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"TOWARD SUSTAINABLE MANAGEMENT OF GROUNDWATER RESOURCES"

Danube Gorge (Iron Gate), Donji Milanovac, Serbia

19 - 20 June 2019

Geotrip

„ KARST OF DJERDAP AREA - SERBIAN PART“

18, 20 June, 2019

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International Association of Hydrogeologists (IAH)
National Chapter of Serbia (NCS) and
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TABLE OF CONTENT

GROUNDWATER PROTECTION

KARST AND FRACTURED-ROCK HYDROGEOLOGY

MINERAL WATERS AND GEOTHERMAL ENERGY

II part Geotrip Guide

Foreword

The fourth IAH CEG conference (Central European Group of IAH) on applied aspects of hydrogeology will be held between 18 and 20 June 2019 in Donji Milanovac, the Geoheritage Djerdap - Danube Gorge area, Serbia. The conference is organised by the IAH Serbian National Chapter, the Serbian Geological Society, the Faculty of Mining and Geology of the University of Belgrade, and the IAH Karst Commission.

The first CEG conference was organised by the IAH Hungarian National Chapter in Morahalom, Hungary, in May 2013. The aim of this event was to provide a series of conferences organised by IAH chapters in different Central European countries as forums for researchers, experts and students to present their activities, to exchange experience and to discuss scientific cooperation. One of the important features of the CEG Conferences is that they are open to participants from other part of the world, not from Central European Countries only.

The second CEG conference was hosted and organised by the IAH National Chapter of Romania in Constanza on the Black Sea coast. The series continued with a third meeting organised by the IAH National Chapter of Croatia that was part of activities during the 44th IAH Congress (2017) in Dubrovnik, Croatia.

The general subject of the fourth IAH CEG Conference is “Towards Sustainable Management of Groundwater Resources”. This is divided to four hydrogeological areas of concern: 1. Water supply and sustainable groundwater management; 2. Groundwater protection; 3. Karst and fractured rock hydrogeology; 4. Mineral waters and geothermal energy.

From the organizational point of view, this fourth CEG Conference may be coupled with an IAH Karst Commission Geo Trip that is to be held in the karst area of the Serbian and Romanian sector of the Carpathian-Balkanides, (broadly the same region of the Danube Gorge) between 14 and 17 of June. Some participants will not want to miss this excellent opportunity and so may want to be involved in both events.

About forty papers, including four plenary talks, will be presented over three sessions. The pre-conference field trip (June 18) includes a visit to some significant karst localities and a boat trip through the most interesting section of the Danube Gorge and its important historic heritage points. The post-conference tour on June 20 includes a visit to Mesolithic Iron Gates Culture dated about 9000 BC, Viminacium Roman City and legionary fort, and Golubac fortress located at the entrance of Danube Gorge.

Dr. Petar Milanović

President of IAH Serbian National Chapter

PLENARY CONTRIBUTIONS

GEOHERITAGE OF DJERDAP AREA - AN ASPIRING UNESCO GEOPARK

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(by Maran Stevanović A. Extract from article: *Activities on the establishment of Djerdap geopark (Serbia) and candidature of the area to the UNESCO global geopark network*. Bulletin of the Natural History Museum, 2017, 10: 7-28)

Geopark is clearly defined territory in which main activities are oriented to exploring, protecting and promoting not only internationally important geoheritage but also other valuable natural and cultural resources in the area through tourism development, aiming to stimulate and engage the local communities, enhance their socio-economic status, advance geoconservation and, create a balance between the economic growth and environmental protection (Mc Keever & Zouros 2005, Maran 2010). A geopark is managed by an appropriate defined structure, organized according to the national legislation, able to enforce the protection, enhancement and sustainable development policies within its territory. Activities in geopark are primarily financed through local and national sources, supported by regional development funds of the European Union.

Establishment of geoparks, the European Geoparks Network (EGN) and the UNESCO Global Geoparks Network (UNESCO GGN) was one of the most important international geoconservation initiatives. The European Geoparks Network currently comprises 70 regions in 23 countries whereas the Global Geoparks Network, established in 2004, encompasses 127 areas worldwide, including European geoparks.

The Working Group of National Geoparks in Serbia, established in early 2014 under the umbrella of the Ministry of Agriculture and Environmental Protection, have analyzed the natural, cultural, scientific, educational and tourism potentials of certain areas in Serbia. Based on the evaluation of several prospective regions, it was decided to choose the Djerdap area for a candidacy to the UNESCO Global Geoparks Network due to its geographic position, valuable natural and cultural resources, a long tourist tradition and enhanced employment opportunities as well as real economic benefit for the people who live there primarily through the development of geotourism.

The Djerdap aspiring geopark is located in the northeastern part of Serbia, along the border with the Republic of Romania. It covers spatially an area of 1330 km^2 and includes the area of the Djerdap National Park, but exceeds its territory for additional 692 km^2 (Fig. 1). The Djerdap National Park (NP) is one of the five national parks in the Republic of Serbia. The area of the NP Djerdap is divided into three different protection zones. The first zone (8%) refers to the strict protection of natural and cultural heritage. The second one (21.5%) surrounding the first zone and applies to the special nature values (specific ecosystems, geological and geomorphological sites) and natural areas around cultural monuments. The third zone (70.5%) applies to the territory outside the borders of the first and second protection zones and permits activities related to: tourism, sports, recreation, forestry, water use, potential exploitation of mineral resources, urban construction and development.

Although the NP Djerdap was established in 1974, the Public Enterprise "National Park Djerdap" (PE "NP Djerdap"), was officially founded some twenty years later, after the enact of Law on National Parks in 1993. The PE "NP Djerdap" is in charge for the realization of management concept, based on: preservation and sustainable use of natural and cultural heritage, implementation of the prescribed protection regimes, supervision of protective conditions and measures, prevention of all activities and actions that are opposed to national, regional and local laws as well as those that represent threats to protected area.

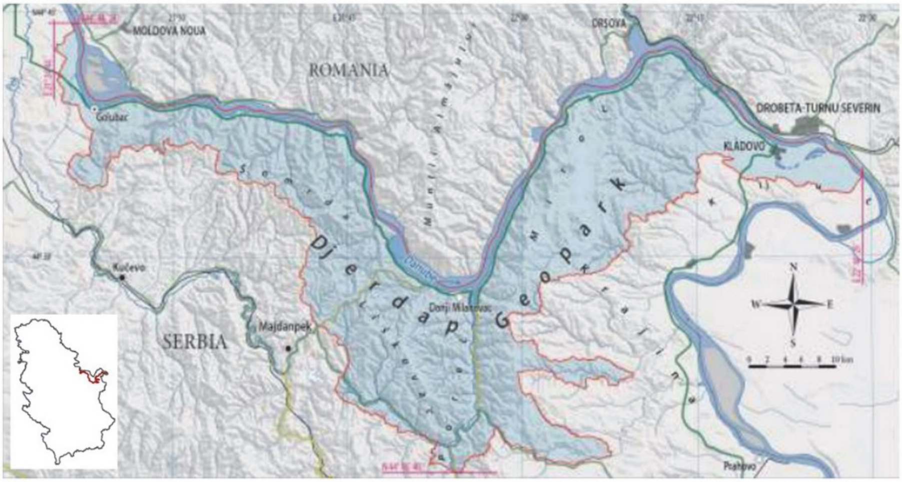

Fig. 1 Location map and boundaries of Djerdap

Djerdap Gorge is the most prominent natural phenomenon in the area. On its 117 kilometers long path from Golubac to Kladovo, the Danube River cuts into the perimeter of Southern Carpathians and connects the Pannonian Basin on the west and Dacian Basin on the east (Maran Stevanović & Ćalić 2017). Considered to be the longest incising composite gorge in Europe, it encompasses four smaller gorges (Golubac or Upper Gorge, Gospodjin Vir, Kazan and Sip) and three valleys among them (next to the cities Liubcova, Donji Milanovac and Orşova). This area hosts more than 50 different types of forest and bush communities that inhabits various and rich fauna. Due to its geographical position, available natural resources and mild climate, the area has been a dwelling place for several civilizations, from the Mesolithic time to the present.

The Gorge is one of the best studied areas of the Balkan Peninsula; it has been, and still is, researched by renowned national and international geologists, geomorphologists, botanists, zoologists, archeologists and historians. Achievements and results of their research are documented in a wide range of scientific, expert and popular publications.

Geodiversity

Several geological entities can be distinguished in this area, each with complex tectonic structures and lithology.

The oldest rocks are the Precambrian amphibolite facies that originated from deeper parts of the Earth's crust. The Paleozoic units consist of the Lower Cambrian volcano-sedimentary rocks, Ordovician schists, Carboniferous marine and continental deposits and Permian red sandstones and spilites (Grubić 1980, 1997, Krstić & Maslarević 1997). These deposits were highly tectonized and metamorphosed due to the large tectonic movements of the Variscan orogeny.

During the Jurassic, the entire area was invaded by marine transgression and the sedimentation cycle continued until the beginning of Upper Cretaceous. The Jurassic limestones, marls and cherts, Lower Cretaceous claystones, marlstones, sandstones and limestones and early Upper Cretaceous conglomeratic limestones, sandy claystones and thin bedded marlstones were formed during this period (Grubić 1980, Rabrenović 1997, Rabrenović & Vasić 1997).

In the adjacent area, deposition of the Upper Cretaceous rocks was accompanied by a multiphase magmatism, and thus produced a huge volcanogenic-sedimentary series - the Timok Magmatic Complex, over 2.000 meters thick (Banješević 2010). During the Paleogene, intrusive igneous rocks were formed following geodynamic evolution of the Carpathian orogen. In the Oligocene, several fresh-water basins existed along the main longitudinal faults. The Miocene, dominantly Badenian marine sediments were deposited within the 'trans-Carpathian strait system', which connected the Western (Pannonian) and the Eastern (Dacian-Black Sea) provinces of the Paratethys (Stevanović 1990). Fluvial, slope and cave deposits are formed during the Quaternary.

The geoheritage list includes 63 proposed geosites that testify type sections of geological units, illustrations of tectonic processes, fossiliferous localities, representative landforms and effects of weathering, erosion or landform evolution, unusual mineral occurrences or sites of exceptional natural beauty. The importance and value of selected geoheritage were assessed based on the attributes of each particular phenomenon, including how representative it is, how valuable it is in terms of science, education, geoconservation and tourism, how vulnerable it is to potential threats as well as by its comparison with the similar sites at the international, national, regional and local level (Maran Stevanović 2015).

The category 'internationally important geosites' is assigned by members of the Working Team for the establishment of Djerdap Geopark to five sites, namely Djerdap Gorge, Pesača, Greben ridge, Boljetinsko Brdo and Vratna natural bridges. Djerdap Gorge is the most complete manifestation of geodiversity and biodiversity phenomena, which along with cultural-historical heritage signifies an integrated natural and cultural resource not only in Serbia but also in Europe (Fig. 2).

The sites Pesača, Greben ridge and Boljetinsko Brdo altogether represent unique sedimentological-paleontological complex that illustrates a part of geological history of the Tethys Ocean during Jurassic-Lower Cretaceous time. The most significant outcrop for scientists and researchers refers to the Lower, Middle and Upper Jurassic lithological units occurring at the road section Pesača. Abundant remains discovered at this section include fossilized brachiopods, bivalves, ammonites and belemnites (Fig. 3). An impressive profile of the Middle Jurassic reddish, nodular marly limestones rich in fossils is exposed at the Greben ridge; this site is considered to be the best exposure of Jurassic-Lower Cretaceous succession in this part of Carpathian-Balkanides. Boljetinsko Brdo is one of the most scientifically important sites simply because it depicts the Lower Cretaceous (Upper Barremian) deep-water sediments where new genera and species of ammonites were identified (Vašíček et al. 2014)

Fig. 2 Geodiversity of Djerdap Gorge: a) Vratna stone-bridge, b) Boljetinska Reka Gorge, c) part of Pesača section, d) Boljetinsko Brdo, e) Greben ridge (photo: A. Maran Stevanović)

The category ‘nationally important geosites’ is assigned to eight sites: Boljetinska Reka Gorge, Traces of Carpathian Strait, Ridan–Golubac, Peridotites of Miroč, Rakin Ponor, Korešin Potok, Gradašnica Cave and Rajkova Pećina Cave. Due to their significance for the development of geology and geomorphology in Serbia, they have been used as reference sites by the national scientific community.

Fig. 3 Ammonites from Greben ridge (Mesozoic Invertebrate Collection, Natural History Museum in Belgrade) (photo: A. Maran Stevanović)

The most significant geological collections, containing specimens from the Djerdap area have been gathered as the result of lengthy geological investigations and museological works. They are kept in the Natural History Museum in Belgrade, the Faculty of Mining and Geology, University of Belgrade and the Serbian Geological Survey. Some of these specimens signify geological and museological rarities because they derived mostly from sites, which have been destroyed or are no longer accessible (partially submerged by the artificial Djerdap Lake) and represent an important resource that cannot be replaced (Fig. 4).

Biodiversity

Geopark area belongs to one of the largest and the most northerly European refugees for Tertiary flora, with more than 50 different types of forest and bush communities, out which 35 are relict (source: Red data book of Flora of Serbia). Representatives of approximately 1100 vascular plants inhabit this territory (Stevanović 1996). Well-developed polydominant forests mainly consist of Tertiary relicts: beech, walnut, Turkish filbert, yew, linden, Caucasian lime, nettle tree, common lilac and common holly. The representatives of 16 Balkan endemics can be found here, including Pančić’ maple, endemic variant of hawkweed, viola, thyme, bear’s breeches, mouse-ear chickweed, bellflower, and others (source: Institute for Nature Conservation of Serbia).

Approximately 150 bird species are registered in the area, but this number is not final (source: Djerdap National Park, Institute for Nature Conservation of Serbia). Among the most important representatives are pygmy cormorant, lesser spotted eagle, booted eagle, white-tailed eagle, golden eagle, peregrine falcon, corncrake, black stork, the Eurasian eagle-owl, the Ural owl, the Eurasian scops owl, the Alpine swift, red-rumped swallow and others. Due to the diversity of birds and the presence of rare, endangered bird species, the area of Djerdap National Park has been declared an Important Bird Area (IBA).

Fig. 4 Biodiversity representatives of Djerdap Gorge: a) the European smoke tree, b) common holly, c) the Ural owl, d) wolf (photo: A. Maran Stevanović & S. Marinčić)

The abundance of mammals is largely due to the well-preserved habitats; representatives of species such as otter, wildcat, Eurasian lynx, brown bear, chamois, deer, roe deer and different bats are specified within the Preliminary Red List of Vertebrates of Serbia. Today, about 60 fish species are reported in the Danube Gorge (source: Djerdap National Park). The most notable representatives are catfish, zander, pikeperch, sterlet, common bream, the European chub, common barbell and asp. However, Lendhardt and others (2004) indicate that many native species, including sturgeon, common carp, common barbell, zander and catfish, have been decreasing since the construction of dams Djerdap I and II.

Cultural heritage

Djerdap area is also known, nationally and internationally, for its exceptional cultural and historical monuments dating from the Mesolithic period to modern times. Certainly, the most significant and valuable representative of the cultural heritage is the archeological site Lepenski Vir, named after the great whirlpool in the Danube middle course (Srejović 1972). It contains settlements from different periods: the Early Mesolithic (Proto Lepenski Vir, 9500-7500 BC); Late Mesolithic (Lepenski Vir Ia-e and Lepenski Vir II, 6300-5900 BC) and Early Neolithic period (Lepenski Vir IIIa-b, 5900-5500 BC). As the archeological site was discovered in the zone which was planned to be submerged by reservoir water of the hydroelectric plant Djerdap, the remains of the houses and shrines were moved together with associated artifacts to a new location, above and away from the original one.

The prehistoric site Rudna Glava, located nearby the town of Majdanpek, offers well-preserved evidence of early copper mine works that provided an important insight into the prehistoric mining activities in Europe (Filipović 2015). Mine shafts were carved into the hillside, with scaffolding constructed for easy access to the ore veins. Radiocarbon dating indicates that the mine was in use throughout the late 6th and first half of the 5th millennium BC – during the regional Late Neolithic period and spanning the entire duration of the Vinča culture.

The area along the Danube had been an important trade route and connection between the Western and Eastern territories of the Roman Empire; among the oldest material evidences are the Trajan's Plaque (*Tabula Traiana*), the remains of Trajan's Bridge, and Diana Fortress near Kladovo.

Djerdap area is also recognizable among the tourists by the remains of recently reconstructed Golubac Fortress, a medieval fortification which 'welcomes' the visitors at the very entrance to the gorge, and Fetislam, the Turkish fortification at the exit.

Human resources

Geopark comprises the territory of four municipalities (Golubac, Majdanpek, Kladovo and Negotin), which belong to the administrative districts of Bor and Braničevo, respectively. As the entire region of eastern Serbia, the geopark area is also characterised by an unfavorable demographic trend and population density − fewer than 30 inhabitants per square kilometer, and by critically high average age of the population (44.6 years) (Maran Stevanović 2017).

The largest hydropower dam and reservoir system along the entire Danube River Basin - the Djerdap Hydropower Plant System is located at the Djerdap Gorge. It consists of two dams (Djerdap or Iron Gate Dam I and II), which main activities are the electricity production and provision of services to river and lake transport, particularly the navigation of boats through the dam canal system. The Djerdap I hydropower plant was built between 1964 and 1972, 943 kilometers from the confluence of the Danube into the Black Sea (source: ICPDR 2016). The Djerdap II is the second largest hydropower plant on the Danube River between Serbia and Romania, constructed in the period 1977−2000.

As indicated by Macura and others (2013), flooding the area had many negative social effects: the majority of arable land was submerged; villagers were removed to less fertile land and changed their way of life; settlements lost their municipal status; administration centres were relocated to neighboring cities. The growth rate has been declining since the early 1980s, which is reflected consequently in the rapid aging of the population, the abandonment of rural settlements, and deficiency in the agricultural labor force. Poor economic situation in the entire country in the past two decades contributed to intensive migration of local residents to urban centres and abroad, particularly the younger population.

To achieve socio-economic recovery and develop the population, it is necessary to stimulate and activate the existing tourist and economic potentials: improve and supplement the tourist offer with new content and activities, invest in and develop agricultural production, revitalize old crafts, and better place for traditional products. This would provide conditions for work and employment of the local communities, especially the younger generation, and prevent further downward population trend (Maran Stevanović, 2017).

Recent activities on the establisment of Djerdap geopark

During 2016, members of the Working Team for the establishment of Djerdap Geopark accomplished detailed research to appraise situation in the field, identify risk factors and the level of vulnerability of geological and cultural-historical sites, in order to timely undertake necessary measures and actions to improve the preservation of these objects. Arranging the sites and their surroundings carried out during the early 2017 and the first 20 selected geosites, including both internationally and nationally significant, were prepared for tourists[1].

The nomination process of Djerdap Geopark also took place in stages. In line with clearly defined Operational Guidelines for the UNESCO GGN, as a mandatory first step, members of the Working Team submitted the letter of intent through the official channel - the National Commission for relation with UNESCO. The preparation of comprehensive application dossier started at the beginning of 2016, and included the fulfill of five main sections: A) Identification of the area, B) Geological heritage, C) Geoconservation, D) Economic activity & business plans and E) Interest and arguments for becoming a UNESCO Global Geopark. Application file also entailed the following required annexes: 1) self-evaluation document, 2) repeated section of the geological heritage, 3) an endorsement of relevant local and regional authorities and a letter of support from the National Commission for UNESCO, 4) a large scale map of the proposed UNESCO Global Geopark showing clearly defined boundary of the proposed geopark with all marked towns and villages, sites of valuable natural and cultural heritage and tourism facilities and 5) geological and geographic summary with a detailed map and standard UN geographical maps with the geopark location. The final point in nomination procedure was submission of the formal request for membership. With minor revisions, the dossier was accepted in early 2017, and, in the middle of the year, experts from UNESCO GGN were appointed for evaluation in the field. The field evaluation mission was carried out at the beginning of August 2017, with positive appraisal. However, the evaluation process for the Djerdap area has not been completed yet due to decision of the UNESCO Global Geoparks Council to defer this candidature for a maximum of two years to allow for improvements to be made to the quality of the application.

The Djerdap aspiring geopark has the opportunity to become a unique natural laboratory – an open-air museum in which geological, ecological and civilization history of this part of southeast Europe will be presented and interpreted to visitors in an exciting and engaging way. Real sustainable development of the region can be obtained through

[1] Site-preparation included: vegetation removal, cleaning of crumbled fragments, preparing and setting up information panels and making the pathways (access roads, parking and sanitary facilities).

various tourism activities, since the concept of the Djerdap Geopark offers visitors a wide range of possibilities: to see, walk, touch, perceive and enjoy one of the geologically, historically and culturally richest regions in Serbia.

Tourism presents a major challenge to the Djerdap area, but it is also an opportunity for local and regional development. Particular attention should be paid to long-term planning of educational programmes to protect nature and the environment at the local level, in order to enhance the knowledge and raise awareness of the local population and representatives of the local governments about the natural resources and opportunities for economic development and prosperity that can come from sustainable use of natural resources.

The main advantages of Djerdap are: unpolluted environment; diversity of natural resources, geological in particular; attractive landscapes; rich flora and fauna; numerous cultural and historical attractions; and kindness and hospitality of local residents. The significance of admission of this area in the UNESCO Global Geoparks would be manifold: it would raise awareness of the local population about nature protection and strengthen their identity, provide an opportunity to exchange ideas, strategies and experiences concerning the protection and conservation of nature and natural resources with other geoparks, while the Geopark would acquire the trademark that would make it known throughout the world.

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DAMS – GEOLOGICAL RISKS AND ENVIRONMENTAL IMPACTS

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Abstract. The main targets of dam constructions are positive impacts focused to the water regime improvement and consequently to regional prosperity. Generally, the role of dams and reservoirs is regional socio-economic development by irrigation, flood control, power production, water supply, recreation purposes, reduction of deforestation, reduction of drought periods, for fishing farms, mining purposes, navigation, to ennoble landscape including development of new infrastructure, to provide new possibility for employment and many other secondary benefits.

However, as a consequence of dam and reservoirs constructions the number of different negative (sometimes unpredictable) environmental impacts and uncertainties can't be avoided. Some of impacts can be disastrous, with large scale mortality and a great financial liability, particularly when dams and reservoirs are situated at geologically inadequate rock mass. The common negative impacts are also: the population migrates from inundated areas; the reservoirs cover arable land, settlements and infrastructure; deep reservoirs provoke induced seismicity and induced collapses; water fluctuation provoke landslides along the reservoir banks; in some cases important cultural and historical monuments are inundated; questionable impact on biodiversities, survival of the wild life and endemic species is endangered; tailings contain dangerous chemicals; and regime of surface and underground water is considerably changed. In number cases, socio-economic constrains related to migration from submerged regions and transboundary problems are very pronounced.

Key words: *dams, reservoirs, floods, dam failures, landslides, biodiversity.*

Introduction. From very ancient time dams appears as only effective structures to tame the river waters. Construction of dams started a few thousand years ago. Primary role of dams is to store or to divert waters. The oldest known are Jawa dams in Jordan (~ 3000 BC). In Egypt the Kosheish Dam was constructed in period 3000-2900 BC and Saad El-Kafra Dam about 2610 BC. The Anfantang reservoir in China was built in 6 century BC, and 30 m high gabion dam was constructed around 240 BC in Shanxi province.

In Iran dam constructions dates from before 2000 years (Bahman Dam); Shapour and Mizan dams constructed to time of King Shapur I, before 1700 years; the Tilkan and Sheshtarz Dam, before 1000 years (Figure 1). The Amir Dam north of Shiraz, 1000 years old, still is operational (IRCOLD, 1993). In Spain the Proserpina Dam, 22 m high, was built at 2nd century and still is operational.

Later, at 20th century, except individual dams started construction the large hydro-systems, which consists of number of dams and reservoirs, to change water regime at large catchment areas: Tennessee Valley Authority (29 dams); USA, dams along the

Yangtze River in China; Southeast Anatolia Project (21 dams); the Volga-Kama cascades, Russia (11 dams); and dams at the Karun River catchment in Iran (16 dams). According ICOLD World Register of Large Dams, 1998, the main purpose of large dams is irrigation - 37%, multipurpose use - 22% and electricity generation, -16%. For water supply only are constructed 12%, for flood control 6%, recreation 3%, and other purposes 4% of large dams (tailings dam are excluded).

At USA only, including all dams (not large dams only), the main purpose is recreation - 33.8%), flood control - 15.6, for anti-fire use - 13.7%), irrigation - 9.5%, water supply - 9.4%, for electricity production - 2.9%, and rest for many different purposes.

Fig. 1. Kavar Dam, Iran. Photo P. Milanović.

Flood regulation and impact on population. Historically, thousands of years the primary role of dams was protection of settlements and arable land against flood and for irrigation. Presently, flood control and irrigation are still at top of importance, but usually dams and reservoirs are multifunctional including power production, water supply, sediment control and landscape improvement including recreation.

The Tennessee Valley Authority (Tennessee River, USA), founded in 1933, is one of the largest dam-reservoir projects for flood control, navigation, power production and irrigation (Tennessee Valley Authority Project, 1949, 2005). In natural conditions water regime was unfavourable for agriculture and life. In natural conditions thirty percent of population in the Tennessee Valley was affected by malaria. To construct 29 dams and reservoirs more than 15,000 families was displaced. Except electricity generation the flood control and well-organized entire water regime are great benefit for huge region. More than 1000 kilometer of navigation channels has been constructed as part of this project, also. One of important positive environmental impacts is possibility to control surface water regime with regard to malaria elimination.

In natural conditions the Nile River provoked huge floods every year. At same time the flood water deposited about four million tons of nutrient-rich sediments per year. To prevent floods the first modern dam at Aswan was built in 1889. This dam was not enough high and effective, and a new Aswan High Dam, was constructed in period 1960 – 1970 a few kilometers upstream. Over 60,000 Nubians was relocated from the reservoir area. The Reservoir contains volume of 169 billion cubic meters. About 17% of reservoir is in Sudan. After dam construction the annual floods are under control and the navigation properties of the Nile River are considerably improved. However, artificial fertilizers have to be used instead of natural nutrients. Quality of soil for farming also decreases. Negative impact due to lack of sediments at delta region is one of negative environmental consequences.

According to the historical records floods of the Yangtze River, China occurred 214 times from 185 BC to 1911 AD. Only in past two centuries more than half million people died due to floods. In 1840 about 156,000 persons lost lives during flood period; in 1931, 145,000; and in 1954, about 33,000 persons. In 1981 flood devastate 3.3 million hectares of arable land causing suffering of 28 million people. During more recent flood, 1998 over 1,500 people died (Figure 2).

Fig.2. Three Gorges Dam, China, Photo P. Milanović. In corner, borehole core, photo Junbing Pu.

Millions of hectares of arable land have been demolished and temporarily out of use. Number of villages completely disappears. During flood 1954, 18 million should escape from area. The Wuhan City of 8 million people was 3 months covered with flood water.

By construction of Three Gorges Dam, 2005 (181 m high, 2335 m long) frequency and level of major floods are reduced at minimum and the large ships are able to navigate from Shanghai 2,400 km upstream. Because of project requirements about 1.13 million of people are relocated.

By construction of Akosombo Dam in Ghana to create one of the largest world reservoirs the Lake Volta about 15,000 houses was inundated and resettled 78,000 people. From the Ataturk Reservoir area (Turkey) about 55,000 people were relocated, and from the Manantali Reservoir area (Mali) 15,000 people were displaced. To realize the Ilisu Dam Project (Turkey) at least 55,000 people has been displaced. For project of the Everkiiskaya Dam (Central Sibiria, Russia) about 7000 local people is necessary to be relocated and huge area flooded (9000 km^2).

For construction the Moses – Sanders Power Dam at St. Lawrence River between Canada and U.S.A 6500 people of Eastern Ontario were dislocated.

Dam failures. One of the worst possibilities related to negative environmental impact of dams is failure risk. The first known dam failure, as reported by Herodotus, was collapse of the Saad Ei-Kafra Dam in Egypt during first flood, ~ 2500 BC. In modern history the oldest reported failure was Blackbrook I Dam (Great Britain, 1799). Official worldwide database and case histories of dam incidents and failures are not still completed. According to the ICOLD Bulletin 99, Dam Failures, Statistical Analysis (without China), a total of 5,268 dams were built until 1950 (117 of them failed), 12,138 dams were built during the years 1951-1986, (59 of them failed).

The world's recorded dam disaster occurred 1975 in China (Banqiao Dam,). Because of strong hurricane and precipitation of 500 mm at three days the Banqiao Dam together with Shimantan Dam and 62 small dams were totally demolished. The water wave high 6 – 10 m and 12 km wide flooded more than million hectares. More than 26,000 people has been killed by water wave and a few times more died from epidemics, estimated more than 150,000 totally. Eleven million people lost homes.

Number of failures occurred due to dams are situated at geologically inadequate foundation or foundation was not properly treated. Failures are sometimes catastrophic provoking number of lost lives or evacuation of thousands of people living downstream of the dams: Malpasset (France, 1956) 325 person lost lives; St. Francis (US, 1928) 450 killed (Figure 3); Baldwin Hills (US, 1963) enormous damage downstream; Teton (US, 1976) 14 killed.

Dam failures and subsequent floods are reported in the case of dams situated in karstified rocks, particularly in evaporates. For instance, the failure of San Juan reservoir (Spain) occurred during test filling (2001). The flood wave of 3000,000 m^3 transported about 3,350 tons of solid material (Gutierrez at all. 2003).

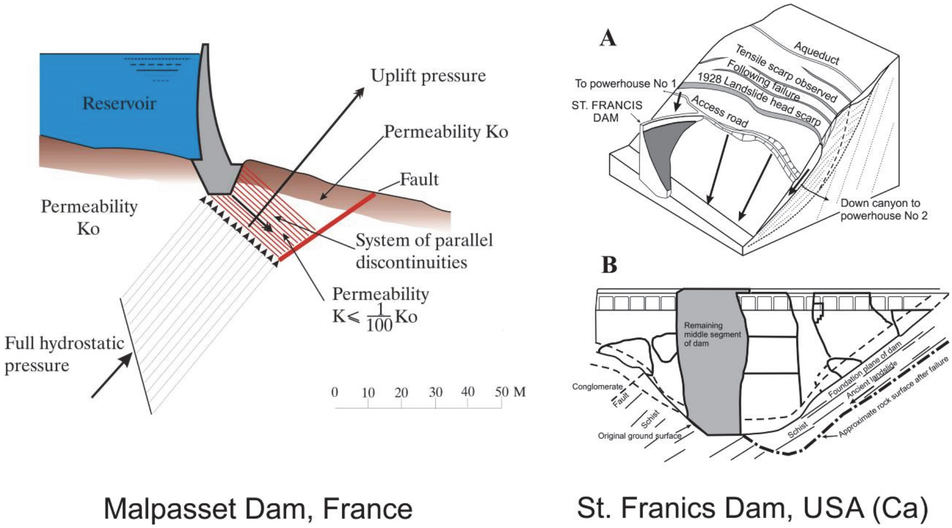

Fig. 3. Failures of Malpasset Dam and St. Francis Dam (A) 3D presentation and (B) cross section after collapse (Rogers, J.D., and Hasselmann, K.F. 2013).

Stability of the foundations of the Mosul Dam in Iraq has recently become of major concern to the world. In the case of failure about 1 million of people will lost lives and 7200 km^2 of land will be flooded.

Thousands of inhabitants close downstream from the dams all over the world are permanently under psychological and mental pressure due to possible dam failure. Some of them seek for relocation of his houses to safest places. In the case of the Mulholland Dam (65 m high concrete gravity dam) disaster of St. Francis dam was reason for enormous protest of citizens of Hollywood, leaving downstream from the dam. To solve that, mostly psychological problem, the downstream dam face was covered, 1933, by huge earth mass (earth-filled toy).

Reservoir slope instability and induced collapses. Reservoir slopes are exposed to different kind of hazards. The most common is potential for landslides to cause a wave which might overtop the dam crest causing dam failure and disastrous flood wave downstream from the dam. According Schuster 2006, at least 254 large dams worldwide have been subjected to landslide activity. The most common types of hazard are instability of slopes and deterioration of reservoir water quality due to solution process if slope consists of evaporates.

In the case of Vaiont Dam (261 m high dam in Italy), a huge landslide suddenly slides into the reservoir. On the October 9, 1963, for 45 sec only, a volume of about 300 million cubic meters plunged into the reservoir. The landslide length was 1.850 km and average thickness 157 m. Maximal thickness of the slide rock mass was 330 m. It created water wave which overtopping the dam crest more than 100 m high. Catastrophic water way completely demolished small town Longarone, two km downstream, and six more settlements. About 1700 inhabitants lost lives and number of industrial structures has been completely destructed (Selli at al. 1964). The dam structure itself was not damaged at all (Figure 4).

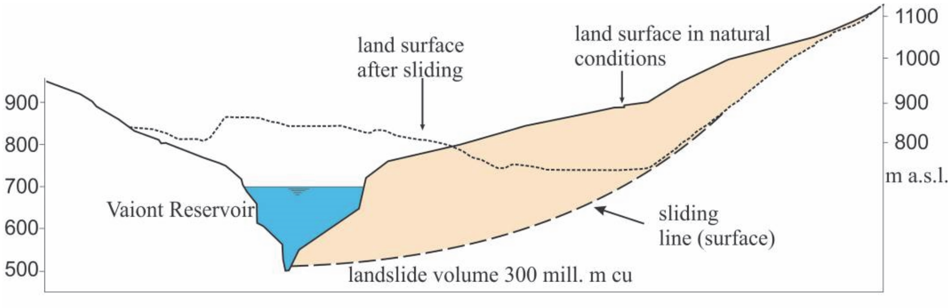

Fig. 4. Catastrophic landslide in Vaiont Reservoir - cross-section (Selli at al. 1984).

At number of cases a massive stabilization structures are constructed to eliminate hazard during reservoir operation. Induced slope stability is extreme problem along the 650 km of the Three Gorges Reservoir. Among the number of potential landslides 33 are declared as serious. For example, the Lianziya potentially sliding rock mass, located about 25 km from the upper stream of the Sadoung dam site of the Three Gorges (China), have volume of 2.26 million m^3. A deep pre-stress bolting, up to 3000 kN, are used to improve slope stability (Lu, 2001).

Collapses induced by dam construction and reservoir operation are spatially independent random events because are unpredictable and practically instantaneous (Figure 5). Particularly are frequent and harmful when dams and reservoirs are situated in karstified rock mass.

Mostly these events occurred immediately after reservoir impounding however (Hutovo, Herzegovina, Lar, Iran), however in some cases has occurred after 17 years of reservoir operation (Hammam Grouz, Algeria), up to 25 years (Mavrovo, North Macedonia).

Tailings dam failures. Tailings dams are more vulnerable than other dam types. In the case of failure environmental impact is catastrophic and long lasting. Because tailings usually contain high concentration of different chemicals, they represent potential threat of environmental contaminant. At some cases tailings are contaminated by extremely dangerous chemicals as heavy metals or cyanides.

The “Chronology of major tailings dam failure, between 1960 – 2011” registers 221 tailings dam incidents. Tailings dam failures occurred due to many different reasons but mostly after heavy rainfall due to overtopping, seepage, foundation failure, or due to dam wall failure or liquefaction during earthquake. According Rico at al. 2008, a corps of 147 cases of worldwide tailings failures, 39% happened at US, 12% Chile, 10% UK, and 4.8% occurred in the Philippines.

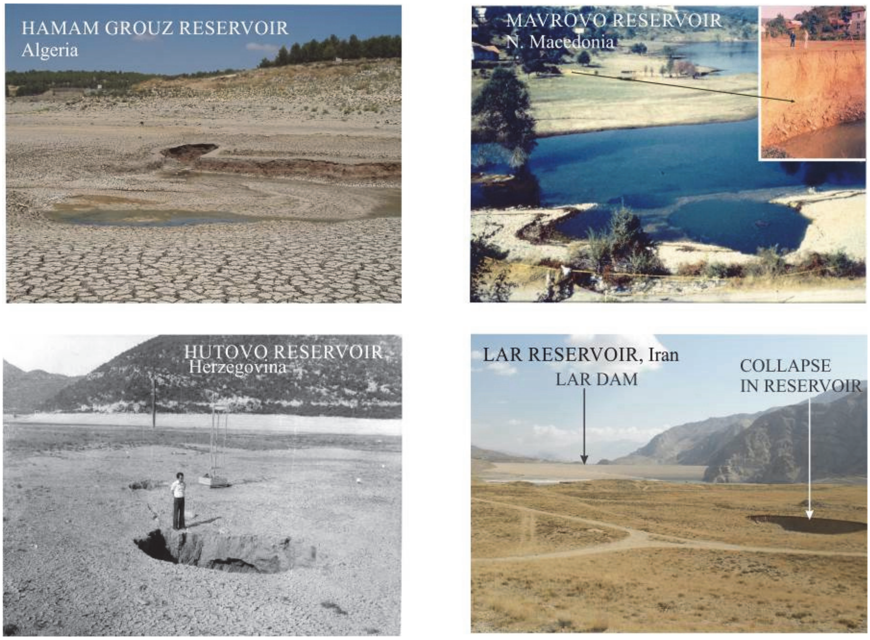

Fig 5. Collapses occurred during first filling or as consequence of reservoir operation. Photos, P. Milanović

The worst impacts of tailings dam failure are great number of killed people. From 1960 till 2010 at 23 cases of tailings failures killing people were reported. Drastic examples are: failure of the Sgorigrad, 1966 (Bulgaria), 488 people lost lives; the Stava, 1985 (Trento, Italy), 268 killed; Taoshi, 2008 (Shanxi province, China), 254 are killed; El Cordobe Dam, 1965 (Chile), 200 killed; Aberfan, 1966 (Wels, UK), 144 death persons; Buffalo Creek, 1972 (W. Virginia, USA), 125 people lost life; Mufulira 1970 (Zambia) 89 killed persons. The most recent are Mariana dam failure also known as the Benito Rodrigues dam disaster, 2015 (Brazil), 19 killed persons and Brumadinho Dam disaster, 2019 (Brazil) with 150 death and 182 missing. Common impacts after tailings failure are also: demolishing of houses; relocation of people; inundation of agricultural land; groundwater pollution and catastrophic consequences for biodiversity in downstream area, particularly for fishes.

Dams and heritage protection. During dam construction, in some cases, very important monuments and internationally recognized old civilization heritage sites are threatened to be inundated by reservoirs. Some of them are part of world heritage protected by UNESCO. In many cases reservoirs may flood national parks, caves of archaeological importance or old necropolis, monasteries, graveyards, and ancient bridges.

The most famous are the Abu Simbel temples in Egypt built in the middle of the Nubian Desert (presently reservoir) by king Ramsses II, ruled from 1290 to 1224 B.C (19th dynasty). After construction of the Aswan Dam both monuments (monument of the

Ramsses II and monument of his wife) were sawn into 1036 blocks, thirty tones each, plus 1110 blocks from surrounding rock. Monuments were replaced and reconstructed 90 m above original level (Figure 6).

Fig.6 Abu Simbel, Egypt. Photo P. Milanović.

By construction of dams at the Trebišnjica River (BiH) two ancient monasteries (built at 1232 and at first part of 14th century) and one bridge, constructed at the first part of 16th century, a nationally recognized cultural heritage have been dislocated out from the reservoir areas.

Construction of the Lower Gordon dam in southwest Tasmania would have flooded a large karst area containing caves of great archeological importance. The project was abandoned for legal and environmental reasons in 1983, (Kiernian, 1988).

During construction of the Iron Gate Dam at the Danube River number of historical monuments, including ruins of the old bridge over the Danube River, dated from 28 to 104 AD (time of Roman Emperors Tiberius, Claudius and Traianus) has been flooded by the Reservoir. To prevent the monument "Tabula Traiana" the limestone block heavy 250 tons was sawn and lifted 20 m to be above the reservoir level. The old prehistoric settlement (Lepenski Vir) dated between 5 and 6 millennia BC which represents one of the oldest cultures in this part of Europe was relocated above the Danube Reservoir level.

Along the Three Gorges Reservoir (Yangtze River) about 1,300 archeologic sites including 30 Stone Age localities are carefully investigated and about 1,200 of them replaced at the higher places. However, some irreplaceable historical artefacts are permanently inundated. The old Greek and Roman City Zeugma, larger than Pompei, founded 300 BC, on Euphrates River, was inundated after construction the Birecik Dam, 1999 (Southeast Anadolian Project, Turkey). Zeugma mosaics are declared as one of the best-preserved Roman Mosaic collection in the world. Ancient city is submerged but famous mosaics are replace in the museum of Gazi Antep.

The Ilisu Dam (Southeast Anadolian Project, Turkey) upper Tigris River, 65 km from Syrian border, inundated the Hasankeyf an internationally recognised Roman, Byzantine and Otoman hystorical and cultural heritage site. Hystorical monuments include thousands of caves carved more than 2000 years ago are submerged. About 50 villages and 15 small towns along the Tigris valley would be displaced (Smith, 2000).

Dam project Coa Valley in Portugal was cancelled because of the important Ice age rock art, outside of caves.

Dams and ecosystem. After dam construction is not simple to keep ecosystem parameters upstream and downstream from dam at same level as it was in natural conditions. Most frequently two crucial parameters, temperature and flow regime are disturbed, particularly if purpose of dam is power production. In that case the reservoir water body is not thermally and hydraulically homogenous. Magnitude and frequency of reservoir fluctuations are rapid and huge. Thermal stratification is quite pronounced. Consequences of water quality disturbance upstream from dam are transferred to downstream flow. Enormous daily flow fluctuation and velocity due to hydroelectric power plant operation could have negative effect on flora, fauna and physical properties of river bed. To prevent or to minimize downstream negative environmental impact the guaranty ecological flow is essential requirement (Đorđević & Dašić, 2005).

One of the most serious environmental consequences of dam construction is obstruction to fish migration. Dams are barriers for migratory fishes: salmon, trout, sturgeon, alewife, skate, eel and many others. Multiple dams along the river considerably worsened situation for migratory fishes, but in the case of dams in the Glomma River system (Norway) at the eight dams are constructed efficient fish ways along the 122 km of river (Linlokken, 1993).

Karst underground is very rich with various fauna. Often, as a result of dam construction in karst, a large volume of caverns in the aeration zone is flooded or on other case the temporary flooded karst channels become permanent dry. At both cases the cave habitat for a number of rare and endemic species is endangered: Normandy Dam (Tennessee, USA), Melond Dam (California, USA), Scrivener Dam (Australia), Grančarevo and Gorica Dams (BiH), Seymareh Dam (Iran). Project of the underground Ombla Dam (Croatia) is temporary frozen due to environmental reasons.

Other impacts. Dams and reservoirs in general have a considerable impact on regime and quality of water. In karst environment impact can occurred at remote springs provoking local and transboundary environmental and political problems. Triggered (induced) seismicity has been documented at more than 60 cases during reservoir filling. However, except a few cases only (Koyna and Hsingfengieag) the human and material losses were negligible. As consequence of damming the estimated reservoir surface is more than 4000.000 km^2. Due to very hot weather or due to strong wind evaporation from reservoirs surfaces can be about 2 m^3/m^2 per year. Some impact on local area exist, however long-time monitoring and observations does not exists, except subjective impression of local people. For instance, impact of the Krasnojarsk Dam (Russia) at the Yenisei River stretch 200 km downstream have influence on local climate by provoking freezing fog. Submergence of large springs by reservoirs and its consequence on water quality and reservoir integrity is frequently subject of discussions and analysis.

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GEOLOGY AND HYDROGEOLOGY OF CARPATHIAN-BALKANIDES OF SERBIA – AN OVERVIEW

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Introduction

Carpathian-Balkanides in eastern part of Serbia characterised by moderate continental climate and hilly-mountainous relief intersected by numerous basins and river valleys, with abundant, but still unproperly utilized groundwater reserves. The northern boundary is the Danube River, the eastern/northeastern boundary is the state border with Bulgaria (toward which the Carpathian-Balkan mountain range continues), and its western border runs along the edges of the Velika Morava and Južna Morava valleys (Fig.1).

The mountains of the Carpathian–Balkan arch are mostly unpopulated and used by the local villagers for specific crop cultivation or grassland during the summer months. Most of the hills are covered by forests or pastures. The area is a prospect for the development of tourism, it is accessible by many roads, rich in clean waters, and boasts beautiful landscapes and features such as caves, waterfalls and springs, including several spa and medical centers. Annual average rainfall ranges from 600 mm to 750 mm, while the annual average air temperature for the entire region is around + 9ºC.

The main settlements are (from north to south): Donji Milanovac, Kladovo, Negotin, Majdanpek, Bor, Zaječar, Sokobanja, Knjaževac, Pirot (all with between 10000-60000 citizens). The demographic trend in the region is negative: the rural population is gravitating towards local industrial centers mainly Bor and Zaječar.

Geological setting

Carpathian-Balkanides represent geologically heterogeneous and morphologically very dissected belt of orogenic systems belonging to the northern branch of Alpides stretching in the Central and Southeast Europe along more than 2.000 km (Grubić, 1991). In geographical maps to larger scales, Carpathian-Balkanides are distinguished as a unique morphological unit, while the problem of the boundary and connection between the South Carpathians and Balkanides has been the subject of numerous controversies for almost a century (Cvijić, 1900). Until Mid of 20 Ct. significant geological investigations have been done by Radovanović, Žujović, Kossmat, Kober, V. Petković, Luković.

The belt of Carpathian-Balkanides is comprised of West Carpathians, East Carpathians (Transylvanian Alps) and Balkanides. Grubić (1994) distinguishes: external and internal Exomolassides, lower and upper Externides, external and internal Centralides and external and internal Internides. Even in this belt there are a number of geological and morphological problems at the boundaries of the mentioned units. To this belt also belong the mountains of central Hungary, Apuseni mountains in Romania, Strandža in Bulgaria.

One of the main properties of Carpathian-Balkanides is their heterogeneity which is reflected in a marked inconsistency of their units. Carbonate rocks are represented in all geologic units of Carpathian-Balkanides. They are found in ancient crystalline terrains in the form of redeposited rocks, and lenticular younger carbonates. They are, however, mostly found in a major part of internal Centralides and internal Internides in which the Mesozoic limestones and dolomites build up thick columnar sections formed in carbonate platforms of that time. In these regions in Slovakia, Romania, Hungary, Serbia and Bulgaria, almost all forms of karst occurrences except for large karst poljes are developed. The study area in Serbia consists of several mountain massifs, the majority of which are built from carbonate rocks (Fig. 1).

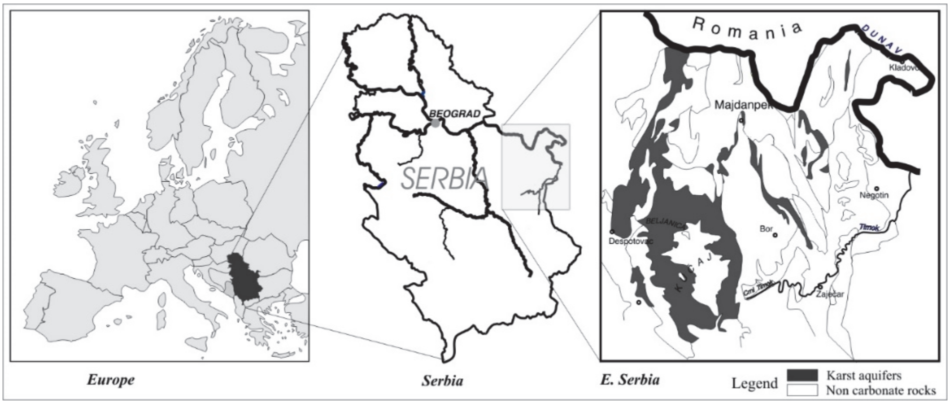

Fig. 1 Location map of northern part of Carpathian – Balkanides in Eastern Serbia and karst aquifers distribution

In Eastern Serbian Carpathian-Balkanides there occur geological formations starting from the oldest ones, the Precambrian to the youngest ones, the Quaternary. The Precambrian is represented mostly by metamorphites of a higher degree of crystallinity. The Paleozoic appears as completely developed but widely exposed to the surface. During the Triassic and Lower Jurassic, mostly terrigenous and carbonate facies were formed. The major part of the study area was invaded by the Middle Jurassic marine transgression, and the sedimentation cycle continued until the end of the Lower Cretaceous (Albian). Throughout this period, thick deposits, primarily of carbonate rocks, were formed to a total thickness of about 1300 meters. Carbonate rocks are characterized by the non-uniformity of the facies with prevalent limestone but also by "impure" varieties in lower sections, such as sandy limestones of the Doggerian, or Oxfordian-Kimeridgian chert limestones. The carbonate complex was formed mostly during the Tithonian, Valanginian, Hauterivian, Barremian and Aptian and it predominantly contains pure carbonates or magnesium carbonates.

In the Timok tectonic trough on the eastern part of Carpathian arch, a volcanogenic-sedimentary series over 2000 meters thick (andesites, pyroclastics, tuffa) was formed during the Senonian and the Paleogene.

Clastic sediments, marls, clays, and sands were deposited in a number of the intermountain depressions filled with lake waters during the Neogene (e.g. Žagubica, Bogovina, Sokobanja, Babušnica, Pirot). The sandy water-bearing layers could have an artesian pressure (confined aquifers) and are tapped in several locations (e.g. Negotin, Zaječar). Most recent are alluvial sediments which follow major streams in the region (Nišava, Timok, Resava etc.).

Intensive tectonic movements with faulting and accompanying magmatic activity were repeated in a number of phases; the neotectonic and seismic activities have continued until the present. Epirogenic uplifts during the Alpine orogeny are related to a deeper magmatic activity, which was reflected on the surface of the terrain in the form of ring structures.

Major part of carbonate massifs is represented by separate anticlines with a core composed of older rocks (Kučajsko-Beljanički massif, Svrljiške planine, Suva planina, etc.).

The Senonian tectonic graben stretches NNW-SSE at over 50 km. The graben is lowered between regional faults - Zlotska and Pečko-Svrljiška. Along the flank of the fault there are the Mesozoic limestones, often with intrusive plutonites with hydrothermally metamorphosed rocks. The thickness of volcanic (andesite) sedimentary formations in central parts is over 3000 m.

The regional fault structures have formed two basic strikes: 1) NW-SE, the older system of longitudinal faults, and 2. E-W (NE-SW), the younger transversal system. Along the reversed regional faults there can be distinguished regional horizontal movements as well (the nappe of red Permian sandstones, the nappe of Vidlič). There have been recorded over 50 discontinuities longer than 10 km, some of which being traced over 150 km in length, with partially covered parts. Porečko-Timočki fault (N-S), one of the most prominent discontinuities also caused the fracturing and movement of the gabbro massif parts of Deli Jovan and Zaglavak, at over 50 km. Apart from the regional, the formation of thermal and thermomineral waters was greatly influenced by the local fault and fracture systems.

Hydrogeological setting

The two main aquifer systems concerning groundwater reserves and potential for potable water supply are karst aquifer in Mesozoic carbonate rocks and alluvial aquifer. In terms of mineral waters and geothermal potential the fissured aquifers in volcanic rocks and artesian Neogene aquifers, although both with smaller extensions than latter two, are of major importance (Fig.2).

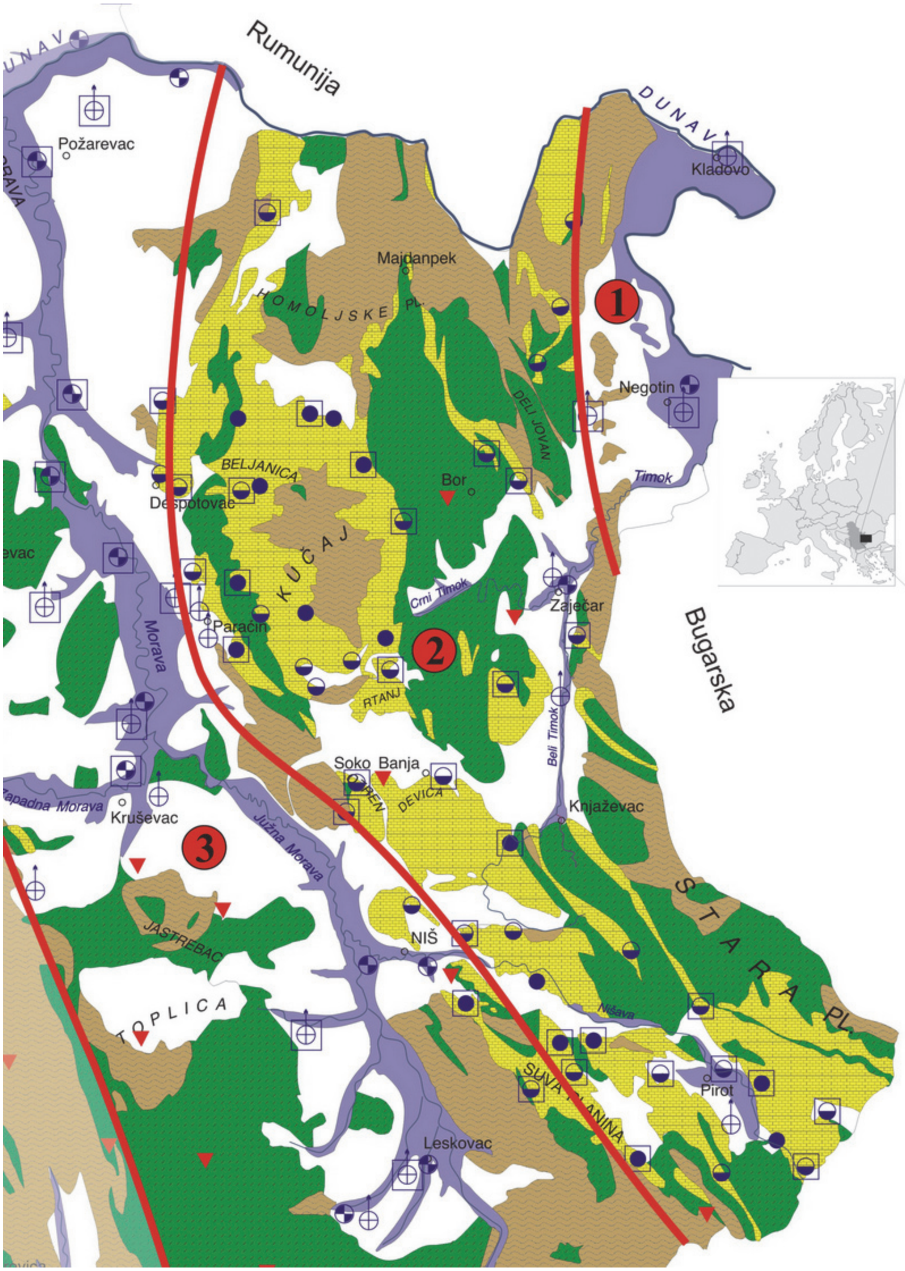

Fig. 2 Hydrogeological sketch map of eastern Serbia and main groundwater sources (based on Hydrogeological digital map of Serbia, Stevanovic & Jemcov 1996, reprinted from Stevanović et al. 2011). Legend: 1. Dacian basin, 2. Carpathian-Balkanides, 3. Serbian-Macedonian massif; Yellow – Karst aquifer, Green – Fissured aquifer, White – Neogene basins' sediments, Blue – Alluvial aquifer; Blue dots – springs and wells, if squared – utilized for potable water supply

Wide distributions of karstic areas, abundant reserves, sparsely populated catchment areas and excellent quality of **karst groundwater** where chlorination is often the sole water treatment, have been the reasons for its extensive use. Estimated dynamic groundwater reserves exceeding 12 m^3/s (Stevanović, 1994, 2009). This region features a large number of karstic springs, 16 of which have a minimum yield of more than 100 l/s (Stevanović, 1994). Majority of cities and industrial centres in the region are consumers of karstic groundwater, in total, more than 30 karstic sources have been tapped for centralized water supply. In this way, contribution of water from Carpathian karstic aquifers contributes to potable water supply of Serbia with almost 10%. However, many large springs such the biggest one – Mlava spring (discharges 0.25-16 m^3/s) is not yet tapped out and represent a big national potential as alternative source in case that negative impact of climate changes further diminish water reserves during prolonged periods of drought.

Although the total dynamic reserves often surpass by far the exploitation rates, tapped springs generally characterized by high discharge fluctuations and low summer/autumn spring yield. This is a problem for the most of waterworks, because most of the tapping structures are constructed simply to tap the natural discharge of the springs and thus depend solely on the natural flow regime.

Aiming to overcome this problem, during the last three decades several successful aquifer control projects have been completed in karst of eastern Serbia (Stevanović *et al*., 2007). Counting on water replenishment during the following wet season, these projects include over-pumping and groundwater extraction during a limited time period. The most common methods of regulation applied in the region are the drilling of large-diameter wells, and, in the case of ascending vauclusian springs, the installation of pumps and pumping from siphon channels.

The largest regulation system is constructed for the mining and industrial centre of Bor. After extensive and complex hydrogeological researches in 1990s, four exploitation wells were drilled in vicinity of natural Mrljiš spring (Stevanović, 2010). Several performed pumping tests verified their summary yield to be in range of 240-320 l/s, producing the depression in the Mrljiš spring zone of less than 2 m (Fig. 3). As such, optimal extraction rate of the source, as compared to the minimal springflow, has increased almost four-fold. System is operational since 2002, including the monitoring system on nearby Crni Timok River in order to ensure ecological natural flow for dependent eco systems downstream.

“Modro oko” in Krupac village is one of the five karstic springs (0.04-11 m^3/s) tapped for the water supply of Niš. Undertaken aqua-speleological exploration of deep siphonal channels enabled to install the high capacity pumps and then after to drill two new wells. As result, when required amount of tapped water could six times enlarge minimal natural springflow (Dimkić *et al*., 2003).

A few similar smaller systems are also operational for cities Ćuprija and Knjaževac, while some others are under evaluation and feasibility.

Karst ground waters are regularly low mineralised, odourless and tasteless. Occasional in periods of heavy rain, short-lasting (rarely longer than 2-3 days) turbidities of gravity springs' waters make one of the major problems in regard of their usage.

Fig. 3 Pump house over the well located next to natural Mrljiš spring

Alluvial aquifer is mostly utilized for smaller settlements distributed along the valleys of Pek, Mlava, Crni and Beli Timok, Timok, Nišava and other rivers. The largest source is artificial recharge system located in alluvium of Nišava, which supplying city of Niš, along with several tapped karst springs. Although water-bearing sediments are not very thick (up to 10 m) Mediana source system (Dimkić *et al*. 2007) by 16 recharge ponds (Fig. 4) supporting water supply reliability and resolving groundwater quality problems of Niš (max. capacity 600 l/s, as an average 50% of that is actually utilized).

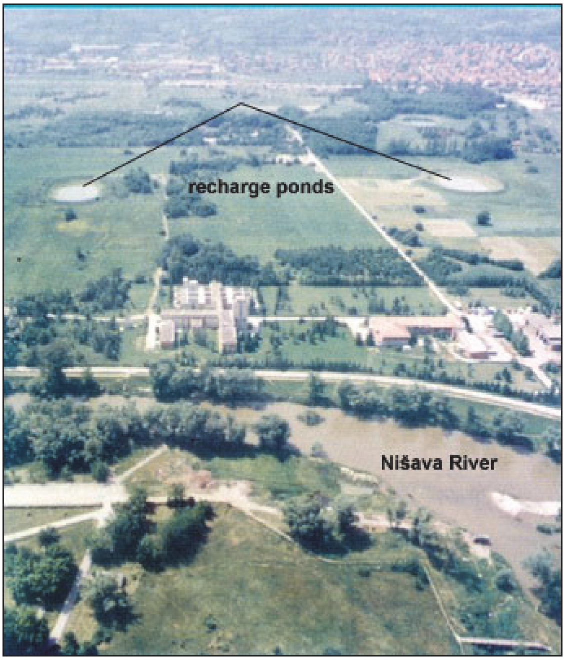

Fig. 4 Aerial view on Mediana source - Niš

Clastic sediments, marls, clays, and sands were deposited in a number of intermountain depressions filled with lake waters during the **Neogene** (e.g. Žagubica, Bogovina, Sokobanja, Babušnica, Pirot). The sandy water-bearing layers could have an artesian pressure (confined aquifers) and are tapped in several locations (e.g. Negotin, Zaječar).

Fissure aquifer in andesite rocks is the best reservoir of thermal and mineral waters in Serbian Carpathians (Dragišić, 1981). Fissure aquifer of volcanogenic-sedimentary complex of Timok tectonic zone (Fig.2) contains several important thermal and thermomineral occurrences with the water temperature ranging from 30-40ºC (Brestovačka spa, Gamzigradska spa, Sokobanja, Nikoličevo, Šarbanovac).

Volcanic activity and creation of thick deposits of volcanic-clastic material occurred during the Senonian. Thermal and mineral water occurrences are connected with large fault strike NNW-SSE together with a younger fault strike NE-SW. During the Laramidian orogeny, both of these fault systems activated and served as paths for uplift of the granodiorite group of plutonites. In the final phase of magmatic activity in the andesite massif, along the said faults, there occurred circulation of hydrothermal solutions which caused the alteration of the surrounding rocks.

According to the chemical composition, thermal-mineral waters related exclusively to volcanic rocks primarily belong to the sulphate class. As such, the typical chemical composition of Brestovačka spa waters is as follows (Dragišić & Stevanović, 1994):

$$M_{0.39\text{-}0.53}\frac{SO^{4}_{61\text{-}74}HCO^{3}_{15\text{-}30}Cl_{9\text{-}11}}{Ca_{49\text{-}68}Na{+}K_{18\text{-}47}Mg_{0\text{-}9}}T_{17\text{-}41}pH_{7.9\text{-}8.7}dH_{10.4\text{-}13.9}$$

Karstic aquifer is also reservoir of thermal waters and more that 20 springs are discharging waters with temperature over 20^0C. Seven of them even more than 25^0C, while natural yield can be larger of 50 l/s as in case of Krivi Vir thermal spring (Fig. 5), Niška banja, Rgoška banja.

Fig. 5 Large karst thermal spring of Krivi vir discharging between 60-200 l/s

According to the preliminary assessment, some 1.7 m^3/s of groundwater in eastern Serbia can be extracted and sustainably used for heating / cooling systems (Stevanović *et al.* 2011). This potential flow resulted from the calculation which took into consideration prioritized water utilization for drinking and industrial water supply, ecological flow for downstream water dependent eco-systems, and the average water temperature ranging from 10-30°C.

The total potential thermal power which can be generated from subgeothermal waters for large settlements in the region is assumed to be around 33 MWt, which corresponds to some 16 % of their total heat demands (Stevanović *et al.* 2011).

Conclusions

The Carpathian-Balkan region of eastern Serbia is a treasury of clean groundwater, which may represent an important additional or alternative water source for future regional water supply. The main water resources are accumulated in karst and alluvium aquifers.

Nevertheless, the heat of groundwater of fissure, but also karst and Neogene artesian aquifers, could be an important source of geothermal energy, which may very much support an aim to increase contribution of “green”, in totally consumed energy in the country.

Taking in consideration importance of fresh and thermal water their systematic monitoring and preventive protection from pollution should one of the priorities of water sector of Serbia.

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GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERISTICS OF THE ĐERDAP AREA

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INTRODUCTION

The Serbian part of the Iron Gates (Serb. Đerdap) is located in South East Europe and the northeastern part of Serbia, on the very border with Romania. The Đerdap area extends for about 100 km along the right bank of the Danube River, from the town of Golubac to Karataš near Kladovo. It intersects diverse geologic formations, from Precambrian to contemporary (Fig. 1). The area formally became a national park in 1974.

The primary natural phenomenon in this area is the magnificent Đerdap gorge on the Danube River, comprised of four smaller gorges (Golubačka Klisura, Gospođin Vir, Kazan and Sipska Klisura) and three ravines (Ljupkovska, Donjomilanovačka and Oršavska). They abound in geomorphological features, such as canyons, escarpments, sinkholes, ponors, caves and the like).

Prior to the impoundment of the Danube, there were several powerful karst springs along the right bank, whose water drove watermills on several locations. Today, these springs are submerged in the Đerdap Reservoir and are visible only at extremely low river stages. They function as freshwater vruljas.

GEOLOGIC FRAMEWORK

The geologic framework of the Đerdap area is diverse and extremely complex. It is a product of geologic and tectonic processes from the Precambrian to the present day. From Golubac through to Karataš, Precambrian, Paleozoic and Mesozoic formations have been identified along the right bank of the Danube. They include the Golubac nappe, the Gethicum nappe (Gethicum), the Danubicum parachton (Danubicum), the Gethicum outliers, the Krajina nappes (Krainicum), and the Prebalkanic autochton (Prebalkanicum) (Grubić et al., 1997). On several locations, younger Neogene and contemporary Quaternary sediments overlie older geologic formations.

The Precambrian comprises highly-metamorphic crystalline schists – so called Gethic overthrusts, including amphibolites, migmatites & gneisses, gneiss-granites, and serpentinites (Žujović, 1893; Urošević, 1908; Kalenić et al., 1980; Kalenić et al., 1997).

The Paleozoic formations are represented by green schists and metamorphed sandstones of the Cambrian period and Carboniferous sedimentary rocks (conglomerates, sandstones and claystones), with seams of stone coal (Bogdanović, 1977; Kalenić et al., 1997). The

Mid-Carboniferous featured Hercynian granitic intrusions (granodiorites, granite-monzonites and granites) in the zone between Brnjica and Mt. Miroč, accompanied by veins of mostly aplites and pegmatites (Milovanović, 1953; Vasković and Matović, 1997). The youngest Paleozoic rocks in the Đerdap area are Permian red sandstones, conglomerates and claystones. The Permian also includes intrusions of quartz porphyries, riodacites, basalt and volcanogenic sedimentary rocks (Kalenić et al., 1980).

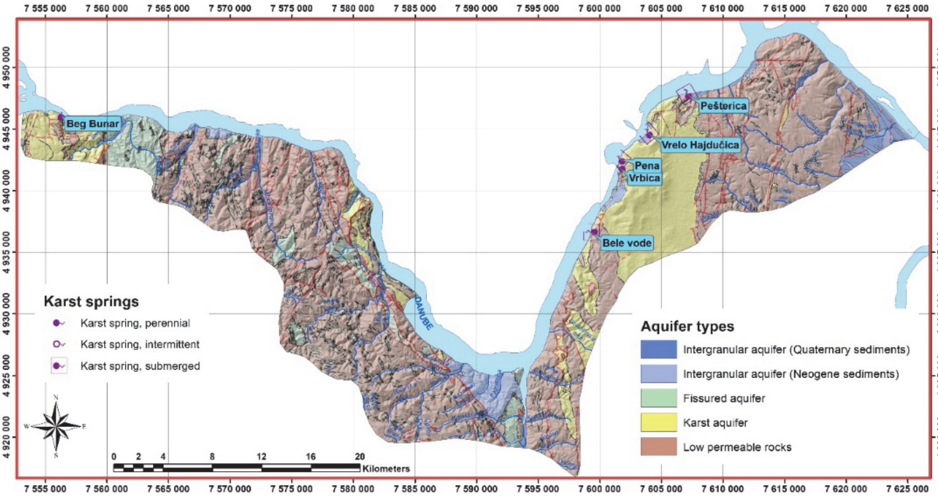

Fig 1. *Geological and hydrogeological schematic*

The Mesozoic comprises Jurassic and Cretaceous sedimentary formations, with considerably different deposits west and east of the Poreč River.

The Jurassic is represented by three divisions: early, middle and late. The Liassic transgresses and discordantly overlies crystalline schists. It is comprised of quartz sandstones, in part conglomeratic and coarse-grained in the basal series, as well as clayey sandstones and coaly claystones. Parts of the lower reaches contain seams of stone coal in the quartz sandstones. The sedimentary rocks of the Mid-Jurassic (Doggerian) discordantly overlie Late Carboniferous schists, Hercynian granites and Cambrian schists. They are built up of sandstones, claystones and sandy limestones. The spread of the Late Jurassic carbonate rocks is much larger, and they are represented by various types of limestones (Milovanović, 1953; Bogdanović, 1977; Vasić et. al., 1997).

The Cretaceous is well developed in the Đerdap area. The Early Cretaceous is represented by Neocomian limestones transitioning into sandy limestones, sandstones and marls (non-carbonate rocks) in the upward direction. Sinaia beds are a special Neocomian development, of a flysch nature, which gradually give way to sedimentary rocks of the Barremian/Aptian. These sedimentary formations are represented by organogenic limestones, marls, claystones and sandstones. Albian/Cenomanian formations transgress the Barremian/Aptian or Late Jurassic in Mt. Miroč. They are represented by conglomerates, sandstones, claystones and sandy limestones. The biostratigraphy of the

Cenomanian, Turonian and Late Senonian in the eastern wing of the Miroč anticline and the Krajina syncline has been documented (Bogdanović, 1977; Bogdanović et al., 1980; Rabrenović, 1997).

The Tertiary. In addition to Paleogene dacite-andesite intrusions in the Golubac Mountains and small masses of Laramian plutons (granodiorites and diorites in Mt. Miroč, where they intrude into Precambrian schists of the Gethic overthrust), the Tertiary also includes Neogene sediments. The spread of these sediments is within isolated Neogene basins created in the Middle Miocene, within the very Đerdap gorge (near Donji Milanovac and Dobra on the Danube). They are built up of conglomerates with multiple interchanges of clayey sands and clays (Stevanović P, 1977).

The Quaternary. The Quaternary comprises alluvial sediments of small right-bank tributaries of the Danube (the Brnjička, the Dobranska and the Porečka) and small masses of debris beneath limestone escarpments in the Đerdap gorge. Recent sediments of the Danube have largely been flooded by the Đerdap Reservoir.

HYDROGEOLOGICAL CHARACTERISTICS

The complex geologic framework and the presence of different types of rocks and sediments in the Đerdap area have resulted in the formation of fractured, karst, Neogene and alluvial aquifers. In addition, there are zones poor in aquifers (Fig 1).

Fractured aquifers. They generally occur in granitic, dacite-andesitic and serpentinites. Their water-bearing capacity is relatively low.

Aquifer in granodiorites. A fractured aquifer poor in groundwater is formed above the local base levels of erosion. It is drained via springs whose capacity is less than 0.01 l/s. Within the Brnjica pluton, in a place called Brnjica on the Danube, there is only one artesian well that is 70 m deep (Q = 0.8 l/s). The chemical composition of the groundwater drained from shallow parts of the granitic rocks has a low mineral content and is of the HCO_3-Ca type, contrary to the subartesian aquifer where the groundwater is of the HCO_3-Na type.

The granitic rocks have hydrogeologically been investigated in any detail only at the dam of the Đerdap hydroelectric power plant on the Danube. Open fractures were detected while underground galleries were being built, from which groundwater flowed at a rate of 1.0 to 2.0 l/s. The water permeability of the granites near the dam is 5-12 lugeon units (Semiz, 1966).

Karst aquifers. They are formed in carbonate rocks, on several isolated locations, from Golubac (at the entrance to the gorge) to near Đerdap 1 HPP at the exit from the gorge (Golubac Mountains, Gospođin Vir gorge, and Mt. Miroč with the Golubinje, Gradašnica and Dževrinska Greda karst). The carbonate rocks are Mesozoic, represented by Doggerian sandy limestones; Oxfordian-Kimmeridgian limestones with chert and dolomite; massive and banked Tithonian limestones; Valendian-Hauterivian banked, sandy and marly limestones; and Urgonian massive and banked limestones of the Barremian-Aptian age. Despite tectonic damage, karstification is not uniform and depends on the type of carbonate rock. As a result, some areas are rather poor and other rich in surface and subsurface karst features.

Karst aquifer in the Golubac Mountains and the Gospođin Vir gorge. The Golubac mountains (especially their northern parts) are not as karstified as the neighboring areas and, consequently, the groundwater reserves are small (Stevanović Z, 1988, 1977). Very few speleological features in this zone, compared to the Miroč karst, support this finding (Mandić, 2015). There are several gravitational emergences of groundwater associated with the karst aquifer in the Golubac Mountains, which J. Petrović (1968) distinguishes as the "karst hinterland of the Upper Gorge". Downstream from a spring in the Golubac City Fort, several springs exist: Ridan, Stari Majdan (Beg Bunar) and Livadice, of which only Beg Bunar is not captured for local drinking water supply (Stevanović, 1988; 1997). The capacity of these springs varies considerably during the year and the minimum is always less than 5 l/s. The Beg Bunar karst spring is located at the apex of an abandoned quarry, at a distance of about 30 m from the Danube. In dry periods, its discharge capacity drops to less than 1.0 l/s, whereas at high groundwater levels of the karst aquifer in the hinterland its capacity exceeds 300 l/s (Fig. 2).

Fig. 2. *Beg Bunar (minimum, average and maximum discharges)*

Apart from the emergences in the Đerdap gorge, a small part of the karst groundwater is drained into the Brnjička River, upstream from the village of Brnjica. There are several small springs, the largest of which, called Jelenska Stena, is captured and delivers Q = 1.5 l/s. Downstream from the Golubac Mountains, in the Gospođin Vir gorge karst, where the spread of the carbonate rocks is smaller and the content of the sandy component larger, there are several karst springs of low capacity (Q < 0.3 l/s). These springs are located at Sokolovac.

*Karst aquifer of central Miroč***.** This aquifer is situated above the Đerdap Reservoir, in the hinterland of Kazan. The surface area of the exposed karstified rocks is 105.11 km^2 and that of non-karst, which gravitates towards the Miroč aquifer, is 41.04 km^2 (Prohaska et al., 2002). The karst comprises dolines and sinkholes, with no surface runoff for the most part. There are many surface and subsurface morphological features. The most distinct are fluvial relief elements, sinkholes, ponors, and dry and blind valleys (Cvijić, 1921; Milić, 1965; Ćalić, 2015).

Surface water which originates in a part of the terrain built up of impermeable non-carbonate rocks, sinks as it enters the limestone mass, along well-defined ponors and underground conduits, and gravitates towards the local base levels of erosion. Water balancing and hydrometric investigations of the Miroč karst revealed a total average subsurface runoff of Q_{av} = 1.396 m^3/s, of which 1.028 m^3/s is attributed to submerged springs and 0.268 m^3/s to the Blederije Spring (Prohaska et al., 2002).

Groundwater drainage in the Đerdap gorge is governed by the base level of the Danube and the positions of impermeable rock masses that underlie limestones. Following impoundment of the Danube at Đerdap, five large and several small karst springs ended up 15–25 m below the reservoir water level. It should be noted that some of the karst springs (Pena and Trajanova Tabla) had been partly drained below the pre-impoundment water level of the Danube.

Beginning with the most upstream spring of Bele Vode, the downstream springs in the Đerdap gorge include Pena, Hajdučka Vodenica (Hajdučica), Trajanova Tabla and Pešterica. Available discharge data are sparse. The discharge of Bele Vode is estimated at Q=10-2000 l/s*;* of Hajdučka Vodenica Q=20-1000 l/s, and Pešterica Q =20-1500 l/s (Petrović, 1968; Stevanović, 1996; 1997). According to C. Vasov (1974), prior to impoundment of the Danube at Đerdap, Trajanova Tabla Spring emerged from a vertical fracture at a rate of approximately 3.5 l/s, while part of the groundwater was drained below the water level of the Danube.

The Blederija Spring is in fact a cluster of springs comprised of two "cold" springs and one "subthermal" (T = 17.5 ºC) spring of the ascending type. Based on multiyear monitoring, its discharges are: Q_{min} = 17.0 l/s, Q_{max} = 2660.0 l/s, and Q_{av} = 210.0 l/s (Živanović et al., 2016).

The submerged springs can be observed only at low stages of the Đerdap Reservoir (Fig 3).

In the southwestern slopes of Mt. Miroč, there are small aquifers in the catchments of the Gradašnica and Golubinjska rivers. Streams that flow from the non-carbonate bedrock sink and emerge via cave-type springs (springs of the Gradašnica and the Golubinjska). Their minimum yield is less than 1 l/s.

Fig. 3 *Hajdučka Vodenica Spring*

East of central Miroč, there is a karst aquifer called Dževrinske Grede, formed in a narrow belt of Tithonian limestones. The rift extends to the south for about 18 km and its width varies from several meters to a maximum of 700 m. The limestones are squeezed between Proterozoic-Paleozoic schists to the west and Early Cretaceous marly sandstones to the east. They are extensively fractured and karstified, with a large number of karst features (Ćalić, 2008). The karst aquifer called Krečnjačke Grede gravitates towards the Đerdap gorge and is drained via several small springs, the largest of which is located in Matovića Krš and its discharge is 3.0 l/s (Ćalić, 2008)

Neogene aquifers. In the vicinity of the Đerdap gorge, the spread of these aquifers is small (areas surrounding Donji Milanovac and Dobra). They are formed in relatively thin strata and lenses of sands, sandstones and conglomerates. The groundwater level is subartesian and the capacity of a 100-120 m deep wells is relatively low (1.5 to 3.0 l/s). The spread of the aquifers is much greater to the west (Braničevo Neogene Basin) and east of the Đerdap gorge (Dacian Basin).

Alluvial aquifers. These aquifers are found in recent alluvial deposits of the Danube's right tributaries in the Đerdap gorge (the Porečka, the Dobranska and the Brnjička rivers). The sediments are of a dual-layer formation, with clayey-sandy deposits on top and coarse-grained sand and gravel below. The water tables of the alluvial aquifers closer to the Danube are under the influence of the Đerdap 1 HPP reservoir and necessitate protection of the riparian lands (at Donji Milanovac, Dobra, and Golubac) from groundwater. Despite good hydraulic conductivity of the aquifers, the groundwater is underutilized because of considerable pollution from municipal activities (Brnjica and Donji Milanovac) and mining operations (villages along the lower course of the Porečka River) (Dragišić et al., 1997). Far more significant alluvial aquifers are found east of the Đerdap gorge, especially in the first Danube terrace (Komatina and Dragišić, 1997).

Terrains poor in aquifers. A considerable part of the Đerdap area is occupied by terrains built up of rocks with low hydraulic conductivity which classifies them as terrains poor in aquifers. These are primarily the Precambrian highly-metamorphic crystalline rocks (gneisses, gneiss-granites and amphibolites), Paleozoic sandstones and green schists and Early/Middle Jurassic and Early/Late Cretaceous sandstones and clayey-and-marly rocks. These rocks are often extensively fractured, but the fractures are filled with clayey products from the weathering core, which prevent the formation of significant aquifers. Exceptionally, the formation of local aquifers is possible. Such aquifers are drained via weak, generally seasonal springs.

Permeability of crystalline schists. The spread of Precambrian crystalline schists in the Đerdap area is large. They build up parts of the Gethic overthrust. Above the Danube, there is a fractured aquifer poor in groundwater, which is drained via springs. The capacity of these springs is generally less than 0.01 l/s. While galleries were being built on the Đerdap 1 HPP dam site, minor occurrences of groundwater in the form of drops were detected, as well as very rare minor springs in the deeper reaches of the galleries. The rate of groundwater flow to well PS drilled to approximately 100 m below the water level of the Danube is only 2.0 l/min. In most cases, the permeability of the crystalline schists is less than 1 lugeon. A higher permeability has been detected only in several boreholes drilled in amphibolites, where it amounts up to 2 lugeon (Semiz, 1966; Kujundžić et al., 1969, 1966; Benčila et al. 1969).

Based on the chemical composition of the groundwater drained from the aquifers in the crystalline schists above the water level of the Danube, TDS is low and the groundwater type HCO_3-Ca, in places with elevated concentrations of Mg^{2+} and Na^+ ions. Hydrochemical testing of the groundwater below the water level of the Danube revealed a considerably different chemical composition. In the tectonic zone near the dam, on Crkvište Island, the groundwater is aggressive, of the SO_4-Ca type, with SO_4^{2-} ion concentrations ranging from 1421.0 to 4208.0 mg/l. High sulfate concentrations in the groundwater, occurrence of Fe_2S and accumulation of sulfate minerals in borehole cores were attributed to the oxidation of H_2S gas from a deep fault zone (Semiz, 1966).

Thermal waters. Prior to impoundment and the creation of the Đerdap 1 HPP reservoir, at a place called Dževrin, on the very bank of the Danube, there used to be a subthermal spring where the water temperature was 18 ºC. The capacity of that spring was 0.58 l/s. The composition of the groundwater classified it as belonging to the sodium-chloride type, with a dry residue of 1.25 g/l (Leko et al., 1922). J. Žujović (1983) also mentions this spring, stating that cold sulfur water emerges below Dževrin. The position of the spring leads to the conclusion that the water comes from Precambrian crystalline schists.

There are several subthermal karst springs associated with the above aquifers, which extend beyond the Đerdap area (Dragišić et al., 1988: Dragišić and Ćalić-Ljubojević, 2003).

- Spring in the southern part of the Golubac Mountains, in a place called Krivača (T = 17.5 ºC),
- Blederija Spring 1 on the southeastern fringe of the central Miroč karst (T = 17.5 ºC), and
- The Banja Spring in the central part (T = 17-19 ºC) and the Banjica Spring on the southern fringe of the Dževrinska Greda karst (T = 17-19 ºC).

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ABSTRACTS

A NEW REGIONAL CONCEPTUAL MODEL ON THE HYDROGEOLOGY OF SOUTHERN DOBROGEA BASED ON SEISMIC SURVEYS AND HYDRO-GEOLOGICAL DATA REVISITING

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Extended Abstract

The Southern Dobrogea represents a sector of the Moesian Platform delimited by major faults Capidava-Ovidiu, to the north and Intra-Moesian (Calarasi-Fierbinti-Sabla), to the south, by Danube River to the west and Black Sea to the east. This region covers a surface about 5000 km^2. The modern history of water supply to the City of Constanta is mostly related to the first *cismea* (Turkish name for a specific water intake structure) built on 1864.

Groundwater flow has been investigated both by means of environmental isotopes methods (Tenu *et al.*, 1975; Tenu *et al.,* 1987; Davidescu *et al.,* 1991), and by means of artificial tracers (Gâstescu & Hîncu, 1971; Gaspar & Orãșeanu, 1987). In 1986, the discovery of the Movile cave populated by an exceptional fauna community (Constantinescu, 1989), significantly contributed to the development of several complex research programs in the area. A structural model proposed by Dinu *et al.* (1989) has been improved by Zamfirescu *et al.* (1994) – later on, endorsed and improved by Zamfirescu *et al.* (2006) and consists of a mosaic of almost isometric (31) structural blocks. This model represented for more than 20 years the basis for different hydrogeological researches or engineering projects, some of which also included numerical modelling. Although the Southern Dobrogea block was thought to share with the Moesian platform a relatively simple, platform-like evolution, the new data as well as the integration of the huge number of wells drilled in the area (over 2000 wells, but mostly to TDs less than 500m) shown that the Southern Dobrogea area has a more complex geological evolution, whose history has been marked by several episodes of deformations.

Throughout the present paper a new conceptual model of the aquifers of Southern Dobrogea based on 2D seismic survey conducted during 2013-2014 over some 3500km^2, is proposed. Among others the results of this regional investigation pointed out that (Figure 1):

- Tectonic blocks of different sizes are separated by two fault systems oriented NNE-SSW and WNW-ESE.
- The position of different limits varies from one block to other.
- The crystalline bedrock is steeply plunging westward (to the Danube River), leading to a significant increase of carbonate complex thickness (over 1000 m), trending upward towards the NE (north Constanta area) and plunging to the south and east (along the coastal area).

The model conceptualization relies on the identification of the formations that play an important role in the groundwater-flow scheme because they are either major aquifers or major aquitards, in order to create an alternating sequence of aquifers and aquitards. Consequently the initial stack of 35 layers of different lithology was reduced to a pile of five units through an iterative process combining various considerations on *geometry* (spatial extent and thickness of each unit), *hydrogeological properties (*combination of the successive geological formations that have a similar hydrogeological role) and *hydraulic behaviour (*obtained from various pumping tests conducted on the exploratory or in water supply wells, mostly at the well completion moment).

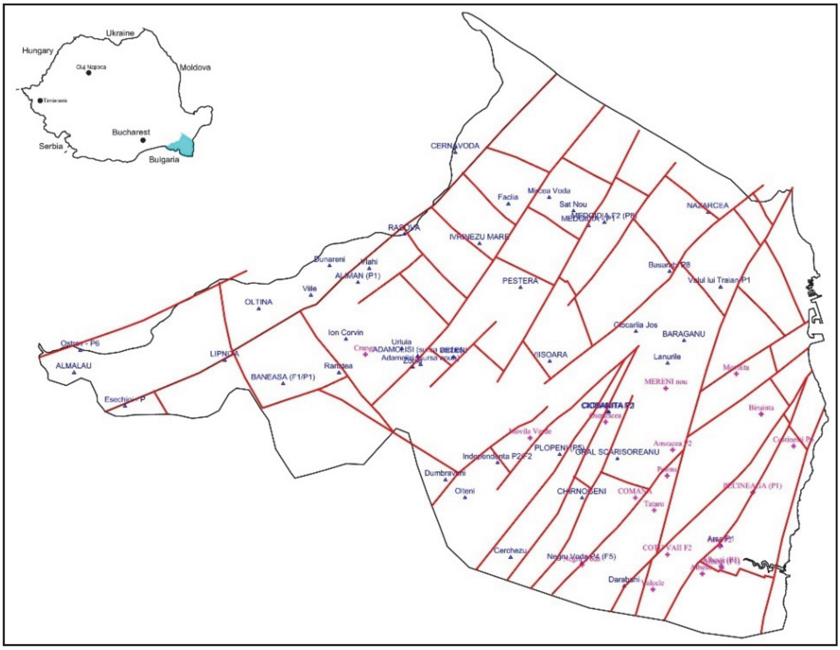

Figure 1. Schematized new structural map of Southern Dobrogea
(Upper left corner: Romania contour with study area in light blue)

Albeit they can still have "stratigraphic" names we preferred neutral letter code and consequently the succession of these hydro–units (from bottom to top) represents a bottom aquitard (unit **D**) a lower aquifer (unit **C**) an intermediate aquitard (unit **B**) and an upper aquifer (unit **A**). The Quaternary deposits playing alternative aquitard or aquifer role were assigned to a unique unit (**Q**) eventually supplying the main underlying aquifer units. Within the proposed conceptual model the *hydrogeological* cross-sections as that in Figure 2 above, may visually differ from classical *geological* cross-sections mostly because the limits of the hydro-units are not always stratigraphic. Noteworthy, important differences in hydrodynamic properties in relation to drilled depth were also identified in deep wells (opening the whole thickness of the aquifer) tested at different depths. Along the conceptualization, data from wells were considered as superseding the information inferred from seismic surveys particularly to the base of Jurassic and below. Conversely it can also be assumed that some limits in wells are erroneous due to the various sources of the exploited data and documents. A further conciliation of the existent geologic and hydrogeologic data from wells with the new structural map is more than recommended.

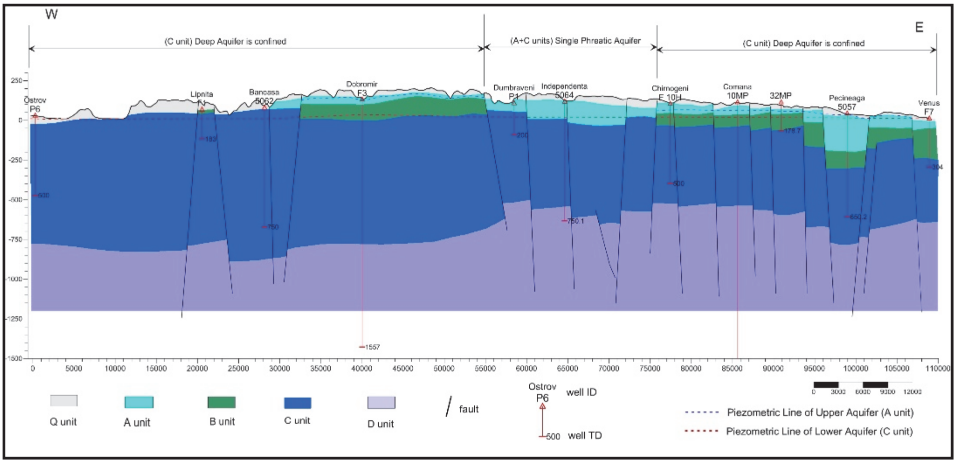

Figure 2. Hydrogeological cross-section W-E (Danube-Black Sea Coast) throughout the Southern part of Southern Dobrogea (horizontal/vertical distances/depths in meters).

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Key words: *regional conceptual model, carbonate aquifers*

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GROUNDWATER DROUGHT – CASE STUDY FROM DRAVSKO PTUJSKO POLJE

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Drought is a complex phenomenon and can be defined in many ways. It is a globally-growing problem that occurs on a time scale ranging from months to years. There are several types of drought, but the least investigated is groundwater drought. Only recently intensive research on groundwater drought started.

In Slovenia, there are almost no data on groundwater drought. In the paper, we are focused on statistical analysis of groundwater level time series of individual observation wells, which can determine periods of groundwater drought. In the study we have applied several statistical analyses. The first method is based on ranking statistics defined by lower percentiles that indicate low groundwater level. Another approach was based on univariant index, on the so-called Standardized Groundwater Index – SGI.

As a case study unconfined Quaternary aquifer of "Dravsko-Ptujsko polje" was chosen. The results show that the groundwater deficits in the observation wells appear simultaneously but differ in intensity and duration of each drought period along the area. The important conclusion is that the intensity of groundwater drought does not depend on the length of an event. Observation wells positioned on the western rim below Pohorje Mountains which can be understood as a recharge area have higher amplitude of groundwater fluctuations than the others. The result of this are more intensive dry periods with longer duration. On the other hand, we have locations in the central and eastern part of the "Dravsko-Ptujsko polje" with more damped fluctuation, which leads to less intensive but more frequent groundwater drought events.

Key words: *groundwater drought, frequency analysis, groundwater level trends, groundwater deficits*

STUDY OF THE PHREATIC AQUIFER RESOURCES IN THE BUZĂU AREA, ROMANIA

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This research paper studies the phreatic aquifer from which Buzău city, Romania, partially secures the need of its population in potable and industrial water. The final result is a numerical model of the groundwater flow that has associated a conceptual model of the hydrostructure.

The necessary data for creating the conceptual model was collected from over 250 hydrogeological boreholes, from the data base of the National Institute of Hydrology and Water Management, Romania, and it consists of the lithology encountered while drilling, constructive information of the wells, the results of the pumping tests and water levels in the period of interest.

The studied area is situated in the Buzău River alluvial fan, as such that spatial and parametrical schematizations were realized for entire alluvium, while the hydrodynamic schematization being done only around Buzău city.

Eleven cross-sections were made to define the vertical and horizontal extent of the Buzău river alluvial fan. The deposits consist of sand, pebbles and gravel with thin layers of clay. The thicknesses of permeable layers vary between 5 – 28 m.

The studied parameters were the hydraulic conductivity which varies between 8.0 and 35.0 m/day and the quantity of precipitation which had a value of 80.0 l/m^2 in July 2017. The hydrodinamic spectrum for the studied area was realised by using the elevation of the water level alongside the Buzău River and in the hydrogeological boreholes between 18 and 19 of July 2017.

A steady state mathematical model was created for the area around Buzău city, using the extension FREEWAT in the program QGis, introducing the information collected while defining the conceptual model. The modeled area was selected so it will contain the hydrogeological boreholes that supply the city with water. The groundwater supply system of Buzău city is composed of 87 wells, from which 30 exploit the phreatic aquifer.

The natural direction of the groundwater flow is from the Buzău Subcarpathians to the Romanian Plain, NW-SE. In the calibrated numerical model, the hydrogeological wells that exploit the phreatic were introduced and several simulations with varying debits have been performed in them. The results show that starting from a specific extraction flow there are several boreholes in which the water level goes below the aquifer bottom. This simulation was done to highlight the effects that an overexploatation can have on the aquifer. In the wells that are near the river an explanation is the fact that the groundwater is drained by the Buzău River and the phreatic aquifer has a thickness of only 8.0 m.

Mathematical models for groundwater flow are important tools for highlighting the effects of anthropogenic activities on aquifers. In the case of this work, a model was made for Buzău city to calculate the resource of the phreatic aquifer and to present the effect that a possible inappropriate exploitation of the hydrostructure could have.

Key words: *alluvial aquifer, water supply, modeling, Buzău River and city*

NEEDS FOR BETTER MONITORING AND STUDYING OF GROUNDWATER IN CIJEVNA TRANSBOUNDARY RIVER BASIN (MONTENEGRO – ALBANIA)

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We are witnessing frequent negative impacts on transboundary water resources, manifested as a consequence of over-exploitation, pollution, insufficient research and limited information sharing between transboundary countries. The minimum criteria that need to be met for the purpose of proportional and sustainable use of transboundary water resources, we defined on the transboundary Cijevna River Basin, which represents a very fruitful terrain for the development of a methodology for transboundary water resources management. The insufficient hydrogeological investigation, the lack of continuous water monitoring, limited cooperation between the Albania and Montenegro in a mentioned basin, were good reasons for the taking of a transboundary Cijevna River Basin as a pilot area for the design of the methodology of transboundary water management.

The transboundary Cijevna River Basin, built mostly by limestone, is an eclectic example where we can present the whole process of the designing of the transboundary river basin management, from the phase of establishing of the monitoring of the surface and groundwaters, further hydrogeological investigations to acquire information about groundwater characteristics, areas of recharge and drainage, and the most important calculation of water budget.

The recommended automatic monitoring system with stations for the continuous measurement of the level and quality of groundwater in both countries (“exit“ Albania – “entrance“ Montenegro) would be one of the first of its kind when it comes to transboundary aquifers not only in the Balkans but in Europe. As such, it is recommended for implementation in the Strategic Action Plan of the DIKTAS project (“Transboundary aquifers of Dinaric karst“).

Key words: *transboundary water management, monitoring, groundwater, Cijevna*

AN INTERDISCIPLINARY APPROACH TO UNDERSTANDING HIGH NITRATE CONCENTRATIONS IN THE VARAŽDIN ALLUVIAL AQUIFER

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Groundwater pollution with nitrate is a concern in alluvial aquifers underlying agricultural areas worldwide, because it causes the degradation of groundwater quality and contamination of drinking water supplies. High concentrations of nitrate in groundwater usually derive from synthetic nitrogen fertilizers and manure applied in agriculture, septic systems and other wastewaters. The surrounding area of the town of Varaždin is an example of area with high nitrate content in groundwater due to industrial and extensive agricultural production. High amounts of chicken waste, mineral fertilizers and agrochemicals are used during corn and vegetable cultivation. Demands for drinking and industrial water rise because of growing production. High concentrations of nitrate caused the shutting down of the pumping site “Varaždin”.

The research area is located upstream of Varaždin and compromises the catchment areas of the pumping sites “Varaždin” and “Vinokovščak”. The aquifer of the research area is composed of gravel and sand with variable portions of silt. The general groundwater flow direction is NW-SE and is parallel to the Drava River. The recharge of the aquifer occurs by means of precipitation infiltration and percolation of surface water. The covering layer of the aquifer is not continuously developed. Such conditions are favourable if they are considered from the aspect of aquifer recharge, but also make the aquifer quite vulnerable to pollution from the surface.

Since problems relating to high nitrate concentrations occurred in the study area, intensive research of source, distribution and fate of nitrate and nitrogen related species is being conducted. For the research purposes, a monitoring network has been established. Water samples are being taken from 10 observation wells and 4 surface water locations on monthly basis. Prior to sampling, electrical conductivity, pH, temperature and dissolved oxygen content are determined by using portable WTW probes. Groundwater and surface water samples are being collected for various analyses: major cations and anions, REE, stable isotopes D, ^{18}O and ^{13}C in water, stable isotopes ^{18}O and ^{15}N in nitrate and nutrients (nitrate, nitrite, ammonia, phosphate, TN and TOC). As the following steps, the surface water and groundwater analyses will be compared to determine the role of surface waters on aquifer recharge and nitrogen cycle. The sources of nitrate will be identified by comparing stable isotopes ^{18}O and ^{15}N in groundwater and ^{15}N in solids. In addition to water sampling, soil samples are also being collected during various vegetation cycles and from different land use plots to define the soil's mineralogical and chemical composition and its role in nitrogen cycle. These results will be combined with land use analysis and applied/extrapolated for the whole research area. All of the results will be used together to build a conceptual model of Varaždin aquifer which will serve as a basis for numerical modelling of groundwater flow and transport of nitrates. The research is performed as part of the TRANITAL project that is funded by the Croatian Science Foundation (HRZZ) and supported by Young Researchers Career Development Project - Training of New PhDs – HRZZ & ESF.

Key words: *alluvial groundwater, nitrate, interdisciplinary, Varaždin*

IMPACT OF CLIMATE CHARACTERISTICS ON GROUNDWATER IN POSAVINA (SERBIA)

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The observations of climate variations on the territory of Serbia in the past 20 years, especially in the Sava River Basin, have led to conclusion that the major floods (for example in 2014), winter and summer droughts (in 2000, 2012) had great impact to the groundwater table and quality of arable land in this area.

The major groundwater reserves in porous aquifers of Serbia are accumulated in thick Quaternary and Neogene aquifers. Alluvial aquifers of large rivers are particularly important and widely used for drinking water supply. The main purpose of investigating the Posavina area was to define general water balance (surface water, precipitation, and groundwater). The methodology applied assisted in assessing the impact of climate characteristics and surface water to the shallow aquifer, which may allow efficient planning for sustainable use and groundwater protection.

On the territory of Republic of Serbia, the Sava River makes an extensive alluvial plain between 3-15 km wide and more than 80 km long. According to hydrogeological researches, alluvial formations of this aquifer are made of gravel-sandy and sandy sediments, while fine-grained and slurry sands and clays make overlying layer. The depth of the water-bearing layer varies between 12 m and 20 m (Stojadinović *et al.* 2005) and reduces towards edge of the alluvial fan depth. Gravel-sandy sediments, as a water-bearing environment, have good filtration properties with the hydraulic conductivity rate of 10^{-4} m/s. Water-impermeable clays make an underlying stratum to these highly water-permeable formations. Groundwater recharge is from precipitation and from irrigation to some extent. However, main recharge to this aquifer is surface water of the Sava River. The analysis of the groundwater regime point out that groundwater table weakens with the distance from Sava. Generally, groundwater table is 3 m deep, while in the zone of exploitation dynamic level in wells is at depth of 3.5-4 m.

The shallow groundwater analysis has been carried out in the area at the locations Laćarak (Srem) and Bogatić (Mačva). Correlation of the results from piezometers in Srem and Mačva indicates mere differences in groundwater levels and imply on changes that occur at the same time. Groundwater levels are directly related to the amount of precipitation in the Posavina area during the observation period.

In periods when significant quantities were reduced, the depth of the groundwater level was lower, and vice versa (Tomić *et al*. 2019).

Comparative analysis of the annual rainfall (P), Sava River water level (H) and groundwater level changes (ΔH) recorded their mutual interdependence. This means that the rainfall as well as river water levels directly determine the position of groundwater table of shallow aquifer (Tomić *et al*. 2019).

Understanding the process of groundwater recharge and taken the hydrogeology into account is therefore essential in the assessment of climate change impacts. Quantifying the future evolution of recharge over time requires the reliable forecasting of changes in key climatic variables.

Key words: *alluvial aquifer, climate variations impact, interrelation surface-groundwater, Sava River basin*

VULNERABILITY ASSESSMENT AND MAPPING IN RELATION TO CLIMATE CHANGE - KUPA RIVER CATCHMENT

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Certain water quantity and quality related issues, which might subsequently arise due to irregular spatial distribution of water resources, can be further amplified in case of increased weather extremes and inadequate land use. The irregularity stems from specific and complex hydrogeological structures whose unique example is the Kupa River catchment area that can be divided in two diverse parts – alluvial and karstic. Alluvial area is characterized by intergranular porosity and groundwater flow through layers of variable thickness and composition. As opposed to alluvial area, karst is characterized by fracture-cavernous porosity and fast groundwater flow along preferential paths, low retention capacity, infiltration and discharge of water within the same groundwater body and high intrinsic vulnerability of aquifers due to lack of overlaying layers.

The Kupa River catchment area is not only faced with adverse seasonal flood impacts but also inadequate land-use practices, which the population is not inclined to change. This coupled with hydrotechnical objects, which have strongly modified hydrological system and water regime, make water resources protection and flood mitigation even more challenging. Given the catchment's transboundary character, achieving synergy between water management goals, spatial and economic growth while adapting them to climate change is one of Croatia's sustainable development priorities, but also part of transnational efforts encompassed within CAMARO-D project (Danube Transnational Programme). As site specific best management practices implemented through the project's lifetime, direct pilot area activities were hydrogeological field investigations, vulnerability mapping of Kupa River catchment area and climate change modelling (Turc (1954) and Langbein (1962) empirical models).

A comprehensive vulnerability assessment was carried out with the help of GIS tools, by compiling and overlapping layers of natural (intrinsic) vulnerability and potential hazards of anthropogenic origin. The vulnerability and hazard assessment were based on good practices of previously renowned methods, esp. recommendations of European COST 620 project. As protection against floods is

one of the main CAMARO-D objectives, hazard map was further overlapped with flood risk map.

In addition, hydrological modelling of possible impacts of climate change on water resources was carried out. Correlation and comparison of measured (historical 1961-1990 and recent 1981-2010) and modelled data for 30 year reference period (2041-2070) pointed out how hydrological regime of the Kupa River catchment is going to experience decreased discharge, more frequent extreme events and significant increase in temperature.

Overall results were introduced to relevant decision makers and practitioners in the form of a catalogue of measures targeted at raising awareness and encouraging their involvement on a local, regional and national level.

Key words: *vulnerability assessment, GIS, karst, climate change, Kupa*

DELINEATION OF PROTECTION ZONES IN KARST AQUIFERS: A CASE STUDY FROM EPIRUS AREA, NW GREECE

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The karst aquifer systems of Greece are developed in carbonate sedimentary (limestone, dolomite) and metamorphic rocks (marbles) and contribute significantly to water supply for domestic and irrigation use. Both types of rocks are well karstified due to intensive tectonic stress and relief, forming excellent aquifer systems with commonly high yield boreholes and large storage capacity. It is worth mentioning that the karst aquifers are highly vulnerable to external pollution and anthropogenic activities due to karstification and rapid infiltration. Several different methods for karst aquifer vulnerability assessment and mapping exist. Until now, nine (9) main karst groundwater vulnerability mapping methods have been used: EPIK, REKS, RISKE, RISKE 2, PI, Slovene approach, KARSTIC, COP & COP+K, and PaPRIKa method.

This work deals with the delineation of protection zones around boreholes in karst aquifers. Initially, the vulnerability of the aquifer system has been assessed using the PaPRIKa method. PaPRIKa constitutes an index method which is based on the structure and function of the aquifer and it is usually applied in Geographic Information System (GIS) environment. Aquifer structure includes two factors, protection (P) and rock type (R), while aquifer function is based on infiltration (I) and karstification (Ka). In addition, the hydraulic characteristics (hydraulic conductivity, travel time) of the aquifer, as well as isotope analysis, were used to delineate the protection zones. The aforementioned method was applied in a complex karst aquifer of Epirus region, NW Greece. This system is part of the groundwater system of Mitsikeli-Vellas, which is developed in limestones and discharge from many karst springs (Touba, Vela, Krya, etc). The yield of the boreholes ranges between 50-100 m^3/h, whilst the hydrochemical type of karst groundwater is calcium-bicarbonate ($Ca\text{-}HCO_3$). The main pollution sources in the wider area are wastes from poultry farms, agricultural activities and septic tanks used to collect municipal wastewater.

According to the vulnerability assessment, isotopic analysis and the hydraulic data the protection zones II and III from a strategic group of boreholes extend 1.1 km and 8 km, respectively. The delineation of the protection zones constitutes a useful tool for groundwater protection and sustainable management of the karst systems. Finally, a set of measures is proposed aiming at water quality protection and sustainability of this karst aquifer system.

Keywords: *groundwater; karst aquifers; PaPRIKa method, protection zones, Greece*

PROTECTION OF MINERAL GROUNDWATER RESOURCES IN HARGHITA COUNTY, ROMANIA

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In Romania the establishment of protection area is regulated by the Government Decision no. 930/2005 for the approval of the Special Norms on the character and size of the sanitary and hydrogeological protection areas. Protection areas is being establish for: groundwater or surface water sources, as well as their associated catchments for drinking and industrial water supply, natural mineral water, therapeutic mineral water, geothermal water and therapeutic sludge. Three sanitary protection areas are established in Romania: *the severe sanitary protection area* includes the land around all the sites where any use or activity location that could lead to pollution or contamination of water sources is prohibited; *the sanitary protection area with restriction regime* includes the territory around the sanitary protection area with severe regime so delimited that by applying protective measures, depending on the local conditions, the danger of water quality deterioration will be eliminated; *the hydrogeological protection area* includes the territory between the supply area and the discharge area on the surface and/or underground of groundwater through natural emergencies (springs), drains and drillings and has the role to provide protection against severely degradable or non-degradable pollutants and the regeneration of the flow through the capture operations.

Protection measures are set up by several authorities: *National Agency for Mineral Resources (NAMR)* - establishes hydrogeological protection areas for natural mineral water, therapeutic mineral water, geothermal water and therapeutic sludge; *Ministry of Forests and Waters (MFW)* - establishes hydrogeological protection areas for: groundwater or surface water sources, as well as their associated catchments for drinking and industrial water supply.

Ministry of Health (MH) – establishes sanitary protection areas (both areas) for groundwater or surface water sources as well as their associated captures for drinking and industrial water supply, natural mineral water, therapeutic mineral water, geothermal water and therapeutic sludge

The water pollution process can occur as a result of human, economic and social activities, the main risks being:- pollution with pathogens: bacteria, viruses or other living organisms; chemical pollution with: phyto-pharmaceuticals and

compounds of nitrogen, phosphorus and potassium resulting from the application of fertilizers in agriculture, chemicals from industrial activity radioactive substances; thermal pollution with high temperature waters.

The delimitation and setting limits of the hydrogeological protection area is based on the following: direction of water flow in the aquifer, from the supply area to the discharge zone (in this case NW-South); determining of the boundary conditions of the aquifer; determining the supply area of the aquifer (in this case, determining the altitude at which the water reaches the aquifer); determining the relative water age of the aquifer; timely monitoring of the physicochemical and microbiological composition of the aquifer water; identification of physicochemical and microbiological compounds in the area, which can lead to aquifer pollution; establishing of industrial and agricultural restrictions for the protection of the aquifer; limiting the number of boreholes that will open this aquifer, and if it is still necessary to execute boreholes that will open the aquifer, they will be perfectly insulated to avoid any contamination from the higher polluted aquifers or with high risk of pollution.

Key words: *protection areas, natural mineral water, polluting factors, protection areas delineation, Harghita County*

DRINKING WATER PROTECTION THROUGH EFFICIENT LAND USE PRACTICES – SOUTH DALMATIA CASE STUDY

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Water quality and quantity are often degraded due to combination of negative anthropogenic and external factors, such as improper land use activities, certain management deficiencies, knowledge gaps, climate changes or catastrophic events. Through Interreg CENTRAL EUROPE project PROLINE-CE, interdisciplinary and innovative approach is demonstrated by applying integrated land use management scheme, linking together hydrochemical models, land use cover, climate change models and existing knowledge regarding best management practices for water protection and non-structural flood mitigation.

In Croatia, drinking water resources, although generally of good quality and quantity, are coming under increased pressure, particularly in coastal Mediterranean region of Dalmatia, where summer seasons are very dry and warm, causing prolonged droughts. Within PROLINE-CE, two pilot areas were chosen for further investigations: (i) Imotsko polje and (ii) part of South Dalmatia (Prud, Klokun and Mandina mlinica springs).

These pilot areas are located in famous Dinaric karst region, characterized by very complex hydrogeological features and forms, such as poljes (karst fields), springs, ponors (sinkholes), estavelles and preferential groundwater flow paths. In order to identify whether some types of land use (e.g. agriculture) have negative impact on groundwater and surface water quality or quantity, *in situ* measurements of physicochemical parameters (T, pH, EC, O_2, HCO_3) and hydrochemical laboratory analyses (atomic absorption spectroscopy, ion chromatography, stabile isotopes - ^{18}O and ^{2}H analysis) are conducted on water samples from twenty springs throughout pilot areas. Additionally, climate change models are developed in order to raise awareness of key decision makers to facilitate necessary changes in management schemes and to improve existing infrastructure.

On the basis of preliminary results, main drivers in terms of negative effect on drinking water quality and quantity are intensive agricultural activity, very high

losses in water supply system (up to 80% for some systems in pilot area), illegal waste dumps, outdated sewage system with high leakage and many improvised cesspits, insufficient wastewater treatment, negative changes is land use, occasional flooding of poljes, prolonged droughts and unfavorable climate change scenarios which predict reduction of discharge from 2021-2050.

Through PROLINE-CE main outputs, namely DriFLU charta, transnational strategy applicable outside project area is devised. DriFLU provides direct guidelines and concise logic framework for implementation of best management practices and policy improvements, aiming to achieve function-oriented land use.

Key words: *land use, water quality and quantity, best management practices, PROLINE-CE, Dinaric karst*

TRANSPORT OF PHARMACEUTICALS IN COARSE GRAVEL UNSATURATED ZONE

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Among emerging contaminates pharmaceuticals are the most demanding chemical for understanding of their transport in aquifers. In Slovenia we are very often experienced with relatively thick unsaturated zones above high yield unconfined aquifers which are important for drinking water and industrial water supply. All around the world not many data are available about transport characteristics of such coarse gravel unsaturated zones. In spite of this fact transport data are urgently needed for understanding of pollutant transport and to implement proper aquifer management strategies for their protection.

In the paper we are representing one of the first tracing experiment in the unsaturated zone of coarse gravel with the thickness between 25 to 37 m in the lysimeter positioned in the area of Selniška dobrava east of city Maribor (NW Slovenia) for determination of such data. The tracing experiment was conducted as multitracer exercise where deuterated water was infiltrated together with certain amounts of pharmaceuticals (propyphenazone, caffeine and carbamazepine). During the experiment tracers were detected at various depths and for each of them breakthrough curves were obtained. Based on the measured breakthrough curves backward modeling in combination of analytical (solutions for advection dispersion equation) and numerical methods (HYDRUS-1D) were performed. Results gave important results. Hydraulic parameters for unsaturated zone were estimated (parameters of van Genuchten model) and transport parameters for all three tested pharmaceuticals were determined.

Key words: *pharmaceuticals, unsaturated zone, van Genuchten model, transport parameters, tracing experiment*

UNEXMIN PROJECT: AN AUTONOMOUS UNDERWATER EXPLORER FOR FLOOD MINES – GOALS, STATUS, PERSPECTIVES

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UNEXMIN is an EU-funded project within the *Horizon* 2020 program (*RIA: Research and Innovation Action*). The consortium gathered around the project consists of 13 research organizations and private companies, from seven countries, with University of Miskolc as a project coordinator. Among the members of the consortium is European Federation of Geologists (EFG), whose local partner is the Serbian Geological Society (SGD). The project started in February 2016 and it is planned to last for 45 months, until October 2019. The main goal of the project is development of a robotic explorer that will autonomously map flooded mines. This will allow gathering of valuable geological information that cannot be obtained in any other way. Ultimately, this information could open new exploration scenarios on the re-opening of Europe's abandoned mines.

The UNEXMIN Consortium is developing a novel robotic mine surveying system to be used for the autonomous mapping of flooded underground mines. The Robotic Explorer platform, made by three robots – UX-1a, UX-1b and UX-1c, will use non-invasive methods for autonomous 3D mine mapping for gathering valuable geological, mineralogical and spatial information. The robot needs to be able to fit into small mine openings and to resist high pressures when operating down to a depth of 500 m. Each of the robots carry a defined set of instruments and characteristics, including water sampler; conductivity and pH measuring units; sub-bottom profiler; magnetic field measuring unit; natural gamma ray measuring unit; UV and SLS imaging units; multispectral camera; acoustic cameras; laser scanners; SONARs and systems for autonomous control and movement.

As a part of the UNEXMIN project the European Federation of Geologists created a database of flooded underground mines in Europe, which is publicly available at the project website (www.unexmin.eu). There is a special focus on mines that produced metallic minerals in the past, and on mines that cannot be re-surveyed by scuba divers due to their depth or difficulty of access. EFG also collected information on any flooded mines/structures that are of cultural and/or archaeological importance and could now be re-surveyed with the UNEXMIN technology. These activities EFG was conducting in cooperation with national geological societies and organizations, from which Serbian Geological Society is one of the EFG's linked third parties. Along with collection of data about flooded underground mines which could be interesting for application of developing technology, SGD under the support of EFG is involved in project promotion and dissemination activities.

The technology developed by UNEXMIN will increase Europe's capacity to re-evaluate its abandoned mines for their mineral potential, with reduced exploration costs and increased investment security for any future mining operations. The technology is being deployed in four trial sites in Europe since June 2018, following completion of the first UX-1 robot. The trials at the Kaatiala pegmatite and Idrija mercury mines are completed and data is being processed and analysed. The next trials are going to be in the Urgeiriça uranium (March 2019) and Ecton lead-zinc mines (May 2019). During these pilots, UX-1 is improved after each trial session. Final outcomes of the project, along three prototype robots will include establishing of a company for offering the technology to the market. Along with mineral resources exploration, it is expected that technology developed under the project will be utilized in karst environment, for exploration of other heritage sites and in conducting varies underwater measurements.

Key words: *robotics, autonomous systems, abandoned mines, raw materials, European Federation of Geologists, Serbian Geological Society*

MICROBIAL WATER QUALITY INDICATORS MONITORING AT BUZGÓ KARSTIC SPRING IN SLOVENSKÝ KRAS MTS. (WEST CARPATHIANS)

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Sampling for microbiological parameters of water quality of the Buzgó karstic spring in Krásnohorská Dlhá Lúka (Slovenský kras Mts., Eastern Slovakia) was performed between March 2015 and December 2017, but only eight samples in monthly intervals were taken in 2015, next 65 in approximately weekly interval in hydrological year of 2017. Results were compared to spring's discharges and meteorological phenomena as precipitation and air temperature courses. The most observable correlation with water stages was found in the cases of microorganism cultivable at 22 °C and 36 °C. Population of these microorganisms was bound to local meteorological phenomena in much lesser extent. Contrary to the results of previous investigations, indicators of faecal contamination were regularly found in Buzgó springs' water. The influence of high water stages is less observable and is particularly pronounced in growth of enterococci population, in lesser extent also *Escherichia coli*. No correlation with hydrological data was found for coliform bacteria. Microbiota in the karstic water here is probably mostly influenced by two independent factors: water stage in the underground hydrological system of the Krásnohorská jaskyňa Cave behind the Buzgó spring, and occasional human visits to this system. The second factor mostly influences population of faecal contamination indicators. Results of monitoring also confirmed persisting low population of microorganism cultivable at 22 °C and 36 °C and dominance of the first type of microorganisms in the whole cycle of seasonal changes here.

Key words: *monitoring, karstic groundwater, coliform bacteria, enterococci, Krásnohorská jaskyňa Cave*

POST MINING HYDRODYNAMICS OF THE KARST AQUIFERS IN KIZEL COAL BASIN (THE WEST URALS, RUSSIA)

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Perm region is an old mining region. Mining has been underway for more than 300 years. Potash salts and coal were the main types of exploitable mineral deposits in the twentieth century. Coal deposits are located in the Pre-Urals, geologically confined to the West-Urals folding zone. The high prevalence of karst rocks is typical for this area.

Deposits of the Kizel coal basin are the subject of study. These deposits were developed from the end of the 19th to the beginning of the 2000s. High water inflows were common - total drainage reached 10-12 thousand m^3/hour. The mines have been flooded since the beginning of the 90s of the last century, by now all the mines have been flooded, 16 springs of mine waters have been formed. High discharge rates - up to 1000 m^3/hour during snow melting are typical for these springs, the total average annual flow rate of springs of mine waters is more than m^3/hour. The waters of the mine water springs are sulphate high-metal with low pH. These springs for tens of kilometers pollute the rivers of the Kama basin, the Volga tributary. Attempts are being made to reduce the environmental damage caused by the spouting of mine waters since the early 2000-s.

Geofiltration models have been developed for all watersheds of mine fields. The location in the unique for each field geological structures - synclines and anticlines is taken into account. The geofiltration pattern and stratification of model layers is the main problem. The model took into account aquifer complexes confined to rocks from the Permian to the Devonian age. The angles of incidence of rocks reach 70^0, the total depth varies from full pinching to 1200 m. The width of catchments is from 5 to 14 km with a length of 2-3 times more.

The balance structure of the groundwater formation at different stages of the territory development was first evaluated. The following stages are considered: natural conditions, the situation at the end of mining, the current situation with mine springs, forecast for the implementation of various water protection measures. Resources of the coal-bearing strata provided no more than 50% of the

mine drainage flow. In the simulation, it was necessary to add to the model the interaction of the coal aquifer with the overlying (Visean-Artinsky) and underlying (Franco-Tournaisian) aquifers.

Clear seasonality of mine springs flow rates has been established. Due to the consumption of surface runoff, up to 50% of the flow rate of springs is formed. Solved model tasks for years of different water content confirmed this. Drainage of surface runoff by ditches is proposed here as a basic water protection measure. Embedding of the spout points is effective where the springs are small in terms of discharge rate. The implementation of this event will lead to the cessation of outflow and increased discharge in the bottom of the rivers. To ensure the centralized discharge and concentrated purification of groundwater, options for organizing pumping from coal-bearing strata or Visean aquifer are also considered.

Key words: *geofiltration model, karst, mine floor, river pollution, Kizel coal basin*

THE CATASTROPHIC DECLINE OF PRESPA LAKE LEVEL AND LAKESIDE KARST PHENOMENON

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In southeaster Albania, on the border with North Macedonia and Greece, there are located the lakes Big Prespa (253.6 km^2) and Small Prespa (47.4 km^2). Both lakes are linked by a small canal with a sluice that separates the two lakes. The absolute mean level of Prespa Lake is considered 850 m above sea level, and maximal elevation of 852.91 m was registered in 1993. During the period 1963-2003 a successive lowering of the lake level continued, with some interruption of this tendency during the period 1977-1986. The lowest elevation of 844.42 m has been registered in 1963, with cumulative amplitude for the period 1963-2003 of 8.29 m. Some specialists give the following hypothesis to explain the lake water decrease: a) increase of the transmissibility of the karst aquifer separating the Prespa Leke from the Ohrid Lake, and such intensifying the draining of the first lake to the second one; b) change of the climatic conditions in recent years, and, c) increase of the lake water use by the local population for agriculture and industrial purposes.

However, the analyses of some meteorological and archaeological facts suggest that Prespa Lake level decrease is a consequence of the climatic conditions, which changes in the past seems has been more intensive than today. The lake level lowering can be, also, triggered by some karst phenomena registered at the lake area as it is the Zaver swallow hole. These phenomena need to be investigated and described better.

Key words: *lake level decrease, karst phenomena, climatic conditions change, Prespa Lake*

INFLUENCE OF RESERVOIR AND DAM UTILIZATION ON KARST AQUIFER BEHAVIOR - EXAMPLE OF BILEĆKO RESERVOIR (TREBINJE, BOSNIA AND HERZEGOVINA)

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The results of multiannual observation of groundwater fluctuations of a wider area of Bilećko reservoir (Trebinje, B&H) indicate that there is a good hydraulic connection of the reservoir and a part of the karst aquifer of the reservoir right side. In some further parts of the right side of the aquifer, due to complex lithostratigraphic features and tectonic composition, the influence of the reservoir is changeable, so hydrogeological and hydrodynamic characteristics of how this aquifer part functions, have not been clearly studied up to now. On the basis of some earlier data, when the reservoir level is lower than 360 m a.s.l., there can be a change of the natural condition in that aquifer part as well. Because of this, as well as due to the fact that the theory on the circulation of water from the Orah zone (the right bank of the accumulation) to the identified karst springs on lower positions has not been either dismissed or approved for now. Also, there is possibility of occasional local change of hydrodynamic conditions of karst aquifer when the water levels in the reservoir are different. The studies presented in this paper have been conducted with the aim of providing additional and clearer explanations of how the karst aquifer functions under different reservoir conditions.

Key words: *karst aquifer, groundwater fluctuation, hydrodynamic conditions, Bilećko reservoir*

STYLOLITES: WHEN THEY BECAME CONDUITS FOR FLUID PATHWAY?

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Dissolution process is a complex phenomenon controlled by several factors (lithology, porosity, stress orientation, environmental conditions, networks of fractures) but in the karst field, compressional tectonic structures, as like stylolites, are never been taken into consideration. In fact stylolites are planes of dissolution that play an important role in fluid circulation during carbonate deformation. They are formed by a pressure solution processes that dissolves the soluble particles and leads to an enrichment in insolvable, non-carbonate particles (NCP) along their planes. Although they seem macroscopically planar, stylolites have an extremely variable shape from the meso- to microscale, with variable porosity and permeability. Because of this, they have a strong effect on regional fluid flow and the formation of reservoirs since they can act as barriers or conduits for flow. In this research we integrated field work with lab analysis. The field work was carried out in a karst area in the South Italy (Alte Murge), where using the method of Caine (Caine, 1996), we reconstructed the permeability of the three fault zones focusing on joints, faults and stylolites. The lab analysis (chemical, petrographic and physical) were perfomed on selected samples representative of the main 4 different shape of stylolites with key examples of various types of stylolites.

Chemical and petrographic (SEM and FTIR) analysis allow us to characterize the mineral content and submicroscopic arrangement of stylolite structures to determine which role the NCP and the distribution of pores in and around the stylolites have on fluid circulation. Because the investigated stylolites are relatively narrow, (around 30-50 µm) we also applied Micro XRD and Micro XRF. Micro XRD helps in high resolution determination of the mineral composition and structures of NCP, supported by initial micro XRF to obtain the internal element distribution. Micro CT analysis characterizes the spatial distribution of the voids in and around stylolites and visualizes which pores are connected. A database has been set up to classify the different shape and composition of stylolite structures. Despite the different provenance and composition of analyzed limestone samples, NCP are mostly kaolinite, palygorskite and illite in all stylolites. The results showed here allowed to explain the behavior of stylolites in fluid-rock interaction.

Key words: *stylolites, permeability, fluid-rock interaction, Alte Murge*

GROUNDWATER TURBIDITY DYNAMICS IN KARST HYDROGEOLOGICAL SYSTEM. CASE STUDY: SUVA PLANINA MT., SE SERBIA

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Karst groundwater often has a great quality, requiring only disinfection prior to for water supplying system. On the other hand, almost every karst spring, has a recurring problem with turbidity in the course of the year. Dry periods during a year results in partial or complete depletion of karst aquifer, while during rainy periods watershed response to rainfall could be sudden with random changes in quantity and/or quality. Turbidity is one of the groundwater quality parameters affected by storm events and which change is obvious. In those cases, the main problem is increased number of bacteria in groundwater, usually flushed from the ground surface. The difficulty in handling this phenomenon is that karst hydrogeological systems are heterogeneous and discontinuous systems, which consist of highly transmissive vertical and horizontal conduits, along with low transmissivity fractures in rocks (dual porosity). Permanent monitoring of karst springs represents an advantage in management of karst aquifers especially for water supplying. Long monitoring time-series make possible performing stochastic analysis to gain insight into the causal relationship between precipitation and karst groundwater parameters.

Karst aquifers cover almost 30% of territory of Serbia, with potential yield of around 4000 l/s, due to this fact karst aquifers represent significant natural resource. Research presented in this paper has been conducted in the eastern part of Suva planina Mt., that is a part of the Carpathian-Balkan mountain chain. Regional folding of Mesozoic limestones created Suva planina Mt. plunging anticline and longitudinal structures of Suva planina Mt. and Lužnica regional fault, both NW-SE direction. Faults that are of local importance are transversal to the above-mentioned regional dislocations and evidently caused enhancement of karst process. In the foothill of Suva planina Mt. several karst springs are discharging primarily on the locations of the intersection of longitudinal and transversal faults. Monitoring of quantity and quality of Mokra and Divljana karst springs has been established for the purpose of better management of water supply system. This research includes stochastic analysis of time series of rainfall, spring discharge and turbidity recorded daily at both springs for one hydrologic year (01/10/2016 – 30/09/2017). Stochastic analysis of time-series has showed that Mokra karst aquifer has long memory effect (51 days), while

Divljana karst aquifer has short memory effect (10 days). Also, the analysis has showed that rainfalls and turbidity have short "memory" of only 2 – 3 days. Cross correlation analysis between rainfalls and discharge of both springs pointed out 10 days delay, while cross correlation between rainfalls and turbidity showed only 3 days delay and little inertia of the karstic systems regarding turbidity. The complex hydrodynamic behaviour related to the system hierarchy is thought to be the origin of turbidity. The fast infiltration through the unsaturated zone causes a flushing effect and a turbulent quick flow in the highly transmissive conduits with very high velocities.

Key words: *turbidity, dynamics, stochastic analysis, karst hydrogeological system, Serbia*

HYDROGEOCHEMICAL PATHWAYS OF THE KARST - FISSURED AQUIFER SYSTEM, PIROT (SERBIA)

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Groundwater flow has an influence on hydrochemical patterns indicating different processes and the chemical characteristics of the recharge area and aquifer material, that can be changed during time due to different structural-geological and hydrogeological conditions in the aquifer. Hydrochemistry evolution is presented by studying the groundwater quality parameters of the aquifer. The karst-fissured aquifer in the contact of Danubian and Getic unit (Pirot district) is a good example of how structural geology and litho-geochemical environments influence on groundwater composition, creating groundwater bodies with a specific origin (hydrosomes) and their hydrochemical facies (distinct hydrochemical zones within hydrosomes).The hydrogeological system is formed on the contact of two regionally important tectonic units representing first-order structures within the Carpatho-Balkan orogenic system, and the contact of these units is represented by the Vidlič thrust. Na/Cl and Li/Cl molar ratio, EC, ORP, SO_4 content were used to separate hydrosomes: (I) brackish to saline groundwater upcoming from dissolution of evaporite minerals such as halite (NaCl) and gypsum ($Ca_SO_4 \cdot 2H_2O$), related to shallow marine conditions in late Early Cretaceous, characterized by the deposition of both clastic and carbonate sediments, (II) slightly brackish oxic and anoxic (H_2S rich) groundwater within the Lower Jurassic sandstones - where dissolution by sulfuric acid has an important contribution to groundwater chemical composition, (III) low-mineralized oxic karst water which differs in temperature - from cold (10 ºC), sub-thermal (17 ºC),to thermal (30 ºC) waters. Each hydrosome consisting of a genetic succession of several facies units, whereby the concentrations of the trace and ultra-trace elements were used to identify the pathways and the hydrochemical processes of groundwater flowing within the karst-fissured aquifer system. Saline groundwater (Na-Cl-SO_4 water type) in highly karstified zone undergo mixing processes with the typical low-mineralized karst groundwater making up productive karst aquifer. The presence of chloride and sulfate ions affects the faster development of the karstification process in this area. In anoxic, H_2S rich groundwater is detected the highest concentration of REE (Σ 56 μg/L), without a pronounced Eu and Ce anomaly, indicating hydrochemical steady-state conditions. This zone is related to oxidation of sulfide minerals in sandstones and conglomerates and water percolation through the strata of black bituminous limestone of Lower Jurassic age. Extremely reducing environment and the presence of organic matter are favorable conditions for the distribution of ultra-trace elements, which have not been detected in other waters in the area. Geotectonic conditions on the terrain caused the occurrence of different facies of karst aquifer, primarily different in temperature and microelement composition. Deeper circulation in the Triassic rocks of Vidlič thrust enabled occurrence of thermal water (Sr, Zn, Ni, Ga, Te, Tl, Hf), while sub-thermal water (Si, Ti, Hf, Ta, Th, Nb, Zr) is a result of mixing process of thermal fluid raised from deeper layers through preferential pathways in the Vidlič thrust and cold water in a karst aquifer. Hydrochemical system analysis and microelementsin groundwater alloweda better understanding of the hydrochemical pathways of the complex karst-fissured groundwater system.

Keywords: *hydrochemical system analysis, microcomponents, complex aquifer system, groundwater circulation*

PRELIMINARY RESULTS OF THE PHYSICO-CHEMICAL AND HYDROCHEMICAL MONITORING IN KARST SPRINGS OF NORTH PELOPONNESE

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The karstic environment of North Peloponnese is characterized by karstic features, such us, poljes, dolines, sinkholes, caves and small or large karstic springs. In the region of the famous from the ancient mythology *Stymphalos,* large karstic springs, the front of Stymphalia – Driza springs, discharge the karstic groundwater system of Ziria Mountain. A few kilometers to the west the large springs of Planitero discharge the karst aquifer of Xelmos Mountain. Both springs are of significant importance. The front of Stymfalia springs is used for the supply of drinking water to the city of Corinth, while now days a big debate is in progress for further use of the spring water for the supply of drinking water to the city of Kiato. Planitero springs are used for irrigation purposes and feeding of fish farms. Water sampling of the springs has been carried out for the last two years in monthly basis, while the physico-chemical parameters of the Stymphalia springs were measured in hourly basis. The first results of this study will be provided in this presentation.

Key words: *karst features, karst springs, water sampling, North Peloponnese*

HOW DOES THE DISSOLUTION KINETICS AFFECT THE EVOLUTION OF THE SOLUTION PIPES?

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Dissolution by a reactive flow is a complex phenomenon influenced by a number of different parameters, including flow rate, diffusion rate of the reactant, reaction rate and the pore space characteristics of the host rock. Depending on the values of these parameters, the dissolution patterns will have different morphological features. In particular, there is range of parameters where the dissolution front becomes unstable, which is accompanied by a formation of pronounced dissolution channels, which are called solution pipes in geological literature and wormholes in the petroleum industry, where they are produced to stimulate the flow from oil reservoirs. In the natural settings, these features are formed in rocks with a very high porosity and then with a rather large flow rate. Their shapes are strongly related to their characteristic sizes. At the macroscale (1-10 metres) they are usually almost cylindrical with a diameter from a few cm up to a meter, while at microscale they show a highly ramified, fractal-like shape. To investigate this variability and to understand their formation and evolution, we are conducting microfluidic experiments using a self-constructed microfluidic cell. We are using a system consisting of two polycarbonate chips in which it is possible to have a control on flow rate and on the aperture. The lower plate has an indentation that can be filled with gypsum, while on the upper chip there is a reservoir that allows water to be supplied to the system in a controlled way. We are using powder gypsum during these experiments because it has a very simple chemistry, high solubility in water and therefore allows a greater speed of dissolution The two chips are joined together with an ultrathin, double coated tape of variable thickness that allows us to control the aperture of the system, which can thus be regarded as an analog fracture. As the gypsum chip is dissolved, we observe the appearance of fingers of different shapes and densities, depending on the flow rate and the aperture. We report the results of these experiments and relate the observed features with the natural shapes found in the epikarst systems.

Key words: *dissolution, solution pipes, microfluidics*

THE LARGEST GEOTHERMAL INVESTMENT BY PANNERGY IN NW HUNGARY

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The geothermal energy investment mitigating emission of pollutants of fossil energy sources has been established by the PannErgy Group in the area of Bőny and Pér just outside the city of Győr in four years.

The Győr Geothermal Project currently consisting of two producing and two injection wells opened and started its operation on November 24, 2015. The geothermal system annually supplies the Audi Hungaria Plc. and Győr-Szol Plc. (urban heating energy supplier) companies jointly with approximately 700 000 GJ green energy. The geothermal energy serves more than 24 000 apartments and 1046 other customers in the heat energy system of Győr, furthermore it covers at least 60% of the needs of Audi Hungaria Plc. factory. The production of this heat amount by geothermal energy instead of natural gas means that it lowers the annual emission of carbon dioxide by 46 000 tons.

Long exploration and planning preceded the successful start. The Pre-Cenozoic basement in the surroundings of Győr is also made up of Upper-Triassic carbonate rocks. Their good water capacity is known from deep drilling and karstic sources, but their exact volume was previously not examined. During the first phase of the exploration the geological and geophysical data available about the area were purchased and re-evaluated. In this context the seismic profiles of the area earlier identified in the 1980s have been reassessed and reconsidered, which led to new 2D seismic measurements in the second phase of the exploration during 2013-14. Based on the results of the measurements along the four lines the first drilling site was assigned which discovered the good water capacity Upper-Triassic carbonate rocks in the area of Pér in 2300 meters depths.

In the third research phase between 2014 and 2015 a 3D seismic measurement took place by which another three drilling sites were appointed and successfully established. The four wells of the system all targeted the Upper-Triassic age carbonate aquifer: the production wells of Bőny reached the target zone about 2490 meters depth while the injection wells of Pér reached it approximately 2300 meters depth. The well head temperatures of the production wells are 99 and

101 °C their current production (circa 900-930 m^3/h, one well operating with pump, the other freeflow) enables the heat transfer of 52 MW.

The heart of the Győr Geothermal System (consisting of 17 kilometres of pipeline and two production and two injection wells) is the Bőny Heat Center, from where one can navigate the heat production and transfer with modern technology. Beyond serving primary customers the intent is that the *returning heat water* still containing potential heat energy could as well serve secondary customers thus increasing the efficient exploitation of the heat of the produced water.

Key words: *deep geothermal, seismic exploration, geophysical exploration, seismic processing, complex interpretation*

USE OF A PROCESS-BASED METHOD TO ASSIST MINERAL WATER RESOURCE PROTECTION - CASE OF HAZARDOUS THREATENS IN SANCRAIENI - CIUC AREA, ROMANIA

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Natural mineral waters in general and sparkling water in particular are highly valuable commodity with specific characteristics and consequently the assessment of the vulnerability to pollution/contamination of such resources is of maximum importance for long term exploitation of a specific aquifer.

The post-volcanic phenomena of the Eastern Carpathians are noticeable in a well-known area where the combination of CO_2 affluxes (the mofettic aureola) and water bearing layers lead to the formation of numerous mineral water springs with a century's history of commercial bottling.

The main purpose of this research was the quantitative and qualitative protection of natural mineral water resources in the Sâncrăieni area, in the frame of integrated management of multiple environmental pressures: andesite aggregates quarry, tailing pond of former cinnabar (epithermal mineralization of HgS) exploitation.

Several field investigation methodologies including drilling of shallow exploration boreholes, pumping and injection tests, chemical analyses of collected samples from springs and exploitation/exploration boreholes, sampling and analysing for environmental isotopes were employed for the assessment of hydrogeological conditions, both hydrodynamic and hydrochemical, in the particular area of Lower Ciuc Basin.

Based on the field and laboratory results and on all other available data, a geological-hydrogeological conceptual model was developed as a basis for a further groundwater flow and transport model. Furthermore a numerical model (using FEFLOW commercial code) was developed in order to emphasize the potential evolution of a point source contaminant (mercury) toward the exploited source(s).

Key words: *natural mineral water, volcaniclastic aquifer, hydrogeological model, resource protection*

THE ORIGIN OF AMMONIA IN CARBONATED MINERAL WATERS AND ITS UNDERGROUND TRANSPORT IN THE NORTH-EASTERN PART OF EASTERN CARPATHIANS

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In many cases of Romania mineral waters (the northern part of Neogene Volcanic Area from Eastern Carpathians), especially the carbonate waters have ammonia in concentration over 0.5 mg/l. The problem is if ammonia concentration is due the anthropogenic pollution or it is an endogen origin.

Using the geological, hydrogeological and hydrochemical data analysis resulted in creation of a conceptual model for aquifer spatial position, groundwater movement and mineralization, and ammonia occurrence. Geological and tectonically aspects, mineral aquifer recharging, groundwater flow direction, absence of surface pollution sources and correlation of hydrochemical data, all they indicated the underground origin of ammonia. In practical terms, the aquifer is generated in Quaternary granular deposits and in fissured and fractured andesitic rocks. The groundwater was mixed with carbon dioxide on the fault area where the ammonia was also produced in underground volcanic zones and migrated in mineral water of terrestrial earth crust. The correlation between ammonia concentration and chlorine and barium chemical species confirmed the deep origin of ammonia.

In aquiferous media, groundwater flow and mass transportation mathematical modeling using Visual Modflow software package were simulated in natural and in artificial conditions (mineral water abstraction by two wells) including the evolution during the time of ammonia plume in the mineral aquifer. After groundwater flow and ammonia transport simulation, the mechanism of propagation of this chemical species, the size of ammonia plume, the preferential transport directions, the area with great concentration of ammonia have been finally elucidated.

Key words: *ammonia origin, ammonia plume, mineral waters, groundwater flow and mass transportation modeling, Romania*

CHEMICAL AND ISOTOPIC CHARACTERISTICS OF THERMAL WATERS IN NORTHWESTERN PART OF CROATIA

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On the pilot area of DARLINGe project, which is situated on the transnational zone of Croatia, Slovenia and Hungary favourable geothermal conditions prevails. Two main thermal aquifer complexes can be distinguished: in Mesozoic carbonates which are main thermal aquifer in the northwestern part of Croatia and in Pontian sediments, which are main thermal aquifer in the northeastern Slovenia, and southwestern Hungary and irrelevant for Croatia in the area because it contains "cold" waters. Northwestern part of Croatia represents the southwestern margin of the Pannonian Basin System (PBS), and it is characterized by high average geothermal gradient (49 °C/km) and surface heat flow (76 mW/m^2). Locally on the pilot area geothermal gradient is higher and it is in the range from 60 to 65 °C/km and surface heat flow is in the range from 80 to 96 mW/m^2.

During the pilot action WP7, thermal waters were sampled and analysed at the Hydrochemical laboratory of the Department of Hydrogeology and Engineering Geology of Croatian Geological Survey. Prior to sampling, the electrical conductivity (EC), pH and temperature (T) were determined using portable WTW probes. Total alkalinity, anions (NO_3^-, SO_4^{2-} and Cl^-) and cations (Na^+, K^+, Mg^{2+} and Ca^{2+}), $\delta^{18}O$ and δD and tritium were analysed in 30 samples. The noble gas content, carbon-14 and carbon-13 were measured in two samples.

According to the major ionic composition, water from Varaždinske toplice belongs to a NaCaMg-HCO_3SO_4 mixed type; Stubičke toplice waters belong to a CaMgNa-HCO_3SO_4 mixed type; while the rest of thermal waters belong to the CaMg-HCO_3 type. It can be observed that the groundwater chemistry is primarily controlled by the dissolution of carbonate rocks (dolomite and limestone). In addition, the saturation indices of the observed thermal waters with respect to calcite and dolomite mineral phases indicate the dissolution of carbonate rocks. Also, nMg/nCa ratio at the some springs indicated the influence of ''cold'' water during the higher water level on thermal water. In all samples, tritium activity was below 0.5 T.U. The $\delta^{18}O$ and δD showed that thermal waters have meteoric origin.

Key words: *water type, stable isotopes of D and ^{18}O, tritium, thermal waters, Croatia*

CHPM2030 – AN INNOVATIVE GEOTHERMAL PROJECT OF THE EUROPEAN UNION'S HORIZON 2020

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CHPM2030 is 42-months on-going project funded by the European Union (EU) under the programme HORIZON2020. The project is coordinated by the University of Miskolc – Faculty of Earth Science & Engineering, Hungary. The partners are organizations from 9 European countries, while 17 European geological societies, including the Serbian are contributing as "Linked third parties" supported by the European Federation of Geologists (EFG).

The strategic objective of CHPM2030 is to develop a novel and potentially disruptive technological solution that can help satisfy the European needs for energy and strategic metals in a single interlinked process. In the CHPM technology vision, the metal-bearing geological formation will be manipulated in a way that the co-production of energy and metals will be possible, and may be optimized according to the market demands.

Working at the frontiers of geothermal resources development, minerals extraction and electro-metallurgy the project aims at converting ultra-deep metallic mineral formations into an "orebody-Enhanced Geothermal Systems (EGS)" that will serve as a basis for the development of a new type of facility for "Combined Heat, Power and Metal extraction" (CHPM).

The methodology of the technical part (WP1-WP6) contains the following steps: EGS-relevant review of metallogenesis and ore deposit formation, understanding the rock-mechanical characteristics of orebodies from an EGS perspective; Laboratory experiments and simulations for orebody characteristics, leaching metals from the orebody (metal content mobilization using mild leaching and carbon nanoparticles); Laboratory experiments: recovery of the metal content by high-temperature, high-pressure geothermal fluid, recovery by electrolysis and by gas-diffusion electroprecipitation and electrocrystallization. Additional power generation by reverse electrodialysis; Conceptual framework for CHPM power plant, process optimization and simulations, CHPM schematics and blueprints; Integrated sustainability assessment: economic feasibility, social impact, policy considerations, environmental impact, ethics concerns; Planning of pilots (South

West England, Iberian Pyrite Belt, Romania, Sweden, European outlook), road mapping.

The project will increase the number of potentially viable geothermal resources all over the Europe, and introduce in global market some advanced technologies for EGS as hydraulic fracturing of the "leaching" approach under environmentally safe conditions.

The team of Serbian experts contributed to the project by collecting information on deep geothermal and metal enrichment sites which could be further evaluated as potential pilot sites for implementing CHPM methodology. As most prominent the two sites from Timok eruptive massif in Eastern Serbia, namely Borska reka and Čukaru Peki have been studied in more details. The project team has also worked on dissemination of obtained results.

The final project's meeting is taking place in May 2019, while the end of project is envisaged for 30 June, 2019.

Key words: *geothermics, extraction, heat, metal, EFG, EU*

GEOTHERMAL RESOURCES OF SERBIA

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On the basis of previous research on geothermal energy, it is determined that the territory of Serbia is characterized by its significant potential and possibilities of use. Creating geothermal database enables us to perceive the resources we have and that can be used.

Geothermal database contains more than 100 cells with various information, such as: location, object's ID, quantity, temperature, characteristics of object, lithology, hydrogeological parameters, composition of water, and source of data… The data is collected from available documentation and publications. Currently, the database contains 315 objects (spring, borehole) registered on 145 locations with water temperature more than 20 °C. Maximum temperature of 111°C is registered in Vranjska Banja. Geothermal resources are mostly used for balneology and recreation, around 100 registered resources. Additionally, geothermal water is used for heating, watersupply, bottling for fishing, and agriculture and as a technical water. 26% of all geothermal resources are used by local population or not used at all. All data are shown on hydrogeological map, where is stand out of different aquifer types: intergranular, karst, fractured, fractured-karst and water impermeable terrain. The highest temperatures are registered in south Serbia, from Vranjska Banja to north-east direction- Tulare-Sijarinska Banja- Lukovska Banja- Miraševac- Jošanička Banja, furthermore in Vojvodina, especially on the north-east border and Mačva.

Based on geothermal database the following is calculated: utilization of geothermal energy for direct heat, temperature of reservoirs according to geothermometers and different maps are created (map of water temperature; map of geothermal resources in use; map of maximum temperature of reservoirs; map of utilization of geothermal energy, map of chemical composition), hence the status of research is defined.

Moreover, silicon geothermometers are the most reliable for geothermal resources of Serbia. According to quartz geothermometers the highest temperature is expected in Vranjska Banja and Kuršumlijska Banja, 147 ºC.

Thermal capacity of all resources is 190 MW with temperature dropping on 20 ºC, and the highest thermal capacity is in Vranjska Banja, 31.07 MW. The total installed thermal capacities in 2010 are 100.8 MWt, while the annual use of geothermal energy in Serbia is 1410 TJ/year with a capacity factor of 0.44. According to the installed capacities, including 2014, the total is 104,554.00 MWt (with heat pumps 115,644.00 MWt), while 1,714.00 TJ/year is in use (with heat pumps 1,802.48 TJ/year). Overall, the total installed capacity in Serbia is 86.9 MWt, while the annual geothermal energy use is 1,113.22 TJ/year with a capacity factor of 0.53.

New results are the consequence of not taking into account the objects that are no longer in use (as well as Zvonačka Banja, Kravlje, Kuršumlijska Banja) and correction of water capacity according to available documentation.

Key words: *geothermal resources, geothermal energy, geothermal database, thermal water, Serbia*

BENCHMARKING METHODOLOGY TO FOSTER ENERGY PRODUCTION EFFICIENCY

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Efficient energy production while maintaining or achieving good status of thermal waters is an important issue worldwide. A benchmarking methodology has been developed which aims to provide an informative, easily comparable, quantitative tool for thermal water management in regions of geothermal energy usage. As part of the DARLINGe project, this will be tested and evaluated in selected thermal aquifers of the Pannonian Basin in Bosnia and Herzegovina, Croatia, Hungary, Romania, Serbia and Slovenia, based on a unified and harmonised approach.

As a first step, potential beneficiaries of the benchmarking methodology and their objectives have been identified. The five major groups of beneficiaries are: 1) management authorities, international organizations, 2) licencing authorities, 3) research organizations and universities, 4) investors in geothermal use, and 5) thermal water users. In the second step ten relevant criteria of the benchmarking methodology were defined, including transparent, harmonized, well defined and understandable terminology; a methodology with world-wide application, not dependent on local geothermal exploitation characteristics; informative, quantitative results, which are grouped into five categories (bad, weak, medium, good and very good). All data and information will be kept anonymous to avoid problems with data privacy. The key issues which can affect the quality of the benchmarking were identified and efforts will be made to minimize their impact, both during data collection and evaluation.

In the current project five benchmarking indicator types have been defined: 1) management, 2) technology and energy, 3) environment, 4) social, 5) economic. The smallest data collection and data presentation level (site/country/object/aquifer/region/river/project) was also defined for each indicator. The indicators related to management are: licencing procedure, monitoring requirements, monitoring setup and passive monitoring. The indicators related to technology and energy use are: operational issues, cascade use, thermal efficiency, and utilisation efficiency. Environmental issues are tackled with the reinjection, the over-exploitation, and the status of water balance indicators. Although waste water management should be an important environmental indicator, the current availability of present monitoring data in the Pannonian Basin show it cannot yet be applied, so it will be tested only at one Croatian river section. The social indicator will be tested based on the public awareness on site level. An example how to calculate the financial burden as an economic indicator will be presented on the level of the DARLINGe project.

For the final benchmarking assessment, results of all indicators are weighted and joined according to indicator types and re-calculated into one number which is of use when comparing the different geothermal exploitation sites.

Key words: *energy production, groundwater, thermal water, benchmarking, Pannonian Basin*

WELL-LOGGING IN THERMAL WELLS

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The measured value of most of the well-logs must be corrected according to the borehole conditions. After only correction they give the actual, supposedly true, value. The temperature log may be the simplest of all, and its values hardly need any correction. Trustworthy it is, the temperature log does not show the actual, natural temperature of the given depth, but the recent history of the borehole. This is understood well in case of the open-hole temperature measurement during the drilling, when the borehole is under the effect the mud circulating. However, the deep, multi-filtered wells can be very interesting as well (Figure 1). After shut-in, the natural or production induced pressure head difference result cross-flows between the filters. The temperature logs could show these crossflows as we show them in some case of our practice. Such interpretation uses the temperature logs measured during production and a while shut-in (the longer, the better) well.

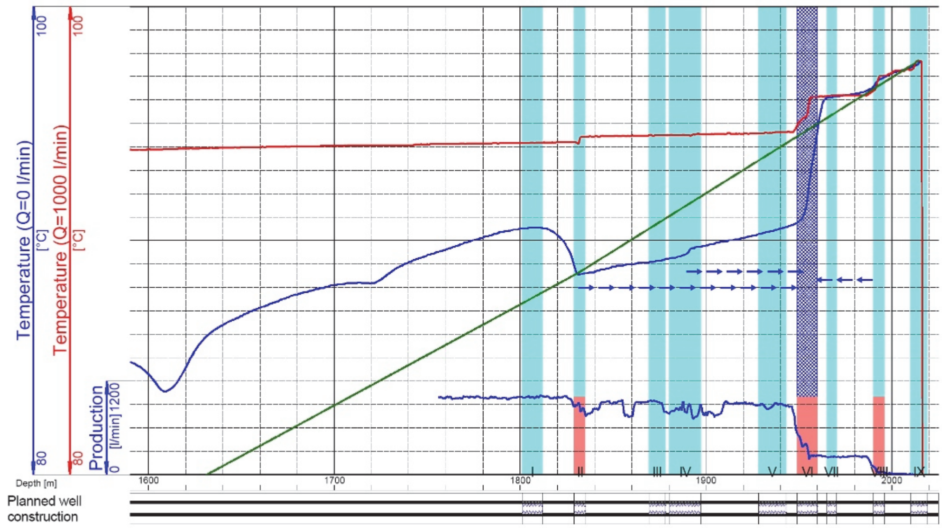

Figure 1. Example of a temperature log in deep geothermal well

Key words: *thermal wells, well-logging, temperature log, deep wells, multi-filtered wells*

UNDERSTANDING AND IMPORTANCE OF RARE EARTH ELEMENTS IN HYDROGEOLOGICAL SYSTEMS

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Rare earth elements (REE) constitute a unique series of elements in nature due to their specific features that make them powerful tracers of fundamental geochemical processes. These properties derive from the fact that the REE are generally trivalent are thus chemically fractionated from their nearest neighbors in the periodic table, and have ionic radii decrease with increasing atomic number (i.e. the lanthanide contraction). This lanthanide contraction imparts subtle and systematic differences in the chemical properties of REE across the series that are largely predictable, and thus highly useful in studies of those processes that fractionate REE in the environment. In geochemistry, the REE generally refers to the lanthanides (La–Lu) and Yttrium (Y). Hydrogeologists apply the same principles used by geologists to infer water-rock interactions, hydraulic connectivity between geologic units, and groundwater mixing members. Understanding the geochemistry of REE is important from both the standpoint of their potential use for investigating water–rock interactions, as well as for tracing groundwater flow.

In this work, a compilation and analysis of data of REE in natural waters were performed, focusing on their content and distributions in several types of groundwater (fresh, cold CO_2-rich, thermal and mineral) and corresponding aquifers. The results indicate that the rock source and solution chemistry play important roles in controlling patterns and amount of REE in groundwater. When regarding migration of these elements in different hydrogeochemical environments, the best way to analyze multivariate REE data was using the plot of reference-normalized concentrations. Normalized pattern captures key features of REE profile and allows comparison between samples and depicts anomalously enriched or depleted elements. The observed trends in REE distribution patterns among samples enhanced similarities and dissimilarities of their chemical evolutionary processes. Typically, the distribution pattern within the REE may be interrupted at Ce and Eu. Cerium occurs in the Ce^{4+} oxidation state under oxidizing conditions and europium is the only lanthanide that, under reducing conditions, can be divalent. The variations in the magnitude of the Ce anomaly could result in the difference in residence time of circulation groundwater. The positive Eu anomaly was not determined in only a few samples. The three hypotheses have been proposed for explaining positive Eu anomalies in groundwaters: (i) positive anomalies in the aquifer sediments through which they flow; (ii) preferential dissolution of Eu–enriched minerals (e.g., plagioclase); and (iii) preferential mobilization of Eu^{2+} during water–mineral interaction compared to the trivalent REE.

This study of REE has helped to highlight some of the processes and problems occurring in complex geochemical systems. The results showed that anomalies of Ce and Eu and interelement ratios between groups of REE are good indicators of the geological source and the mechanisms controlling their migration in water. These new variables enabled making groups of samples that share similar hydrogeochemical properties and indicate the influence of different types of rocks on the genesis of a hydrochemical composition of groundwater.

Key words: *REE, hydrogeochemical fingerprint, groundwater flow tracers, hydrogeological systems*

CHEMICAL AND ISOTOPIC COMPOSITION OF GROUNDWATER IN GEOTHERMAL BOREHOLE PVGT-LT1 (LITOMERICE, CZECH REPUBLIC): GENERAL IMPLICATION OF ORGANIC ADDITIVES IN DRILLING FLUID

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An exploratory geothermal well PVGT-LT1 with a depth of 2110 m was drilled in Litomerice, Czech Republic in 2007. The upper part of borehole (< 850 m) with solid casing is grouted to prevent leakage of higher quantities of water from closed system. The lower part of the borehole is seated in crystalline rock. The borehole is artesian with low yield ($Q = 0.7\ ml \cdot s^{-1}$) and very low specific capacity. Execution of pumping test is further complicated by the fact that water is saturated with gas (CH_4). The purpose of the borehole is to investigate the geothermal potential in the tectonic structure of the Eger rift. The main objectives of the project were fulfilled when the assumed temperature of 65 °C and a temperature gradient of 33.4 $°C.km^{-1}$ were confirmed at a depth of 2110 m in Proterozoic schist.

Conductivity measurements recorded an increase in water conductivity in the 400 m to 600 m section in 2015. Conductivity was about 1.1 $mS.cm^{-1}$ in the upper part of the borehole, while in the lower part of the borehole it exceeded 20 $mS.cm^{-1}$.

Measurement with a YSI EXO1 probe (combined temperature, pressure, conductivity, and redox potential sensor) was carried out in the summer of 2018 to a depth of 190 m. We found that the boundary of the water with increased conductivity had risen to depth of 110 m since 2015. After pumping about 200 l of water, samples with conductivity of 17 $mS.cm^{-1}$ were taken from the depth of 80 m for major ions analyzes, analysis of selected trace elements, analyzes of ^{13}C and ^{14}C in carbonates, and determination of tritium content. Composition of gas released from the water (mostly CH_4) and ratio of $^{13}C/^{12}C$ from CH_4 were also analyzed.

The results of analyzes reveal that the composition of the newly acquired groundwater samples differs significantly from the previously reported results of the samples taken at the borehole head. This illustrates the need for careful approach to groundwater sampling in the case of deep wells with low yield. Anomalous isotopic composition of the carbonates dissolved in the groundwater

compared with isotopic composition of the released gas on the other hand indicate that a common source of carbon is carboxymethyl cellulose (CMC) used as drilling-fluid additive controlling fluid loss. It can be assumed that biological degradation products of CMC injected into the borehole and fractures of surrounding rocks have temporarily distorted original chemical composition of groundwater in the borehole.

Key words: *geothermal borehole, groundwater chemistry, contamination, isotopic composition of carbon*

METAGENOMIC MICROBIOME ANALYSES OF NATURALLY CARBONATED MINERAL WATER FROM LOMNIČKI KISELJAK, SERBIA

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The naturally carbonated mineral water from a spring called Lomnički Kiseljak, traditionally used for balneotherapy and commercially bottled, is extracted froman unconfined intergranular aquifer, whose matrix comprises Neogene clays, sandstones, conglomerates and clastic tuffites. They are underlain by Late Cretaceous flysch formations, represented by a sequence of sedimentary rocks, including marls, sandstones, cherts and limestones, in places alternating with Precambrian crystalline schists (gneiss, quartzite and amphibolite), with intercalations of acidic granitic plutons (orthoclase, plagioclase, amphibole, muscovite, quartz, etc.). In 2018, metagenomic microbiome analyses of this water were conducted for the first time in Serbia, applying Next Generation Sequencing (NGS) techniques.The sample came from a 9 m deep well with a capacity of 30 L/s, located within the hydrogeologic province of the Serbian Crystalline Core, as the oldest part of the Balkan Peninsula. DNA was extracted by filtration. After library preparation following the16S rDNA gene Metagenomic Sequencing Library Preparation Illumina protocol, the libraries were sequenced on a MiSeq Sequencer. Denoising, paired-end joining, and chimera depletion was performed starting from paired-end data using the DADA2 pipeline. Taxonomic affiliations were assigned using the Naive Bayesian classifierintegrated in qiime2 plugins, with taxonomic assignation related to the SILVA_release_132 database. Based on its physical and chemical characteristics, the carbonated mineral water from Lomnički Kiseljak belongs to the bicarbonate class (HCO_3^- 1586.0 mg/L) and sodium subclass (Na^+ 500.0 mg/L), and has a relatively high mineral content. Depending on external hydrologic conditions, TDS ranges from 2500 to 6700 mg/L. The water is cold (9.8°C to 14°C), mildly acidic (pH 6.5), and has elevated concentrations of dissolved CO_2 (990 mg/L) and free CO_2 (2000 mg/L). Active and disjunctive fault zones are the primary areas of carbonated water movement and storage. The relatively high concentration of CO_2 originates from thermal metamorphic processes on a crystalline substrate, caused by granitic intrusion. According to diversity and richness indexes (Chao1, ACE, Shannon, Simpson and Fisher), the microbial alpha diversity washigh. The most relatively abundant taxonomy rank was Rhodobacteraceae family (more than 56%). Other families (Gallionellaceae and Burkholderiaceae) from the Gammaproteobacteria class

were also detected (1.5 and 3.4%), respectively. Interesting results were obtained at the genus level, with a relative abundance of more than 1% for the following genera: *Maritimimonas* (5.8%), *Phreatobacter* (4.2%), *Planktosalinus* (2.7 %), *Acinetobacter*(1.5%), *Geminocystis* (1.2%) and *Sulfuritalea* (1.1%). The research shows that even mineral water,whose TDS and CO_2 concentration are a typical, like that from Lomnički Kiseljak, is characterized by specific microbial communities. Very little is known about this subject matter at present, at least in Serbia. Apart from their significancein terms of determining the stability of the well and the sanitary and hygienic adequacy of the particular water resource, the results of this research complement standard hydrogeological investigation methods with the latest advances in molecular biology in Serbia and worldwide.

Key words: *carbonated mineral water, metagenomic microbiome analyses, 16S rDNA, aging well health risk.*

METAGENOMIC MICROBIOME ANALYSES OF SALINE MINERAL WATER FROM SLANKAMEN BANJA, SERBIA

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The saline mineral water captured and used for multiple purposes by the Special Hospital for Neurological and Post-traumatic Disorders "Dr. Borivoje Gnjatić" in Slankamen, Serbia, is formed in an unconfined karst-fractured aquifer whose matrix comprises Pliocene and Miocene lithotamian, ceritic and sandy limestones, which discordantly overlie Anisian and Ladinian limestones and serpentinites. In 2018, metagenomic microbiome analyses of this water were conducted for the first time in Serbia, applying Next Generation Sequencing (NGS) techniques. The sample came from well B-1 (Slanjača), which is 3.6 mdeep, has a capacity of 0.5 L/s, and is located within the hydrogeologic province of the Pannonian Plain. DNA was extracted by filtration. After library preparation following the 16S rDNA gene Metagenomic Sequencing Library Preparation Illumina protocol, the libraries were sequenced on a MiSeq Sequencer. Denoising, paired-end joining, and chimera depletion was performed starting frompaired-end data using the DADA2 pipeline. Taxonomic affiliations were assigned using the Naive Bayesian classifier integrated in qiime2 plugins with taxonomic assignation related to the SILVA_release_132 database. Based on its physical and chemical characteristics, the saline mineral water in Slankamen Banja belongs to the chloride class (Cl^-– 4150.0 mg/L) and sodium subclass (Na^+– 2370.7 mg/L), and has a relatively high mineral content (TDS –7435 mg/L). It is cold (T – 17°C) and low alkaline (pH 7.4), with elevated concentrations of significant balneotherapeutic microelements: Sr^{2+}(50 mg/L), B^{3+}(3.23 mg/L) and J^- (2.7 mg/L). The absolute age of the water is estimated at 132,500 years. According to diversity and richness indexes (Chao1, ACE, Shannon, Simpson and Fisher), the microbialalpha diversity was high. The most relatively abundant was the Rhodobacteraceae family (19.9%), followed by Rikenellaceae, Methylophagaceae and Gallionellaceae (9.5, 4.4 and 1.3%), respectively. The dominant genera in the sample were: *Chlorobi*(10.3%), *Methylotenera* (8.5%), *Flavobacterium* (4.6%), *Melioribacter* (3.7%) and *Dechloromonas* (3.2%). Other, relatively less abundant genera were detected as well, including: *Terasakiella* (1.8%), *Sedimenticola* (1.6%), *Thermincola* (1.4%), *Arcobacter* (1.3%), *Bellilinea* (1.2%), *Methyloprofundus* (1.1%) and *Pseudomonas* (1.0%). Although the relative abundance of some genera was in the 1-0.5% range, they should still be mentioned: *Sulfurimonas, Fervidobacterium,* *Gallionella, Thermoanaerobaculum, Hydrogenophilus* and *Magnetovibrio*. The conclusion is that the saline mineral water in Slankamen Banja supports the development of specific biocenoses. Very little is known about this subject matter, at least in Serbia, given that up to the end of the past century hydrogeologists generally believed that mineral water was not a suitable environment for life forms due to the restrictive nature of the geologic framework in which the water occurs.The results, apart from their significance in terms of determining the sanitary and hygienic adequacy of the particular water resource and the stability of well B-1 (Slanjača), help solve the puzzle of all the tested parameters that characterize an occurrence of mineral water.

Key words: *saline mineral water, metagenomic microbiome analyses, 16S rDNA, health risk, Serbia.*

GEOTRIP FIELD GUIDE

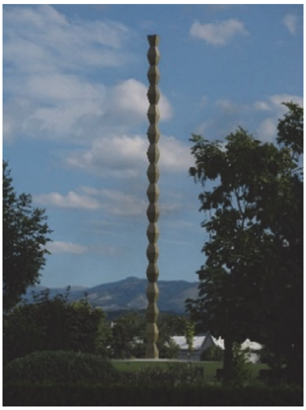
Organization of the Geotrip (Stevanović Z., Iurkiewicz A., Popa I.)

The idea to invite colleagues from all over the world and present beauties, we may say even wonders of geology, landscape, culture, of the Southern Carpathians and Danube which are shared between Romania and Serbia is not new. There were many events, excursions and special trips organized by the geologists of the two countries since the end of the 19 century. Some of them were jointly organized, such as post conference field trip of the "*Theoretical and Applied Karstology*" in 1996, or the International conference "*Geology of the Danube Gorge*" in 1997. Long-term successful cooperation between Romanian and Serbian geologists got a new platform in 2016, when a bilateral agreement – Memorandum of Understanding has been signed between Serbian and Romanian geological societies. It was thus very logical to first author of this introduction, when he started to chair the IAH Karst Commission (KC) in 2017 to propose to organize one international geotrip in karst of Southern Carpathians, in Romania between rivers Danube and Olt, and in Serbia in Djerdap gorge area. Geotrips were practiced in the first decades of the KC work and idea to renew this activity on annual or bi-annual basis was uniformly accepted by actual members and friends of the KC. The success of this idea is witnessing by number of participants of this geotrip.

The tour comprises sites in both countries but decision was to publish separate geotrip guides, this thus contain just explanations for the sites to be visited in Serbian side, while the route in Romania is illustrated by some photos from archive of Z. Stevanović.

Romanian karst

Day 1: Donji Milanovac (Serbia) - Crossing Romanian border at Djerdap Dam on Danube (Port de Fier) – Baia de Arama – Ponoarele (stone „God bridge“, karrenfeld, Podului cave) – Closani Cave, Brebina (Trout Nursery lunch) - Izvarna karst spring (supplying water to city of Craiova) –Tismana Monastery and cave – Tirgu Jiu



Day 2 Sohodol / Runcu gorges – Trgu Jiu (Monumental complex "The Heroes Path" of Brancusi) – Muierilor cave – Polovragi cave and Oltet gorges – Olari (Horezu) village pottery – Lunch - Horezu Monastery, UNESCO heritage site – Horezu

Day 3: Costesti – Open air museum of Trovanti (alternatively Bistrita gorge, narrowest in Romania) – Craiova – Lunch (optionally visit of Corcova Winery) - Turnu Severin – Crossing border to Serbia – Donji Milanovac (dinner, overnight stay)

Serbian karst

Day 1 Valja prerast stone bridge – Majdanpek copper mine field – Rajkova cave – Boljetin / Geological cross – section over Jurassic limestones – Lepenski Vir archeological site – Donji Milanovac






Day 2 Djerdap National Park Visitor centre – Presentation of activities and nomination for UNESCO Geo Park – CEG Conference - Boat tour over deep Danube gorge – Donji Milanovac

Day 3 Golubački grad fortress on Danube and Viminacium Roman Limes military camp archeological site

Danube Gorge – An overview

(compiled by Z. Stevanović and D. Milovanović from the Proceedings of the International Symposium "Geology in the Danube gorges", D.Milanovac 1997, and Field Trip Guide in the Framework of the XVI Serbian Geological Congress 2014)

The Danube River Basin is Europe's second largest river basin, with a total area of 801,463 km². More than 80 million people from 19 countries share the Danube catchment area, making it the world's most international river basin (ICPDR, 2009).

The Danube River Basin (www.researchgate.net, uploaded by Albert J. Kettner)

Danubian gorge is the largest, deepest and the most beautiful gorge in Europe. It separates Banat Mountains from the Eastern Serbian Mountains and connects the Pannonian and the Dacian basins. The gorge is approximately 100 km long, extending from Golubac to the Romanian town Gura Wye.

Serbian famous geographer, Cvijić, started from the fact that the Pannonian and the Vlachian-Pontian basin were about ten million years ago filled with sea-water and with numerous islands rising above (Grubić, 1972). Although these two seas were partially separated by low-altitude Carpathian-Balkan mountain range, the communication between them was established. One of these connections like inlet was on the route of the present Danube flow. Additionally, Cvijić (1908) emphasized that the decrease of the sea level resulted in overrun of the Pannonian Sea into the lower Vlachian-Pontian Sea. Therefore, the outflow between these two seas was formed. The further evolution turned both seas into lakes while the outflow "Pra-Djerdap" remained. Finally, before the last ice age took part, large lakes were either broken into smaller or disappeared allowing the Danube to flow across bottoms of the Pannonian and Vlachian-Pontian basins (Marović *et al*. 1997).

The Danube River, after crossing territories of 11 European states enters Near Golubac, the Upper or the Golubac gorge, which is composed of Jurassic and Lower Cretaceous limestones, Hercynian granite, Paleozoic schists and green Ripheum/Cambrian complex. The Danube reached, before the construction of dam, 400 m in width while isolated cliffs Babakaj (limestone) and Stenka (granite), rose from its bottom.

Another gorge, Gospođin Vir is downstream. It is composed of green schists, Permian red sandstones with porphyrite, Gresten type Liassic, Clausian beds, micrite of the Upper Jurassic and Neocomian, Barremian, Aptian and Albian marls and marly limestones with ammonites. Danube cut its channel, 200 to 380 m wide, in these rocks up to 82 m depth before being dammed - the greatest river depth in Europe. In this section of the gorge were on the right bank of the Danube, at Lepenski Vir, discovered remains of a prehistoric settlement which have had approximately 120 homes and 400 to 500 inhabitants. Remains of specific architecture, civilization and culture, dated back to some eight to four thousand years ago, have been relocated to a place out the reach of the Danube waters.

Behind the noticeably Greben cape, the broad basin of Donji Milanovac where Danube is nearly 2 km wide, is. There it receives the right tributary, Porečka Reka. The basin is mostly filled with Miocene marine sediments that suggest the presence of trans-Carpathian Miocene straits. The famous Kazan (Cazane) gorge is downstream of the Porečka Reka confluence. It consists of Veliki Kazan and Mali Kazan and the small Dubovo basin between, which is on the Romanian side. The Danube is in Veliki Kazan only 150 - 170 m wide and up to 54m deep in places. Nasty barren limestone walls and cliffs rise exceeding occasionally 300 m above the water. Crystalline schists, Hercynian granites, Jurassic and Lower Cretaceous limestone, Albian marls, Upper Cretaceous flysch and Sinaia beds are exposed in Kazan. During the ancient Roman times the narrow Trajan's road was cut in steep Kazan cliffs. It was the only pass through the gorge for centuries. At the end of the gorge is the well-known *Tabula Traiana*.

Leaving Kazan, the Danube enters into the extensive Oršava basin and receives the big left tributary, Černa. The basin is built of crystalline schists, granites, Sinaia beds, Upper Cretaceous flysch and Neogene sediments. Two islands, Ogradina and Ada Kale, are situated in the upstream and downstream ends of the Oršava basin. On the Serbian side of the basin is the city of Tekija.

The last structure of the channel, the Sip gorge, lies down the Černa. This gorge consists of crystalline schists, Jurassic limestone, Sinaia beds and Upper Cretaceous flysch. Although is this strait neither very narrow (its width is about 500 m) nor its sides are particularly high, the swarms of projecting cliffs (Pregrada and Prigrada barriers) downstream of Sip, caused the biggest trouble to navigators. It was these cliffs that revealed the name ”Iron Gate”. At the exit from the canyon, the big hydroelectric power plant Djerdap has been built, representing now one of the largest structures of that kind in the world, actually the fifth in the world.

Kazan Gorges on the Danube River (from Police plateau)

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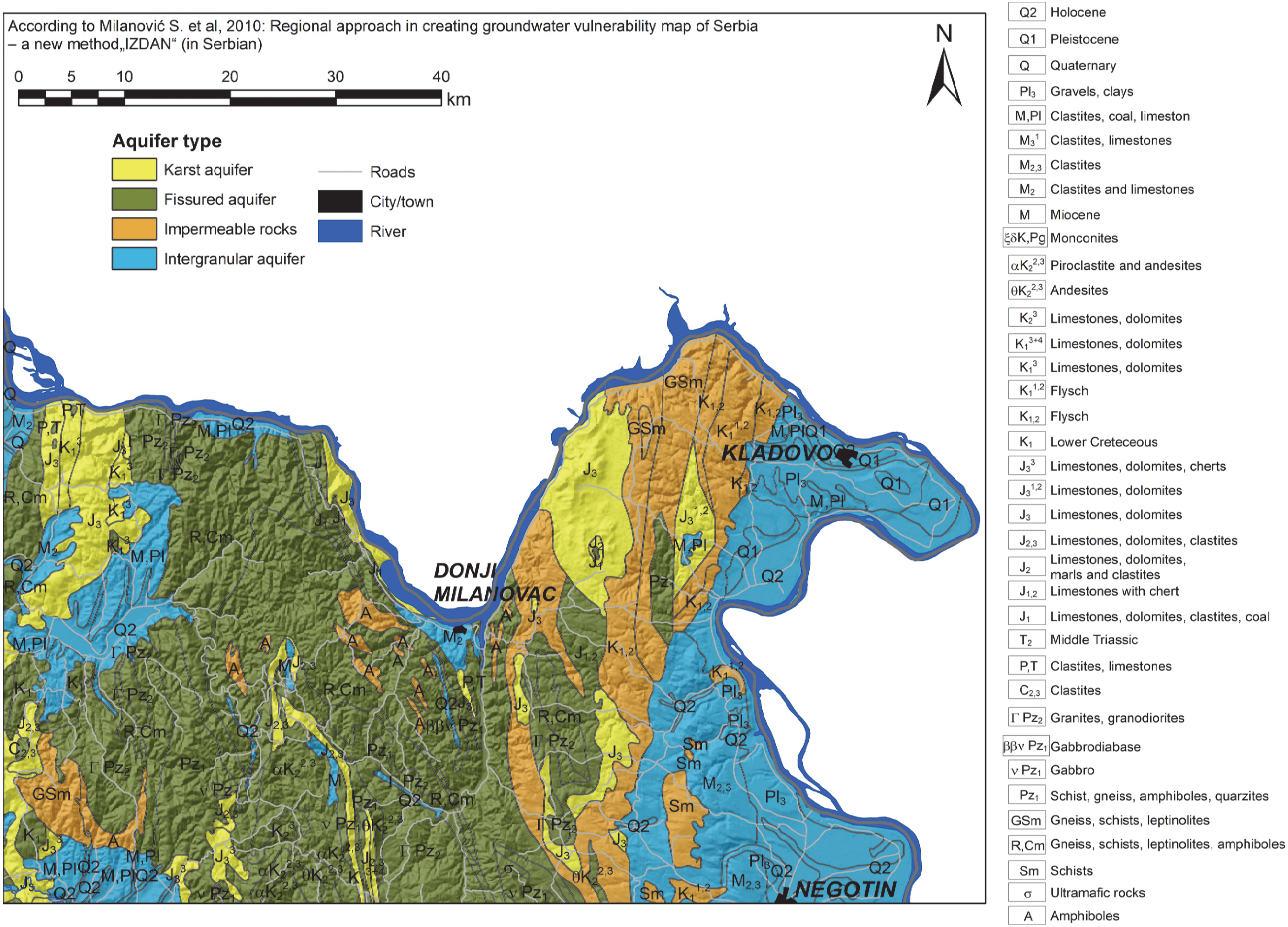

According to Milanović S. et al, 2010: Regional approach in creating groundwater vulnerability map of Serbia – a new method„IZDAN“ (in Serbian)
0 5 10 20 30 40 km
N
Aquifer type
Karst aquifer
Fissured aquifer
Impermeable rocks
Intergranular aquifer
Roads
City/town
River
DONJI MILANOVAC
KLADOVO
NEGOTIN
Q2 Holocene
Q1 Pleistocene
Q Quaternary
Pl3 Gravels, clays
M,Pl Clastites, coal, limeston
M3 1 Clastites, limestones
M2,3 Clastites
M2 Clastites and limestones
M Miocene
ξδK,Pg Monconites
αK2 2,3 Piroclastite and andesites
θK2 2,3 Andesites
K2 3 Limestones, dolomites
K1 3+4 Limestones, dolomites
K1 3 Limestones, dolomites
K1 1,2 Flysch
K1,2 Flysch
K1 Lower Creteceous
J3 3 Limestones, dolomites, cherts
J3 1,2 Limestones, dolomites
J3 Limestones, dolomites
J2,3 Limestones, dolomites, clastites
J2 Limestones, dolomites, marls and clastites
J1,2 Limestones with chert
J1 Limestones, dolomites, clastites, coal
T2 Middle Triassic
P,T Clastites, limestones
C2,3 Clastites
Γ Pz2 Granites, granodiorites
ββν Pz1 Gabbrodiabase
ν Pz1 Gabbro
Pz1 Schist, gneiss, amphiboles, quarzites
GSm Gneiss, schists, leptinolites
R,Cm Gneiss, schists, leptinolites, amphiboles
Sm Schists
σ Ultramafic rocks
A Amphiboles

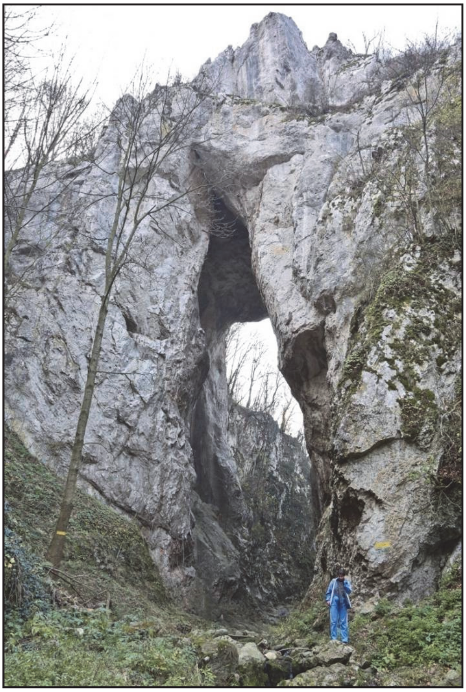
VALJA PRERAST, NATURAL BRIDGE

(by Milovanović D., Kličković M., from the Field Trip Guide
in the Framework of the XVI Serbian Geological Congress 2014)

"Prerast" is a limestone arch forming a natural bridge - the remnant of the roof of a short, wide tunnel-like channel of a water-course. This landform is a common geomorphologic feature in Carpathian karst of eastern Serbia.

Two models have been proposed for the creation of natural bridges. One (earlier) was given by Cvijić (1924) who assumed that a natural bridge is a result of an advanced stage in the river cave history, i.e. the remnant of a cave roof that has collapsed. The other, more recent model is given by Gavrilović in 1998: "Natural bridges are often found at the contact of calcareous and non-calcareous rocks. In a river channel, these rocks are of different resistances to erosion break at the contact and let water percolate into carbonate rocks. Rocks break at the lowest point of the contact line in the relief, and further through carbonate rocks to the ponor zone." According to the same author, the creation of a natural bridge of a cave or tunnel depends only on the width of the carbonate rock layer.

The natural bridge on the Valja Prerast, a right tributary of the Saska River near Majdanpek, was created after the latter model. This landform is located 1.3 kilometers upstream of the Valja Prerast confluence with the Saska River. It forms a large natural stone bridge in a narrow belt of massive Tithonian/ Valanginian limestones. The Valja Prerast channel, at the altitude of 290 m, is only 1.5 m wide, narrowed by the construction of a road under the bridge. The bridge opening at the base, at the river bed and road level, is 9.7 m wide and 36.8 m high. Limestone of the bridge arch is 8 m thick, its upper level is 44.8 m high. The riverbed under the bridge slopes approximately 6 m, or 60%.



Valja Prerast near Majdanpek

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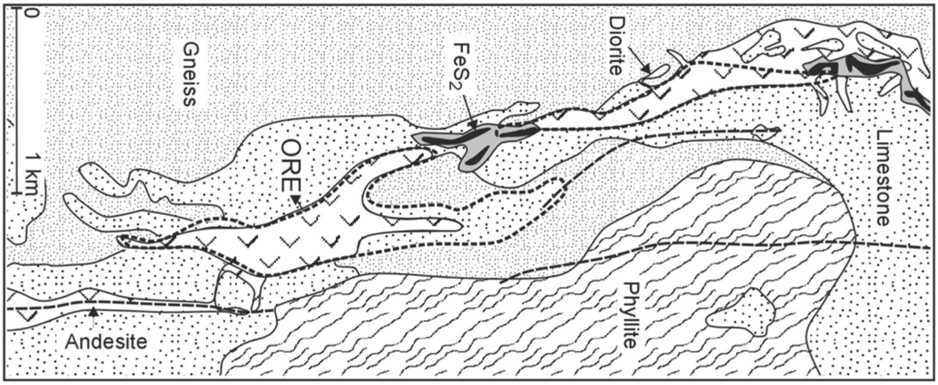
MAJDANPEK ORE FIELD

(by Banješević M., modified, from the Field Trip Guide
in the Framework of the XVI Serbian Geological Congress 2014)

The Majdanpek ore field is located in the far northern part of the Timok magmatic complex. In its central part is located the Majdanpek copper deposit formed in andesite massif of Upper Cretaceous and Paleogene ages.

Until 1962, the Majdanpek deposit was a mine of massive pyrite and limonite. Since 1962, this large porphyry copper deposit was mining by open pit with annual output of 12-14 Mt. The reserves exceeded 800 Mt of ore, containing 0.4-0.8% Cu, and 0.25-1 g/t Au (the mine operation started with ore grade of 0.82% Cu and close to 0.8 g/t Au). Apart from the copper, the deposit had significant reserve of massive pyrite (about 15 Mt), and a few million tons of lead zinc ore (grade 7% Pb+Zn). Pyrite contains 3-15 g/t Au.

The Majdanpek deposit consists of several type of ore mineralization: the dominant porphyry copper mineralization, massive sulphide pyritic ore bodies, skarn magnetite mineralization, and lead-zinc sulphides orebodies of massive replacement and hydrothermal vein types. The Majdanpek deposit was formed along a very narrow (up to 300 m. wide) and 5 km. long zone between the Jurassic limestone and the Old Paleozoic gneisses. This zone was intruded by minor dykes and sub-volcanic intrusive bodies of andesite, and dykes of quartzdiorite porphyry, which occur sporadically indicating a larger pluton at depth.



Geological sketch map of the Majdanpek porphyry copper deposit.

In the Majdanpek deposit, currently, mining activity proceeds in two areas: Southern Area and Northern Area, in which all so far discovered ore bodies of different mineralization types are located:

Ore bodies of Southern Area. Porphyry copper deposit "Southern Area" - Majdanpek is the largest one in Majdanpek ore field. It is located to the S-SW from Majdanpek at the distance of about 500 m. It contains the largest ore body of Cu-Au porphyry mineralization and ore body of massive Cu-Au-Ag pyrite mineralization. Bearing in mind its dimensions at presently uncovered area, the lowest open pit benches, as well as data from exploration drill-holes, it may be concluded that it contains significant ore reserves with incompletely established quality.

Ore body “Southern Area” is spatially localized in hydrothermally altered andesites, micaschists and gneisses of amphibolite facies. In hanging wall of deposit to K+200m. andesites have been predominant rocks in direct geological structure of the ore body, in order that, with the increase of depth, their percentage contribution should be diminished. As a difference from andesites, which, under the influence of hydrothermal ore-bearing solutions to a lesser degree and surface degradation, have been disintegrated, gneiss-granites as rock complexes are characterized by larger hardness due to higher content of silica and represent a more stable operating environment.

Ore bodies of “Northern Area”. Mining field Northern Area is located about 1 km N-NW from Majdanpek and this field contains: polymetallic-gold deposit “Tenka” (Tenka-l, Tenka-2 and Tenka-3), porphyry, i.e. stockwerk-impregnation ore body “Dolovi-l” and “Central ore body”, massive-sulphide ore body “Dolovi-2” and Cu-pyrite ore body “Stari Dusan” and limonite ore body “Blansard”.

Northern area ore body in Majdanpek

Polymetallic-gold deposit “Tenka”. This deposit is located in the far northern part of “Northern Area” of copper deposit Majdanpek. It comprises the area of irregular trapezoid form, whose strike is N-S, longer side about 650 m., while shorter side ranges from 150 -250 m. Polymetallic sulphide mineralization is spatially limited to the western part of ore mineralized zone. Polymetallic, as well as Cu-pyrite ore mineralization has been deposited in scarnized limestones, tectonic breccias and partly in andesites.

Drainage of open mine pit of Majdanpek

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RAJKOVA CAVE

(by Lazarević R., Dragišić V., Stevanović Z., modified from the Field Trip Guide in the Framework of the XVI Serbian Geological Congress 2014)

The Rajkova Pećina cave is located 2 km. from Majdanpek near Mali Pek River and the Veliki Zaton artificial lake. Rajkova Pećina got its name from the renowned the Duke Rajko (Vojvoda), who is thought to have lived in the 19th century. According to tradition, he was an innkeeper by day, but by night he robbed Turkish caravans and hides a treasure in this cave. The cave was first explored by Jovan Cvijić in 1894 (results published in 1895) but research was not continued until the 1970s, when restarted under the leadership of Radenko Lazarević. The cave was firstly opened to visitors in 1975, while touristic path was revitalized and extended in 2014-2016.

Rajkova Cave is formed in Upper Jurassic massive reef limestones of the Konjska Glava limestone massif. The carbonate rock complex lies over pre-Cambrian and early Paleozoic schists and under Upper Cretaceous (Senonian) rocks of a flysch complex, in its southern extent (Stevanović *et al*. 1996).

This and the nearby Paskova Cave were formed by the Rajkova and the Paskova Rivers, which developed their hydrographic basin on crystalline schists. Both rivers flow to the south and sink at the contact of these rocks with the Upper Jurassic limestones through concentric swallow holes, and partly run under ground, emerging on the surface in Rajkova and Paskova Caves.Through its long history, the Rajkova Reka has formed cave channels at two levels: the higher dry and the lower a river cave system. The two cave levels are physically differentiated: upstream swallow hole and outlet spring caves. Each part of the cave has two speleological systems or floors, each specific in morphologic and hydrologic characters.The total length of all explored cave channels in both dry and river systems is 2304 m., or about 2380 m. including the breaks (Lazarević, 1976 updated). The cave abounds in speleo-thems: stalactites, stalagmites, draperies, dripstones, flowstones. The Crystal and the Hedgehog Halls are two notable chambers of the cave system.Opening of new paths and extension of touristic route enable visitors to evidence an excellent example of creation of perpendicular net of channels of underground stream as result of numerous faults and fractures of that same direction. The Rajkova cave stream appears at Rajkova cave karst spring just beneath the main entrance. Water of that spring is utilized to support potable water supply of the Majdanpek city. Average discharge is around 40 l/s (Stevanović, 1991).

Rajkova cave speleothemes

Rajkova cave spring, the pipe divert part of water to the city

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BOLJETIN AND PESAČA JURASSIC AND CRETACEOUS SECTIONS

(by Rabrenović D., Vasić N., from the Field Trip Guide in the Framework of the XVI Serbian Geological Congress 2014)

Boljetin River Gorge

In the small and beautiful gorge of Boljetin river is exposed continuous geological column from transgressive Dogger to Aptian.The base of this geological column is of red Permian sandstones and ignimbrites in Lepena. The Jurassic part of the column is divided into following formations:

Bivolja Stena Formation is the lowest unit (6 m) composed of sandstones and conglomeratic sandstones (Bayesian).

Lepenski Vir Formation (15 m) in the lower part is composed of Bayesian sparitic limestones and in the middle and upper part of knotty micrites and biomicrites with filaments and Callovian ammonites (*Macrocephalites macrocephalus*).

Pesača - Greben Formation, first 10 m. are platy and layered micrites, biomicrites with filaments and radiolarians, and the upper part is with cherts (Oxfordian). In upper level is interchange of layered and platy, gray and reddish micrites, biomicrites with filaments and radiolarians, intrasparites, intrasparudites and cherts. Fossils (ammonites and aptichuses) originate from knotty limestones in Upper Kimmeridgian and Upper Tithonian. The sediments of Lower Cretaceous are divided into geological formations.

Limestones and sandstones in Boljetin Gorge

Berriasian (17 m) is composed of gray ("lithographic") micrites with aptichuses and rare chert nodules. **Valanginian** (38 m) includes gray marly micrites and marls with cherts. Hauterivian (60 m) is of gray-greenish marly micrites and marls with ammonites.

Barremian and Aptian (120 m) is represented by alternation of marls and marly limestones with Barremian ammonites (downward) and by gray-greenish marls and clayey sandstones with ammonites and rare belemnites (upward).

Pesača section

On the Danube River bank between Pesača and Dobra the complete Jurassic lithological column is developed, from the Earliest Jurassic - basal Hettanginian facies to Lowest Jurassic -Tithonian sediments. Therefore, the development of Jurassic and Cretaceous deposits in this area is considered to be an important part of geological history of Mesozoic evolution in this part of Europe. A typical column of the South Carpathians can be observed at the Pesača.

Earliest Jurassic of the Pesača (Hettanginian, Sinemurian)

The beginning of Early Jurassic transgression is marked by medium-grained, whitish to light-reddish, up to 2.5 m, quartz sandstones with slight appearances of oblique bedding. Stratigraphically, the whole series (up to 35 m. thick) corresponds to Late Hettanginian and Sinemurian. First fossils of Early Jurassic pelecypods *Cardiniagiganteus* (Quenstedt) in this column were found in the pile of beds with stratigraphic height of 35-39 m.

Plensbachian

Along the old road by Pesača, a few tens of steps from new road, a three particularly thick beds of sandy limestones (sandy biomictites) and sandstones with brachiopods can be encountered. The most common brachiopod species are: *Terebratula grestensis*, Suess., *Lobothyris punkata* (Sowerby)**,** *Rhynchonella variabilis Sow*., *Liospirjerina rostrata*.

Black limestones (biomicrites) contain abundance of pelecypods, brachiopods, less frequently belemnites. The following species were determined: *Pseudopecten (P) equivalves, Pecten liassinus, Liogryphaea gigantea, Liogryphaea cymbium, Entolium (E) lunare; Belemnites: Belemnites pexilosus.* Above biomicrites with pelecypods lies a pile of siltstones and clayey biomicrites with belemnites, brachiopods (stratigraphic height 70-73 m).

Complete sedimentological determination of these sandstones as “sandy calcite-ankerite-siderite rocks” with chamosite oolites was carried out by Vasić (1992). Ammonite species *Hyldaites striatus*, as well as a number of belemnite specimens were found, which implied the Toarcian age of pile of sandstones with chamosite oolites.

Middle Jurassic (Dogger)

Within Middle Jurassic rocks in this area two facies can be distinguished: “Claus beds with ammonites” and “Possidonian beds”. Claus beds are typically developed on Greben, while Possidonian beds were observed by the Pesača. The determined Brachiopod species was *Cymatorhynchia quadriplicata*.

The most commonly present are the species from the genera: *Phylloceras, Calliphylloceras, Holcophylloceras, Bullatimorphites, Macrocephalites, Cadomites, Perisphinctes etc*.

Middle Jurassic sediments in Pesača zone

Late Jurassic (Malmian)

The final part of the Pesača lithostratigraphic column is marked with complete development of all Late Jurassic equivalents, as well as the transition to Early Cretaceous (Oxfordian, Kimmeridgian, Tithonian and transition to Berriasian). Lithologically, the development of these sediments was very composite, which implies very specific deposition environment characteristics.

Oxfordian

Oxfordian rocks conformably overlie red-colored Middle Jurassic beds (facies of marls and marly limestones with *Bossitra alpina*), and they are represented by gray and yellowish bedded marly limestones with cherts. The limestones are micritic, with variable bed thickness (5-25 cm). Total thickness of all the bedded limestones in this column is about 28 meters (interval 206-234). These deposits are green, sometimes pink in color, and very hard.

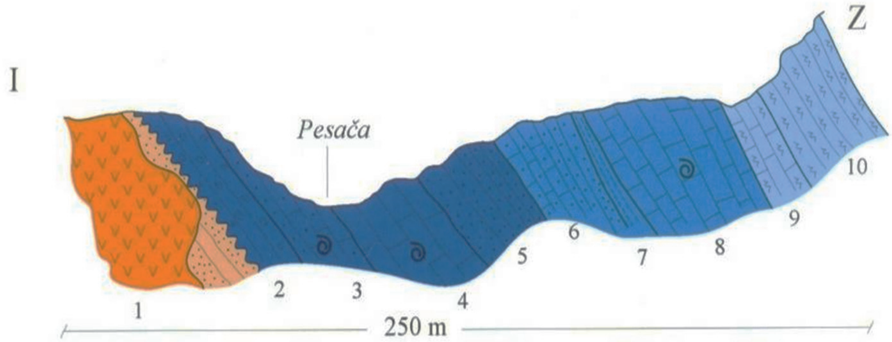
Kimmeridgian

Kimmeridgian stage sediments can be found across a large area from the Pesača to Donji Milanovac. The bedding and color of these sediments, along with a wide distribution, makes them very remarkable on the outcrops, especially in Gospođin vir gorge. Some of the localities are granted the status of “Objects of Special Importance”, such as the

Boljetinska river canyon and Lepensko hill. Between the Pesača and the village of Dobra, the red-colored sediments known as "accanthic limestones" or "beds with *Aspidoceras accanthicum*" were discovered in the Pesača canyon, and steep escarpments of Sokolovac.

Tithonian

Tithonian stage is the most widely distributed and the thickest among all the Jurassic stages. Tithonian limestones constitute the areas of Sokolovac, Dojke and Bosmanski cape, extending further towards upper part of Kozicka River as small isolated limestone patches. Regarding distribution patterns, two parts can be distinguished within Tithonian deposits - lower part, represented by bedded limestones with cherts, overlying Kimmeridgian red sediments, and upper part, represented by massive limestones with chert nodes, which is the final member in Jurassic column of this area. The lowest horizons, overlying Kimmeridgian deposits, may seldom contain ammonite shapes from the genus *Lytoceras*, however, upper horizons are lack of any microfauna. On the way from the Pesača to Bosman and Bosmanski cape the transition from massive Tithonian limestones to Early Cretaceous thin-bedded and plated shaly limestones is observed.



Geological profile of Pesača (after Rabrenović & Vasić). The classic development of marine Jurrasic in the Southern Carpathians (proposed for the State protection). Key: 1. Permian clastics and volcanics, 2. Basal conglomerates and sandstone of Lower Jurassic, 3,4,5. Barrier-laggon clastics and carbonate with marine fauna (Upper Liassic) 6,7. Sub-arcose and limestone of the Lower Dogger, 8. Layers of Bossitra alpina and ammonites, Doger, 9. Limestone with cherts from the Upper Jurassic, 10. Radiolarites, Upper Jurassic.

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CULTURAL HERITAGE OF THE SERBIAN LOWER DANUBE: LEPENSKI VIR, GOLUBAČKI GRAD, VIMINACIUM

(compiled by Z. Stevanović)

Lepenski Vir

(Source En.wikipedia.org/wiki/Lepenski_Vir, modified)

Lepenski Vir is an archeological locality discovered in 1960 and explored from 1965 to 1970, when protective excavation was carried out in many archeological localities on the Danube banks affected by construction of the Djerdap I power plant on the Danube. Lepenski Vir is located in Djerdap Gorge, in a small cove near the Boljetinska Reka mouth. The eponym is the Lepenski Vir cultural locality which, between 6800 and 5400 B.C. in a limited area of Djerdap, gave a specific architecture and a monumental stone sculpture, unique in Europe of the time, and in prehistorically era in general.

The sculptures of Lepenski Vir are made of massive cobbles, decorated with paints and featured and ornamental engravings. The featured sculptures represent styled human face, or torso with head, and those of animal's fish images and stag heads.

House bases, cast in compact calcareous mass of reddish color, have distinctly geometrical shapes of truncated circle sector. Rectangular hearth, built up of upside stone blocks, runs across the median line of the house, encircled with wide stone plates, sacrificial altar, and cobble-sculptures. In front of the hearth, at the face of the house, oblique stone steps are laid. Houses are facing the river and are built around a free space, some kind of square. Remains have been excavated, under old Neolithic layers, of seven successive communities of the Lepenski Vir culture, separated in three layers (Protolepenski Vir, Lepenski Vir I, and Lepenski Vir II).

Lepenski vir, archeological locality

Golubac old town

(Source: En.wikipedia.org/wiki/Golubac_Fortress, modified)

The monument of medieval military architecture. According to traditional narrative stories it was built between 13th and 15th century in order of military defense and for controlling migrations of people in the mainland as well as along the Danube. The Old Town base was set on steep cliffs and escarpments of Cretaceous rock that descended deep into the Danube. Historical sources about the City are scarce. It is assumed that it was built by Hungarians in the second half of the 13th century for defense of properties on the right Danube bank. The Old Town has frequently changed rulers. Hungarians, Serbs and Turks were alternating until the Second Serbian rebellion (1815) when the Golubac city was liberated and soon after lost its importance as a fortified city.

Architectural basis of the Old Town is irregular, adapted to configuration. The Old Town fortress consists of 9 towers with square bases, about 25 m. in height. Towers are mutually connected with 3 meters thick walls. Towers were built mainly of stone with small amounts of brick. Quadrangular tower, which is surrounded with water represented former orthodox temple. Interior and stairs are built of wood. The town was below the wall on the west side surrounded by water trenches, though the entrance to the fort was over movable bridges. Access to towers is now very inconvenient, but in the nearby future is planned a comprehensive reconstruction of the city, including displacement of traffic. In 1948 the Golubac city was declared as a cultural monument and in 1979 was announced as the monument of outstanding importance in Serbia. The Old Town Golubac also represents the entering, western gate of the National Park Djerdap, and its recently reconstructed including opening of visitor center with exhibition room.

Golubac fortress

Viminacium

(https://en.wikipedia.org/wiki/Viminacium, modified)

The remains of Viminacium, the capital of the Roman province of Moesia Superior, are located on territories of the villages of Stari Kostolac and Drmno, about 12 km from the town of Kostolac and about 130 km SE of Belgrade. Viminacium was one of the most important Roman cities and military camps in the period from 1st to 4th centuries. Its exceptional strategic importance was reflected both in the defense of the northern border of the Roman empire and in turn of communications and commercial transactions.

The city dates back to the 1st century AD, and at its peak it is believed to have had 40,000 inhabitants making it one of the biggest cities of that time. It lies on the Roman road Via Militaris and it witnessing also how Danube riverbed has deviated to the north during last 2 millennia.

Although as of 2018, only 3 to 4% of the site have been explored, many remains of temples, streets, squares, amphitheatres, palaces, hippodromes and Roman baths have been discovered. Viminacium also holds a distinction of having the largest number of graves discovered in any Roman archaeological site. Until 2018, 15,000 graves have been discovered.

Viminacium had been devastated by Huns in the 5th century, but was later rebuilt by Justinian. It was completely destroyed with the arrival of Slavs in the 6th century. Today, the archaeological site occupies a total of 450 hectares (1,100 acres).

Modern reconstruction and remnants of the Viminacium city walls

In vicinity of Viminacium is located the second largest Serbian open coal mine Kostolac. During the excavation of coal several well preserved mammoths have been discovered and today settled in provisional museum at the site.

"Vica" – the mammoth bones exposed

Tabula Traiana

(https://ro.wikipedia.org/wiki/Tabula_Traiana)

Tabula Traiana is a memorial plaque on the Serbian Danube bank built by Emperor Trajan in honor of the Roman victory over the Dacian kingdom after the Second Dacian War (105 - 106).

"Tabula", 4 m long and 1.75 m, marks the location of the ancient wooden bridge built over Danube, which allowed imperial troops march towards Dacia. The tabula is fixed to the stone and there are two dolphins floating and an eagle in the sky. Over time, Tabula suffered from the natural weather and was not covered by the water, with the construction of the Djerdap (Iron Gates) dam, it was lifted about 30 m. The holes in the rock where the bridge beams were fixed are still visible today.

Tabula Traiana

Not far from Tabula on the Romanian Danube bank there is big Dacebal's sculpture carved in limestone rocks in 1990s. The face sculpture of Dacebal (Decebalus) is 43m high and 32m and commemorates the last king of Dacia, who fought against the Roman emperors Domitian and Trajan to preserve the independence of his country, which corresponded to modern Romania.

Dacebal - the tallest rock relief in entire Europe (Romanian side of Danube)

Golo brdo – panoramic view

(after N. Vasić, reprinted from the Field Trip Guide in the Framework of the XVI Serbian Geological Congress 2014)

This view sight offers an outstanding panoramic view on the narrowest parts of the Danube gorge in Mali and Veliki Kazan, as well as on steep limestone cliffs at Mali and Veliki Štrbac (Miroč Mt.) and Mala and Velika Čuka in Romania.

The cross-section through Veliki and Mali Štrbac includes Riphean-Cambrium green schists, Hercynian granite-monzonite of Pecka Bara, transgressive Liassic and Dogger clastics (conglomerates, conglomeratic sandstones, sandstones, siltstones with pyrite concretions and sandy limestones with poorly preserved fauna).

Dark gray to almost black micrites with rare chert nodules and rare microfauna originate from Lower Malmian, while an alternation of limestone, dolomitic limestone and calcitic, fauna-rich dolomites, particularly with *Cladocoropsis mirabilis*, *Trocholina alpma* etc., are from the Upper Malmian.

The Cretaceous geological column encloses an alternation of various kinds of allochemical limestones (wackstone, packstone and greinstone) with rich and diverse Neocomian and Barremian-Aptian microfossil association (algae and foraminifers). The cited deposits are folded into the two large east-vergent anticlines (Veliki and Mali Štrbac) with a syncline of Duboka between. Conspicuous ruptures in Miroč limestones are numerous faults and joints. Fault mirrors parallel to Danube flow (311/74°) are particularly well expressed. Due to large thicknesses and thick slope deposits only individual parts of the geological column are accessible.

Veliki Kazan in the Danube gorge