 SG, radon and thoron monitor

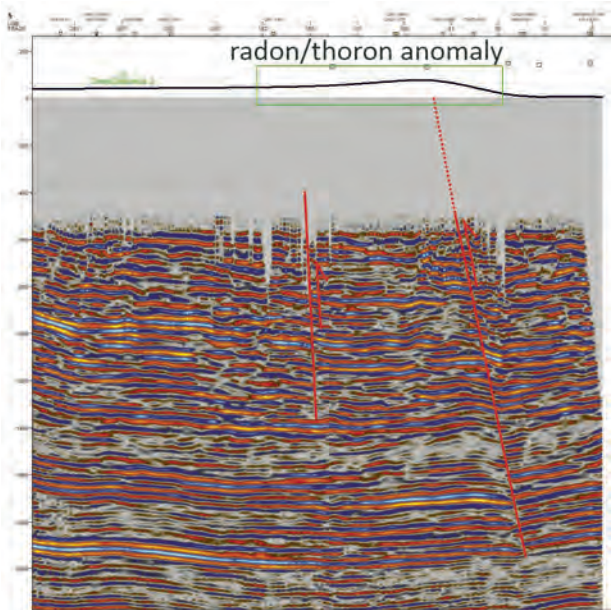

Figure 2. Seismic profile with interpreted faults and radon/thoron anomaly

was registered over fault in the area of Moslavačka gora (CVETKOVIĆ *et al.*, 2021). Further work will focus on detection of faults based on seismic interpretation, which is expected to explain the registered anomalies.

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BIOMETRIC CHARACTERISTICS OF PLANKTONIC FORAMINIFERA *PSEUDOHASTIGERINA MICRA* FROM THE FLYSCH DEPOSITS OF THE ISLAND OF HVAR (DINARIC FORELAND BASIN)

BIOMETRIJSKE OSOBINE PLANKTONSKE FORAMINIFERE *PSEUDOHASTIGERINA MICRA* IZ FLIŠKIH NASLAGA OTOKA HVARA (DINARIDSKI PREDGORSKI BAZEN)

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Ključne riječi: *planktonske foraminifere, biometrija, eocen, fliš, Hvar*

Istraživane su fliške naslage otoka Hvara (uvale Zaraće i Podstine). Prikupljenim uzorcima mikropaleontološki je analizirana frakcija 63–1000 μm i u većini dominiraju kućice planktonskih foraminifera. Biostatigrafska interpretacija uzorkovanih stupova napravljena je prema tropskoj zonaciji planktonskih foraminifera (WADE *et al.*, 2011). Naslage u uvali Zaraće, ukupne debljine 48 m, u cijelosti odgovaraju E15 Globigerinatheka index zoni (priabon). Odlikuju ih visok udio planktona (P/B indeks > 0,9) i nizak indeks fragmentiranosti foraminiferskih kućica (manji od 5 %). Naslage u uvali Podstine su debljine oko 34 m, priabonske starosti, a istaložene su tijekom E15 i dijelom E16 Hantkenina alabamensis zone. Primjetan je porast udjela planktonskih foraminifera idući od starijih prema mlađim naslagama (P/B indeks od 0,83 pa do 0,91) koji prati i povećanje indeksa fragmentiranosti planktonskih foraminifera (od 10 prema 14 %). Foraminiferskom zajednicom dominiraju pripadnici porodice Globigerinidae, no brojne su i male foraminifere iz rodova Pseudohastigerina, Streptochilus i Tenuitella.

Vrsta Pseudohastigerina micra prisutna je u svim istraživanim uzorcima, te je izabrana za biometrijska mjerenja. Smatra se da je bila oportunistička vrsta, bez simbionata koja je živjela u miješanom (površinskom) sloju (LUCIANI *et al.*, 2010). Veličina kućica se mijenja tijekom vremena, početkom oligocena kućice su bitno manje, a jedinke vrste manje brojne u zajednici što se, u nedostatku provodnih vrsta, ponekad koristi kao kriterij pri razlučivanju granice eocena s oligocenom (PEARSON *et al.*, 2018).

Za biometrijsko istraživanje odabrana su dva uzorka iz uvale Podstine i pet uzoraka iz uvale Zaraće u kojima je stupanj očuvanja kućica P. micra bio dostatan za precizna biometrijska mjerenja. Postoji jedan rad u kojem je naprav-

ljena biometrijska analiza kućica ove vrste (CORDEY *et al.*, 1970), stoga su procedura i odabir mjerenih parametara uglavnom slijedili metodologiju opisanu tim radom. 50 kućica vrste P. micra nasumično je odabrano i fotografirano s bočne i spiralne strane. Svakoj kućici izmjeren je najveći promjer, visina i širina najmlađe klijetke, te broj klijetaka u zadnjem zavoju. Uz to identificiran je tip ušća, koje kod ove vrste varira od visokog luka do bipartitnog, podijeljenog na dva luka.

Mjerenjem je utvrđeno da u svim istraženim uzorcima prosjek maksimalnog promjera kućice iznosi od 140,3 do 159,9 μm, što je manje od holotipa (170 μm). Najmanji maksimalni promjer kućice imaju u uzorku iz zone E15, u starijem dijelu naslaga uvale Zaraće, a to je ujedno i uzorak u kojem ova vrsta ima najveću zastupljenost u zajednici (11,3 %). Širina i visina najmlađe klijetke variraju neovisno o ostalim mjerenim parametrima dok je prosječan broj klijetaka u zadnjem zavoju ujednačen, krećući se između 6,2 i 6,4. Bipartitan tip ušća je vrlo rijedak, te niti u jednom uzorku broj jedinki s ovakvim ušćem ne prelazi 4 %. Ovi rezultati ukazuju da je *P. micra* u sutropskim do umjerenim uvjetima kakvi su vladali tijekom gornjeg eocena na prostoru današnjeg otoka Hvara, imala kućice manjih dimenzija od pripadnika iste vrste iz tropskih područja.

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GENESIS AND EPIGENETIC EVOLUTION OF THE MINJERA BAUXITES, CROATIA, ISTRIA
GENEZA I EPIGENETSKI RAZVOJ BOKSITA MINJERE, HRVATSKA, ISTRA

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Pyritisation of bauxites occurs as a result of their epigenetic reduction during the formation of swampy environments in the bauxite cover during the initial phase of the transgression, which commonly follows the formation of the bauxite. The Minjera bauxites, which formed during the terrestrial phase which lasted between the Late Cenomanian/Late Santonian and Early Eocene, were pyritised. The epigenetic pyritisation of these bauxites was related to the transgression that followed their formation, which led to the formation of ponds and swamps in the paleo-depressions in the karstified terrain, such as the sinkholes and canyons filled with the bauxite. Therefore, all of the Minjera bauxite bodies are covered by Lower Eocene Liburnian beds formed in such environments.

The Minjera bauxites have been mined in the past, but only the pyrite-containing bauxite was used in the production of alum and vitriol, while the red bauxite was left in the tailing heaps in the area. Pyritised bauxite samples from two Minjera bauxite bodies (D-1 and D-15) were collected, with the aim to reconstruct their genesis and the processes which led to their formation and subsequent pyritisation. Two main types of bauxites, the grey bauxite and the pyritised bauxite, were distinguished based on their mineralogy, geochemistry as well as their structure and texture. The grey bauxite contains

high amounts of kaolinite and moderate to high amounts of diaspore, while containing no or little böehmite. Iron sulphides, represented mainly by pyrite and sporadically by marcasite, are generally present in very low amounts in this type of bauxite and appear as veinlets and crystal clusters in the matrix and bauxite clasts and as replacements of iron oxide rich laminae in ooids. This type of bauxite is also enriched in bases and large ion lithophile elements compared to pyritised bauxite, which is likely related to lower leaching intensity. Pyritised bauxite contains high amounts of böehmite and iron sulphides, while containing very little to moderate amounts of kaolinite, and almost no diaspore. Iron sulphides appear in these samples in many different morphologies and textures. They replace the iron oxide-rich laminae within the ooids and the fine-grained matrix between the bauxite clasts and ooids. In samples where the matrix was not completely pyritised, the pyritisation started from many crystallisation centres, from which iron sulphides grew outward, either in the forms of framboids or rosettes composed of needle shaped crystals. Iron sulphides in these samples commonly crystallize along the fractures, which is also seen on a large scale, in the form of centimetre-thick veins of iron sulphides parallel with the boundary between the bedrock and the bauxite. Both bauxites are enriched in heavy REEs, and display a slight negative cerium anomaly, which indicates the influence of marine porewater. Different textures and morphologies of iron sulphides suggest variations in the saturation with iron and sulphur and are probably linked with the sea-level variations during the initial stages of the transgression, which could have affected the production of organic matter in swampy environments that developed in the cover of the bauxite during this stage. The ingression of marine porewater was most likely the source of sulphur, which was derived from the microbial reduction of sulphur in the organic matter-rich environment. The pyritisation appears to have affected each bauxite deposit differently, since the grey bauxite is almost exclusively found in the D-15 deposit, while the pyritised bauxite is found only in the D-1 deposit. Besides their distinct epigenetic evolution, this also suggests that bauxites of different grades formed contemporaneously in the area, as the D-15 body is composed mainly from highly kaolinitic grey bauxite and the D-1 body from the highly böehmitic pyritised bauxite. This is probably related to different morphologies of the two bauxite bodies, as the D-1 body is much larger and steeper (> 20 m) than the D-15 bauxite body (< 5 m). The differences in their morphologies likely developed as a consequence of their different palaeotopographical positions, which led to different rates of chemical weathering between the two bauxite bodies.

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NON-KARST AREAS IN THE KARST AREA OF CROATIA
NEKRŠKA PODRUČJA NA PODRUČJU KRŠA RH

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Za potrebe Programa ruralnog razvoja Republike Hrvatske (RH) za programsko razdoblje 2021. – 2027. godine izrađen je projekt Određivanje područja s prirodnim ograničenjima ili ostalim posebnim ograničenjima s kalkulacijama uz utvrđivanje vrijednosti kontekst indikatora broj 41 „Organska tvar u tlu" i broj 42 „Erozija tla vodom" za programsko razdoblje 2021. – 2027. Uredbom (EU) br. 1305/2013, propisano je da ukupna površina područja s posebnim (specifičnim) ograničenjima može iznositi maksimalno 10 % u odnosu na ukupnu površinu države, a što bi u slučaju Hrvatske iznosilo 5659,4 km^2. U skladu s time RH je predložila da se u područje s posebnim (specifičnim) ograničenjima uvrste otoci i poluotok Pelješac. Osim toga, predloženo je da se u područje s posebnim (specifičnim) ograničenjima uvrsti i prostor krša u kojem su osim depopulacije i zapuštanja poljoprivrede prisutni i vrlo teški uvjeti za bavljenje poljoprivrednom proizvodnjom uvjetovani vrlo razvedenim krškim reljefom. Prije svega, u području krša, poljoprivredna proizvodnja je otežana zbog velikog broja vrtača po jedinici površine i vrlo često velikom kamenitošću površine.

Krško područje prikazano je i analizirano prema definiciji krša iz Izvješća o stanju u prostoru RH (2003).

Karta područja pod kršem u RH izrađena je u mjerilu 1:100.000 temeljem Osnovne geološke karte (OGK) RH izdvajanjem „nekrških područja“ pomoću GIS alata. Prilikom utvrđivanja granice krša uvažavana je cjelovitost prostora s karbonatnim vapnenačkim i dolomitnim stijenama. Ukupna površina krškog područja Hrvatske iznosi 28.218,83 km², što predstavlja oko 50 % ukupne kopnene površine RH. Međutim na tom području ima i manjih dijelova koji nisu krš i nemaju krška obilježja.

Područja koja nemaju krška obilježja i porijeklo unutar prostora krša imaju površinu 2156,51 km². Ta područja uglavnom sačinjavaju: aluvij, barski sedimenti, deluvij, eolski pijesci, glaciofluvijalni sedimenti, gline, jezerski sedimenti, klastiti, morene, pijesci i pješčenjaci, prapor, proluvij, sipari, terra rossa i treset. Najzastupljenije nekrške geološke jedinice u ovom prostoru jesu sedimenti nastali djelovanjem vode, leda i vjetra. Analiza zastupljenosti „nekrških područja“, osim na razini države, provedena je i na razini jedinica lokalne samouprave. Jedinica lokalne samouprave zadovoljava uvjete za svrstavanje u područje s posebnim (specifičnim) ograničenjem ako na svom području ima najmanje 50 % površine krša. Sve JLS koje zadovoljavaju kriterij za uvrštenje u područje s posebnim (specifičnim) ograničenjem, a nisu svrstane u gorsko planinsko područje ili područje s prirodnim ograničenjem imaju mogućnost biti svrstane u područje s posebnim (specifičnim) ograničenjem. JLS uključivat će se u područje s posebnim (specifičnim) ograničenjem sukcesivno sve dok se ne zadovolji uvjet od 10 % teritorija RH.

Uvrštavanjem prostora krša u područja s posebnim (specifičnim) ograničenjima omogućit će se nastavak ne samo korištenja poljoprivrednog zemljišta koje je trenutno u upotrebi, već i ponovna rekultivacija poljoprivrednog zemljišta zapuštenog zbog otežanih uvjeta korištenja. Rekultivacija će se ostvariti kroz potpore predviđene za područja s prirodnim i posebnim ograničenjima u poljoprivredi, koja služe kao pomoć poljoprivrednim proizvođačima koji imaju više troškove poslovanja ili niže prihode poslovanja zbog težih uvjeta gospodarenja.

THE ROLE OF LOCAL COMMUNITIES IN DOCUMENTING AND PRESERVING *EX SITU* GEOHERITAGE: AN EXAMPLE FROM THE CITY MUSEUM OF ČAZMA

ULOGA LOKALNE ZAJEDNICE U DOKUMENTIRAJU I OČUVANJU *EX SITU* GEOBAŠTINE: PRIMJER GRADSKOG MUZEJA ČAZMA

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The participation of motivated volunteers in scientific research has increased significantly in the last decade and has become the basis of a relatively new concept of "citizen science". "Citizen science" could be defined as the participation of amateurs in scientific research helping to generate new knowledge and information (GURA, 2013). However, in the field of geology, especially paleontology, the role of motivated amateurs and their collaboration with scientists and different professionals has been noted as far back as the 1700s leading to the development of internationally significant collections that influenced the assessment and protection of in situ geoheritage (LEE *et al.*, 2020). Here we present valuable donation of ex situ geoheritage collection from Moslavačka Gora that came into the focus thanks to the employees of the City Museum of Čazma and their interest in valuating and protecting local geodiversity and geoheritage.

Although not yet fully acknowledged for its geodiversity, mineral and rock treasures of Moslavačka Gora have occupied the Croatian scientific community for over 170 years. Ljudevit Farkaš Vukotinović wrote the first Croatian petrographic work about the rocks of Moslavačka Gora (VUKOTINOVIĆ, 1852) and his simple geologic map of the Moslavačka Gora was the first geological description of Croatian territory. Detailed mapping was conducted almost one century later by KOROLIJA & CRNKO (1986) and CRNKO (1991).

The long history of public and scientific interest on Moslavačka Gora continues today with raising awareness for the need of assessment and protection of the local ge-

odiversity and valuable *in situ* and *ex situ* geoheritage. The donation of geologic samples collected by Mladen Kolenc to the City museum of Čazma counts a total of 105 rock fragments and minerals. It is currently being scientifically valuated to become a part of the museum's Natural history collection. The donation comprises igneous, metamorphic, and sedimentary rocks from the area, but also rare specimens of minerals quartz and tourmaline, mostly known from the early petrographic work in the area conducted by Vukotinović and his successors. According to major trends in current presentation of geoheritage collections (VAN GEERT, 2019), the Mladen Kolenc donation will be presented through the concept of a local heritage of the area, alongside other cultural and natural "treasures" of the local community. Selected specimens will be exhibited not as primarily scientific specimens, but rather in connection with the geologic and historic evolution of the Moslavačka Gora territory.

The historic note about the smoky quartz diadem crafted from the quartz specimens from Moslavačka Gora that was presented as a wedding gift to the last Austrian-Hungarian Crown princess, Stephanie of Belgium (KIŠPATIĆ & TUĆAN, 1914), valuates some of the donated samples as parts of the Croatian historic and cultural heritage, too. These samples put the City museum of Čazma alongside the Croatian Natural History Museum in Zagreb that conserves multiple quartz specimens from Moslavačka Gora, including the one published on the postal stamp by Croatian Post in 2018. The also important, tourmalines from the donation, on the other hand, can be considered as samples of scientific heritage since the investigation of different tourmaline occurrences from Moslavačka Gora enhanced the interpretation of igneous evolution of the massif (e.g. BALEN & BROSKA, 2011; BALEN & PETRINEC, 2011). Hopefully, this cooperation between the local enthusiast i.e. "citizen scientist", city museum and the scientific community will result in an enhanced interpretation and mediation of the *ex situ* and *in situ* geoheritage of Moslavačka Gora to the general public.

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BIOSTRATIGRAPHIC ANALYSIS OF ISTRIAN FLYSCH: VALIDATING THE MIDDLE EOCENE AGE

BIOSTRATIGRAFSKA ANALIZA ISTARSKOG FLIŠA: UTVRĐIVANJE SREDNJE EOCENSKE STAROSTI

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Keywords: *Flysch, Nannoplankton, Planktonic foraminifera, Eocene, External Dinarides*

Foreland basins are structural basins and areas of sediment accommodation created during the uplift of the adjacent orogenic belt (DECELLES & GILES, 1996), and are filled with thick sedimentary successions (that thin away from the belt) eroded from said orogenic belt. In Istria, flysch along with Foraminiferal limestones,

forms the foreland basin sediment successions, deposited in the basins once formed in front of the rising outer Dinarides. Establishing a chronological framework of the Istrian Flysch depositions is crucial for the reconstruction of the temporal evolution of the Dinaric orogenic belt. Some studies have argued for late Oligocene (even Miocene) age of the Istrian Flysch (ŠPARICA *et al.*, 2005; MIKES *et al.*, 2008), while other confirm the Middle Eocene age (BABIĆ *et al.*, 2007; ĆORIĆ *et al.*, 2008; LUKIĆ *et al.*, 2022). The aim of this study is to present new biostratigraphic data found on calcareous nannoplankton and planktonic foraminifera from the marls intervals in Istrian Flysch. In total six successions have been investigated (Plomin, Ripenda, Katun, Koromačno, Pićan and Šublentica), with 34 analysed samples. Samples were taken from massive/laminated marl intervals and from marl rip-up clasts found in megabeds (Plomin and Koromačno). Based on sedimentological analysis and biostratigraphic analysis of calcareous nanoplankton and planktonic foraminifera, it can be concluded that the sedimentation of the investigated flysch deposits took place in a deep-water marine environment ranging from the middle Lutetian (Zone E9) to the middle Bartonian (Zone E13). The water column was very well stratified and hosted numerous groups of planktonic foraminifera and calcareous nanoplankton. The microfaunal communities are well preserved and highly diverse, which indicates optimal marine conditions with normal salinity, a well-stratified water column and warm surface water.

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THE IMPORTANCE OF PRECISE EARTHQUAKE HYPOCENTER LOCATION FOR GEODYNAMIC ANALYSIS OF THE STUDIED AREA

VAŽNOST PRECIZNOG ODREĐIVANJA LOKACIJE ŽARIŠTA POTRESA KOD ANALIZE GEODINAMIKE ISTRAŽIVANOG PODRUČJA

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Ključne riječi: *geodinamika, potresi, žarište*

Precizno lociranje potresa važan je aspekt znanstvenih istraživanja seizmički aktivnih područja. Pomoću njega dobivamo bitne informacije o potresu, poput lokacije žarišta potresa (pri čemu je vrlo bitna preciznost određivanja dubine žarišta) te njegove magnitude. Ove značajke izuzetno su bitne u procjeni seizmičkog hazarda na seizmički aktivnim područjima, gdje postoji ozbiljnija opasnost od ugroze za ljude i imovinu. Jedan od temelja kvalitetne procjene seizmičkog hazarda jest procjena maksimalne moguće magnitude potresa, ali i parametara aktivnih dionica rasjeda, te razumijevanje rasjednih sustava na kojima se potresi mogu dogoditi, a što se može procijeniti na osnovu poznavanja geodinamike područja od interesa. Upravo iz tog razloga vrlo je bitno što preciznije odrediti lokaciju žarišta pojedinog potresa.

Određivanje lokacije žarišta potresa moguće je ostvariti ručnim ili automatiziranim metodama. Ručne metode vrlo su vremenski zahtjevan postupak, no relativno precizan pri određivanju osnovnih značajki potresa. S druge strane, automatizirane metode detektiranja seizmičkih događaja iz zapisa sa seizmograma te daljnja obrada s ciljem određivanja lokacije epicentra, dubine žarišta te magnitude puno su vremenski efikasnije i omogućuju brzi pristup osnovnoj analizi seizmičkih događaja. Nažalost, zbog ograničenja starijih računalnih algoritama koji provode ovakve automatske detekcije seizmičkih događaja, odredbe vremena nailaska P i S valova te naposljetku i odredbe lokacije žarišta i magnitude, ovakav potpuno automatizirani pristup pokazao se nedostatan za kvalitetnu i detaljnu analizu pojedine serije seizmičkih događaja. Nedavni primjer su zagrebačka i petrinjska serija potresa iz 2020. godine, gdje je na osnovu analize lokacija žarišta potresa definirana 3D geodinamika šireg epicentralnog područja. Ovome se može doskočiti djelomično ručnom obradom automatski detektiranih seizmičkih događaja, pri čemu preciznost određivanja vremena nailaska P i S valova, a time i lokacije epicentra i dubine žarišta potresa raste. S druge strane, ovakav pristup je vremenski zahtjevniji. Najmodernije metode istraživanja u smislu određivanja lokacije žarišta potresa te procjene seizmičkog hazarda idu u smjeru puno kompleksnijih računalnih algoritama koji koriste strojno učenje. Princip rada ovakvih algoritama pokazuje mnoge prednosti u odnosu na algoritme starije generacije koji su do sada najčešće bili korišteni kao metode pokušaja kompletne automatizacije procesa detekcije i određivanja osnovnih značajki seizmičkih događaja.

CHEMICAL COMPOSITION OF MINERAL AND THERMAL WATER OF SERBIAN-CRYSTALLINE CORE REGION

KEMIJSKI SASTAV MINERALNIH I TERMALNIH VODA NA PODRUČJU SRPSKOG KRISTALASTOG JEZGRA

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Keywords: *chemical composition, thermal water, mineralization, Serbian-Crystalline core*

Dominant geological composition of Serbian-Crystalline core (SCC) is made of high to medium-grade meta-igneous and meta-sedimentary rocks, such as gneiss, mica schist, amphibolite, amphibole-biotite schist, amphibole-pyroxene schist with sporadic occurrence of marble and migmatites. Various granitoids have penetrated the SCC mostly along major faults (PETROVIĆ PANTIĆ *et al.*, 2015). Tertiary magmatism caused the formation of groundwater with higher temperature.

Groundwater of Prolom Banja and Ribarska Banja are alkaline and low mineral waters. Alkaline environments in Prolom Banja favor the dissolution of vanadium from andesite (V= 7.9 μg/L). Dominant composition of groundwater is HCO_3-Na, with temperature of 32 °C. Water is used for balneotherapy, recreation and bottling – "Prolom voda".

Groundwater of Ribarska Banja is HCO_3-SO_4-Na, SO_4-HCO_3-Na, with higher content of F and Ga and temperature between 26 and 54 °C. Water is used for balneological purposes, and for heating of balneological objects.

All other thermal waters are mineralized with dominant content of Na+, and the variable ratio of HCO_3- and SO_4^{2-}, enriched with CO_2 or H2S gasses, as well as B, F, Cs, Ge and Rb. Chemical composition is a consequence of the deep water circulation, long mean residence time, and interaction between water and the reservoir rocks (PETROVIĆ PANTIĆ *et al.*, 2015). The presence of these elements indicates the dissolution and enrichment of waters with minerals contained in igneous rocks (PETROVIĆ *et al.*, 2012) like tourmaline, apatite, fluorite and biotite.

A very specific chemical composition of groundwater was registered in Viča, with a high concentration of B 22.9 mg/l and F is 15.7 mg/l, as well as elevated concentration of Ge (141 μg/l) and Zn (2.19 μg/l). This water also contained heavy rare earth elements (HREE), which are not commonly found in the environment or in groundwater. Complex geology, ore deposits, and circulation of hydrothermal fluids have created conditions for the formation of such a chemical composition. This groundwater was bottled under the name of "Milan Toplica", however, today is used by the local population only.

In a small area of Bujanovačka Banja waters are extracted from different lithological units. Mineralization of

water is between 3.2 and 3.6 g/l. Generally, water from granite grus and granite has high As, F, Be, Cs, relative to water from sandstone and marl, in which elevated concentrations of U and W is registered. All waters contain high values of B, Ge, Rb, and Sr.

In Sijarinska Banja waters are extracted from different depths, 7 to 1232 m. There are 18 boreholes and springs, which are used for balneotherapy. Water from the deepest borehole is used for hotel heating. However, all water samples have almost the same chemical composition (enriched with above mentioned elements and CO_2), with temperatures from 20 up to 76 °C.

A borehole with depth of 300 m, in Tulare (near Sijarinska Banja), is drilled through hydrothermally altered rocks where groundwater with temperature of 26 °C and TDS of 4615 mg/L occur. The main type of water is Na-HCO_3–SO_4, enriched with B, F, Ge, Sr (2.73 mg/l), and NH_4^+ (4.4 mg/l). In addition, Cu and Au sulfide mineralization is registered and the local population uses the water.

The highest groundwater temperature of 105 °C in Serbia is registered in Vranjska Banja. Water is HCO_3-SO_4–Na to SO_4–HCO_3–Na type. Besides the aforementioned elements for all mineralized water of SCC, this water contains Cs (35 to 47 μg/l) and W (138 to 150 μg/l). The water is used for balneology, heating, agriculture, and in industry for wool processing.

Complex tectonic-geological conditions caused forming of thermal waters enriched with a wide range of chemical elements.

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PREVIEW OF CREATING HYDROGEOLOGICAL MAP 1:100.000 ON THE TERRITORY OF SERBIA WITH THE RESULTS FROM THE SHEET SMEDEREVO

PREGLED IZRADE OSNOVNE HIDROGEOLOŠKE KARTE 1:100.000 NA TERITORIJI SRBIJE SA PRIKAZOM REZULTATA NA LISTU SMEDEREVO

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Keywords: *hydrogeological map, hydrogeological mapping, explanatory booklet, water supply, Serbia*

A basic hydrogeological map (BHGM 1:100,000) is significant for rational groundwater management and presents an excellent base for further applied research.

The 87 map sheets in scale 1:100,000 cover the area of Serbia. Five sheets of BHGM are fully completed, 10 sheets are in revision, and another seven are in progress. All map sheets are completed based on the instruction according ŠARIN (1988), using the ESRI ArcMap software. Each sheet contains cross-sections, legend, and hydrogeological characterization of lithostratigraphy, as well as a cadastre of groundwater objects and occurrences.

The hydrogeological characterization is done according to the type and properties of rocks, from permeable to impermeable. Permeable rocks are classified based on porosity (n), transmissibility (T), specific capacity (q), and spring and well capacity (Q). Carbonate rocks are classified based karstification degree.

Hydrogeological conditions of the terrain, with the emphasis on the most important aquifers, are described in detail in the explanatory booklet. Besides, groundwater reserves, groundwater balance, thermal and mineral water, groundwater quality, water supply, groundwater protection, and hydrotechnical facilities are included.

Sheet Smederevo is one of the completed and revised sheets (map: PETROVIĆ PANTIĆ *et al.*, 2021; explanatory booklet: PETROVIĆ PANTIĆ & MANDIĆ, 2021). It covers the central part of Serbia, south of Belgrade. The western part has a higher elevation, where the Kosmaj and the Avala mountains stretch. The Neogene basin covers central part of the sheet.

Quaternary and Pre-Quaternary sediments are dominant on the terrain (intergranular type of porosity). According to the transmissivity, the Quaternary sediments are classified as: very good (alluvium of Velika Morava T=1728 up to 4320 m^2/day (LUKIĆ, 2009) and Danube T = 1210 m^2/day (TOMIĆ, 2007); medium (minor river alluvium); and low (river terraces and loess). Quaternary sediments such as flood facies, proluvium, deluvium, loess, and sand-gravelly clays are classified as predominantly impermeable.

Pre-Quaternary sediments mainly cover the central part of the sheet Smederevo and could be found in the underlying bed of Quaternary sediments. These sediments contain sand, sandy clay, sandstone, and gravel. Transmissibility of the aquifer in medium-grained sand is between 0.69 and 95 m^2/day (ŽIVANOVIĆ, 2013). Limestone (karst-fractured type of porosity) partially occur in the area of Kosmaj Mountain, however, their presence is higher at depth. By calculating, the groundwater reserves in the amount of 40.5 l/s are from karst aquifer. Alterations of clastic and carbonate rocks, as well as intrusive rocks, occur in the western part of the sheet. These rocks have no significant importance from a hydrogeological point of view.

From the aspect of hydrogeological potential, the most significant are alluvial deposits of Velika Morava, Pre-Quaternary deposits and carbonate rocks.

Overexploitation, well aging, ground water quality, and great losses on water supply network are major problems of water supply in the most settlements systems.

The expected groundwater capacities exceed the existing exploitation reserves, which will be more prominent in the coming years (PETROVIĆ PANTIĆ *et al.*, 2016).

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THE ROLE OF SEAGRASSES IN SEDIMENT ACCUMULATION AND BEACH PROTECTION AGAINST EROSION ON CROATIAN BEACHES

ULOGA NAPLAVINA MORSKIH CVJETNICA U AKUMULACIJI SEDIMENTA I ZAŠTITI OD EROZIJE NA HRVATSKIM PLAŽAMA

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Ključne riječi: *banketi posidonije, Dugi otok, morfodinamika, pijesak*

U obalnim područja Sredozemnog mora rasprostiru se livade morskih trava. Među važnijim taksonima te skupine je zaštićena vrsta Posidonia oceanica (dalje posidonija). Ona je temelj primarne produkcije u moru, snižava koncentraciju ugljičnog dioksida, povećava koncentraciju kisika i pruža stanište brojnim organizmima (MATEO *et al.*, 2006). Njene livade smanjuju energiju morske vode čime postaju zamka za sediment i mjesto su intenzivnog nakupljanja biogenog sedimenta, čime mijenjaju sliku morskog dna (KOCH *et al.*, 2006). Naplavine posidonije na obalama stvaraju čvrste strukture, tzv. bankete, koje obalni prostor čini otpornijim na eroziju (MATEO *et al.*, 2006). Pojava banketa učestalija je na obalama drugih država Sredozemnog mora, dok je u Hrvatskoj poznato

svega nekoliko takvih lokacija. Radi zahtjeva za kupališnim resursima, dugogodišnja praksa uklanjanja banketa bila je uobičajena diljem Sredozemlja i Hrvatske.

Plaže kao sedimenta tijela duž hrvatske obale nisu uobičajena pojava (PIKELJ & JURAČIĆ, 2013). Šljunčane plaže dominiraju, a pješčane su rijetkost. Posebno su rijetke pješčane plaže kojima sediment čine recentni bioklasti, a čija se proizvodnja, taloženje i raspoređivanje veže za livade i bankete cvjetnica. Dva takva primjera nalaze se na Dugom otoku.

Na plažama Sakarun i Lojišće na Dugom otoku provedene su sveobuhvatne analize sedimenta plaže, njihova biogeomorfološka karakterizacija, profiliranje i digitalno modeliranje tijekom perioda praćenja od godine dana, kako bi se ispitala veza između dinamike sedimenta u prisutnosti livada i banketa morske cvjetnice.

Sakarun je polu-ruralna plaža, značajno izložena antropogenom pritisku uslijed turizma. Većina tijela plaže sastoji se od šljunka koji odgovara osnovnoj stijeni. Kontinuiranom izloženošću valovima juga oblikovan je šljunak plaže te produbljena istoimena uvala (PIKELJ & JURAČIĆ, 2013). Tome je pogodovala karbonatna breča u podlozi (jedinica Veli Rat; FUČEK *et al.*, 2016), sklonija mehaničkom trošenju u odnosu na druge obalne stijene na otoku. Bioklastični karbonatni pijesak u najboljem slučaju u tankom sloju prekriva < 1/3 površine plaže, a čine ga u najvećoj mjeri ostatci mekušaca, foraminifera, serpulida, ježinaca i mahovnjaka. Prirodna dinamika šljunka i pijeska je pod neposrednim utjecajem valova juga koji na plažu dolaze pod kutom ~90°. Osim djelovanja na sediment, isti valovi su ključni za stvaranje i nestajanje banketa. Oni su u periodu praćenja prekrivali ~1/3 plaže. Ovisno o lokaciji i izloženosti, banketi su mjestimice vrlo impregnirani sedimentom te tvore biogeomorfološke strukture. Prve procjene pokazale su da njihovim uklanjanjem nestaje minimalno 37 m3 karbonatnog sedimenta, mahom pijeska. Uz procjenu brzine taloženja karbonatnog bioklastičnog pijeska u umjerenim morima, te površinu njegovog stvaranja na mjestima unutar i izvan zaljeva na kojima se rasprostiru livade posidonije, otprilike upola manja količina pijeska godišnje stiže na plažu u odnosu na količinu koja se iznese, što rezultira erozijom koja je na plaži Sakarun primijećena posljednjih godina. Obzirom da je Sakarun visoko-energetska plaža, a na takvim plažama banketi značajno sudjeluju u morfodinamici u kontekstu stvaranja bermi i drugih oblika (SIMEONE, 2008), uklanjanje banketa može vremenom pojačati eroziju plaže.

Lojišće je udaljena plaža na dnu kratke uvale i značajno manje pod utjecajem čovjeka: naplavine posidonije se ne uklanjaju. U potpunosti se sastoji od bioklastičnog pijeska na stjenovitoj karbonatnoj podlozi. Izostanak krupnog šljunka s ove plaže pripisuje se kompaktnijem mikritnom vapnencu u podlozi (jedinica Sveti Duh; FUČEK *et al.*, 2016), kao i djelomično zaštićenom položaju plaže od valova juga. Bioklastični pijesak plaže je identičnog sastava kao onaj na plaži Sakarun. Profiliranje i uspoređivanje digitalnih modela u periodu praćenja pokazali su manju dinamiku naplavina posidonije, niže bankete jednako impregnirane sedimentom, ali izgrađene na značajnije stabilnom pijesku relativno nepromijenjene debljine i morfologije. Unos bioklastičnog pijeska i naplavina posidonije na plažu Lojišće također su rezultat djelovanja valova juga, ali ne direktnim unosom, već kombinacijom refrakcije valova i činjenice da se ispred uvale nalazi jedna od najuščuvanijih livada posidonije na Dugom otoku.

Stvaranje bioklastičnog sedimenta na obje plaže je usko vezana za livade posidonije u ili ispred njihovih uvala i djelovanjem prevladavajućih valova juga. Isti mehanizam ključan je za nakupljanje naplavina i stvaranje banketa. Ipak, uzimajući u obzir mofodinamičke procese na plažama, uklanjanje banketa s nisko-energetskih plaža čini se manje problematično nego s plaža visoke energije. Imajući na umu rijetkost pojave bioklastičnog pijeska na plažama u Hrvatskoj, upravljanje banketima posidonije trebalo bi biti uključeno u upravljanje obalnim područjem.

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ASSESSMENT OF CONTAMINATION OF RECENT FLUVIAL SEDIMENTS BY COMPARISON WITH EARTHQUAKE-INDUCED SAND BOILS

PROCJENA ONEČIŠĆENJA RECENTNIH RIJEČNIH SEDIMENATA USPOREDBOM S PJEŠČANIM VULKANIMA IZAZVANIH POTRESOM

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Keywords: *alluvium sediment, contaminant load, earthquake, liquefaction*

Potentially toxic elements (PTEs) are important chemical constituents in any environment. Their variability and distribution in sediments is usually determined by the lithology, but human impact is felt in different environmental compartments through elevated concentrations of PTEs (LUČIĆ *et al.*, 2023). Distinguishing between natural and anthropogenic sources is not always straightforward due to variations in source material. Therefore, most environmental studies use different approaches to estimate the contamination level: (I) by using common geological background, i.e. the average composition of the continental crust (RUDNICK & GAO, 2003), (II) by normalize the metal concentration using a conservative element as Al, Fe or Ti (BÁBEK *et al.*, 2015), (III) by measuring the concentrations in the silt-clay fraction of the sediments (VDOVIĆ *et al.*, 2021), and (IV) by using the non-polluted sediment as a background (BAKKE at al., 2010). While the last-mentioned approach may seem the most accurate it is difficult to find the unpolluted sediments to use as background. This pertains particularly to the rivers where sediment transport and deposition could change daily, and most of the river systems are, at least to some extent, branded by anthropogenic influence.

In this work, surface sediment samples from the Sava and Kupa rivers were investigated and compared to the samples of sand boils formed during the Petrinja earthquake. A destructive M 6.2 earthquake hit the town of Petrinja in December 2020, characterized by significant ground failures, mostly related to landslides, subsidence, and liquefaction (POLLAK *et al.*, 2021). The latter refers to phenomenon when loose, water-logged sediments near the ground surface lose their strength in response to ground shaking. The buildup of pore pressure forces the water carrying sand particles to the surface, forming volcano-like sand boils.

The earthquake of Petrinja brought loose sandy sediments of the river Sava alluvium to the surface (Fig. 1 left). The samples of sand boils (SI-3 samples, KAS-4 samples, MB-6 samples, and ND-1 sample; Figure right) were immediately sampled and then investigated with respect to their sedimentological, mineralogical, and geochemical characteristics and compared to recent sediments of the Sava and Kupa rivers (K1-K4 and S1-S3; Fig. 1 right). The main idea was to examine the possibility to use the results of sand boils characterization as a background in the investigations of recent river sediment pollution by toxic metals. Our preliminary results have shown lower contaminant load in sand boils samples compared to recent surface sediment. A complete sedimentological, mineralogical, and geochemical similarities and differences of the two sediment groups will be presented as a result of this work, as well as their suitability for future use in estimating contaminant loads in the study area.

Figure 1. The example of sand boil (left) and sampling locations (right)

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PRELIMINARY TERRAIN AND LANDSLIDE ROUGHNESS ANALYSIS BASED ON LIDAR DERIVED DATA IN THE KUTINA AREA

PRELIMINARNA ANALIZA HRAPAVOSTI TERENA I KLIZIŠTA NA PODACIMA LIDAR SNIMANJA U PODRUČJU KUTINE

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Keywords: *roughness, landslides, LiDAR, Kutina, Croatia*

This research is based on data collected during the implementation of an Interreg IPA CBC project – safEarth (Transnational advanced management of land use risk through landslide susceptibility maps design). High resolution LiDAR (Light Detection and Ranging) scanning of 71 km2 on the southwest slopes of Mt. Moslavačka Gora, between the city of Kutina and the G. Jelenska settlement, enabled detection and characterisation of more than 1200 landslides (POLLAK *et al.*, 2022). That research is here extended with a focus on terrain and landslides roughness analysis.

The terrain surface roughness analysis is based on a LiDAR-derived DEM with a resolution of 0.5 x 0.5 m, using the universally applicable standard deviation of slope (SDS) (FRANKEL & DOLAN, 2007; BERTI *et al.*, 2013; GARRISS, 2019). The calculation was performed in a 3 x 3 m moving window, which is primarily dictated by the intention to quantify the variability of the terrain surface in very small and shallow landslides which are found in the research area.

A separate analysis of the surface roughness of particular geological units and landslides in them is performed to quantify the magnitude of disruption caused by sliding. The results indicate that the roughness of natural terrain for particular units differ according to lithology, topographic position and geological setting. High roughness (SDS > 2) is noted for the Pliocene clastic sediments which are very susceptible to water erosion and have a dense network of gullies and water incised channels. Hard bedrocks (such as magmatic and metamorphic rocks) and coarse grained sediments (gravels, conglomerates and sands) of Daranovci formation (M_2) also have high average roughness (SDS ~ 2). Miocene clastic sediments, loess, deluvial and alluvial Quaternary sediments have lower roughness values (SDS < 1.7).

As expected, the analysis displays a significantly higher average roughness of landslide areas than the roughness of unaffected slopes. The difference in SDS values is from 45 to almost 80 %. That fact can be used to detect active slopes in which we may expect to find landslides (BERTI *et al.*, 2013), and speed up visual detection of landslides in large areas.

The analysis of landslide roughness and its other features (such as landslide size, shape, depth, position at the slope, and morphology of coluvial material) also reveals differences between different landslide models: slides on

top of hard rock masses, slides in firm soil mixtures, landslides in sands and landslides in dominantly coherent soil complexes.

The average roughness of particular landslides is also used to compare landslides activated in the same geological units and similar conditions. If we suppose that the same lithology in a similar natural environment generate analogous landslides with comparable magnitudes of features which are then equally weathered/eroded during time, the present roughness may correspond to relative landslide age. Using that analogy, we could indirectly assume the order of activation of landslides in zones where there are several generations of sliding, but, it is important to note that this analysis should be done with great care because roughness is also influenced by other factors like: micro-location topography and hydrogeological conditions, volume and depth of the depleted material. Therefore, more exact research of roughness and landslide age correlations should involve the determination of their absolute age (LaHUSEN *et al.*, 2016).

It's important to point out that in this analysis, the human impact on the average roughness of slopes was not evaluated. Namely, it is apparent that a great resolution of the DEM and slope data detects edges of household parcels, road edges, cuttings and plowing marks, all of which raise the roughness of the natural terrain. Alternatively, flattened terrain at infrastructure locations smooths natural terrain irregularities. Therefore, in further studies anthropogenic interventions should be filtered from the detailed analysis of roughness of natural slopes.

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INSTALLATION OF A WEATHER STATION AT POKLEK, MT. ŽUMBERAČKA GORA, IN ORDER TO MONITOR AND ANALYSE PRECIPITATION ON CATCHMENT AREA OF THE RAKOVAC SPRING

POSTAVLJANJE METEOROLOŠKE STANICE NA POKLEKU, ŽUMBERAČKA GORA, S CILJEM PRAĆENJA I ANALIZE OBORINA NA PRILJEVNOM PODRUČJU IZVORA RAKOVAC

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Keywords: *spring Rakovac, weather station, discharge,* $\delta^{2}H$ *and* $\delta^{18}O$ *isotopes*

The Rakovac spring is located in the Žumberak Mountains (north-western Croatia), about 700 m south of the village Poklek. In 2018, monitoring of the spring discharge started in order to determine the possibility of water usage from the Rakovac spring as an additional source of drinking water for the needs of the public water supply of the City of Samobor. For that purpose, the rectangular sharp-crested weir was built immediately downstream of the spring and automatic pressure and electric conductivity gauges (loggers) were installed. In order to expand existing research and more reliably determine precipitation in the catchment area of the Rakovac spring, the Davis Vantage Pro2 weather station was recently installed in the Poklek village (Fig. 1), the hearth of the Rakovac spring catchment area. Previously used precipitation data from two weather stations monitored by the Croatian Meteorological and Hydrological Service were relatively unrepresentative for the catchment area of the Rakovac spring since weather

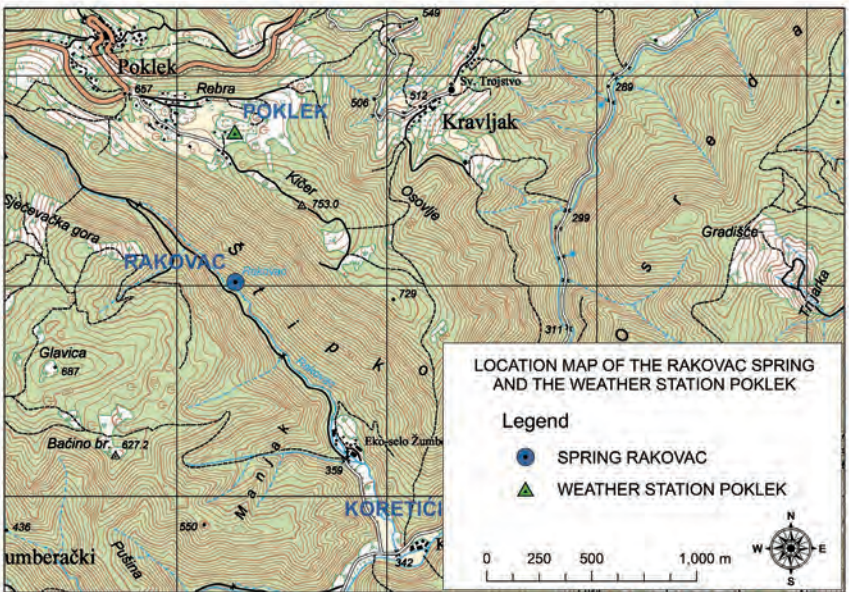

Figure 1. Location map of the Rakovac spring and the weather station Poklek

stations are distanced approximately 11.8 km (Rude weather station) and 5.5 km (Mrzlo Polje Žumberačko weather station) from the Rakovac spring, respectively. The newly installed weather station in the Poklek village is equipped with an anemometer which measures wind speed and direction, a tipping-bucket precipitation collector which measures the amount of precipitation and sensors for air temperature, humidity, and barometric pressure. Additionally, the Palmex RS-1 precipitation sampler was installed enabling the collection of precipitation samples. Precipitation samples and groundwater samples from Rakovac spring are collected on a monthly basis, and in-situ parameters are measured also on both locations, specifically pH, dissolved oxygen, electric conductivity, temperature and turbidity. Samples are collected for stable water isotope analysis (δ^2H and $\delta^{18}O$) in order to characterize the influence of precipitation fallen on the spring catchment area on the water discharge of the Rakovac spring. Newly installed weather station will help in acquiring representative precipitation samples and data for the Rakovac spring catchment area and make the results of further research more reliable. Poklek weather station current measurement data are made public and can be viewed on the website:

https://www.weatherlink.com/embeddablePage/show/737a90b5f5b1494c829894158571afd7/summary.

GEOPARK BIOKOVO–IMOTSKI LAKES – "A PLACE BORN OF CRYSTAL-CLEAN WATERS AND TOWERING ROCKS"

GEOPARK BIOKOVO–IMOTSKA JEZERA – „MJESTO NASTALO IZ ČISTOĆE VODE I SNAGE KAMENA": ZNAČAJ GEOTURIZMA KAO JEDINSTVENE TURISTIČKE PONUDE

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Ključne riječi: *Biokovo–Imotska jezera, Geopark, geoturizam*

Područje Geoparka Biokovo–Imotska jezera nalazi se u Republici Hrvatskoj, u srednjoj Dalmaciji, u Splitsko-dalmatinskoj županiji koja je prostorno najveća županija Republike Hrvatske. Ukupna površina Geoparka iznosi 533,22 km². Područje je to koje je sa sjevera omeđeno po-

graničnim prostorom između Republike Hrvatske i Bosne i Hercegovine, između sjeverne Dalmacije i zapadne Hercegovine (dalmatinsko zaleđe Biokova), a na jugu granicom Parka prirode Biokovo, koju tanki priobalni pojas dijeli od Jadranskog mora. Kroz to geografski jedinstveno područje prostire se planina Biokovo, kao dio planinskog masiva Dinarida, čiji je najviši vrh Sv. Jure (1762 m nm) treći najviši planinski vrh u Republici Hrvatskoj. Grad Imotski je najveće administrativno središte Geoparka Biokovo–Imotska jezera i u njemu se nalazi i njegovo sjedište.

Plodno Imotsko polje zanimljivo je reljefno obilježje Geoparka Biokovo–Imotska jezera. Između njega i planinskog masiva Biokova (1762 m nm) nalazi se prostrano krško područje na kojem se smjenjuju nizovi brda i uvala. Polje i krški prostor u njegovoj neposrednoj okolici bogati su vodom. Duž cijelog Imotskog polja protječe rijeka Vrljika – ponornica po mnogočemu jedinstvena krška rijeka, koju stanovništvo naziva „hraniteljicom života“, zbog izvorišta pitke vode, zahvaljujući kojima polje ima izvrsne uvjete za poljoprivredu. U unutrašnjem dijelu Geoparka riječ je o tipičnom terenu visokog dinaridskog krša, koji je svjetski poznati locus typicus specifične krške morfologije. Taj je prostor karakterističan po krškim poljima, jezerima, rijekama, kanjonima, uzvisinama, izvorima, ponorima, špiljama i jamama. Dalje, kada krenemo južnije, bliže priobalnom dijelu našeg Geoparka nailazimo na veličanstvenu planinu Biokovo. Građu u nižim dijelovima prema moru i na suprotnoj zagorskoj strani čine pretežito eocenske fliške naslage, dok su viši dijelovi oblikovani u mezozojskim karbonatnim sedimentnim stijenama. Vršnim dijelom dominiraju ponikve. Neke su izrazito duboke, čak i više od 100 metara. Neke su urušene, dok se neke nastavljaju u duboke jame. Ovaj specifični oblik površinskog krša naziva se poligonalni ili mjesečev krš jer podsjeća na kratere Mjesečeve površine. U ovom dijelu su također prisutni svi tipični fenomeni krša – vrtače, škrape, kamenice, špilje, ledenice i jame.

Područje Geoparka Biokovo–Imotska jezera jedinstven je prostor dinarskog krša, kao i područje od iznimne kulturne baštine, bogatog povijesnog naslijeđa i prirodne vrijednosti koja obuhvaća veliku raznolikost staništa, vrsta biljaka i životinja, ali isto tako i geološku raznolikost zastupljenu u brojnim geološkim tvorevinama nastalim u različitim razdobljima prošlosti Zemlje. Upravo taj veliki potencijal ovog područja je razlog zašto Geopark Biokovo–Imotska jezera postaje treći UNESCO-ov Geopark u Republici Hrvatskoj.

Pristupanje Geoparka Biokovo–Imotska jezera u UNESCO-ovu obitelj Svjetskih Geoparkova pridonijelo bi podizanju svijesti o važnosti zaštite geološke i geomorfološke baštine te prepoznavanju geoturizma kao jedinstvene turističke ponude.

Podizanjem svijesti i edukacijom o važnosti geološke baštine geoparkovi UNESCO-a lokalnoj zajednici daju osjećaj ponosa i jačaju njihovu identifikaciju s područjem na kojem žive. Otvaranjem inovativnih obrta i novih radnih mjesta potiče se stvaranje novih izvora prihoda kroz geoturizam, osnažuje se lokalna zajednica, a istovremeno geološki resursi područja ostaju zaštićeni. Geološka baština povezana s prirodnom i kulturnom baštinom unapređuje održivo korištenje resursa, ublažava učinke klimatskih promjena te smanjuje rizike povezane s prirodnim katastrofama.

Udruga Geopark Imotska jezera i Javna ustanova „Park prirode Biokovo“: PLAN UPRAVLJANJA GEOPARKOM BIOKOVO-IMOTSKA JEZERA 2022-2026 (2021, 2023).

APPLICATION OF GEOCHEMICAL FACTORS TO ASSESSMENT OF POTENTIALLY TOXIC ELEMENTS CONTAMINATION IN ALLUVIAL SOILS

UPOTREBA GEOKEMIJSKIH FAKTORA ZA PROCJENU ONEČIŠĆENJA POTENCIJALNO TOKSIČNIM ELEMENTIMA U ALUVIJALNIM TLIMA

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Keywords: *PTE, statistics, enrichment factors, spatial distribution*

The subject of this study are alluvial soils formed in Kalinovac (Podravina), Croatia. The objectives of the study are to determine the concentration of potentially toxic elements (PTEs) such as Cu, Zn, Pb, Cd, Ni and Cr in the soil, to distinguish geogenic from anthropogenic PTE sources (agrochemicals, traffic), to determine the correlation between the analysed PTEs in the soil, and to create maps of spatial distribution of PTEs in the study area. To

achieve these objectives, geochemical analysis of alluvial soil in the study area was conducted. Based on the concentrations determined, the following factors were calculated: Enrichment Factor (EF), Contamination Factor (CF) and Geoaccumulation Index (I_{geo}). Statistical data processing on 56 samples was also carried out, including the calculation of the correlation matrix, hierarchical cluster analysis (HCA), and principal component analysis (PCA) using Statistica 13.5 software. In addition to the statistical methods, maps of the spatial distribution of each PTE content, EF, CF and I_{geo} were created using GIS tools. Chromium levels range from 145 to 403 mg/kg, well above the maximum allowable concentration of 80 mg/kg. Soil Cd concentrations vary from 0.8 to 15 mg/kg, well above the allowable concentration of 1 mg/kg. Chromium shows a negative correlation with Fe (–0.51) and As (–0.61), while it shows a positive correlation with Si (0.78), pH (0.57), and contents of silt (0.66) and clay (0.51). Nickel shows a positive correlation with Zn (0.67), pH (0.52), and silt content (0.57). Copper shows a pronounced negative correlation with Al content (0.64) and pH (–0.57). Zinc shows a moderately pronounced positive correlation with Al content (0.57), pH (0.57), and silt content (0.56). Cadmium shows a negative correlation with Si (–0.60), Al (–0.62), pH (–0.58), and silt content (–0.57). Lead content shows a stronger negative correlation with Fe (–0.61). The results for all studied factors (EF, I_{geo} and CF) show that Cr is most likely of geogenic origin, while Cd is of anthropogenic origin. Chromium is most likely the result of weathering processes of basic and ultrabasic igneous rocks transported with the alluvial material from the Eastern Alps. In the case of Cd, the source could be related to agrochemicals since the site is located in an agricultural area.

By applying all the methods used in this study, it is possible to distinguish between geogenic and anthropogenic sources of PTEs in alluvial soils. Furthermore, this work established that excessive use of agrochemicals may contribute to elevated concentrations of specific PTEs.

APPLICATION OF MATCHING PURSUIT FOURIER INTERPOLATION FOR MERGING 3D SEISMIC DATA OF DIFFERENT VINTAGES

PRIMJENA MATCHING PURSUIT FOURIEROVE INTERPOLACIJE ZA UČINKOVITU INTEGRACIJU 3D SEIZMIČKIH PODATAKA RAZLIČITIH GENERACIJA

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Keywords: *Pannonian basin, Seismic surveys merging, 5D matching pursuit Fourier interpolation*

Over the past three decades, the Pannonian Basin has undergone extensive 3D seismic campaigns with diverse objectives, employing various acquisition configurations and processing techniques. The substantial overlap between different surveys enables the integration of individual datasets into a unified 3D volume, resulting in a focused subsurface image with enhanced confidence levels at the boundaries of each 3D survey. Bearing that in mind, the entire polygon of the new, well-sampled 3D survey Međimurje Extension acquired in 2021 (referred to as the Master survey), as part of the exploration program on the SZH-01 block within the Croatian part of the Pannonian Basin, was intentionally designed to facilitate the merging process with the adjacent 3D project Međimurje acquired in 2006 (referred to as the Add-in survey). It was consistent with the project objectives, which aimed to construct a new geological model, expand the prospect portfolio, and further reduce risk through calibration with existing fields.

Both surveys included in merge share a nearly identical shooting direction in an orthogonal geometry. However, they differ in terms of shot and receiver station spacing (Fig. 1), resulting in distinct CMP bin sizes and coverage. To process both surveys as part of the merge, it was necessary to align them on a regular, common processing grid. This grid was created by extending the native grid of the Master project to encompass the Add-in data. Equalizing the differences in surveys geometry involved up-sampling and reconstructing vintage data acquired with a coarser bin grid to match the regular, denser target locations simulating the Master survey. This process was carried out using weighted 5D matching pursuit Fourier interpolation (MPFI). The objective was to meet the fidelity requirement for pre-stack migration, ensuring that the sampling was as equidistant as possible without spatial aliasing. MPFI algorithm operates in the space-frequency domain across five dimensions: one temporal and four spatial (inline, crossline, offset, and azimuth). It utilizes an iterative procedure to calculate the Fourier spectrum of irregularly sampled data within overlapping spatial

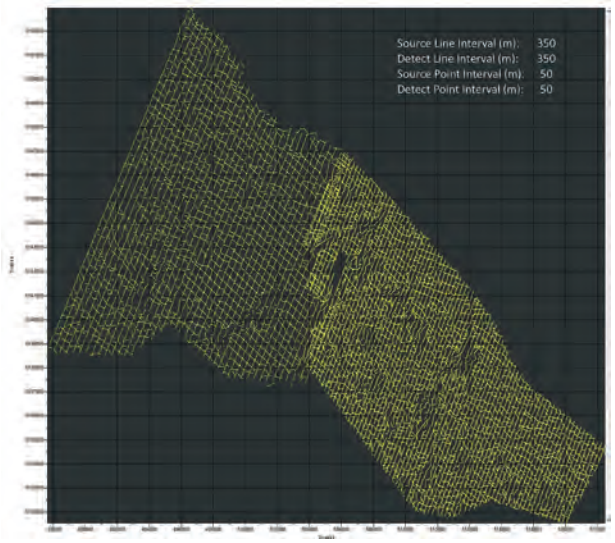

Figure 1. Surface positions before MPFI

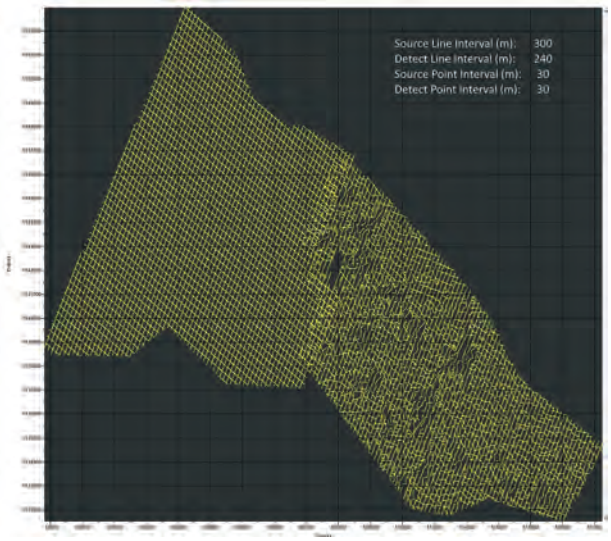

Figure 2. Surface positions after MPFI

and temporal windows. To address aliasing, priors were employed under the assumption (SCHONEWILLE *et al.*, 2009) that the spectrum distribution at higher aliased frequencies could be extrapolated from the energy distribution at lower unaliased frequencies (in this case from 10–20Hz). The estimated spectrum was then used to reconstruct the data at new spatial positions (Fig. 2).

The effective interpolation of vintage pre-stack data resulted in both 3D surveys being aligned to a common grid with a similar fold. This allowed migration to more offset planes and consequently generated improved migrated image for optimal interpretation and enhanced subsequent amplitude versus offset (AVO) analysis.

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RARE EARTH ELEMENTS IN BAUXITE DEPOSITS IN THE DINARIC REGION; THE POTENTIAL OF MONTENEGRO AND CROATIA

ELEMENTI RIJETKIH ZEMALJA U LEŽIŠTIMA BOKSITA NAPODRUČJU DINARIDA; POTENCIJAL CRNE GORE I HRVATSKE

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Keywords: *bauxite, rare earth elements, Dinarides, Montenegro, Croatia*

Rare earth elements (REE) are a group of chemical elements that represent critical commodities in modern industry and are essential in many modern technologies. The last published list of CRM (2020) contains 30 different mineral resources (COM/2020/474 final). The bauxite as CRM is included in the list for the first time, while REE's, both light and heavy, are at the top of the list when it comes to their economic importance, and especially the supply risk. The Dinaric region, since the period before and especially after the WW II produced significant quantities of bauxite mainly for aluminium production. Today bauxite is becoming an interesting

potential source of CRMs (REE) which is fuelling a new interest in bauxite related research (TOMAŠIĆ *et al.*, 2020, 2021; RADUSINOVIĆ & PAPADOPOULOS, 2021; RADUSINOVIĆ *et al.*, 2022). The Dinaric region with mainly karstic bauxite-bearing areas, in which larger deposits have been formed, have a great potential for further research. Bauxites formed in more favourable paleogeographic conditions with suitable climate, longer hiatus, better permeable underlying carbonate rocks, parent material primarily enriched in REE, are the factors that influence the concentration of REE bearing minerals in deposits.

The Jurassic bauxite deposits in Montenegro fit into this model, especially the largest and highest quality ones: Biočki Stan, Đurakov Do and others, but also those with an elevated SiO_2 content such as the Liverovići deposit (RADUSINOVIĆ, 2017; RADUSINOVIĆ & PAPADOPOULOS, 2021), which indicates that other Jurassic deposits of the Dinaric region may be enriched in REE as well. The argument for this statement is also the high content of REE in the bauxites of Istria, especially the Rovinj deposit (TOMAŠIĆ el al., 2020), then the indicated elevated content in the bauxites of the Sretnica Mountain in Bosnia and Herzegovina.

The highest determined average REE content in the bauxites of the Tošići–Dujići deposit, and high content in the Jukići–Đidare and Gljev deposits in Croatia (TOMAŠIĆ el al., 2020), as well as Blizanci and Bivolje Brdo–Zelenikovac in Bosnia and Herzegovina, indicate that even in bauxites of Late Eocene, under favorable paleogeographic conditions and bauxitization of the parent material, significant amounts of these metals can be concentrated.

The bauxite formations in Montenegro have significantly different ΣREE (La–Lu, Y, Sc) average contents. The highest contents were detected in the Jurassic bauxites of the Vojnik–Maganik and Prekornica ore regions from the Early Jurassic, Middle Jurassic–Oxfordian and Late Triassic underlying bed, and amount to 1057, 1019 and 995 mg/kg, respectively. The Triassic bauxites of Gornjepoljski Vir deposit have an average total content of 732 mg/kg. Jurassic bauxites from the ore regions of Western Montenegro and Orjen have a ΣREE 516 mg/kg, while Paleogene bauxites from Ulcinj region and Boka Kotorska have average values of 516 and 415 mg/kg, respectively. The lowest average total content, of 309 mg/kg, was shown by Cretaceous bauxites of the ore regions of Western Montenegro and Čevo. Bauxite deposits of Jukići–Đidare contain an average of 1019 mg/kg of ΣREE, while the bauxites of the Mamutovac deposits contain an average only 521 mg/kg of ΣREE. In the Tošići–Dujići deposit, bauxites contain an average 1793 mg/kg of ΣREE, which makes them the most promising in terms of REE content compared to other Croatian bauxites. This overview of REE in the karst bauxites shows that the REE have different distributions and therefore potential in different stratigraphic settings in the Dinaric region.

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SEISMOSTRATIGRAPHIC INTERPRETATION OF THE MESOZOIC SUCCESSION IN THE AREA OF PALAGRUŽA AND MLJET ISLAND WITH A REFERENCE TO THE PETROLEUM POTENTIAL

SEIZMOSTRATIGRAFSKA INTERPRETACIJA MEZOZOJSKOG SLIJEDA NASLAGA IZMEĐU PALAGRUŽE I MLJETA S OSVRTOM NA NAFTNOGEOLOŠKI POTENCIJAL

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Keywords: *Adriatic Carbonate Platform, Southern Adriatic, Mesozoic, 2D seismic, seismostratigraphy*

We investigated Mesozoic carbonate succession in the offshore area of Southern Adriatic, between Palagruža and Mljet island. The aim of the study was to investigate distribution of Mesozoic successions which can be attributed to the Adriatic Carbonate Platform (ACP) and deep-water Adriatic Basin (AB) (VLAHOVIĆ *et al.*, 2005; which is very thick (in places more than 8000 m FANTONI & FRANCIOSI, 2010). A further goal was to define seismic facies distribution of these two paleogeographic units and use them for the analysis of possible play and prospect evaluation in that area.

The research was done on the basis of 2D seismic, logging data of six wells and published data. Different seismic facies were defined based on the amplitudes, frequencies, and paleogeographic position. They were correlated with facies defined in the geological reports of the wells. Well to seismic tie was conducted identifying the main stratigraphic horizons on seismic and by synthetic seismogram on available wells. Seismic interpretation defined the spatial distribution of chronostratigraphic boundaries and the most significant unconformities e.g., Messinian unconformity, Top Mesozoic unconformity, and Mid-Triassic unconformity.

Parts of the carbonate platform and deep-water basin, as well as salt diapirs and their influence on the underground structures, are clearly visible on the seismic of the area. Facies analysis determined the geological development of the area through the Mesozoic and the spatial distribution of sedimentary environments. Possible plays are attributed to the slope sediments of Adriatic Carbonate Platform of Mesozoic succession and Paleocene–Miocene sandstones. The Adriatic Carbonate Platform slope play is presented by coarse grained debris sediments. The Paleocene–Miocene sandstone play is presented by calcareous clastic sediments of "flysh" unit which are prone to occurrence within the salt diapir traps. Within the carbonate complex, the position and distribution of the Jurassic rocks of Emma formation (MAZZUCA *et al.*, 2015) are defined as they represent the source rocks for both plays. The seal rocks of the possible plays are Paleocene–Miocene and Pliocene–Holocene classic fine-grained deposits.

Findings here present the geological evidence for further basin evaluation and play and prospect investigation in the Southern Adriatic define identified plays together with petroleum system elements.

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RECENT KNOWLEDGE ABOUT THE KARST SPRING MILJACKA IN THE KRKA BASIN
NOVIJA SAZNANJA O KRŠKOM IZVORIŠTU MILJACKA U SLIVU KRKE

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Ključne riječi: *hidrološke značajke, vodna bilanca, sliv, male vode*

Izvorište Miljacka locirano je u kanjonskom dijelu Krke, na području s vrlo razvedenim speleološkim sustavima (Miljacka I – V) s pojavama istjecanja na stalnim i povremenim izvorima. Za vodoopskrbu se crpi prosječno svega oko 0,072 m^3s^{-1}.

Postojanje snažnog izvora svega 9 km udaljenom od toka rijeke Zrmanje, koju karakteriziraju gubici vode iz njenog toka, kao i rezultati trasiranja kod Mokrog polja (vjerojatnije iz ponora u depresiji lociranoj južno od samoga toka Zrmanje a ne iz samoga korita) generirali su uvriježenu postavku da je izvorište Miljacka podzemni nastavak toka Zrmanje te da vode Zrmanje predstavljaju njen glavni dotok (FRITZ & PAVIČIĆ, 1982; TERZIĆ *et al.*, 2010, 2014). Izvorište Miljacka i povezanost Zrmanje i Krke bilo je i tematika hidroloških radova BONACCIJA (1999) te BONACCIJA & LJUBENKOVA (2005).

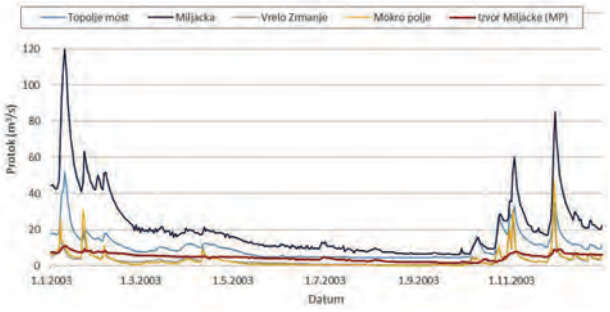
Unatoč važnosti izvorišta, hidrološke spoznaje o njegovom vodnom režimu bile su vrlo skromne, često i kontradiktorne. Tako su se procjene njegovih minimalnih protoka kretale od 0,200 m^3s^{-1} (HGI, 2008) i 1,94 m^3s^{-1} (GEOLOŠKI ZAVOD, 1985). Stoga su Hrvatske vode pokrenule novi ciklus istraživanja koji je uključivao hidrološki monitoring (15. 3. 2018. – 21. 5. 2020.), hidrološku analizu, dodatna hidrogeološka istraživanja kao i sagledavanja kemizma voda toga izvorišta, rijeke Krke i Zrmanje (GEO-5 d.o.o. & HIGRA d.o.o., 2019, 2020). Rezultati monitoringa iskorišteni su za dodatne usporedbe i analize s podacima hidroloških postaja s dugogodišnjim nizovima podataka u slivu Krke i Zrmanje, kao i modeliranje protoka modelima strojnog učenja – neuronske mreže (MP) i regresijska stabla odlučivanja (Trees.M5P).

Utvrđeno je da u vodnim stanjima između hidroloških postaja na rijeci Krki – uzvodnije Marjanovići i Miljacka postoji prirast protoka, dok se u sušnim razdobljima on ne zapaža. To ukazuje ne samo na postojanje gubitaka vode iz korita i zajezerenih dijelova s uzvodnijeg toka, nego i na okolnost da na izvorištu Miljacka u velikoj mjeri istječu vode čije je porijeklo nužno vezivati s tim ponirućim vodama Krke. Povećanjem vodnosti, povećavaju se i prirasti u protocima Krke na Miljacki na račun povećanih dotoka podzemnih voda izvorišta Miljacka iz njegovog krškog vodonosnika, u čemu stanoviti udjel mogu imati i vode iz sliva Zrmanje. No, on nije dominantan, jer su gubici protoka između postaja Prevjes i Ervenik na Zrmanji puno manji nego li su protoci koji istječu na Miljacki. Utvrđene su i blage unutardnevne fluktuacije istjecanja Miljacke povezane s protjecanjima Krke koji ovise o režimu rada HE Miljacka, odnosno razini vode jezera Brljan.

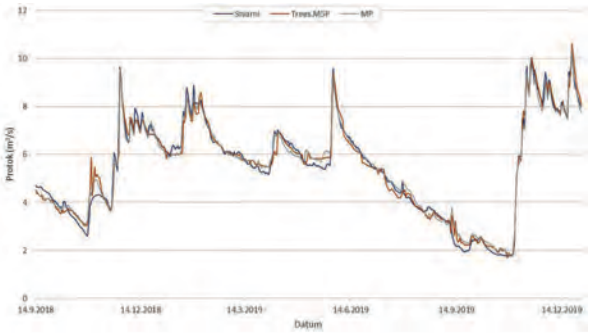
U prilog mogućeg većeg udjela voda s uzvodnijeg dijela toka Krke ide i razmatranje visinskih odnosa i udaljenosti između voda Zrmanje, Krke i izvorišta Miljacka, prema kojima su puno veći gradijenti toka voda iz sliva Krke. Zbog hidrogeoloških značajki Promina naslaga vjerojatno samo manji dio voda koje poniru u Zrmanji eventualno mogu usporeno otjecati prema izvorišnoj zoni Miljacke. One bi se prije mogle očekivati na nizvodnijim dionicama toka Zrmanje, moguće i značajnije nizvodnije od utoka Crnog vrila, čije se vode po kemijskom sastavu značajnije razlikuju od voda gornjeg dijela toka Zrmanje prije njihova poniranja. Bez obzira što se mezozojske karbonatne stijene kao i karbonatni klastiti Promina naslaga tretiraju kao dobro propusne vapnenačke stijene s pukotinsko kavernoznom poroznošću, ipak postoji bitna razlika u vodopropusnosti. Mezozojske vapnence možemo uistinu smatrati dobro propusnim stijenama sa subvertikalnim sustavom infiltracije meteorskih voda do razine vode temeljnice. Prominski klastiti se mogu smatrati srednje propusnim stijenama s blagim nagibom slojeva gdje meteorske vode sporije poniru, pogotovo u paketu klastita gdje je učestalija pojava lapora i laporovitih vapnenaca i koji omogućavaju pojavu povremenih visećih vodnih horizonata. Vidljivo je to u speleološkim objektima u neposrednoj blizini izvorišta Miljacka koji su horizontalno razvedeni po slojevima konglomerata, a voda leži odnosno lagano cirkulira kontaktom pojave lapora.

Tijekom analiziranog razdoblja monitoringa (8. 2018. – 5. 2020.), na izvorištu Miljacka (slika 1) zabilježena je minimalna vrijednost srednjeg dnevnog protoka od 1,75 m^3s^{-1}, maksimalna 10,8 m^3s^{-1}, s prosjekom za navedeno razdoblje od 5,5 m^3s^{-1}.

Hidrološkim modelom generirani nizovi podataka pokazali su da tijekom iznimno sušnih godina protoci Miljacke mogu pasti i na niže vrijednosti, pa je tako za 2003. g. utvrđena minimalna izdašnost od 1,46 m^3s^{-1} (slika 2).



Slika 1. Usporedni prikaz izmjerenih i modeliranih srednjih dnevnih protoka na izvoru Miljacke za cijelo razdoblje od 14. 9. 2018. do 31. 12. 2019.



Slika 2. Usporedni prikaz izmjerenih srednjih dnevnih protoka na postajama Topolje most, Miljacka, Vrelo Zrmanje i Mokro polje te modeliranih (model MP) srednjih dnevnih protoka izvoru Miljacke tijekom 2003. godine

Takve vrijednosti, vezano i uz procjene recesijskih značajki, vjerojatnosti pojave minimalnih godišnjih protoka kao i provedene ocjene utjecaja klimatskih promjena, govore da bi se moglo raditi o izvorištu kod koga se iznimno mogu javiti i ekstremno mali protoci reda veličine oko 1 m^3s^{-1}.

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SEQUENCE STRATIGRAPHIC INTERPRETATION OF THE PLIOCENE TO RECENT INFILL IN THE SOUTHERN PART OF THE ADRIATIC FORELAND SYSTEM

INTERPRETACIJA SEKVENCIJSKE STRATIGRAFIJE PLIOCENSKOG DO RECENTNOG SLIJEDA NASLAGA U JUŽNOM DIJELU JADRANSKOG PREDGORSKOG SISTEMA

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Keywords: *Adriatic foreland, Pliocene to Holocene, 2D seismic, sequence stratigraphy, shelf-break trajectory*

Evolution of the foreland basin sediments in the Adriatic (Messinian – Quaternary) foredeep system was controlled by the Meso and Neoalpine emersed chain. Croatian southern part of this system, comprises the Palagruza Trough and the South Adriatic Basin, is filled with marine clastic succession. Our study, in this area, aims to reconstruct the shelf-edge trajectories and sequence stratigraphy of the Pliocene to Quaternary infill, to describe the migration of the depositional systems and their evolution influenced by the contemporaneous tectonics.

Study is based on the published geological maps, well logs and reports from six wells, and interpretation of 2D seismic sections. Well to seismic tie is done through synthetic seismograms. Mappable seismic facies are defined and correlated with sedimentological facies and depositional processes. Stratal terminations and stratal stacking patterns are investigated in order to define the base level change, main stratigraphic surfaces and system tracts of sequences.

Both ascending and descending shelf-edge trajectories are defined. Ascending trajectories are associated with transgressive and highstand system tracts. Descending trajectories are associated with forced regression and the presence of extensive erosional surfaces on the shelf. Overall progradation characterizes the Pliocene and Pleistocene sediments, firstly filling the Palagruza Trough in the SW direction and then SE progradation towards the South Adriatic Basin. The progradation pattern is interrupted by a base-level rise at the end of Pliocene. By analysing the main sediment transport directions, the two third-order unconformity-bounded stratigraphic units are interpreted.

The results shed light on stratigraphic and tectonic evolution of the southern part of Adriatic foredeep, providing the records of the regional and global controls driven by the local tectonics and emersion, depocenter migration and subsequent basin infill.

MAPPING OF THE SYN-RIFT INFILL AND TECTONIC CONTROL ON THE RESERVOIR DISTRIBUTION: EXAMPLE FROM THE DRAVA BASIN, PANNONIAN BASIN SYSTEM

KARTIRANJE SINRIFTNE ISPUNE I TEKTONSKA KONTROLA DISTRIBUCIJE KOLEKTORSKIH STIJENA: PRIMJER IZ DRAVSKOG BAZENA, PANONSKI BAZENSKI SISTEM

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Keywords: *Drava Basin, reservoirs, syn-rift, seismic data, tectonic control*

The Drava Basin in the SW Pannonian Basin System was originally formed by passive rifting with accompanying sedimentary infill. Although this has been the subject of much previous exploration, an account of tectonic control has been lacking. Based on cores, wireline logging and seismic data, the tectonostratigraphic interpretation and control on depositional systems of the syn-rift infill in the eastern part of the Drava Basin were studied. Reservoir characteristics are investigated based on available petrophysical data from wells and on analogue data from similar settings.

The rifting phase is characterised by the formation of half-grabens, grabens, a sag, and supradetachment basin structures with structural ramp and structural highs. The syn-rift infill can be divided into second-order tectonostratigraphic sequences corresponding to the early and late rift stages. The second-order sequences are further subdivided into third-order tectonostratigraphic sequences formed in response to higher-order tectonic events associated with local rift migration. In contrast to the early-stage structures, the late-stage rift structures are primarily controlled by extensional detachments that represent parts of the Drava Rift Fault System. The early syn-rift is characterised by continental deposition through alluvial fans, fan deltas, and lacustrine environments. The late syn-rift stage is characterised by marine deposition in shallow water, fan deltas, and submarine slope-aprons, with deep marine sedimentation and intense volcanic activity. The ramp, basin slopes, and fault scarp slopes represent the major sediment transport pathways that were involved in the formation of alluvial fans, fan deltas, or submarine slope-aprons. Basinal sedimentation and major depocenters are located within synforms formed by the activity of extensional detachments.

Reservoir quality in syn-rift infill is controlled by the genetic type of coarse-grained rocks which can be present in different depositional facies. Breccia and conglomerates of alluvial fans are of debris (gravity) flow origin, often with mud-rich matrix intervals. Conglomerates and sandstones of fan deltas can be of both gravity or fluvial flow origin and dominantly clast supported with more fine-grained clasts towards the prodelta foresets. Breccia and conglomerates of slope apron facies are deposited as debris (gravity flow) sediments in deeper marine environment. Therefore, the key elements of reservoir quality is mud content in the matrix. Prospective reservoir locations are related to the larger depositional systems which are controlled by the main sediment pathways to the main depocenters. Sufficient transport distance could enable the differentiation of lithofacies within depositional system.

This study gives an example of syn-rift tectonic control and the influence of detachment geometry on basin fill in the SW part of the Pannonian Basin System. We have presented an approach based on 3D seismostratigraphic interpretation of tectonostratigraphic sequences, and correlation of seismic facies with depositional environments. Further, showcase of the syn-tectonic movements control on reservoir distribution is given. Mapping of the reservoir properties on a regional scale is paramount starting point for any estimates of geoenergy potential.

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ROCK PROPERTIES MODELLING ON SELECTED WELLS IN NORTH-WESTERN CROATIA

MODELIRANJE SVOJSTAVA STIJENA NA ODABRANIM BUŠOTINAMA SJEVEROZAPADNE HRVATSKE

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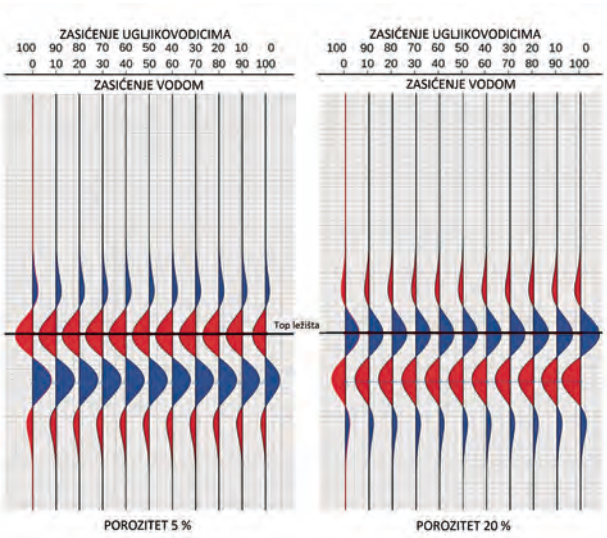
Ključne riječi: *Sjeverozapadna Hrvatska, modeliranje, seizmički odraz, plinsko ležište*

Primarna seizmička svojstva fluida kao što su brzina, gustoća i volumni modul, sustavno variraju s promjenama tlaka i temperature. Modeliranjem svojstava stijena moguće je na seizmičkom prikazu zaključiti kako se ponaša seizmički val ulaskom u stijene zasićene vodom ili ugljikovodicima. Obzirom da je za kompletno, što točnije modeliranje osim primarnog P-vala, potreban i sekundarni S-val neophodno ga je u slučaju kada nije snimljen pokušati procijeniti. Cijeli proces na početku zahtijeva podatke o temperaturi, tlaku, salinitetu i specifičnoj gustoći ugljikovodika u ležištu. Na temelju tih izmjerenih vrijednosti izračunavaju se pomoću Batzle-Wang formule brzina, gustoća i volumni moduli za slučajeve zasićenja plinom, vodom i naftom (BATZLE & WANG, 1992). Tada se pristupa predikciji S-vala zasnovanoj na Greenberg-Castagna metodi (GREENBERG & CASTAGNA, 1992) za koju se koriste karotažne krivulje brzine, gustoće, poroznosti, zasićenja vodom. Također su za točan izračun potrebni volumni moduli i gustoće fluida (voda, plin i nafta) koji su prethodno izračunati Batzle-Wang formulom, kao i relativni volumeni zastupljenih sedimentnih stijena (pješčenjak, lapor, karbonati). Pomoću Gassmannove metode zamjene fluida radi se također i zamjena poroziteta (GASSMANN, 1951). Mijenjanjem apsolutnih vrijednosti poroznosti u postocima kreiraju se karotažne krivulje brzina P- i S-vala, kao i gustoće koje odgovaraju karakteristikama stijena manjih ili većih poroznosti. Modeliranjem svojstava stijena se kao krajnji rezultat dobiva prikaz mogućeg izgleda seizmičkog vala na ulazu u ležište zasićeno ugljikovodicima u stvarnom, izmjerenom slučaju, kao i u slučajevima manjih i većih poroziteta. Također se može pratiti povećanje ili smanjenje amplitude u slučaju stopostotnog zasićenja ugljikovodicima, stopostotnog zasićenja vodom, kao i između te dvije krajnje vrijednosti.

Analizirani primjer plinskog rezervoara ranog post-rifta (slika 1) bušotine A-1 cvjetne strukture Vučkovec-Zebanec-Budafa obilježen je maksimumom negativne amplitude (*trough*) kao ulaskom u ležište. Modeliranjem, veći poroziteti uzrokuju izraženiju negativnu amplitudu, dok manji uzrokuju promjenu amplitude iz negativne u



Slika 1. Modelirani seizmički prikaz manjih (5 %) i većih (20 %) poroziteta za slučajeve zasićenja vodom ili ugljikovodicima (od 0–100 %) na bušotini A-1

pozitivnu. Ugljikovodici imaju relativno mali utjecaj, jer dolazi do vrlo male promjene u akustičkim impedancijama s obzirom na postotak zasićenja vodom. Time se zaključuje da na magnitudu amplitude najveći utjecaj ima poroznost odnosno kvaliteta samog ležišta.

Također je osim zamjene poroznosti moguće napraviti i modeliranje svojstava stijena, tj. brzina P- i S-vala kao i gustoće za krovinu ležišta. Odabiru se manje ili više vrijednosti brzina i gustoća kako bi se simulirala manje ili više kompaktna krovina te pratio utjecaj na odraz seizmičkog vala.

Modeliranje svojstava stijena prvenstveno može biti korisno u analizi područja koja su potencijalna nalazišta ugljikovodika. Na ovaj način moguće je deriskirati nove prospekte koristeći se analogijom dostupnih bušotina istih ili sličnih područja.

Uspješno kalibriranje ležišta ugljikovodika ranog post-rifta potvrdilo je da maksimum negativne amplitude (*trough*) kao ulazak u ležište može vezati za dodatni potencijal na okolnim prospektima. Promjenom poroziteta mijenja se faza (promjena amplitude iz negativne u pozitivnu) te se zaključilo da na analiziranom području takvi primjeri ukazuju na loša rezervoarska svojstva.

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THE SITE HUŠNJAKOVO – AN EXAMPLE OF THE INFLUENCE OF THE CLIMATE CHANGES ON THE GEOLOGICAL HERITAGE

NALAZIŠTE HUŠNJAKOVO – PRIMJER UTJECAJA KLIMATSKIH PROMJENA NA GEOLOŠKU BAŠTINU

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Ključne riječi: *promjena klime, muzej, neandertalac, geološka baština*

Nalazište pračovjeka Hušnjakovo u Krapini prvi je zaštićeni paleontološki spomenik prirode u Republici Hrvatskoj, od 1961. godine. Zahvaljujući velikanu hrvatskog prirodoslovlja, Dragutinu Gorjanoviću-Krambergeru, krapinski lokalitet spada u najvažnija paleolitička nalazišta na svijetu. U Krapini je prikupljeno oko 900 fosilnih ostataka neandertalaca, oko 2500 komada životinjskih kostiju iz razdoblja gornjeg pleistocena, a o materijalnoj kulturi svjedoče nam kamena oruđa, kojih je prikupljeno oko 1200 komada (RADOVČIĆ, 1998). Svi ovi nalazi čine lokalitet Hušnjakovo najbogatijim nalazištem neandertalaca na svijetu. Početkom 70-tih godina 20. stoljeća u neposrednoj blizini nalazišta pračovjeka Hušnjakovo, otvoren je Muzej evolucije. Novi Muzej krapinskih neandertalaca, gdje se sada nalazi stalni postav, otvoren je 2010. godine i jedan je od najposjećenijih muzeja u ovom dijelu Europe. Iako se u krapinskom muzeju ne nalazi zbirka koja je pronađena na Hušnjakovu, već u Hrvatskom prirodoslovnom muzeju, krapinski muzej svojevrstan je interpretacijski centar samog lokaliteta Hušnjakovo i fosilnih nalaza koji su tu prikupljeni.

Tijekom zadnjih pet desetljeća uglavnom se ulagalo u muzejsku djelatnost, no ne i u očuvanje samog Nalazišta koje je gotovo nepromijenjeno još od Krambergerova otkrića. S obzirom da je taj cijeli kompleks izgrađen od žutog miocenskog pješčenjaka, često podložnog eroziji i odronima, 60-tih godina pokušalo ga se zaštiti pomoću drvenih pletera i pošumljavanjem crnogorice, što se nakon nekoliko desetljeća pokazalo pogrešnim pa čak i opasnim. Klimatske promjene su u tijeku te ih je gotovo nemoguće u potpunosti zaustaviti no možemo im se prilagoditi (PÖRTNER *et al.*, 2022). Uz globalno zatopljenje karakterizira ih i učestalost pojave ekstremnih događaja, kao što su poplave, suše i tuča. Najpoznatiji pokazatelj klimatskih promjena odnosno globalnog zatopljenja je porast godišnje temperature zraka. Prema dostupnim podacima s meteorološke postaje Krapina u periodu od 1994. do 2020. godine evidentan je porast srednje godišnje temperature zraka za oko 1,5 °C, kao i broj vrućih

dana. Na istoj meteorološkoj postaji, dostupni podaci ukazuju na učestaliju pojavu tuče (godišnji prosjek 6,3 dana), kao i iznenadne promjene u strujnom režimu vjetra čemu pridonosi specifičan reljef, nadmorska visina itd.

Sve navedene promjene, a najviše nesrazmjer količine kiše u rano proljeće i ranu jesen te snažni povremeni vjetrovi, pridonijeli su tome da se na samom lokalitetu Hušnjakovo u periodu od 2017. do 2022. dešavaju nepogode u vidu odrona pješčenjačkih stijena natopljenih vodom dok je crnogorično drveće iščupano iz terena zajedno s korijenjem. S obzirom da dosadašnje intervencije (zaštita pomoću drvenih pletera i pošumljavanje crnogoricom) nisu bile uspješne, neophodno je lokalitet Hušnjakovo zaštiti na odgovarajući način. Potrebno je prije svega izraditi elaborate geodetskih radova, inženjersko-geoloških kao i građevinskih zahvata na samom terenu kako bi se što prije pristupilo sigurnosnoj sanaciji lokaliteta, što bi osiguralo sigurnost posjetitelja i očuvanje prirodne baštine za buduće generacije.

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REPRESENTATIVES OF THE *ELPHIDIIDAE* FAMILY FROM BUKOVA GLAVA LOCALITY (NAŠICE)

PREDSTAVNICI PORODICE *ELPHIDIIDAE* LOKALITETA BUKOVA GLAVA (NAŠICE)

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Ključne riječi: *sarmat, bentičke foraminifere, Elphidium, Paratethys, paleoekologija*

Danas je poznato više od 200 različitih vrsta roda *Elphidium*, te svega sedam različitih vrsta roda *Porosononion* iz porodice Elphidiidae (WoRMS) koje naseljavaju različite okoliše od unutrašnjeg šelfa do gornjeg batijala i tolerira-ju različite raspone saliniteta, od 0 do 70 ‰ (MURRAY, 1991). Analizom udjela vrsta elfidija s kobilicom unutar fosilne zajednice bentičkih foraminifera mogu se dobiti podatci o nekadašnjim okolišima. Naime, jedinke elfidijuma s kobilicom žive kao epifauna na pjeskovitim podlogama, dok jedinke bez kobilice žive kao infauna i preferiraju muljevite podloge (MURRAY, 2006).

Na profilu Bukova glava, smještenom na sjevernim padinama planine Krndija, metodom muljenja obrađena su 43 uzoraka lapora, te je u 29 uzoraka utvrđen dovoljan broj mikrofosila za odredbu starosti naslaga i paleoekološku interpretaciju okoliša (300 jedinki foraminifera). Osim bentičkih foraminifera, prisutne su i planktonske foraminifere, spikule spužvi, bodlje ježinca, mahovnjaci, ostrakodi te puževi. Zajednice bentičkih foraminifera su detaljno analizirane te je utvrđena jedinkama bogata i raznolika zajednica sarmatskih elfidijuma. Predstavnici porodice Elphidiidae su rod *Elphidium* zastupljen sa 10 vrsta te rod *Porosononion* zastupljen s vrstom *P. granosum*. Stupanj očuvanosti jedinki kreće se od vrlo dobre i dobre u donjosarmatskim naslagama (donji i središnji dio stupa), dok u gornjosarmatskim naslagama (gornji dio stupa), jedinke imaju srednji stupanj očuvanosti (često su fragmentirane te pokazuju tragove otapanja).

Na osnovu bentičkih foraminifera, posebice predstavnika porodice Elphidiidae u donjosarmatskim naslagama lokaliteta Bukova glava izdvojene su tri eko-biozone donjeg sarmata. Eko-biozona *Anomalinoides badenensis* je obilježena izrazitom dominacijom vrste *Anomalinoides badenensis* (D'ORBIGNY), a od elfidija najbrojnije su vrste *Elphidium crispum* (LINNAEUS, 1758) i *E. fichtellianum* (d`ORBIGNY), dok je vrsta *E. hauerinum* (d`ORBIGNY) manje zastupljena. Vrsta *E. reginum* (d`ORBIGNY) pojavljuje se samo u središnjem dijelu stupa i obilježava uski interval *Elphidium reginum* eko-biozone. Dominacija epifaunalnih jedinki porodice *Elphidiidae* koje imaju izraženu kobilicu i/ili bodlje ukazuje na plitkovodni marinski okoliš s bujnom vegetacijom na morskom dnu, te je ova

zajednica živjela u nešto plićem i uzburkanijem okolišu nego zajednica iz *Anomalinoides badenensis* eko-biozone. U sastavu zajednice bentičkih foraminifera *Elphidium haueri-num* eko-biozone prevladavaju elfidiji od kojih treba posebno istaknuti vrstu *E. hauerinum* (d`ORBIGNY), nosioca ove zone. Jedinke elfidijuma bez kobilice žive kao infauna i preferiraju muljevite podloge (MURRAY, 2006) te porast udjela infaunalnih oblika u ovoj eko-biozoni, može upućivati na produbljavanje taložnog okoliša i/ili nešto veću količinu organske tvari u sedimentu.

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POLYMORPH-BEARING MELT INCLUSIONS IN MAGMATIC ZIRCON FROM SLAVONIAN MTS.

UKLOPCI TALJEVINE S POLIMORFNIM MODIFIKACIJAMA U MAGMATSKOM CIRKONU SA SLAVONSKIH PLANINA

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Ključne riječi: *kisele magmatske stijene, cirkon, kumdykolit, kokchetavit, nanograniti*

Slavonske planine smještene u jugozapadnom dijelu Panonskog bazena predstavljaju tzv. otočne gore na kojima izdanjuju stijene kristaline podloge. Osim stijena podloge (pred-)variscijskih starosti, na Papuku i Požeškoj gori pojavljuju se kasnokredne magmatske stijene koje pripadaju tzv. Senonskoj bazaltno-riolitnoj formaciji (PAMIĆ, 1997). Kiseli varijeteti ovih magmatskih stijena (rioliti i granit) specifičnog su geokemijskog sastava (A-tip taljevine) i starosti (~82 mil. god., U-Th-Pb na cirkonima) te ukazuju na geološke događaje krajem krede, koji su rezultirali otvaranjem puteva pogodnih za brzo izdizanje taljevine prema površini. Kisele stijene dominantno su sastavljene od albita, kvarca i K-feldspata uz akcesorni cirkon, apatit, magnetit, hematit (s eksolucijskim lamelama ilmenita u granitu) i monacit te sporadične pojave aegirina(-augita).

Cirkoni izdvojeni iz kiselih varijeteta magmatskih stijena obiluju brojnim primarnim uklopcima veličine uglavnom ≤ 10 μm. Metodom Ramanove spektroskopije određeni su sljedeći minerali prisutni kao uklopci: anatas, albit, (hidroksi-)fluorapatit, hematit, ilmenit, kokchetavit, kristobalit, kumdykolit, magnetit i muskovit. Nalaz kokchetavita i kumdykolita u cirkonu kasnokrednih kiselih magmatskih stijena prvi je nalaz ovih polimorfnih modifikacija K-feldspata i albita u magmatskom cirkonu. Njihov nalaz od velikog je značaja budući da su do sada detektirani samo kao uklopci u metamorfnim mineralima i metamorfnim stijenama koje su nastale u uvjetima iznimno visokih tlakova (eng. ultra-high-pressure, UHP) te se smatraju isključivo indikatorima UHP uvjeta metamorfizma. U zajednici s albitom, kristobalitom, hematitom i muskovitom predstavljaju uklopke taljevine i tzv. nanostijene (nanogranite, BARTOLI & CESARE, 2020) te dokazuju kako ne nastaju isključivo u UHP uvjetima, već mogu biti i indikatori brzog hlađenja stijene (FERRERO *et al.*, 2016).

Uklopci anatasa te uklopci taljevine s kokchetavitom i kumdykolitom dokaz su brzog izdizanja vruće oksidirane taljevine iz područja donje kore, njezin smještaj u (pri-) površinske gornje dijelove kore te posljedičnog naglog hlađenja. Takvo naglo izdizanje bilo je omogućeno otvaranjem dubokih rasjeda (riftova) prilikom tektonskog prijelaza iz kompresijskog u ekstenzijski režim na području današnjih slavonskih planina u razdoblju kasne krede.

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OCCURRENCE OF EMERGING ORGANIC CONTAMINANTS IN DINARIC KARST CATCHMENT OF JADRO AND ŽRNOVNICA SPRINGS, CROATIA

POJAVNOST SPECIFIČNIH ORGANSKIH MIKROONEČIŠĆIVALA U DINARSKOM SLIJEVU IZVORA JADRO I ŽRNOVNICA, HRVATSKA

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Keywords: *emerging contaminants, groundwater, karst, Jadro, Žrnovnica*

Karst aquifers are a globally significant source of drinking water and water important for related ecosystems that harbour often endemic species specifically vulnerable to anthropogenic contamination. The recurrent and widespread occurrence of emerging organic contaminants (EOCs), a vast group of existing or newly synthesized anthropogenic substances, in the water environment and across biological matrices, requires an interdisciplinary approach to solving this pressing scientific and regulatory challenge, with the main aim of protecting water quality, related ecosystems, and subsequently human health. Karst aquifers are perplexing transport systems in which highly variable flow dynamics, direct infiltration via ponors, preferential and rapid groundwater flow in conduits allows contaminants to quickly reach water sources used for drinking water supply. Conventional water treatment processes, such as chlorination often applied in Croatia, have been ineffective in eradicating EOCs and can also lead to forming of more toxic transformation products.

We provide insights into the occurrence and prioritization of 21 EOCs detected in the karst catchment of Jadro and Žrnovnica springs (Dinarides, Croatia) that are used in the water supply. Seven sampling campaigns were conducted to detect the presence of EOCs divided into main groups: pharmaceuticals and personal care products, industrial, agricultural, and lifestyle products. Four sampling sites included Jadro and Žrnovnica springs, Cetina River, and Gizdavac borehole (pumping depth of 266 m). The EOCs concentrations ranged up to 372 ng/L for industrial compound 1H-benzotriazole detected in Cetina River. Insect-repellent DEET was the most frequently found EOC with an average concentration of around 50 ng/L in both surface water and groundwater.

We prioritized detected EOCs according to their persistence (P), mobility (M) and toxicity (T), assessed with the help of in silico tools and search of online databases. Only four out of 21 detected EOCs were not assessed as PMT/vPvM (persistent, mobile and toxic, or very persistent and very mobile), as they did not fulfill persistence criteria. Nearly all EOCs can be characterized as very mobile in the water environment, with only two compounds not being toxic. Karst springs exhibited larger proportions of EOCs meeting PMT/vPvM criteria than surface water (SELAK *et al.*, 2022).

This was one of the first studies on EOCs in Croatian karst, and considering the lack of research addressing EOCs in karst aquifers at the global and national level (LUKAČ REBERSKI *et al.*, 2022), this study provides valuable findings on their potential environmental risk.

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PALYNOLOGICAL CHARACTERISTICS OF THE QUATERNARY DEPOSITS FROM THE KRALJEV VRH SECTION (CROATIA)

PALINOLOGIJA KVARTARNIH NASLAGA SA STUPA KRALJEV VRH (HRVATSKA)

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Keywords: *palynology, Quaternary, Bistra Formation, Croatia*

Section Kraljev Vrh – II (KrV-II) is situated on the northwestern slope of Medvednica Mt. and belongs to the Bistra Formation. At its locus typicus, Bistra Fm. is composed of heterogenous clastic sediments deposited in various settings ranging from alluvial fans to marshes and flood plains (GRIZELJ *et al.*, 2017). In section KrV-II there are developed two lithofacies units, sandy-gravelly facies, and facies of sandy-clayey silts representing alluvial environments ranging from channel infill to flood plains. Palynological analyses were done to define vegetation and climate during the deposition of the formation, as well as supplement sedimentological interpretations of the depositional setting.

Palynofacies of all studied samples are dominated by phytoclasts: in KrV-II 1/1 biostructured, banded, lignified dark brown wood, in KrV-II 3/1 dark brown wood, mostly corroded charcoal, and amorphous organic matter, in KrV-II 5/1 only corroded charcoal. On the other side, in KrV-II 10/1 palynofacies is dominated by light brown phytoclasts: transparent ligno-cellulosic fragments, gelified particles, charcoal, amorphous particles, and resin.

Palynomorph concentrations (STOCKMAR, 1971) are very low ranging from 46 (KrV-II 5/1) to 1055 (KrV-II 10/1) palynomorphs per gram.

The conducted studies of the samples of the KrV-II section showed that they were formed in several different paleogeographic conditions.

The deposits of the KrV-II 1/1 sample were formed under more arid conditions, as evidenced by the predominance of pollen from herbaceous plants. The predominance of *Pinus* pollen among the group of tree species, a low amount of pollen from deciduous plants of the moderate-warm zone, and the absence of pollen from thermophilic species of the Juglandaceae family may indicate warm-temperate climatic conditions during the formation of the studied deposits. According to freshwater algae, we assume the existence of freshwater environment during the period of accumulation of the studied deposits.

During the formation of deposits KrV-II 3/1, the humidity probably increased and the temperature regime of the climate increased. An increase in humidity can be evidenced by a significant increase in the role of tree pollen, and in this group, pollen grains of deciduous plants. The presence of pollen from thermophilic plants *Juglans* spp. and Moraceae in the composition of the spore-pollen spectra indicates an increase in the temperature regime of the climate.

Spore-pollen spectra of sample KrV-II 5/1 yield an insignificant content of pollen and spores, and therefore it was not possible to reconstruct the conditions for the formation of the deposits.

Completely different conditions existed during the accumulation of deposits of sample KrV-II 10/1. Analysis indicates much warmer and wetter climatic conditions during their formation. The dominance of pollen of angiosperms in the composition of the spectra, and in this group – of pollen of the Juglandaceae family plants, as well as its taxonomic diversity, indicates very warm and humid conditions. Carya was the main forest-forming tree species, and Juglans was noted as subdominant. The existence of swamp forests is evidenced by the presence of pollen from Taxodiaceae and Cupressaceae and confirmed by palynofacies. The sporomorph assemblage is similar to the Pollen zone 4 of DSDP Site 380 in the Black Sea (POPESCU *et al.*, 2010). They correlate this zone with MIS 95-63 intervals of Pleistocene age. Material from the studied sample KrV-II 10/1 can also point to the interglacial Pleistocene swamps and riparian forests. The other possibility is that this material was redeposited from older deposits (Pannonian–Pliocene).

Analysis of the preservation, identified palynomorphs, their taxonomic affiliation, as well as palynofacies indicate that the sampled deposits were formed in the Lower Pleistocene: samples KrV-II 1/1 and KrV-II 5/1 during the glacial whereas KrV-II 3/1 and KrV-II 10/1 during the interglacial intervals.

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MIDDLE TRIASSIC CALC-ALKALINE BASALTS AND ANDESITES OF IVANŠČICA AND STRAHINJŠČICA MTS. (NW CROATIA): MINERALOGY, PETROLOGY AND TECTONO-MAGMATIC SETTING OF FORMATION

SREDNJOTRIJASKE KALCIJSKO-ALKALIJSKE BAZALTNO-ANDEZITNE STIJENE IVANŠČICE I STRAHINJŠČICE (SZ HRVATSKA): MINERALOGIJA, PETROLOGIJA I TEKTONO-MAGMATSKI OKOLIŠ NASTANKA

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Ključne riječi: *mineralogija, petrologija, srednji trijas, bazaltno-andezitne stijene, SZ Hrvatska*

Na sjevernohrvatskim gorama Ivanščici i Strahinjščici smještanim na tromeđi južnih Alpa, Dinarida i Tisije izdanjuju kalcijsko-alkalijske vulkanske i vulkanoklastične stijene asocirane (interstratificirane) sa srednjotrijaskim karbonatima i siliciklastičnim stijenama u SZ Hrvatskom Trijaskom Riftnom Bazenu (KUKOČ *et al.*, 2023). Ovo je područje dio jugozapadnog segmenta Zagorje-srednjotransdanubijske smične zone (PAMIĆ & TOMLJENOVIĆ, 1998). Vulkano-sedimentna sukcesija karakterizirana je izmjenom bazičnih i kiselih efuziva s vapnencima, dolomitima te radiolarijskim rožnjacima (KUKOČ *et al.*, 2023; SLOVENEC *et al.*, 2023). Srednjotrijaska (gornji anizik–donji ladinik) starost bazičnih vulkanita, osim na temelju fosilnog sadržaja interstratificiranih sedimenata, određena je izotopnim datiranjem (244,5±2,8 Ma). Vulkaniti su zastupljeni izljevima ili tokovima lava, podređeno tufovima i vulkanskim aglomeratima. Dominantno su porfirne strukture i homogene ili fluidalne teksture, izgrađeni od utrusaka homogenih do umjereno sericitiziranih K-feldspata (sanidina) i albitiziranih plagioklasa te klinopiroksena (augita). Podređeni su sekundarni klorit, amfibol, prehnit, pumpellyit i sericit, dok su akcesorni spinel, titanit i Fe-oksidi. Mikrokristalna osnova je holokristalna ili izgrađena od devitrificiranog vulkanskog stakla. Milimetarske mandule najčešće su ispunjene kloritom.

Kemijski sastav vulkanita karakterizira širok raspon SiO_2 (43,12–57,41 wt.%), MgO (0,98–7,94 wt.%) i K_2O (0,21–8,19 wt.%), te Na_2O i CaO, a visoke vrijednosti LOI (do 10,4 wt.%) indiciraju umjeren do visok stupanj alteracija. Visok sadržaj kalija vezan je za alterirane uzorke i uzorke s modalno većim udjelom K-feldspata. Analizirane stijene kemizmom odgovaraju subalkalijskim bazaltima i bazaltnim andezitima srednje do visoko-K kalc-alkalijske serije. Lave pokazuju evoluirani geokemijski karakter (Mg# = 20–70) i izraženu frakcionaciju (Cr = 14–219 ppm). Iako su zapažene određene varijabilne izmjene mineralnog sastava stijene, kemizam jasno odražava njihov originalni magmatski sastav. Koncentracije elemenata rijetkih zemalja (REE) normalizirane prema koncentracijama u hondritu pokazuju umjereno obogaćenje lakih prema teškim REE [$(La/Lu)_{cn}$ = 2,81–11,22] na razini koncentracija ~ 98–110 puta višim od hondrita. Procijenjena Eu anomalija (Eu/Eu* = 0,62–0,91) je tipična za ranu akumulaciju feldspata ili frakcionaciju pri niskom pritisku. Krivulje prema N-MORB-u normaliziranih koncentracija vulkanita na spider dijagramima pokazuju selektivno sekundarno obogaćenje litofilnih elemenata (Cs, Ba, Rb, K), dok u segmentu elemenata visokog ionskog potencijala (HFSE) pokazuju slabo obogaćenje do osiromašenje na razinama koncentracija 7 do 0,7 puta višim od N-MORB-a. Svi uzorci pokazuju negativnu Nb-Ta i Ti anomaliju jakog intenziteta [$(Nb/La)_n$ = 0,17–0,69; $(Ti/Sm)_n$ = 0,21–0,64] što indicira visoki udio fluida oslo-

bođenih iz subducirane ploče. Vrijednosti omjera Th/La (0,22–0,46) i Th/Ta (11,3–19,4), te pozitivna Pb [$(Pb/Ce)_n$ = 1,66–9,22] anomalija ukazuju na umjerenu kontaminaciju magme kontinentalnom korom (TAYLOR & MCLENNAN, 1985), dok niske pozitivne vrijednosti inicijalnog $\varepsilon_{Nd(245Ma)}$ (do 1,90) uz nizak $^{147}Sm/^{144}Nd$ omjer (do 0,152061) sugeriraju utjecaj subduciranog juvenilnog matrijala (subducirana ploča s malo pelagičkih sedimenata; SWINDEN *et al*., 1990). Stoga osim obogaćivanja fluidima izvedenim iz subducirane ploče, čini se da je magma bila kontaminirana i recikliranim sedimentima iz subducirane Paleotetiske ploče, na što sugerira linearni trend Th/Nb vrijednosti (0,66–1,34) (LEAT *et al*., 2000). Navedeno upućuje na kompleksno podrijetlo srednjotrijaskih bazaltno-andezitnih lava Strahinjščice i Ivanščice u čiji su nastanak parcijalnim taljenjem (~ 5–13%) plitkog plaštnog izvorišta bile uključene dvije izvorišne komponente: (i) fertilni lučni plašt s obogaćenim lakim REE i (ii) subducirani kontinentalni materijal dugotrajno obogaćivan lakim REE. Međutim, tijekom generiranja magme ne može se potpuno isključiti i manji doprinos parcijalnog taljenja dijela kontinentalne kore tijekom uzdizanja i prolaska magme kroz tektonski oslabljene zone kontinentalne kore. Osim parcijalnog taljenja geneza analiziranih stijena uključuje i frakcionu kristalizaciju (MgO/FeO_{UK} = 0,2–1,3).

Kemijski sastav analiziranih stijena analogan je vulkanitima formiranim u okolišu vulkanskog luka andskog tipa kontinentalnog ruba i dobrim dijelom je naslijeđen iz starijih lučnih litologija povezanih sa subdukcijom Paleotetisa (SLOVENEC & ŠEGVIĆ, 2021). Stoga se njihov postanak može objasniti konceptom koji favorizira: (i) aktivnu srednjotrijasku sjevernovergentnu subdukciju Hercinske Paleotetiske litosfere pod Europsku ploču uz taljenje plaštnog klina (STAMPFLI & BOREL, 2002; 2004) ili (ii) otvaranje Neotetisa uz jugozapadnu subdukciju Paleotetiske litosfere ispod sjeveroistočnog ruba Velike Adrije (VAN HINSBERGER *et al*., 2020). Vjerojatniji, drugi scenarij uključuje proces pasivnog kontinentalnog riftinga i nastanak srednjotrijaskih bazaltno-andezitnih serija stijena parcijalnim taljenjem heterogenog litosfernog (subkontinentalnog) plašta metasomatiziranog tijekom ranije Hercinske subdukcije u kasnom paleozoiku, te podređeno procesa taljenja gornje kontinentalne kore i frakcionacije. Površinsko izlijevanje i smještavanje ovih lava zbivalo se u tzv. „simple or half-graben syn-rift" SZ Hrvatskom Trijaskom Riftnom Bazenu.

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MID-TRIASSIC VOLCANO-SEDIMENTARY SUCCESSIONS OF NW CROATIA – IMPLICATIONS FOR THE EARLY EVOLUTION OF THE ADRIATIC MARGIN

SREDNJE TRIJASKE SUKCESIJE SJEVEROZAPADNE HRVATSKE – IMPLIKACIJE ZA RANI RAZVOJ ADRIJE

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Keywords: *volcaniclastic deposits, rifting basins, syn-rift deposits, bimodal volcanism*

Tectonic movements related to the opening of the Neotethys as well as the subsequent Pangea disintegration left their imprints regionally in the form of volcanics and volcaniclastic deposits on the western Tethyan margins. The evidence of such volcanic activity can be recognized in the form of volcanic rocks and volcano-sedimentary successions recorded in the entire Greater Adria promontory. Rift-related tectonic activity is thought to have lasted from Permian to Late Triassic times with the peak of accompanying volcanism taking place in the Middle Triassic. Volcano-sedimentary successions formed during this period in the NW Croatia were investigated at the outcrops found along the slopes of multiple W-E elongated *inselgebirge*. A total of 12 recorded successions can generally be subdivided into two groups based on the composition of volcaniclastic deposits.

The first group is related to explosive volcanic activity and deposition of crystalloclastic and vitroclastic material through pyroclastic density currents in marine areas and syneruptive redeposition processes with turbiditic characteristics. These successions are made of felsic crystalloclastic and vitroclastic tuffs, interlayered with pelagic limestone, radiolarian chert, and conformably overlain by secondary volcaniclastic siltstone and sandstone. Only two sections of this group contain basalt and basaltic volcaniclastic rocks in their lowermost parts. These basaltic volcaniclastics were formed by the auto-fragmentation processes in submarine settings, with volcaniclastic components resedimented distally to the deep marine areas. The successions of the first group generally exhibit a coarsening upward trend, as the topmost part is composed of secondary volcaniclastic deposits of coarse sand size. The secondary volcaniclastics are interpreted as formed with the prevalence of sedimentary processes over volcanic activity. The successions dominated by felsic volcaniclastic rocks were dated by radiolarians as late Illyrian to early Fassanian (KUKOČ *et al.*, 2023).

The second group of volcaniclastic deposits occurs in two recorded sections. They are dominantly represented by basic volcaniclastic lithologies formed by quenching and auto-fragmentation processes, and subsequent reworking and redeposition by gravity mechanisms to a somewhat deeper marine area. These volcaniclastics are mostly composed of basaltic lithoclasts with different textural and mineralogical characteristics. The size of the clasts varies from coarse ash to blocks and bombs. In one of the two recorded sections, the Vudelja quarry, which is dominated by basic lithologies, layers of acidic tuffs were also recorded. Radiometric dating ($^{40}Ar/^{39}Ar$) of plagioclase separates from basaltic volcaniclastic rocks revealed ages of 244.1±2.8 Ma. The calculated age is in relatively good accordance with the earlier research conducted by SLOVENEC & ŠEGVIĆ (2021), which dated comparable volcaniclastic deposits of Kuna Gora at 241.1±5.2 Ma. The second section dominated by basic volcaniclastic rocks is recorded in the Očura quarry. The section is composed of basalts and block-sized autoclastic basalt breccia in the lowermost part. It is followed by a thick interval of calcarenites containing basaltic lithoclasts of fine sand to pebble size, with varying ratio of carbonate and basaltic component in different samples. An increase of grain size is recorded up section, reflected by breccias composed of limestone, calcarenite and clasts of basalt. Carbonate clasts reach up to a meter in size and contain Middle Triassic reefal fauna.

Both described types of successions, despite their different lithology and formation mechanisms, share the same depositional environment, namely deep marine areas of the passive continental margin. These areas were of varying bathymetry due to differences in subsidence of tectonic block. Radiolarian cherts interlayered with the pyroclastic deposits can be regarded as deposited in the deepest basinal areas. The coarsening upward trend indicates filling of the basin and the sedimentary record is characterized by a subtle change in the redeposited (secondary) volcaniclastic material. Basic volcaniclastic rocks which were also formed in deep marine areas were relatively proximal to

shallow marine carbonate, sporadically reef, environment. The temporal relations of all recorded sections imply that volcanic activity influencing the Greater Adria in the Middle Triassic was of bimodal character, capable of producing basaltic effusions and felsic explosions of pyroclastic material at the same time interval.

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CORRELATION OF THE MIDDLE TRIASSIC SEDIMENTARY FACIES WITH ITS DISTRIBUTION IN THE SYN-RIFT STRUCTURES DETERMINED BY 2D SEISMIC DATA – AN EXAMPLE FROM THE EXTERNAL DINARIDES AND NORTHERN ADRIATIC

KORELACIJA SREDNJE TRIJASKIH FACIJESA I NJIHOVA DISTRIBUCIJA U SIN-ROFTNIM STRUKTURAMA ODREĐENIH POMOĆU 2D SEIZMIČKIH PODATAKA – PRIMJER IZ VANJSKIH DINARIDA I SJEVERNOG JADRANA

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Keywords: *Middle Triassic, Syn-rift, 2D seismic, seismic facies, depositional environment*

Tectonic activity related to the opening of the Neotethyan Ocean caused a severe differentiation of sedimentary environments in today's External Dinarides. The climax of the extensional tectonic and accompanying volcanic activity took place in the Middle Triassic. Lower Triassic shallow marine areas were disintegrated and an array of extensional normal faults formed a series of syn-rift structures. This dramatic change and coexistence of differentiated environments is noticed in the outcropping rocks, but showcase of syn-tectonic basins and tectonic control on facies distribution is lacking. Therefore, we combined two datasets to correlate the differentiated Middle Triassic facies, ranging from shallow to deep marine coupled with volcanic activity with their distribution in the syn-rift structures obtained by 2D seismic profiles.

One dataset is represented by detailed field investigation on the Middle Triassic outcrops and sediment successions. Four localities including volcaniclastics were investigated. They crop out in a belt of Triassic deposits extending in the Dinaric strike along the eastern slope of Velebit Mts. The other dataset comprises offshore 2D seismic from adjacent Northern Adriatic.

Jovanović Draga section is composed dominantly of basalts and mafic volcaniclastics. These rocks were formed by basalt effusions in marine environments, their fragmentation in contact with sea water and subsequent redeposition as the newly formed clasts mixed with carbonate clasts in the pelagic and shallow marine realm.

Donje Pazarište section is composed of six facies: flysch-like deposits, carbonate shales, pyroclastic deposits, platy limestones, limestone breccias, and limestone, pyroclastics and chert deposits with slump structures. Sedimentary structures and lithological composition indicate the dominance of gravitational processes as the main mechanism of resedimentation and deposition on toe of a steep slope. The entire section suggests deposition in deeper marine area evidenced by presence of pelagic fossils (ammonoids, thin-shelled bivalves and radiolarians).

On Vinac hill, and the location in the vicinity of the Donje Pazarište section, a pyroclastic flow facies characterized by strong imbrication pattern of the elongated pumice fragments was recognized. On both localities pyroclastics were found in an unclear contact with diplopora limestone, indicating emplaced in a shallow marine area.

At the same time, 2D seismic data indicate profound deformations of Middle Triassic successions caused by

the later tectonic movements, in particular salt diapirism. However, they can be found below thick fill of Mesozoic carbonate and Cenozoic carbonate-clastic succession. Distribution of syn-rift sequences on seismic data vary. They thicken towards the south and offshore, and pinches out towards the North. Structural highs and half-grabens are interpreted, bounded with W dipping normal faults. Mapped structures exhibit NW – SE strike and reach dozen kilometres in width. Within the syn-rift infill four seismic facies were distinguished: A – blurred, low amplitude and frequency, fairly discontinuous, located at structural highs; B – medium amplitude and frequency, fairly continuous at structural highs, C – proximal lobe, hummocky discontinuous, low to medium amplitude, low frequency, within half-graben, next to boundary faults; D – (sub)parallel continuous to discontinuous, medium amplitude, high frequency, within half-graben.

Sedimentary record suggests that the syn-rift sediments of the Middle Triassic were emplaced in very diversified environments, in a confined area. Seismic data exhibit a system of the syn-rift structures that extends towards the south, probably parallel to the Mid Adriatic Ridge. Depositional environments were controlled by local faults activity that formed pathways for basalt effusions, and played an important role in redepositional processes. Knowing the lithologies from the outcropping sections, it is possible to correlate them with the seismic facies of the Middle Triassic syn-rift deposits.

We correlated the flysch-like and carbonate shale deposits of Donje Pazarište section with seismic facies D, within half-graben structures as more distal deposits. Pyroclastic deposit, platy limestone, limestone breccia and slumped limestone, pyroclastic and chert facies are correlated with seismic facies C as a proximal infill next to boundary normal faults. The pyroclastic flow facies emplaced in the shallow marine areas is correlated with seismic facies B close to structural highs. Karstified diplopora limestone is correlated with seismic facies C which indicates elevated palorelief. Although, there are no borehole control to confirm our lithological characterization of seismic facies, the characteristics of seismic reflexes can tentatively lead towards the interpretation and recognition of Middle Triassic syn-rift seismic facies in the offshore External Dinarides and provide valuable evidence for their existence of such structures in the wider area.

NEW MULTI-PROXY EVIDENCE OF HOLOCENE ENVIRONMENTAL AND HYDROLOGIC CHANGES FROM SEDIMENTARY INFILL OF PROKLJAN LAKE (KRKA RIVER, CROATIA)

NOVI MULTI-PROXY ZAPISI HOLOCENSKIH OKOLIŠNIH I HIDROLOŠKIH PROMJENA IZ SEDIMENATA PROKLJANSKOG JEZERA (KRKA, HRVATSKA)

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Keywords: *Krka River estuary, sedimentary environments, seismic stratigraphy, sea-level changes, tufa*

Estuaries are among the most valuable sediment archives since they represent a transition zone between the terrestrial and marine environments. Therefore, they provide invaluable records of sea-level and paleoenvironmental changes. Krka River estuary is a microtidal salt-wedge karst estuary located along the eastern Adriatic coast in central Dalmatia (Croatia). The sedimentary and paleohydrological evolution of the estuary from the late Glacial to the present was reconstructed using multi-proxy analyses. We combined seismic profiles with sedimentary data supported by radiocarbon data, stable isotopes, geochemical and micropaleontological proxies retrieved from four sediment cores recovered from Prokljan Lake. The high-resolution seismic data gave an insight into subsurface geology and revealed up to 20 m of sedimentary infill. We distinguished four seismostratigraphic units deposited above the karst bedrock. The topmost units (units 3 and 4) can be correlated with analysed sediment cores. We suggest that Unit 1 represents the oldest late Glacial fluvial deposits preserved only in the deepest part of Prokljan Lake, when river valley was formed. The overlaying Unit 2 is regarded as tufa deposits, which presumably started

to grow during the postglacial transgression. Tufas developed a system of shallow lakes in the central part of Prokljan Lake and upstream of the lake and enabled the accumulation of fluvio-lacustrine sediment, which represents Unit 3. The topmost Unit 4 represents estuarine/marine deposits accumulated after the Holocene flooding of Prokljan Lake.

Multi-proxy analyses of four sediment cores supported by 22 radiocarbon dates from Prokljan Lake revealed dynamic paleoenvironmental and paleohydrological changes during the Holocene. Our results showed that marine inundation of Prokljan Lake started at the beginning of the Holocene with a restricted inundation in the central part of the lake. Thus, Prokljan Lake stratigraphy displays the existence of a slightly brackish lacustrine environment (ca. > 10 500 cal yr BP – 8300 cal yr BP) with the sea-water intrusion through porous tufa deposits and karst. Further sea-level rise allowed gradual flooding of tufas and estuarine/marine sedimentation at approximately 8300 cal yr BP. Additionally, the period between 8300 cal yr BP and 6300 cal yr BP is characterized by increased detrital input and depleted oxygen isotope values indicating enhanced rainfall and large fluvial inputs, i.e. a distinct pluvial phase observed in the wider Mediterranean region. Further sea-level rise between 6300 cal yr BP and 2000 cal yr BP and drier climate conditions caused the mixing of marine water and freshwater, and thus the formation of a slightly stratified or partially mixed estuary, which can be inferred from the geochemical and stable isotope data. At approximately 3000 – 2000 cal yr BP, the sea level stabilized and present estuarine conditions commenced, i.e. a formation of the salt-wedge estuary. Human activities and catchment erosion are especially evident in the last 500 cal yr BP.

We can conclude that late Quaternary sea-level variations and climate changes were one of the main factors that affected the evolution of the Krka River estuary. Additionally, the morphology of the bay implies complex influences of late Glacial transgression, tufa deposition causing the formation of shallow tufa lakes and progradational flooding of the Krka River canyon.

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RECONSTRUCTION OF THE POST-EOCENE MORPHOLOGY OF THE BOTTOM OF THE VRGORAC LAKE BASED ON GEOPHYSICAL DATA

REKONSTRUKCIJA POSTEOCENSKE MORFOLOGIJE DNA VRGORAČKOG JEZERA NA TEMELJU GEOFIZIČKIH PODATAKA

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Keywords: *Geoelectrical sounding, geomorphology, Vrgorac Lake*

The objectives of the study were to describe the geomorphology of the Vrgorac lake bottom before the sedimentation of the Quaternary deposits and the definition of the lithology based on the results of the geoelectrical sounding, described drill cores, and field research.

Geophysical investigations were carried out in the Vrgoračko polje by the method of specific electrical resistivity – geoelectrical sounding, arranged in five transverse and one longitudinal profile. Fifty-seven geoelectric sounds were measured in a length of about 5300 m. It was performed using the Schlumberger symmetrical array of direct current and potential electrodes with an electric range AB/2 up to 200 meters. A direct electric source was used for the electric power supply. Measuring was made by the transistor compensation instrument (TK-24).

Quantitative interpretation of field-measured diagrams of geoelectric sounding was based on a determination of the value of the electrical resistivity and thickness of registered geoelectric units. Interpretation of measured diagrams of the geoelectric sounding album was performed using two and three-layer theoretical diagrams. These data were used as input for the definitive interpretation of measured results. The parameters which are determined by the method of geoelectric sounding are

the specific electrical resistivity, thickness, and depth for each geophysical unit.

Four lithological members are identified, which are from top to bottom. The first lithological unit corresponds to chalky limestone with values of natural resistivity over 25 Ohm.m, while the second unit is composed of clay with natural resistivity under 20 Ohm.m. The third unit has natural resistivity between 50 and 150 Ohm.m as limestone breccia with clay matrix, and the fourth unit represents limestone with values of natural resistivity over 150 Ohm.m.

The thickness of the uppermost chalky limestone unit is increasing from the NW in all measured profiles. The thickness of this geologic unit varies from 10 to 40 meters.

The limestone breccia unit, most likely formed by underlying limestone disintegration and deposition of the material in the ancient basin, follows the limestone paleorelief. Its thickness is almost the same along the profiles and is about 20 meters.

The deepest geological unit which is observed by geophysical measurement, is limestone. However, it is not observed in all measured profiles. This geological unit is considered a basement rock.

The limestone breccia was found under a geological unit built of clayey sediments. Based on the depth of the limestone breccia, as well as the observed limestone being the deepest geophysical unit, the relief of the bottom of Vrgorac Lake, before the beginning of sedimentation of the Pleistocene clayey sediments, can be reconstructed.

The reconstruction of the bottom of the Vrgorac Lake is shown on the isopach map obtained from the data of geophysical measurements as well as from borehole data and field investigation (POSILOVIĆ *et al.*, 2018).

The bottom of the Vrgorac Lake has an asymmetric transverse profile. The northeastern part of the lake bottom subsided along faults with an NW–SE direction, named the Veliki Prolog-Otrići fault zone, as well as along faults with an N–S direction, the Otrići–Kobiljača fault zone. Geoelectrical sounds recorded along the north-eastern edge of the lake did not yield electrical resistivity values of the basement rocks, up to the investigated level at a depth of 40 meters. Going further from north to south, the rocks of the bottom of the Pleistocene lake were observed in all measured profiles.

The results suggest that the micro-depression south of the Veliki Prolog–Otrići fault zone and the Otrići-Kobiljača fault zone, spanning an area of approximately 2 km^2, may have formed due to several factors, as follows: 1. Rock subsidence in the depression zone, usually caused by the roof collapse of karst caves; 2. Tectonic movements along faults in the sense of block movements of rock entities of small dimensions; 3. Formation of small dimension depressions related to the rheologically weakened zones of the upper crust and the formation of folds with wide amplitudes, which result in the collapse of the upper parts of the crust in a much smaller area.

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SEAFLOOR MASSIVE SULFIDE DEPOSITS ON THE ARCTIC MID-OCEAN RIDGES: AN INSIGHT INTO ORE-FORMING PROCESSES ALONG ULTRASLOW SPREADING RIDGES

LEŽIŠTA MASIVNIH SULFIDA DUŽ ARKTIČKIH SREDNJOOCEANSKIH GREBENA: UVID U RUDONOSNE PROCESE NA ULTRA-SPOROŠIRUĆIM GREBENIMA

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Keywords: *seafloor massive sulfides, hydrothermal processes, critical raw materials*

The Arctic Mid-Ocean Ridges (AMOR), an oceanic ridge system located north of the Arctic circle (66°N), consists of several slow and ultraslow spreading ridges associated with abundant hydrothermal activity (Fig. 1). The ultraslow Mohns ridge segment of the AMOR hosts numerous seafloor massive sulfide (SMS) deposits and represents a nat-

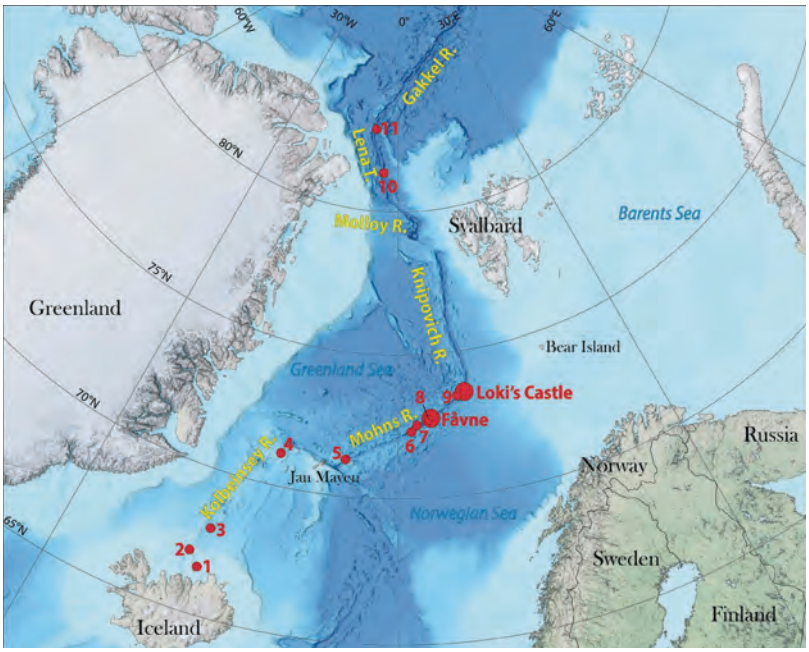

Figure 1. Bathymetric map showing the locations of the Fåvne and Loki's Castle SMS deposits and other known sulfide occurrences (red symbols) along the Arctic Mid-Ocean Ridges: 1) Grimsey; 2) Kolbeinsey; 3) Squid Forest; 4) Seven Sisters; 5) Soria Moria/Troll Wall/Perle and Bruse; 6) Ægirs Kilde; 7) Copper Hill; 8) Gnitahei; 9) Mohns Treasure; 10) Lucky B; 11) Aurora. Modified from PEDERSEN & BJERKGÅRD (2016) and SAHLSTRÖM *et al*. (2023).

ural laboratory to study recent hydrothermal ore-forming processes that drive their formation (PEDERSEN & BJERKGÅRD, 2016).

One of the main characteristics of the SMS deposits found along the Mohns ridge is their diversity in terms of mineral assemblages and metal contents. This study brings new lithology, mineral chemistry, stable isotope and fluid inclusion data obtained from the selected types of SMS deposits.

The Loki's Castle active SMS deposit (73°34'N, 8°9'E; 2400 m) is located near the summit of a 30 km long and 800 m high axial volcanic ridge (AVR). The deposit is characterized by a basalt-hosted sediment-influenced type of the Zn-Cu-Pb mineralization enriched in Au, Ag, and Tl. The Mohns Treasure inactive SMS deposit (73°N, 7°E; 2600 m depth) is hosted by basalts. The mineralization can be subdivided to the Cu-, Zn- and Au-rich types. The Fåvne active SMS deposit (72°45'N, 3°50'E; 3000 m) occurs at the floor of the rift valley northwest of an AVR. The hydrothermal activity is strongly controlled by a normal NE-SW trending fault that underlies the western portion of the field. The deposit is characterized as a basalt-hosted ultramafic rock-influenced type of the Zn-Cu-Co mineralization (SAHLSTRÖM *et al*., 2023). The Gnitahei extinct SMS deposit is hosted by the footwall of the normal fault that underlies The Fåvne deposit. The mineralization is characterized by an enrichment in Au (WOLD, 2022).

While their future role as a source of metals, including those from the critical raw materials (CRMs) list remains uncertain, recent SMS deposits provide unique insights into the hydrothermal processes that may support both deep-sea and onshore exploration.

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STABLE ISOTOPES AND TRITIUM: FROM PRECIPITATION TO SPRING WATER, A CASE STUDY OF LIČKA JESENICA

STABILNI IZOTOPI I TRICIJ: OD OBORINA DO IZVORA, PRIMJER LIČKE JESENICE

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Keywords: $\delta^{18}O$, $\delta^{2}H$, *Tritium*, *LMWL*, *karst aquifer*

Isotopic studies are widely used to estimate the mean residence time (MRT) of groundwater and to determine the location and boundaries of the karst watershed (MALOSZEWSKI & ZUBER, 1982; MALOSZEWSKI *et al.*, 2002; LAUBER & GOLDSCHEIDER, 2014). Application of different assumptions and conceptual models in isotope studies can lead to different, sometimes opposing interpretations. The majority of stable isotope studies in Croatian karst areas estimated groundwater MRT up to several years (MANDIĆ *et al.*, 2008; BRKIĆ *et al.*, 2018; PAAR *et al.*, 2019; STROJ *et al.*, 2020). In contrast to these estimates, other studies estimated much longer MRTs: > 10 years (OZYURT *et al.*, 2014) and > 20 years (HAN *et al.*, 2017) based on tritium and CFC analyses. However, all these studies based their interpretations on the comparison of the results of spring water samples in the studied area with precipitation characteristics measured at the GNIP monitoring station in Zagreb, which is located more than 100 km inland from the studied watersheds. In the case of the Dinaric Karst, which extends along the eastern Adriatic Sea and includes several mountain belts, both stable isotope and tritium content in precipitation may vary spatially depending on many factors, including the difference in the distance from the sea coast or altitude (BRKIĆ *et al.*, 2020). In addition, effective infiltration is strongly biased toward the colder part of the year due to higher evapotranspiration during the growing season.

To test discrepancy between previous water age estimates, stable isotopes and tritium have been measured in the spring water and local precipitation of the Lička Jesenica River in the north western part of the Croatian Dinaric Karst. The river is formed by two main springs (Malo Vrelo and Veliko Vrelo) that share a large karst catchment area of 110 km^2. Simultaneous monitoring was conducted at a major spring Malo Vrelo (MV) representing the draining in regional watershed and a nearby smaller vadose cave spring (CS) located in the MV watershed as smaller scale to compare MRT and mixing processes in the deeper parts of the karst system and shallow one. During the monitoring period, from October 2021 to December 2022, 30 water samples from each spring (MV and CS) and precipitation within the spring catchment were collected at monthly intervals and analysed for stable isotope ($\delta^{18}O$ and $\delta^{2}H$) content. Tritium content was analysed on selected samples of spring water and on cumulative precipitation samples (2021-2022): December to February, March to April, May to June, July to September, and October to November. Stable isotope results show that the main recharge of the two springs is strongly dominated by precipitation from the colder season. Both MV and CS show similar attenuated annual stable isotope variations, indicating efficient mixing of water already within the epikarst and shallower vadose zone of the karst system. The water from MV is more isotopically depleted in all months of the measurement period, which was expected since its catchment area is in a great part at higher altitude than the recharge area of CS.

Preliminary results of the tritium analysis of both springs showed that the tritium content in the sampled water varies, but its variability is within the range of measured precipitation values. Cumulative samples of local precipitation show lower tritium levels during the winter months, followed by elevated levels in the spring. The tritium content in local precipitation appears to be lower compared to the GNIP monitoring station in Zagreb, which shows mean annual content of 7.6 TU in most recent period from 2012 to 2018 (KRAJCAR BRONIĆ *et al.*, 2020), and which has been used in some previous studies in the area. The presence of a delayed annual cycle of tritium and stable isotopes at both springs indicates a significant influence of the very young water component with a residence time of several months. The higher tritium content of the water from CS possibly indicates shorter MRT for this spring compared to MV.

Results showed that the comparison of isotopic properties of groundwater with mean annual precipitation without considering effective infiltration and/or comparison to the results collected at distant meteorological and GNIP stations may both lead to incorrect interpretation.

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SILENT GEOHAZARD – RADON IN MODRIČ SHOW CAVE
TIHI GEOHAZARD – RADON U TURISTIČKOJ SPILJI MODRIČ

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Keywords: *show cave, radon, geohazard, Croatia*

As a naturally occurring geogenic radioactive gas, radon (222Rn) presents potential geohazard in underground confined spaces, such as poorly ventilated caves. Intrigued by relatively high cave-air CO_2 concentration (up to 12,000 ppm) in particular parts of Modrič show cave, and knowing that as CO_2 closely correlate with Rn activity, we conducted two campaigns of radon concentration measurements (integrated and continuous) to estimate the potential risk of radon overexposure of the visitors – tourists, guides and scientists. From 2018 on, radon concentration has been measured by passive LR115 detectors that were exposed from three to six months at eight sites within the cave. The highest values were recorded during the summer seasons in the right passage of Modrič Cave, pointing to seasonal variations controlled by cave ventilation (SURIĆ *et al.*, 2021). Additionally, on finer spatial scale, radon concentrations are controlled by cave passage geomorphology and bedrock architecture (Fig. 1).

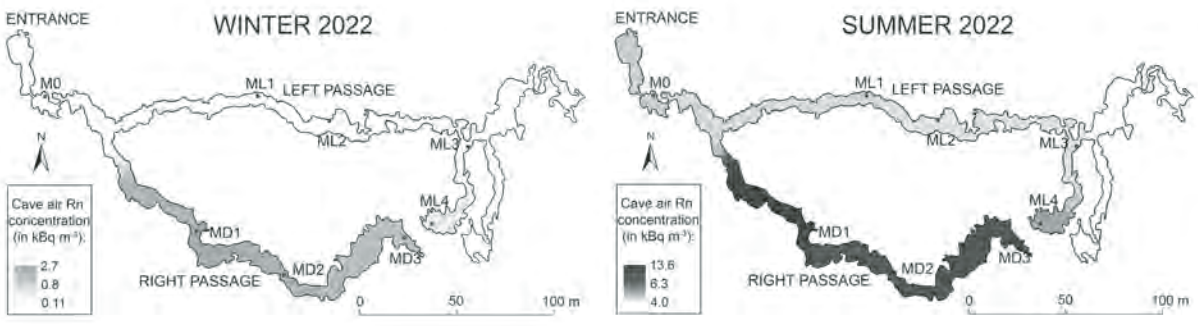

Figure 1. Spatio-temporal variation of radon concentration in 2022 winter and summer seasons

Based on passive detector measurements, the effective dose of radiation for tourists, guides and scientists were assessed to be below the recommended dose limit of 20 mSv y^{-1} (ICRP, 2017); tourists received 75–91 μSv, while scientist during their monthly 2-hour visits received 1.59 ± 0.43 mSv, 1.58 ± 0.43 mSv and 1.70 ± 0.46 mSv in 2020, 2021 and 2022, respectively. Due to the pandemic circumstances, cave guides which are most affected by radon radiation, received harmless doses, as well. However, according to calculated worst-case scenario, cave guide would have received 19.0 ± 5.2 mSv y^{-1} (slightly below recommended maximum value of 20 mSv y^{-1}) in the touristic part of the cave (left passage), but significantly higher dose (34.1 ± 9.2 mSv y^{-1}) in the non-touristic part of the cave (right passage).

Continuous measurements of radon concentration established in 2020 and provided by Tesla TSR 3W at 1-hour resolution, point to short-term variations associated with specific meteorological conditions such as intensive precipitations and bora events, which should be taken into consideration while planning both frequent touristic visits in left passage and/or long-lasting scientific fieldwork in right passage of Modrič Cave.

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THE PALEONTOLOGICAL SIGNIFICANCE OF THE MIDDLE TRIASSIC BASINAL DEPOSITS OF THE SAMOBOR AND ŽUMBERAK MTS.

PALEONTOLOŠKI ZNAČAJ SREDNJE TRIJASKIH BAZENSKIH NASLAGA SAMOBORSKOG I ŽUMBERAČKOG GORJA

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Keywords: *Middle Triassic, biostratigraphy, ammonoids, Anisian, Ladinian*

Since the late 19th and early 20th centuries, researchers have recognized the presence of Middle Triassic basinal successions in the Samobor and Žumberak Mts. (GORJANOVIĆ-KRAMBERGER, 1894). In these deposits, fossils of marine invertebrates were previously found, most notably a rich ammonoid fauna (SALOPEK, 1912, 1918, 1936). Since then, very little attention has been paid to these localities, leaving them with outdated paleontological interpretations. In this study we have re-examined the previously collected paleontological material, as well as carried out field observations of the Gregurić Breg and Vlašić Brdo localities.

In the Samobor Mts., the primary locality is situated in the area of the Gregurić Breg village. Complex tectonic relationships have impeded previous efforts to describe this succession, however, preliminary results of field research are congruent with the conclusions of SALOPEK (1936). Here, the start of Middle Triassic subsidence is marked by the deposition of massive shallow-water limestones above late diagenetic Anisian dolomites. These limestones, which have previously been undated, yielded the foraminifera *Citaella* cf. *dinarica* KOCHANSKY-DEVIDÉ & PANTIĆ, indicating an upper Pelsonian–lower Illyrian age. Upwards, the onset of basinal conditions is marked by a thin, laterally variable interval consisting of nodular deeper water limestones, chert intercalations, and pyroclastics. The red nodular limestone lens, now mostly exploited, has historically yielded a vast abundance of fossil cephalopods. These fossils point to an upper Illyrian – "middle" Longobardian age, suggesting condensed deposition and possibly intra-facies redeposition. Nevertheless, such limestones are useful as "datable disconformities", as they are formed in conditions of low sedimentation rates. Above, the basinal interval continues with silicified, platy limestones interstratified with pyroclastics and marl. This part of the succession can be tentatively ascribed to the upper Longobardian, based on the presence of the bivalve *Daonella lommeli* WISSMANN and

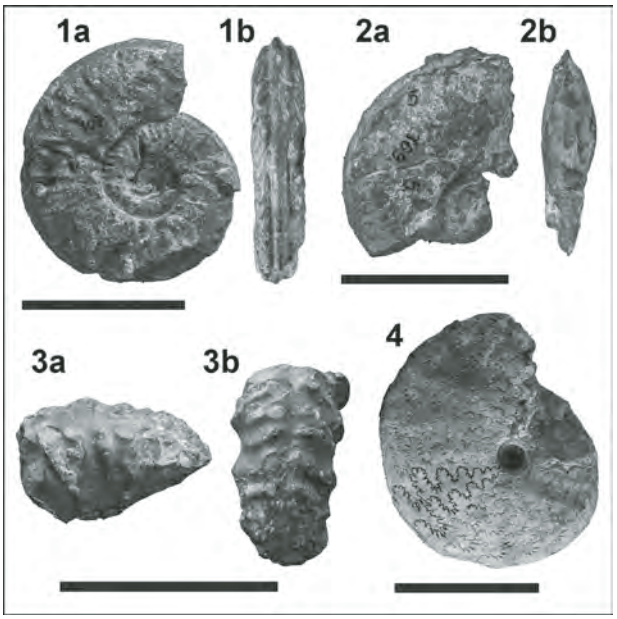

Figure 1. Important Anisian ammonoids from the Gregurić Breg locality: 1) *Halilucites* aff. *rusticus* (HAUER, 1896), HPM 107, in lateral (a) and ventral (b) view; 2) *Hungarites mojsisovicsi* (ROTH, 1871), HPM 109, in lateral (a) and frontal (b) view; 3) *Nevadites* cf. *avenonensis* BRACK & RIEBER, 1993, GPZ III 1651, in oblique lateral (a) and ventral (b) view; and from the Vlašić Brdo locality: 4) *Flexoptychites acutus* (MOJSISOVICS, 1882), HPM 10489, in lateral view. Scale bars are 5 cm.

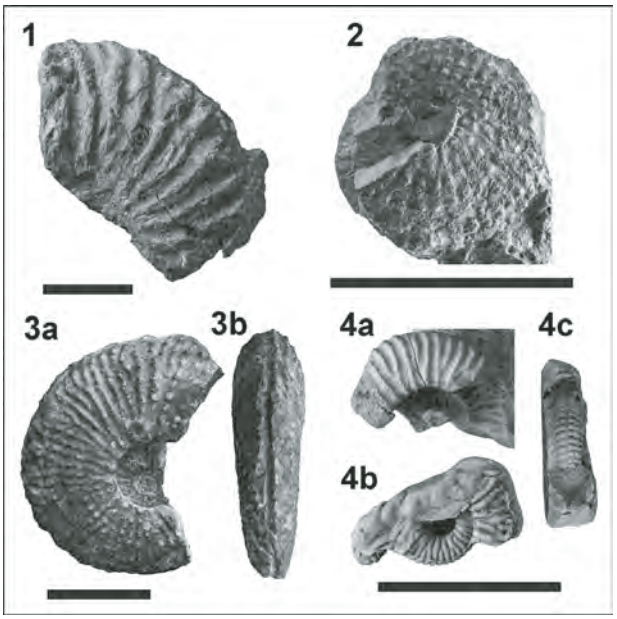

Figure 2. Important Ladinian ammonoids from the Gregurić Breg locality: 1) *Eoprotrachyceras* cf. *curionii* (MOJSISOVICS, 1882), HPM 140, lateral view; 2) *Protrachyceras longobardicum* (MOJSISOVICS, 1882), HPM 193G, lateral view; 3) *Protrachyceras margaritosum* (MOJSISOVICS, 1882), GPZ III 1560, in lateral (a) and ventral (b) view; and from the Vlašić Brdo locality: 4) *Falsanolcites recubariensis* (MOJSISOVICS, 1882), HPM 15ž, in lateral (a) view, lateral view of a mould (b), and ventral view (c) of a mould. Scale bars are 5 cm.

the reported but unconfirmed find of the ammonoid *Celtites epolensis* MOJSISOVICS (SALOPEK, 1918). Basinal deposits are capped by late diagenetic dolomites, likely of uppermost Longobardian – ?lower Carnian age, based on superpositional relationships. The precise dating of these dolomites was not possible, due to a lack of fossil content.

In the Žumberak Mts., Middle Triassic basinal deposits are found north of Krašić, notably in the area of the Vlašić Brdo village and its surroundings. Previous investigations (GORIČAN *et al.*, 2005) indicated that the succession is comprised of cherts, siltites and pyroclastics in the lower part, and of alternating deeper-water limestones and pyroclastics in the upper part. Likewise, they showed that the contact with the underlying Anisian dolomites is probably erosional. However, findings of shallow-water limestones, comparable to those at the Gregurić Breg locality, indicate possible lateral variations in the start of the succession. Although reported (ŠIKIĆ *et al.*, 1979; SAKAČ, 1994; GORIČAN *et al.*, 2005), previous macrofossil data has largely been neglected. According to our observations, ammonoids, although significantly rarer than at the Gregurić Breg locality, indicate a middle or upper Illyrian – "middle" Longobardian age of the upper, limestone-rich portion of the succession. Microfossil data obtained by previous researchers has shown that the lower, chert-rich portion of the succession is lower Illyrian in age (GORIČAN *et al.*, 2005). This possibly indicates a slightly earlier onset of basinal conditions but is otherwise in general agreement with the timing of deposition at the Gregurić Breg locality.

Both areas require further study, with the Žumberak Mts. localities having the potential to provide more fossil findings; in particular, more ammonoid remains found in strata that are not highly condensed. Additionally, fragmentary but significant findings of marine reptile bones at the Vlašić Brdo locality demonstrate the paleontological potential of these localities.

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TAPHONOMIC ANALYSIS OF SKELETAL REMAINS OF ALPINE MARMOT (*MARMOTA MARMOTA*) FROM THE LATE PLEISTOCENE DEPOSITS OF THE PEĆINE U BRINI CAVES NEAR DRNIŠ

TAFONOMSKA ANALIZA SKELETNIH OSTATAKA ALPSKOG SVISCA (*MARMOTA MARMOTA*) IZ GORNJOPLEISTOCENSKIH NASLAGA ISTOČNE I ZAPADNE PEĆINE U BRINI KOD DRNIŠA

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Ključne riječi: *alpski svizac, skeletni elementi, tafonomija, Pećine u Brini, gornji pleistocen*

Pećine u Brini jedno su od najvećih nalazišta alpskog svisca (*Marmota marmota* (Linnaeus, 1758)) na području Hrvatske, a Istočna Pećina u Brini ujedno je najveće nalazište te vrste u Dalmaciji. Fosilni ostatci alpskog svisca pronađeni su u gornjopleistocenskim naslagama Pećina u Brini, nedaleko od Drniša tijekom povremenih i nesistematskih istraživanja 1960. godine koja je predvodio akademik Mirko Malez (MALEZ, 1963). Skeletni ostaci alpskog svisca su u Istočnoj Pećini u Brini pronađeni u stratumu c debljine 40–50 cm koji je opisan kao smeđa šupljikava glina s rastrošenim kamenjem. U Zapadnoj Pećini u Brini kosti svisca su pronađene u tri sloja: crvenkastoj ilovači sa sitnim kamenjem (stratum c; debljina 45 cm), smeđoj ilovači s kamenjem i sigastim prevlakama (stratum d; debljina 45 cm) te u tamnožutoj, malo pjeskuljastoj ilovači (stratum e; debljina 20 cm). Uz ostatke alpskih svizaca u Pećinama u Brini su pronađeni brojni osteološki te odontološki ostatci raznih gornjopleistocenskih životinja kao što su: *Ursus spelaeus*, *Crocuta spelaea*, *Gulo gulo*, *Leopardus* sp., *Equus* sp., *Cervus* sp., *Capra* sp., itd. (MALEZ, 1963).

Obrađene kosti dio su zbirke koja se čuva na Zavodu za paleontologiju i geologiju kvartara Hrvatske akademije znanosti i umjetnosti. Tafonomski je analizirano ukupno 367 pojedinačnih kostiju iz Istočne Pećine u Brini te 11 pojedinačnih kostiju i tri izolirana sjekutića, ukupno 14 skeletnih ostataka iz Zapadne Pećine u Brini. Tijekom tafonomske analize naglasak je stavljen na određivanje faktora akumulacije i postdepozicijske procese.

Rezultati tafonomske analize ukazuju da više od polovice očuvanih kostiju čine kosti prednjih i stražnjih udova planinskog svizca, slijede kosti kralježnice i lubanje, a najmanje je očuvano kostiju prsnog koša. Gotovo cjelovito očuvane kosti (više od 75 % cjelovite kosti) čine većinu uzorka dok je manji dio kostiju djelomično cjelovito očuvan. Tafonomska oštećenja su podijeljena u dvije kategorije prema načinu nastanka pa su razlikovani tragovi trošenja i tragovi predatorstva. Na kostima su determinirani razni tragovi trošenja poput erozije, pukotina isušivanja, biokorozije (djelovanje korijenja i mikroorganizama), mineralne prevlake, itd. Od tragova predatorstva uočeni su tragovi grizenja zvijeri, glodanje glodavaca te tragovi rezanja.

Tafonomska analiza kostiju planinskog svisca ukazuje da su svisci iz Pećina u Brini najčešće bili plijen malih zvijeri poput kune. Također je vidljivo da su nakon smrti njihove kosti često poslužile malim glodavcima za glodanje. Osim što je u Zapadnoj Pećini pronađen manji broj kostiju, one pokazuju više tragova trošenja od onih iz Istočne Pećine.

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IN PURSUIT OF PALINOMORPHS IN THE EARLY CRETACEOUS DEPOSITS OF THE BRIJUNI ARCHIPELAGO (CROATIA)

U POTRAZI ZA PALINOMORFAMA U NASLAGAMA DONJE KREDE NA PODRUČJU BRIJUNSKOG OTOČJA (HRVATSKA)

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Ključne riječi: *starija kreda, vapnenci, palinomorfi, Brijunsko otočje*

Brijunsko otočje s 14 otoka i otočića smješteno je na južnom djelu zapadne obale Istre. Zajedno s okolnim morem i podmorjem proglašeno je Nacionalnim parkom 1983. godine zbog iznimno karakteristične flore i faune, u zajedništvu kulturne i prirodne baštine. Dosadašnja geološka istraživanja na ovom prostoru pomogla su utvrditi starost naslaga i karakteristične fosilne zajednice, a posebna pažnja pridana je nalazima otisaka stopala dinosaura i drugih gmazova koje na području brijunskog otočja možemo naći na nekoliko lokacija (MEZGA & BAJRAKTAREVIĆ, 2004; MEZGA *et al.*, 2007).

U ovom su istraživanju uzorkovane naslage na šest lokaliteta na kojima su zabilježeni otisci stopala gmazova (rt Pogledalo, rt Ploče, rt Kamik i rt Trstike na Velikom Brijunu te na otocima Vanga i Galija). Prikupljeni uzorci vapnenaca klasificirani su prema DUNHAMU (1962) za sve istraživane lokalitete te se mogu klasificirati kao madstoni i vekstoni na lokalitetu rt Pogledalo, pekstoni i grejnstoni na rtu Ploče, vekstoni, pekstoni i grejnstoni na lokalitetu rt Kamik, te vekstoni na rtu Trstike. Uzorci s otoka Vanga klasificirani su kao vekstoni, a Galija kao pekstoni do grejstoni. Mikropaleontološkom analizom određene su foraminifere – posebice Pseudonummoloculina heimi, te ostrakodi i alge. Uzorkovane naslage taložene su tijekom starije krede u potplimnoj zoni i zoni plime i oseke Jadranske karbonatne platforme (AdCP, VLAHOVIĆ *et al.*, 2005).

Uzorci sa svih šest lokaliteta pripremljeni su i za analize palinomorfa kako bi se odredilo postoje li ostaci spora i polena. Dosadašnjim istraživanjem utvrđena je samo prisutnost polena *Pinuspollenites* sp. koji nažalost nije provodan i pojavljuje se od trijasa do paleogena. Uočene su i hife i spore gljiva roda *Glomus* koje prethodno nisu zabilježene, te spore zelenih algi *Tasmanites* sp. i *Ovoidites* sp. Iako ovi nalazi ne ukazuju na točniju stratigrafsku pripadnost istraživanih naslaga, njihova prisutnost nam daje dodatne informacije o paleookolišu tijekom starije krede te mogućem utjecaju kopnenih biljaka na plitkomorske platformne okoliše.

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THE KOLOČEP CHANNEL – LATE QUATERNARY EVOLUTION OF A SUBMERGED KARST BASIN

KOLOČEPSKI KANAL – EVOLUCIJA POTOPLJENOG KRŠKOG BAZENA TIJEKOM KASNOG KVARTARA

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Keywords: *Late Quaternary, Koločep Channel, submerged karst basin, high resolution seismic, sea-level change*

Based on the interpretation of high-resolution seismic profiles, and obtained data of the combined measurements of sediment core has enabled us to reconstruct evolution in Koločep Channel (SE Adriatic Sea, Croatia) during the Late Quaternary. During glacial–interglacial cycles, the bay underwent alternating cycles of marine and terrestrial environments multiple times depending on sea-level variations. During lowstands the bay represented a typical Dinaric karst polje connected with the hinterland catchment as the lowest of the series of cascading karst poljes mutually connected through karst ponors and springs. The upper sedimentary infill of the bay corresponds to the last glacial–interglacial cycle, containing Holocene marine sediments and post-LGM lake/terrestrial sediments which are divided by a major erosional event in the area. The erosional event is caused by Late Glacial freshwater discharge from numerous karst springs (today submarine springs) fed by melting ice in the Dinaric hinterland in Bosnia and Herzegovina. The freshwater flooded the polje, creating an intermittent lake or water course which formed a paleo-river, which acted as a sinking river that submerged the SE side of Olipa Island and resurged as a karst spring on its southern side flowing through the Mljet channel to the Adriatic Sea northwest of Mljet Island. Another scenario is also possible based on the morphologies of the basin and the paleochannels: the notion that the river did not sink but had a paleochannel that was buried by sand redeposited by the eastern Adriatic current during the Holocene. We believe that the major role in evolution of the basin had the sill on 50 m b.s.l. between Olipa and Jakljan islands who was under influence of tectonics in this area. The morphology of the sill connecting the sea with the bay remains unsolved, since the sub-bottom profiler did not penetrate through the sand deposits. But one thing is certain, that with the intrusion of the sea before 12 Cal BP, the marine conditions in the Koločep Channel that are still present today began.

INTEGRATED STRATIGRAPHY OF APTIAN BARJAŠKA FORMATION ON THE ISLAND OF VIS (ADRIATIC SEA, CROATIA)

INTEGRIRANA STRATIGRAFIJA APTSKE FORMACIJE BARJAŠKA NA OTOKU VISU

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Key words: *carbonate platform, Aptian, biostratigraphy, isotope chemostratigraphy, OAE 1a*

The Early Aptian (Early Cretaceous) was a time of significant environmental change affecting low-latitude Tethyan carbonate platforms (HUCK *et al.*, 2010). Many of these changes are characterized by incomplete successions related to emergence and/or drowning. Therefore, only a few successions reveal a preserved and more complete

record of the Ocean Anoxic Event (OAE) 1a (STEUBER *et al.*, 2022). The beginning of the Aptian is marked by the onset of subtidal, more open-platform environments, characterized either by Lithocodium–Bacinella or skeletal, rudist-rich facies. Northern margin of the Adriatic Carbonate Platform (ACP) in the Early Aptian was characterized by rudist-coral-stromatoporoid communities which flourished within a high-energy belt, while other areas of the platform were dominated by oligospecific associations of Toucasia and Requienia. More diverse, Offneria-bearing deposits are to date reported just from a few localities (MASSE *et al.*, 2004).

Up to 1500 m thick succession of the Cretaceous shallow water carbonates is exposed in the western part of island Vis, on the flanks of the Komiža diapir (KORBAR *et al.*, 2012). Among the 1500 thick succession, pre- and post-Aptian deposits are composed of dominantly monotonous peritidal cycles, while the Lower Aptian strata exhibits prominent facies diversification.

An excellent exposure of various Lower Aptian shallow-water carbonate facies is located at Barjaška locality. The Lower Aptian ca. 90 m thick succession is probably the most lithologically diversified intra-platform succession in the peri-Adriatic region. It is characterized by thick-bedded dolostones with remnants of *Lithocodium–Bacinella* oncoids, thin-bedded marly limestones, (dolomitized) slump?-mounds, rudist- and chondrodontid-rich sedimentary bodies including *Offneria* floatstones, *Chondrodonta* and *Palorbitolina* tempestites, chert horizons, and algal-rich subtidal facies. Integrated biostratigraphy and isotope chemostratigraphy (carbon, strontium) reveal the Lower Aptian age of the strata deposited during the OAE 1a. Furthermore, the carbon and oxygen isotopic composition of bulk-rock samples indicates a significant diagenetic overprint, but the Sr-isotope stratigraphy on compact calcite of rudist shells yielded more reasonable, 'normal-marine', values.

The data from the island of Vis shows that significant facies diversification is related to the OAE 1a, while the facies-stacking pattern was driven by coeval sea-level changes. Although the ACP obviously experienced a prominent relative sea-level rise at the beginning of the Early Aptian, intraplatform thickness variations of up to 70 m are probably the result of synsedimentary tectonics. Subsequent shallow-water carbonate deposition is marked by multiple marl horizons that are generally recognized as the regional Aptian–Albian emergence (VLAHOVIĆ *et al.*, 2005; HUCK *et al.*, 2010).

The depositional units observed at Barjaška thus include typical Lower Aptian biofacies observed elsewhere in southern Tethys, but a detailed correlation with other sections and sequences of events related to OAE 1a requires additional studies.

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GEOTHERMAL POTENTIAL OF THE CITY OF SISAK
GEOTERMALNI POTENCIJAL GRADA SISKA

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Keywords: *geothermal potential, Sisak, well test, magnetotellurics*

The exploration area of geothermal water "Sisak" (Fig. 1) is located in the administrative area of the town of Sisak in Sisak–Moslavina County, and comprises 10.78 km^2.

Exploration history of the area goes back to early 20th century. Four deep wells were drilled, in total 2,355 m; 60 wells up to 200 m, in total 4,877 m, 10 shallow wells up to 33 m, in total 194 m. In the deep wells hot water with high iodine content was found in the layers of Pannonian age, Široko Polje formation.

Area was later explored by INA Naftaplin, seismic reflection surveys were done and Sisak-1 well was drilled in 1976. Hydrocarbons in commercial quantities were not discovered, but geothermal water (T=50 °C) was found in the same stratigraphic layers.

Geothermal well Siter-1 well was drilled in 1986 for the purpose of heating the recreation centre in Sisak.

The aquifer in the Siter-1 well is represented by Kutina sandstone (A series), and Krivaj, Bujavica and Mramor Brdo sandstones (B series, 770–1120 m, i.e. vertical depths of 745–1070 m). Water is defined as a petroleum hyperthermal water (T=52 °C) in a partially or fully confined reservoir, fossil water.

After a period of exploration inactivity Sisak Town decided in 2020 to renew geothermal exploration in the area. The Ministry of Economy and Sustainable Development issued a Permit for the exploration of geothermal waters in the exploration area "Sisak" to Komunalac Sisak d.o.o., the company owned by Sisak Town.

In order to finance the exploration activities, Sisak Town and Komunalac successfully applied to EEA and Norway grants. The funding will enable re-testing of Siter-1 well and a magnetotelluric survey as a part of the Geological-geophysical study.

In February 2023 hydrodynamic measurements were performed. An eruptive inflow of geothermal water was achieved. Due to the risk of additional backfilling of the well by sand from the reservoir, the well was throttled when the flow reached more than 16 l/s. Testing results confirmed the possibility of geothermal water production. Laboratory analyses of geothermal water again point to the high iodine content of more than 21 g/l.

Magnetotelluric survey comprised 30 points that enable mapping of geothermal reservoir in the area where seismic data was not available.

After the interpretation of the recorded data, a much more comprehensive picture of the geothermal potential of the town of Sisak was obtained, which will be the basis for Elaborate of reserves and will enable further utilisation of geothermal water for the district heating purposes.

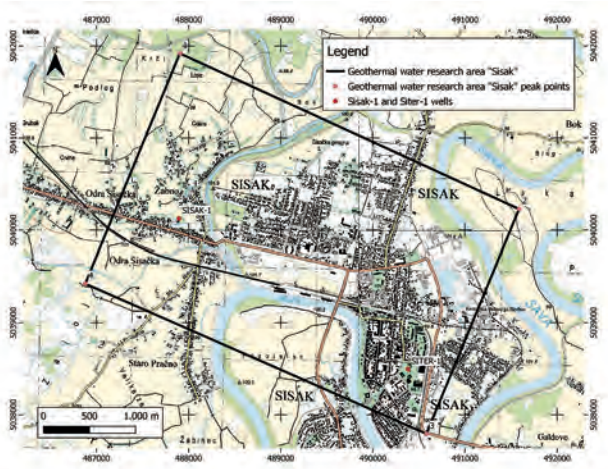

Figure 1. Geothermal water research area "Sisak"

THE EGERIAN TUFFS FROM THE HRVATSKO ZAGORJE BASIN
EGERSKI TUFOVI BAZENA HRVATSKOG ZAGORJA

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Keywords: *Hrvatsko Zagorje Basin, tuffs, Egerian, zircon U-Pb LA-ICP-MS dating*

The Hrvatsko Zagorje Basin (HZB) is located in the southwestern part of the Pannonian Basin. It is a part of the Central Paratethyan realm characterized by the Oligocene-Early Miocene marine sedimentation and extensive record of volcanic activity of yet unconstrained regional tectonomagmatic affiliation and evolution. The only time constraint on the products of this volcanism, represented by both volcanic and pyroclastic rocks, is so far given by K-Ar whole rock dating and field relationships. Thus, we applied zircon U-Pb LA-ICP-MS dating on volcaniclastic rocks from two HZB localities.

Horizontally laminated tuffs were sampled from Donje Jesenje quarry (DJ-1g), interpreted as Eggenburgian based on field relationships and stratigraphy (AVANIĆ *et al.*, 2021, 2018), and Varaždinske Toplice (VT). Sample DJ-1g is composed of glass shards (~37%), fine-grained vitric matrix (~23 vol.%), pumice (~21 vol.%), magmatic crystals (~18 vol.%; predominantly plagioclase – mainly andesine, quartz, minor biotite, hornblende and sanidine, accessory ilmenite, zircon, and apatite), and < 1 vol.% lithic clasts. Some of the vitric components were subjected to devitrification and altered mainly to zeolite and clay minerals (TIBLJAŠ & ŠĆAVNIČAR, 1988). Sample VT has undergone extensive silicification and consists of ~94 vol.% of microcrystalline quartz with recognizable outlines of glass shards. Minor components are crystals (~5 vol.%; quartz and plagioclase) and lithic clasts (~1 vol.%). The bulk rock major element composition of DJ-1g is rhyolitic (74 wt.% SiO2 on anhydrous base), with high LOI (8 wt.%), while VT is characterized by extremely high silica content (89 wt.%). The composition of glass shards (average total 89 wt.%) and melt inclusions in ilmenite (average total 95 wt.%) from DJ-1g is also rhyolitic (77 and 76 wt.% anhydrous, respectively). Due to alteration, glass shards from VT consist almost exclusively of SiO2 (99 wt.% anhydrous). The whole rock trace element analysis shows certain similarities, especially in REE diagrams, characterized by LREE/HREE enrichment and slight MREE/HREE depletion. New zircon U-Pb LA-ICP-MS dating yielded an age of 23.58±0.10 Ma for DJ-1g and 23.278±0.091 Ma for VT, which corresponds to Egerian stage, and is slightly older than previously thought for Donje Jesenje quarry.

These data provide an insight into the Oligocene-Early Miocene magmatism, i.e., Egerian volcanic activity and its products deposited in the HZB.

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GEOLOGICAL INTERPRETATION OF MAGNETOTELLURIC DATA IN THE EXPLORATION BLOCK DINARIDI-14

GEOLOŠKA INTERPRETACIJA MAGNETOTELURSKIH PODATAKA NA ISTRAŽNOM BLOKU DINARIDI-14

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Ključne riječi: *Dinaridi, magnetotelurika, formacije otpornosti, Udbinska struktura*

Istraživanje ugljikovodika je vrlo zahtjevno i vrlo skupo, pogotovo kada se provodi u terenima kao što su to Dinaridi. S jedne strane, morfološka razvedenost terena otežava bilo kakvo istraživanje, a s druge strane, površinska geološka građa dodatno otežava snimanje seizmičkih podataka kao osnovne metode dubinskog istraživanja u naftnoj industriji. Osim seizmičkih, postoje i druge geofizičke metode koje su znatno jeftinije od seizmičkih i premda slabije rezolucije, služe kao njihova prethodnica. Magnetotelurika je jedna od takvih metoda, a Dinaridi su sa svojom morfološkom razvedenošću i geološkom građom upravo pravi poligon za primjenu magnetotelurike. Po prvi puta INA primjenjuje ovu metodu u istraživanju ugljikovodika. Temeljna nepoznanica je dubina zalijeganja gornjojurskog Lemeškog facijesa kao glavne matične stijene u ličkom prostoru. Lemeški facijes je dobro dokumentiran na površini i određen kao nezrela do rano zrela matična stijena (TROSKOT-ČORBIĆ, 2011), ali na dubini od minimalno 3000 m postaje aktivna i sposobna generirati ugljikovodike. Magnetotelurika bi trebala dati uvid u debljinu i dubinu zalijeganja mezozojskog karbonatnog kompleksa kojemu Lemeški facijes i pripada. Kao uža zona interesa odabrano je područje između Korenice i Bruvna, te Gospića i Donjeg Lapca. Rezultati magnetotelurskog mjerenja prikazani su profilno kao otpori stijenskih formacija temeljem kojih se provodi geološka interpretacija. Načelno, profili prikazuju odnose formacija otpornosti kao nisko-otporne i visoko-otporne bez strogo određenih granica između formacija budući da iste vrijednosti otpora imaju različite starosne formacije kao što jedna formacija može imati veliki raspon otpornosti ovisno o njenoj litološkoj građi. Određivanje geoloških granica na magnetotelurskim podacima provedena je usporedbom interpretiranih vrijednosti magnetotelurskih podataka izdvojenih na samoj površini s podacima na geološkoj karti. Odnosi raspona otpornosti određenih formacija uspoređeni su s podacima mjerenih otpornosti teorijske bušotine kroz cijeli geološki razvoj Jadranske karbonatne platforme. Teorijska bušotina je konstruirana temeljem bušotinskih podataka s 13 bušotina i predstavlja kompletan mezozojski razvoj uključujući i permotrijasku podlogu, ali i paleogenski pokrov Jadranske karbonatne platforme. Magnetotelurski podaci su uspoređeni i s podacima geoelektričnih mjerenja provedenih 80-tih godina (ROMANDIĆ, 1987). Geološka interpretacija magnetotelurskih podataka provedena je u skladu s površinskom geologijom. Izrađene su dvije strukturne karte koje prikazuju geometriju dva ključna horizonta otpornosti. Plići horizont se odnosi na donju granicu čistih karbonata zastupljenih s najvišim otporima, dok dublji horizont prikazuje geometriju gornje granice klastita zastupljenih najnižim otporima. Zona između ta dva horizonta pripada mješovitim klastično-karbonatnim facijesima zastupljenih srednjim vrijednostima otpornosti stijena. Horizont donje granice čistih karbonata dokazao je relativno tanki karbonatni pokrov na području Udbine, ali i postojanje plitkih navlaka. Karbonatna tijela se ponašaju kao „plutajući“ mezozojski blokovi na permotrijaskoj klastičnoj podlozi. Horizont po gornjoj granici klastita pokazao je, uvjetno rečeno, geometriju podloge Jadranske karbonatne platforme (VLAHOVIĆ *et al.*, 2005) s dominacijom Udbinske strukture u središnjem dijelu koja svojom veličinom od gotovo 100 km2 tvori najveći strukturni objekt na istraživanom području. Horizont po donjoj granici čistih karbonata pokazao je relativno malu debljinu karbonatnog pokrova kao i malu dubinu zalijeganja nedostatnu za generativnu sposobnost i aktivnost Lemeškog facijesa. U svakom slučaju, magnetotelurska mjerenja dala su novi uvid u dubinsku geološku građu ovog dijela Dinarida, ali i materijal za dodatne polemike.

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HYDROGEOLOGICAL, GEOCHEMICAL, AND HYDROGEOCHEMICAL CHARACTERISTICS OF AN ISLAND'S KARST AQUIFER. BLATSKO POLJE ON THE KORČULA ISLAND

HIDROGEOLOŠKE, GEOKEMIJSKE I HIDROGEOKEMIJSKE ZNAČAJKE OTOČKOG KRŠKOG VODONOSNIKA. BLATSKO POLJE NA OTOKU KORČULI

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Keywords: *karst, hydrogeology, geochemistry, hydrogeochemistry, seawater intrusion, climate changes*

Within a framework of the project "Upravljanje krškim priobalnim vodonosnicima ugroženima klimatskim promjenama" (acronym UKV), funded by the EU via structural funds (Operational programme Competitiveness and Cohesion 2014-2020), a bulk research program was done in the western part of the Island of Korčula, Blatsko Polje aquifer's catchment. Groundwater is being extracted for the public water supply in four pit wells that pump groundwater from the karstic underground through Quaternary sediments of polje. These wells are Studenac, Prbako, Anić, and Franulović-Prcalo (Fig. 1).

The hydrogeological background and the description of their aquifer were taken from previous research (LUKAČ REBERSKI *et al.*, 2022; ŠARIN & SINGER, 1990; TERZIĆ & MARKOVIĆ, 2005; TERZIĆ *et al.*, 2008). The most important well is Studenac which covers the majority of the water demand. Recently, several boreholes were drilled (OSTROŠKI, 2020). Some achieved good results, considering the possibility of extracting groundwater and being a possible solution for the future increase of pumping quantities in the Blatsko Polje aquifer. Since the Blatsko polje aquifer is situated on a karstified island, and the rock mass is built of carbonate rocks, limestones, and dolomites, it is somewhat open to the possible un-

Figure 1. Public water supply wells in Blatsko Polje. A – Studenac, B – Gugić, C – Prbako, D – Franulović-Prcalo

derground intrusion of the seawater. The southern side of the aquifer is partially protected from the intrusion; while in the east is the island's central area, elevated from the research area, and intrusion is not likely due to the gradient. Therefore, the danger of seawater penetration comes from the north and the west coast. The only circumstance preventing it is the hydraulic gradient, which is relatively low but essential. In the sense of predicted climate changes, by the end of the 21st century, the sensitive water balance could be affected, and excessive intrusion could become much more frequent, threatening the water supply. Within the UKV project, climate changes were modeled (CINDRIĆ KALIN, 2021), and water balances, according to the predicted climate change, were calculated. Also, in this pilot area, extensive geochemical research has been done and a reference to the changes in land use (Corine land cover from 2006 to 2018). The study pointed out a decrease in agricultural areas (over 3 %) and an increase in forests and macchia (almost 5 %). All this expertise was included in hydrogeological research of this karst catchment.

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SOURCE ROCK AND HYDROCARBON EVALUATION AND CORRELATION, DRAVA-03, CROATIA

PROCJENA I KORELACIJA MATIČNIH STIJENA I UGLJIKOVODIKA, DRAVA-03, HRVATSKA

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Keywords: *source rock, maturity, Drava-03*

The Drava-03 exploration area (DR-03) is situated in the East of northern Croatia, on the southern edge of the Pannonian Basin System (PBS). In the investigated area numerous oil and gas exploitation fields as well as source rock have been developed. The aim of this paper is to present source rock, hydrocarbon evaluation and data correlation done on more than 400 wells.

Source rocks of the wider area are marls and calcareous marls of Pannonian (mainly Lower Pannonian) and marls, silty marls, siltstones and mudstones of Badenian age (most often stratigraphically undifferentiated Sarmatian–Upper Badenian and Middle Badenian) (HERNITZ *et al.*, 1995; BARIĆ, 2006).

Source rock of Badenian age has been established mainly in the Beničanci plateau and in the northern Dravica and north-eastern Donji Miholjac areas, less often in the southwestern Virovitica area and rarely in the central Bukovica–Orešac–Pčelić area. The average content of organic matter in Badenian source rock is 1.39 % (up to 23 %). The source rock mainly contains kerogen type II, rarely with influence of type III or I. The average value of the HI is 297 mg HC/g TOC. The average values do not emphasize the difference in depositional environments. In the protected shallow water (especially carbonate) environments organic matter is of higher quality (type II and I; > 400 HC/g TOC) while in the deeper waters with a stronger influence of the terrestrial component kerogen type III (< 200 HC/g TOC) is evidenced. In the central and northern areas of the DR-03 area, the Badenian rocks are in the gas window, and in the south and east in the oil window.

Source rock of Pannonian age are analytically determined in the entire investigation area. The source rocks are characterized by different thermal evolution. In the central part of the DR-03 area they have reached a higher catagenetic stage of thermal transformation (gas-condensate to gas window), while in the Beničanci plateau they are immature or in the initial stage of catagenetic thermal transformation (oil window). The average content of organic matter in rocks is 0.87 % (up to 37 %). The source rock contains variable proportions of type II kerogen with a more pronounced presence of type III kerogen and less often type I. The average trend of the HI of immature samples highlights the variation of the average original as a reflection of the variation of the environment and the deposition conditions of the original organic matter. Shallow-water Lower Pannonian marls are of the highest quality type of organic matter and have an average good to very good potential.

The thermal maturity of organic matter has reached the catagenetic stage of thermal conversion, which enables the generation of hydrocarbons in most of the research area. Late catagenesis is dominant in the deeper parts of the basin. Differences in the maturity of the source rocks have been reflected in the types and amounts of hydrocarbons generated. Estimated depth of the oil window (VR 0.5 % Ro) is at 2200±100 m and of the gas window (VR 1.3 % Ro) at 3600±100 m. Source rocks that are buried at depths deeper than 2500 m generally have reached generating conditions.

There are 12 exploitation fields within the DR-03 area. Depending on the depth of deposition, the source rocks have reached different catagenetic stages, which is directly reflected in the type of hydrocarbons generated. The positive genetic correlation of the accumulated hydrocarbons and source rock has been established both in the type of organic facies and in the reached maturity levels.

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HYDROGEOLOGICAL AND GEOLOGICAL INTERPRETATION ANALYSIS OF CORE SAMPLES FROM WELLS CARRIED OUT AS PART OF THE NATURA VITA PROJECT

HIDROGEOLOŠKA I GEOLOŠKA INTERPRETACIJA ANALIZA UZORAKA JEZGRE IZ BUŠOTINA IZVEDENIH U SKLOPU PROJEKTA NATURA VITA

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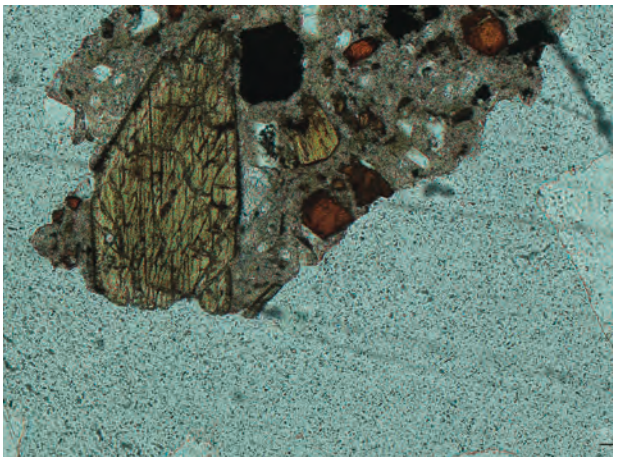
Ključne riječi: *hidrogeološke značajke, mineraloški sastav, hidraulička vodljivost, specifična površina, Kopački rit*

Tijekom 2021. godine prikupljeni su i analizirani uzorci jezgre iz bušotina DPKR-1, PPKR-5 i PPKR-10 izvedenih na području Kopačkog rita u sklopu geoloških i hidrogeoloških istraživanja provedenih za potrebe projekta NATURA VITA. Prikupljeni uzorci nabušene jezgre odabrani su tako da vjerno predstavljaju sve hidrauličke sredine u podzemlju. Uzorci su analizirani u geomehaničkom, geokemijskom i geološkom laboratoriju, a analize su rezultirale osnovnim geomehaničkim, geokemijskim i mineraloškim značajkama materijala.

S geomehaničke strane, uzorcima su definirana odabrana svojstva koja se matematički mogu obraditi i derivirati hidrogeološke značajke. Određen je granulometrijski sastav 99 uzoraka te Atterbergove granice 24 uzorka polupropusnih materijala.

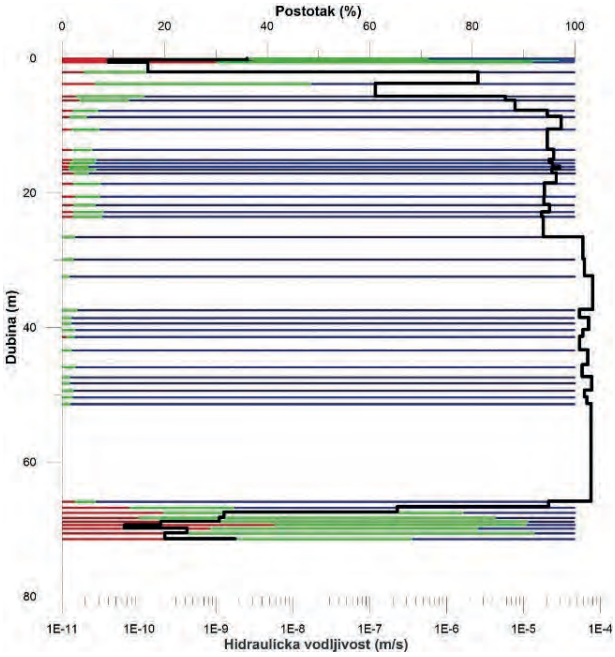
Odabrani uzorci su obrađeni u geološkim laboratorijima i istima je određen osnovni mineraloški sastav (slika 1) metodama modalne analize i rendgenske difrakcije te su za odabrane uzorke definirana osnovna geokemijska svojstva. Također su na odabranim uzorcima provedene palinološke analize u svrhu definiranja starosti sedimenata, sve kao nužan podatak za sedimentološku rekonstrukciju i izradu litofacijesnih zemljovida te za interpretaciju recentne sedimentacije na području Kopačkog rita. Dublji horizonti definirani su kao pleistocenske, a plići holocenske starosti.

Svi podatci dobiveni iz navedenih analiza su hidrogeološki interpretirani korištenjem Kozeny–Carman



Slika 1. Fragment efuzivne magmatske stijene iz uzorka DPKR-1 U41 sa svježim amfibolom (hornblenda) i biotitom

(URUMOVIĆ, 2016) i Slichter (URUMOVIĆ, 2013) modela (nekohezivne i slabo kohezivne naslage) na temelju granulometrijskih podataka te korelacijskom metodom (URUMOVIĆ, 2013) (kohezivne naslage) na temelju rezultata analiza granica plastičnosti. Objedinjeni rezultati omogućili su izradu aproksimativnih hidrauličkih profila podzemlja Kopačkog rita. Hidraulički profili će se, zajedno s hidrogeološkim profilima koristiti za daljnju hidrogeološku obradu te za eventualnu izradu karata ranjivosti područja PP Kopački rit. Isto tako će biti korisni za potrebe izrade Osnovne hidrogeološke karte – list Baranja (u izradi). Rezultati proračuna korelirani su s rezultatima in-situ hidrauličkih testiranja (slika 2) (na bušotinama su prevedena mjerenja metodom slug-testa (PST)).



Slika 2. Hidraulički profil bušotine DPKR-1

Također je u sklopu ovog istraživanja prikazano izuzetno važno svojstvo – vrijednosti specifične površine na mjerilu uzorka. Specifična površina čestice može biti glavni ulazni podatak za modeliranje scenarija eventualne ekološke havarije za slučaj npr. curenja zagađivala prilikom prometne nesreće ili curenja goriva iz spremnika raznih vrsta. Izračun specifične površine temelji se na modelu Kozeny–Carman, tj. na odnosu geometrijskih i statističkih značajki materijala na mjerilu uzorka.

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3D SEISMO-SEDIMENTOLOGICAL CHARACTERIZATION OF NEOGENE MURA BASIN SUCCESSION (PANNONIAN BASIN SYSTEM, CROATIA)

3D SEIZMO-SEDIMENTOLOŠKA KARAKTERIZACIJA NEOGENSKE ISPUNE MURSKOG BAZENA (PANONSKI BAZENSKI SUSTAV, HRVATSKA)

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Keywords: *Neogen Mura basin infill, 3D seismo-sedimentological interpretation 3D seismo-sedimentological characterisation, stratigraphic trapping*

Mura basin, located in the SW part of the Neogene Pannonian Basin System, with extensional rift graben/half-graben architecture, holds complete record of tectonic events

(rifting, syn-post rift compression, final basin inversion), climatic records (Middle Miocene Climatic Optimum) and depositional environments (transgression to late regression cycle succession). Tectonic-sedimentary architecture of Mura graben basin is controlled by interaction of footwall, hangingwall and axial-derived depositional system. Final result is Mura basin characteristic "catch up" infill succession pattern in which sedimentation catches up with the decreasing subsidence.

Seismo-geological interpretation of Mura hangingwall basin on newly acquired and merged 3D seismic cube Međimurje_merge_2022 (~300 km^2) resulted in new geological model of subsurface. 15 interpreted horizons covered syn-rift phase which lasted from the Ottnangian until the middle Badenian, early post-rift phase which lasted from the middle Badenian until the Sarmatian and late post-rift phase from the Pannonian to the Pliocene.

Seismic attribute analysis of 3D prestack and poststack seismic data, calibrated with well logs and core data enabeld seismo-sedimentary characterisation of interpreted subsurface geological model. Geology model of initial transgression cycle from continental to marine depositional environment of the Central Parathetys holds seismo-sediemntological geobodies of alluvial fans, shallow marine carbonate reefs, rock fall talus breccias, high energy shoals, fan deltas, sediment wave basin shales and basin turbidites. Following regression cycle in Pannonina lake with delta prograding system was imaged with seismo-sedimentological geobodies of alluvial/delta plain, delta front, delta slope, prodelta and basin turbidites.

Seismo-sedimentological characterisation of the 3D Međimurje_merge seismic cube gave clearest view of lateral and vertical sedimentary facies distribution trought basin evolution and improved significantly gross depositional maps. The importance of this method is of great importance expecially in hydrocarbon exploration, where it upgraded subsurface insight of spatial distribution of source, reservoir and seal rocks of present petroleum system. Furthermore, as quantitative and qualitative geological and geophysical method it revealed crucial information necessary for unlocking hydrocarbon exploration and development potential within stratigraphic type of HC trapping.

NORTH ADRIATIC SANDSTONE RESERVOIR CHARACTERIZATION USING MACHINE LEARNING

KARAKTERIZACIJA LEŽIŠTA PJEŠČENJAKA U SJEVERNOM JADRANU KORIŠTENJEM STROJNOG UČENJA

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Keywords: *machine learning, reservoir characterization, porosity distribution, lithology discrimination, Adriatic offshore*

Reservoir characterization is essential in the oil and gas industry for optimizing hydrocarbon exploration and production. Research is focused on the importance of reservoir characterization in offshore fields and the challenges that can arise due to the lack of well data or unevenly distributed data. The geological settings of the North Adriatic area result from the interaction of the Apennine fault-and-thrust-belt displacement, foreland ramp morphology, and progradation of the Po River delta. The area is covered by thick sediments (Pliocene, Pleistocene, and Holocene) including limestones, clays, silts, siltstones, sandstones, and sands. Clastic deposits in the research area, belonging to the Ivana Formation and Izabela Member, have high porosity due to the depositional environment, proximity to the source area, and shallow burial depth. The reservoir rock analyzed from image logs suggests deposition in a river/wave-dominated delta system.

The incorporation of pseudo-well data into reservoir characterization models can lead to more accurate and detailed reservoir property estimation, and the use of machine learning methods such as Deep Forward Neural Network (DFNN) can provide valuable insights and reservoir property predictions. Previous studies have investigated the application of machine learning in elastic parameter estimation, demonstrating great potential in improving the accuracy and efficiency of reservoir characterization. DOWNTON & HAMPSON (2018) presented a workflow for the distribution of reservoir density based on rock physics relationships, while DOWNTON *et al.* (2020) presented hybrid theory-guided data science-based methods for reservoir characterization. Seismic data integration in machine learning workflows

allows the simultaneous prediction of synthetic well logs from seismic data sets and does not require the intervention of an interpreter.

In this study, synthetic prestack seismic data were generated, stacked, and used in the seismic inversion process. An extensive library of input data was then utilized to train a DFNN for porosity prediction. The DFNN proved to be an effective tool for accurately predicting porosity, and its success in modelling reservoir properties of the North Adriatic gas reservoir was demonstrated. Different methods of implementation of described seismic reservoir characterization results and their integration with well data in the geological model were tested to find the most appropriate one. The best results in terms of all relevant reservoir properties modelling were achieved by introducing lithology classification and distribution, controlled by well data and seismic results. After the lithology model was set up satisfactorily (Fig. 1), it was utilized to better constrain the porosity distribution based on well data and DFNN porosity volume as main inputs.

The accuracy of porosity calculation is crucial for reserve estimation, as it directly affects the calculation of the volume of hydrocarbons in place. Overestimation or underestimation of porosity can lead to incorrect reserve calculations. The results of this study can serve as a framework for future studies aimed at improving the understanding of reservoir properties and their distribution, especially in offshore fields with limited or unevenly distributed well data.

Results highlighted the importance of reservoir characterization in the oil and gas industry and the challenges that can arise in offshore fields due to the lack of well data or unevenly distributed data. Machine learning algorithms, such as DFNN, can be used to improve porosity prediction and provide valuable insights into reservoir properties. The incorporation of pseudo-well data and the integration of seismic data in machine learning workflows can lead to a more accurate and detailed reservoir property estimation. The study also emphasizes the importance of lithology discrimination in the geological model to better constrain the porosity distribution based on well data and DFNN porosity volume as main inputs.

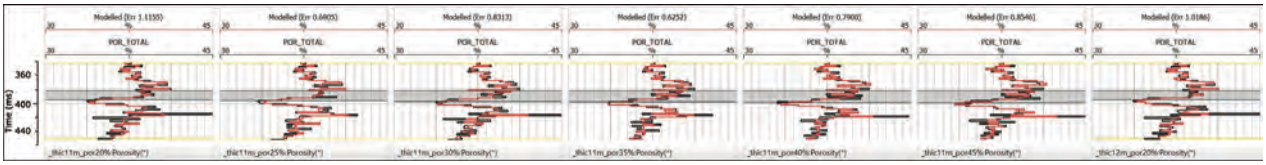

Figure 1. Pseudo-wells profile with modelled (red) and input (black) total porosity

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ROLE OF ALPINE AND DINARIC TECTONIC EVENTS IN THE TRANSITIONAL AREA OF THE SOUTHERN ALPS AND THE INTERNAL DINARIDES – KINEMATIC INFERENCES FROM IVANŠČICA MOUNTAIN (NORTHERN CROATIA)

ULOGA ALPSKIH I DINARIDSKIH TEKTONSKIH PROCESA U PRIJELAZNOM PODRUČJU JUŽNIH ALPA I UNUTRAŠNJIH DINARIDA – KINEMATSKI POKAZATELJI S IVANŠČICE (SJEVERNA HRVATSKA)

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Keywords: *Ivanščica Mt., Southern Alps, Internal Dinarides, Adriatic passive margin, Tectonics, Kinematic analysis*

Ivanščica Mt. is an inselberg in Hrvatsko Zagorje region situated at the junction of the Internal Dinarides, South-

ern Alps and Pannonian basin (SCHMID *et al.*, 2020). Regional tectonostratigraphic units are best exposed on Ivanščica Mt., but in a very complex and still tectonically uncertain relationships. For this reason, we selected Ivanščica Mt. for detailed structural geological research with the main objective to reconstruct its Mesozoic and Cenozoic tectonostratigraphic evolution including the neighboring area.

In Ivanščica Mt., Upper Paleozoic and Mesozoic formations are exposed from beneath up to 2000 m thick Neogene sedimentary cover of the Pannonian Basin. Since the Middle Triassic these formations were a part of the eastern passive continental margin of the Adria microplate. Middle Triassic pelagic and pyroclastic formations related to the opening of the Neotethys were sealed by up to 1000 m thick Upper Triassic platform carbonates. In the Early Jurassic, the study area was also affected by subsidence related to the opening of the Alpine Tethys. This caused the transition from the shallow-marine to pelagic sedimentation. Continuous Jurassic to Early Cretaceous pelagic sedimentation, including radiolarian cherts and pelagic limestones was interrupted during the Hauterivian by terrigenous influx and deposition of mixed carbonate-siliciclastic turbidites. The Middle Triassic to Lower Cretaceous synrift to passive margin succession of Ivanščica Mt. is tectonically overlain by the Jurassic ophiolitic mélange.

Large-scale correlations of regional tectonostratigraphic units made so far propose that the tectonic boundary between the Southern Alps and the Internal Dinarides runs across Ivanščica Mt. (e.g. VAN GELDER *et al.*, 2015). This tectonic boundary is supposed to be a result of the Oligocene-earliest Miocene top-south thrusting of Triassic to Lower Cretaceous carbonate platform to deep-marine succession derived from the Alps over the ophiolitic mélange unit of the Internal Dinarides.

In this study, we first defined different Mesozoic lithostratigraphic units and interpreted their paleogeographic origin. Then, we focused on geological mapping of the study area on a scale 1:25.000, locally on a scale 1:5.000, in order to delineate their spatial arrangement and type of contacts with neighboring units. This was supplemented by kinematic analysis aimed to reconstruct tectonic transport directions. In particular, we studied boundaries of tectonic klippes, which are shown on existing geological map (ŠIMUNIĆ *et al.*, 1982) in a structural position on top of the tectonostratigraphic unit previously mapped as a composite unit comprising Jurassic ophiolitic mélange and Lower Cretaceous turbidites (i.e. the Repno complex and the Oštrc Formation, respectively sensu BABIĆ *et al.*, 1979).

Based on our mapping we were able to clearly delineate spatial distribution of the Repno complex and the Oštrc Formation, as well as to reconstruct for the first time continuous succession from the Upper Triassic shallow-marine deposits to the Lower Cretaceous turbidites (Oštrc Fm.). Besides, the mapping also showed that previously interpreted tectonic klippes of Upper Triassic carbonates on top of the Repno complex represent a set of SE-dipping and NW-verging imbricates, which are clearly sealed by lowermost Miocene deposits. These imbricates consist of the Upper Triassic shallow-marine carbonates, continuously overlain by pelagic Jurassic deposits followed by Tithonian–Valanginian Aptychus limestones tectonically overlain by the Repno complex. The appearance of the Early Cretaceous synorogenic Oštrc Fm. preserved exclusively in frontal imbricates possibly indicates an in-sequence imbrication that propagated towards the NW in the present-day coordinates. This imbrication took place during the Hauterivian to Albian as confirmed by the age of synorogenic Oštrc Fm. (BABIĆ & ZUPANIČ, 1978), which also contain clasts of uppermost Tithonian to Valanginian Aptychus limestones and detrital zircons with Early Cretaceous fission track cooling ages (ZUPANIČ *et al.*, 1981; LUŽAR-OBERITER *et al.*, 2012). This late Early Cretaceous imbrication corelates well with a nappe stacking and a regional metamorphism recorded in nearby Medvednica Mt. (VAN GELDER *et al.*, 2015 and therein), in other parts of the Internal Dinarides (NIRTA *et al.*, 2020) and in the Eastern Alps (NEUBAUER *et al.*, 1995 and therein).

This new interpretation of the pre-Neogene structural architecture of Ivanščica Mt. does not support the south-vergent nappe contact of the Southern Alps and the Internal Dinarides running through Ivanščica Mt. and so indicates that the location of previously proposed tectonic contact should be revisited.

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DISTRIBUTION OF LOWER MIOCENE VOLCANICLASTIC ROCKS IN THE MURA BASIN ACCORDING TO WELL AND SEISMIC DATA

RASPROSTIRANJE DONJOMIOCENSKIH VULKANOKLASTIČNIH NASLAGA U MURSKOM BAZENU NA OSNOVI BUŠOTINSKIH I SEIZMIČKIH PODATAKA

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Keywords: *Egerian-Eggenburgian, Geochronology, Mura Basin, Macelj Formation, Central Paratethys*

Newly available data enables us to gain new insight into the evolution of the Mura Basin, including the time of sediment deposition as well as its distribution.

As it is known, the Mura Basin area is covered with Quaternary alluvial deposits on the south and with Sarmatian-Pannonian and Pleistocene clastic sediments on its northern edge (ŠIMUNIĆ *et al.*, 1982, 2013), so we know little about the Lower Miocene volcaniclastics in this area.

The nearest confirmed outcrops (AVANIĆ *et al.*, 2021) that are geochronologically dated are located west and southwest of the Ina exploration block SZH01.

In the Mura Basin, 34 wells have found volcanoclastic sediments. The sample from nine wells were taken for new geochronological analyses. The rocks are defined as: crystal tuff, lithic tuff, and vitric tuff (acc. SCHMID, 1981), lapilli tuffs, and lapillistones, subordinately pyroclastic and tuff breccias (acc. FISHER, 1966). The extrusive rocks are also present. The volcanic and pyroclastic rocks from Mura basin are mostly classified as: andesite and dacite-rhyolites while trachy-andesite rocks were found only sporadically (WINCHESTER & FLOYD, 1977), trace elements Nb/Y – Zr/TiO2 diagrams).

According to new geochronological analyses of U-Pb LA-ISP-MS on zircon crystals it is establish age of volcaniclastic within the range of 23.19±0.26 to 21.23±0.25 Ma (MATOŠEVIĆ *et al.*, 2023).The analyses yielded the ages Paleogene (Oligocene – Chattian) to the Neogene (early Miocene – Aquitanian), but the significant amount of the deposits is deposited during the Aquitanian, i.e., Egerian and Eggenburgian stages according to the Central Paratethys stratigraphic division (PILAR *et al.*, 2007; KOVAC *et al.*, 2017). According to that this volcanics are the oldest proven L. Miocene andesitic calcium-alkaline volcanism with a high potassium content in the Mura Basin.

The distribution of volcaniclastics in Mura basin was defined according to new geochronology data, 2D and 3D seismic interpretation. It is concluded that volcaniclastic series has a distribution of over 550 km^2, with possibility of extension further east outside the exploration area. On the seismic cross-sections the younger volcaniclastics was separated from older one. Analysing the well data and the newest geochronology data it is notice that the oldest dated volcanoclastic deposits were found in the Mihovljan area (well A, well B). The significant thickness of volcanoclastic sediments more than 2200 meters (well F) indicated the Egerian-Eggenburgian depocenter.

According to analogy with surface data (AVANIĆ *et al.*, 2021), interpreted volcaniclastic sediments from Mura basin could be linked with the surface data. The Vučji Jarek Mb. (Macelj Formation) has dated from 19.2 ± 0.64 Ma to 22.62±0.86 Ma while the age from several wells is 21.23 ± 0.25 Ma – 22.63±0.34 Ma.

Between two volcanoclastic seria (well F) the 260-meter-thick sandstone layer was found compose of: arkose, litho-arenite, and grauwackes type of sandstones. According to the dated age above it (21.23 ± 0.25 Ma) and below it (22.50±0.25 Ma) that sandstones probably represent the missing part of Vučji Jarek Mb. As it stands now, the sandstones probably belong to the R-T system track sequence sedimented during the sea level drop that

is happened at the end of the Egerian (HARZHAUSER *et al*., 2007). At the same time in outcrop data, emersion was documented (unconformity between the Vučji Jarek Mb. and the Eggerian Golubovec Mb., AVANIĆ *et al*, 2021). The sandstone layer probably corresponds to the Egerian-Eggenburgian chronostratigraphic boundary. Of course, a further, more detailed study of the available data would be highly recommendable.

It is speculated that the older volcanoclastic sediments could be deposited in a deeper marine environment because there is no detected sedimentary influx from shallower basin area and because of large thickness of deposited rocks link with geotectonics. The youngest volcaniclastics were probably deposited in shallower marine environment. Large terigen siliciclastic influx in the basin with bioturbation and glauconites grains (core data) goes in favour to that. The shallower marine carbonates sediments, dated by index fossil, were documented in the SE part of the exploration area. According to all available well data, Eggenburgian GDE map Mura basin was made.

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WHEN THE STARS CONNECT – GEOLOGICAL MAPPING AND GEODIVERSITY INVENTORY

KAD SE ZVIJEZDE SPOJE – GEOLOŠKO KARTIRANJE I INVENTARIZACIJA GEORAZNOLIKOSTI

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Ključne riječi: *georaznolikost, geobaština, upravljanje, metodološki okvir, obrazac za inventarizaciju*

Georaznolikost je neobnovljiva, a kada se uništi, trajno i nenadoknadivo se briše trag o događajima iz geološke prošlosti. Prepoznavanje, opis i inventarizacija vrijednih geolokaliteta (izdanaka stijena, minerala, fosila, itd.) je preduvjet za zaštitu i očuvanje vrijedne georaznolikosti. Javne ustanove za upravljanje zaštićenim područjima i/ili drugim zaštićenim dijelovima prirode trebale bi djelovati u smjeru očuvanja i interpretacije georaznolikosti, a posebno zaštićene geobaštine. Iako većina prepoznaje geo-

raznolikost kao sastavnicu prirode, istraženost i provedba aktivnih mjera je djelomična.

Prvi korak u zaštiti i očuvanju geobaštine je planiranje istraživanja georaznolikosti u strateškim dokumentima javnih ustanova, a prvenstveno u planovima upravljanja zaštićenim područjima. Prilikom evaluacije stanja u mnogim zaštićenim područjima utvrđeno je nedovoljno poznavanje georaznolikosti i geobaštine. Stoga se u upravljačkim dokumentima planiraju aktivnosti inventarizacije, vrednovanja i provedbe potrebnih mjera što bi trebalo potaknuti aktivniji pristup prema ovoj sastavnici prirode koja je još uvijek u podređenom položaju u odnosu na bioraznolikost.

Ono što nedostaje je nacionalni metodološki okvir za jasnu, logičnu i objektivnu identifikaciju geološki i geomorfološki vrijednih elemenata (SHARPLES, 2002; PROGEO, 2011; CROFTS & GORDON, 2015) kako bi se podaci o geolokalitetima, mineralima i fosilima sistematski bilježili i unosili u jedinstvenu bazu podataka. Pri dosadašnjoj inventarizaciji korišteni su različiti metodološki okviri i obrađeni raznoliki geološki i geomorfološki elementi zbog čega podaci na nacionalnoj razini nisu u potpunosti usporedivi.

Suradnjom Javne ustanove Nacionalni park Plitvička jezera, Zavoda za zaštitu okoliša i prirode te Hrvatskoga geološkog instituta dogovoreno je testiranje obrazaca za inventarizaciju georaznolikosti što bi trebala biti osnova za definiranje nacionalne metodologije. Svemu je prethodio proces izrade Plana upravljanja Nacionalnim parkom Plitvička jezera kroz koji je prepoznata važnost geologije i geomorfologije u postanku jezera, ostalih krških oblika te samog reljefa, kao i nedovoljna istraženost Nacionalnog parka te nepostojanje sustavne baze podataka o georaznolikosti (JAVNA USTANOVA NACIONALNI PARK PLITVIČKA JEZERA, 2019).

S Hrvatskim geološkim institutom ugovorena je izrada Osnovne geološke karte Nacionalnog parka Plitvička jezera M 1:50 000 na litostratigrafskom principu te istraživanje georaznolikosti i geobaštine na području Nacionalnog parka. Geološkim istraživanjima temeljem znanstvenih spoznaja i putem obrazaca za inventarizaciju georaznolikosti izdvojit će se značajni geolokaliteti za bazu podataka Javne ustanove. Obrazac se temelji na već postojećim obrascima (JAMIČIĆ, 2005; ProGEO, 2011), a dorađen je korištenjem dostupne literature (CROFTS & GORDON, 2020) i prilagođen hrvatskim posebnostima. Obrazac sadrži osnovne podatke o evaluatoru i geolokalitetu, geološke/geomorfološke podatke, procjenu ugroženosti te ocjenu stanja i smjernice za upravljanje (geokonzervaciju).

Kriteriji za odabir geolokaliteta nisu uvijek jasni i definirani, no analizama koje bi trebale uslijediti, usporedbom i vrednovanjem geolokaliteta na nacionalnoj razini, u suradnji sa znanstvenom zajednicom, utvrdili bi se kriteriji sa smjernicama te metodološki okvir za inventarizaciju georaznolikosti. Navedena suradnja dobar je primjer usmjeravanja istraživanja u zaštićenom području ka upravljačkim potrebama kako javne ustanove tako i nacionalnog stručnog tijela za zaštitu prirode.

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DEPTH MIGRATION OF SEISMIC VOLUMEN VIROVITICA SOUTH 3D
DUBINSKA MIGRACIJA SEIZMIČKOG VOLUMENA VIROVITICA JUG 3D

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Keywords: *seismic data processing, depth imaging, Drava basin*

This paper details the Prestack Depth Migration (PSDM) of the 3D seismic data Virovitica South located in the south-eastern uplifted Drava basin margin (called Bjelovar subdepression). Surrounding area of Virovitica South 3D is characterized by shallower structural features near the vicinity of oil matured source rocks between oil and gas discoveries. The goal of depth migration was to further improve the image, better define the structural tectonic assemblage and generate a seismic volume in depth with minimal misties between the borehole EK markers and interpreted horizons.

PSDM is one of the most regarded and highly dependable seismic techniques for visualizing subsurface structures. Its effectiveness stems from its capacity to accurately concentrate and position reflections even in regions characterized by significant lateral variations in velocity (HANITZSCH *et al.*, 2003). A comparison between velocity sections initially acquired through velocity analysis in the time domain on CMP (Common Midpoint) gathers and those obtained through techniques relying on model ray tracing allow more precise estimates of interval velocity to produce enhanced velocity models for PSDM.

For this project, seismic data processed and prepared for time migration served as input to depth migration. Time processed data included relative amplitude preserving noise attenuation using 3D algorithms with high effort on noise removal due to low S/N ratio, amplitude balancing and deconvolution with extensive velocity analysis. Two wells data and two interpreted horizons were used for controlling and evaluating tomographic solutions as well as determining anisotropy parameters.

The velocity model generated during the pre-stack time migration (PSTM) process was used as input for creating the initial velocity model. Firstly, the velocity was converted from RMS to interval velocity, vertically and spatially smoothed and finally accelerated for 2 %. Grid based global reflection tomography was approached towards a final velocity model. After the first iteration, by analysis and implementation of anisotropy parameters (delta and epsilon) the model was converted to anisotropic version. Parameters describing the tilt of symmetry axis (dip and azimuth) were also included into the model. By incorporating anisotropy parameters events were better positioned in depth.

In this project three tomographic iterations were performed. The most well determined, long wavelength features were resolved first (3500 m spatially and 833 m vertically) and the least determined, short-wavelength features were resolved last (1240 m spatially and 264 m vertically). Comparisons with well data indicated that

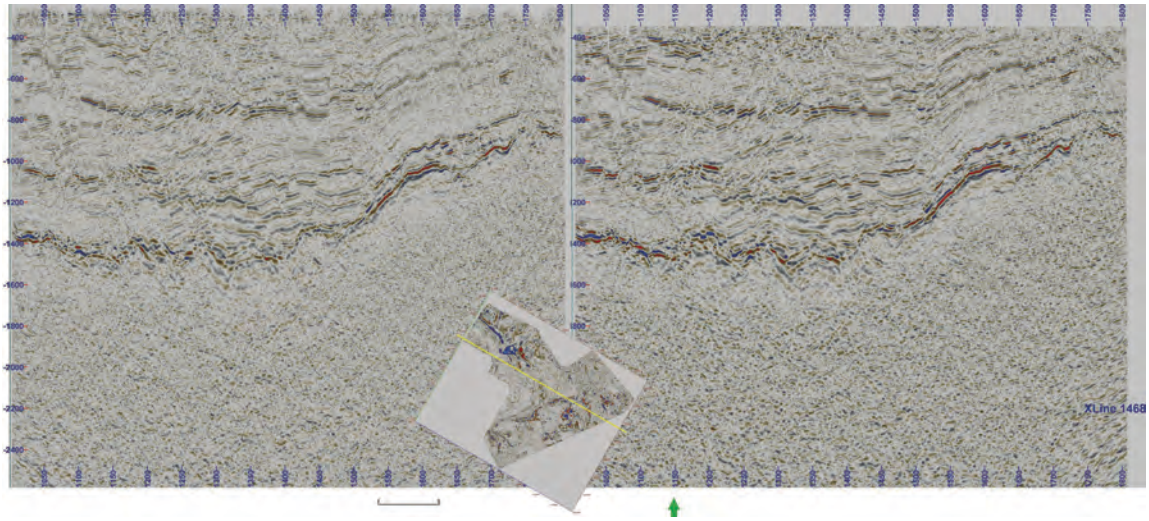

Figure 1. Comparison of results from time (left) and depth (right) migration

such a model represents an appropriate framework for subsequent tomographic iterations.

Compared with time migration, the depth migration of the Virovitica South 3D project (Fig. 1) provides more accurate depiction of underground structures and stratigraphy, more continuity of reflectors, better fault focusing and less noise. Also, it contributes to easier and more reliable interpretation supported by mistie analysis showing differences between interpreted horizons and well data within 18 m.

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THE ADVENTURE OF PROTECTING DINOSAUR FOSSILS
AVANTURA ZAŠTITE FOSILA DINOSAURA

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Prve nalaze fosila dinosaura na području Republike Hrvatske otkrio je prije gotovo 100 godina (1925. godine) austrijski industrijalac A. Bachofen-Echt. Na otoku Veli Brijun je pronašao krupne tridaktilne tragove za koje se smatralo da pripadaju rodu *Iguanodon* i kružne otiske s pet kandži koje je pripisao divovskim kornjačama (BAJRAKTAREVIĆ & MEZGA, 2009). Tek 70-tak godina kasnije započinje se sa sustavnim istraživanjima koje su vodili hrvatski i talijanski znanstvenici (MEZGA, 2009). Do danas je na području hrvatskog dijela Jadransko-dinaridske karbonatne platforme otkriveno 20-tak nalazišta dinosaura.

Uprava za zaštitu prirode tadašnjeg Ministarstva kulture 2005. godine uputila je Državnom zavodu za zaštitu prirode zahtjev za izradu stručne podloge za zaštitu ove vrijedne geobaštine. Nakon 15 dugih godina i birokratskih problema Ministarstvo gospodarstva i održivog razvoja na temelju Zakona o zaštiti prirodi (NN 80/2013, 15/2018, 14/2019, 127/2019) i stručnog mišljenja Zavoda za zaštitu okoliša i prirode proglasilo je dinosaure i njihova nalazišta zaštićenim dijelovima prirode – zaštićenim fosilom (Rješenje o proglašenju fosila dinosaura i njihovih nalazišta zaštićenim dijelovima prirode NN 40/2021). Proglašena su 24 nalazišta na području Istre, Hvara, Dugog otoka i Biokova. Neka od tih nalazišta dodatno su zakonski zaštićena unutar zaštićenih područja Nacionalnog parka Brijuni, Parka prirode Biokovo te Značajnog krajobraza Rovinjski otoci i priobalno područje te Donji Kamenjak i medulinski arhipelag.

Fosilni nalazi upućuju na prisutnost sauropodnih, teropodnih i ornitopodnih dinosaura. Najstariji nalazi datiraju iz razdoblja mlađe jure (Kirmenjak) a najmlađi iz mlađe krede (Žukova). Svako od otkrivenih nalazišta ima svoju vrijednost i specifičnost. Tako je najveće i najstarije nalazište u ovom dijelu Europe otkriveno u kamenolomu Kirmenjak koji broji gotovo tisuću otisaka s preko 20 staza kretanja. Unutar autokampa Solaris nalazi se bogato nalazište s preko 500 otisaka od kojih stotinjak čine čak 32 staze kretanja. Nalazište Gustinja značajno je zbog vrlo dobro izražene pojave dinoturbacija. Na području Nacionalnog parka Brijuni pronađeno je najviše lokaliteta s ihnofosilima (rt Ploče, rt Kamik/Plješivac, rt Trstike/Debele Glava, rt Pogledalo/Barban). Nalazište na rtu Plješivac je zasad jedini poznati lokalitet na kojem su pronađeni otisci stopala ornitopoda u Hrvatskoj. Na nalazištu Žukova na Hvaru pronađeni su otisci stopala koji ukazuju na sauropode dužine preko 20 m koji predstavljaju zasad najveće poznate dinosaure koji su obitavali na području Hrvatske. U uvali Kolone kraj mjesta Bale pronađene su jedine fosilizirane kosti dinosaura u Hrvatskoj. Nalazište je dodatno zaštićeno kao Paleontološki posebni rezervat (ŽEGER PLEŠE & ZWICKER KOMPAR, 2020).

Daljnjim istraživanjima utvrđena su nova nalazišta te će se nakon provedenih analiza uputiti zahtjev Upravi za zaštitu prirode radi proglašenja.

Zaštićenim fosilima dinosaura upravljaju Javne ustanove za upravljanje zaštićenim dijelovima prirode, u ovom slučaju to su Javna ustanova Nacionalnog parka Brijuni, Javna ustanova Park prirode Biokovo, Javna ustanova Natura Histrica, Javna ustanova Natura Jadera, Javna ustanova More i krš te Javna ustanova Kamenjak.

Zavod za zaštitu prirode i Uprava za zaštitu prirode Ministarstva gospodarstva i održivog razvoja u suradnji s Geološko-paleontološkim zavodom Prirodoslovno-matematičkog fakulteta u Zagrebu izradila je obrazac za inventarizaciju te izrađuje Elaborat za potrebe Upisnika zaštićenih fosila dinosaura kako bi se olakšalo upravljanje ovom vrijednom geobaštinom. U Elaboratu će se dati detaljniji opisi nalazišta i svi potrebni opći podaci i geopodaci, ocjena stanja te preporučene smjernice za daljnje upravljanje lokalitetima.

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