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EASTERN ADRIATIC GEOLOGICAL HERITAGE — A POTENTIAL OF COASTAL KARST

Abstract: The coastal area of the eastern Adriatic is characterized by a prevalence of carbonate rocks and well-developed karst. Present freshwater input into the Adriatic is quite large, mostly through coastal and submarine springs (*vruljas*). However, there are also a number of allogenic rivers debouching in the Adriatic along the eastern coast. Most of them have canyon like fluviokarstic valleys, some of them with calc-tufa barriers, some of them partially filled during Holocene highstand (last 7.500 years). Along with submarine caves and drowned karst dolinas they present large potential for establishment of geoparks.

Key words: *Karst estuaries, Submarine karst, Allogenic river, Geoparks, Anthropogenic influence*

INTRODUCTION

Eastern Adriatic coastal area (EAC) is a well known tourist region based predominantly on sun and bathing, therefore being very seasonal (2–3 summer months). The aim of this paper is to show geological peculiarities of the north-eastern coastal zone of the Adriatic Sea, and to indicate its great potential for the economic development, especially in the frame of the year-around *green tourism*. Green tourism means environmentally responsible and ecologically informative and educational tourism. Similar premise were taken in account when geopark initiative was established at the beginning of the century (UNESCO, 2019).

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GEOLOGICAL HERITAGE

The geologic history of the Mediterranean is very complicated. It is an area squeezed between two large tectonic plates, the African and Euroasian plate. In between it is a mosaic of small, still moving plates. One of them is a small rigid continental chunk (Adriatic microplate) that slided through the Tethys (paleo-ocean between Africa and Europe) from Africa to Europe. The collision (subduction) of this microplate with Europe produced the Alps and Dinarides first, and Apennines later.

On top of this Adriatic microplate during Mesozoic a thick succession of carbonate sediments (limestone and dolomite) deposited in shallow water forming Apulia-Adriatic Mesozoic platform. This thick carbonate deposits (up to 8000 m) were base for subsequent karstification. The eastern Adriatic coast

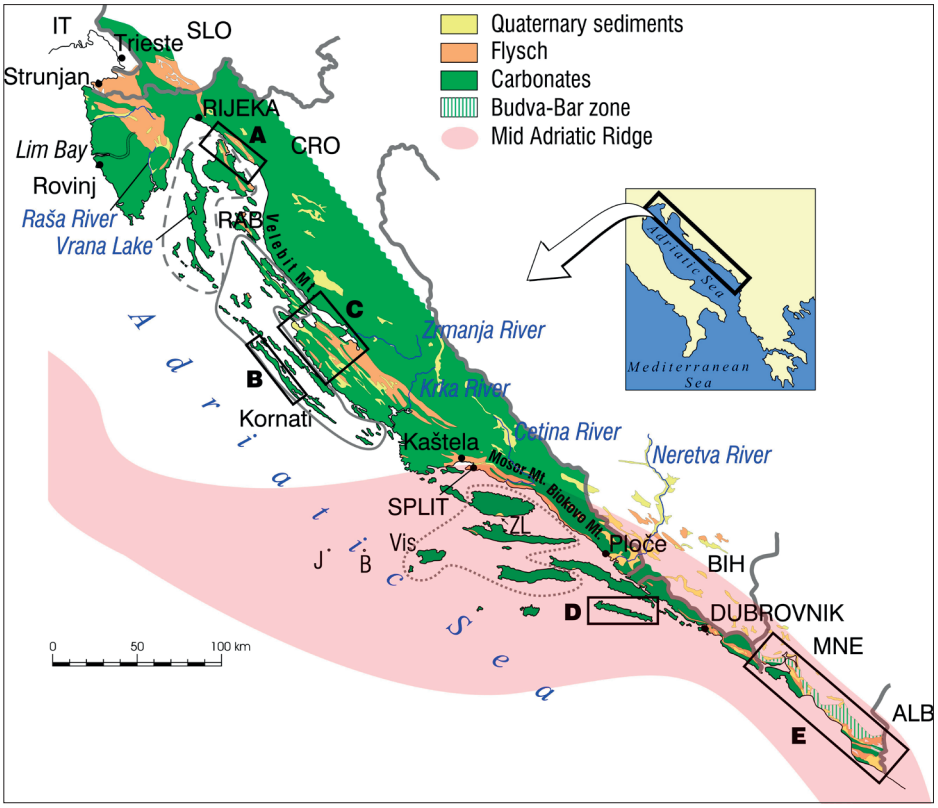

Figure 1. Simplified geological map of the eastern Adriatic coast (EAC). Legend: gray line = northern Dalmatian islands; gray dashed line = Kvarner islands; gray dotted line = southern Dalmatian islands; B and J=indicate location of Brusnik and Jabuka Islets (after Pikelj & Juračić, 2013)

is located at the leading edge of a thin-skinned thrust belt with folded and faulted structures striking northwest-southeast (Vlahović et al, 2005, Korbar, 2009). Therefore, as eastern Adriatic coastal area is predominantly formed in Mesozoic carbonate rocks, it has a well-developed karst (Fig. 1) (Pikelj & Juračić, 2013).

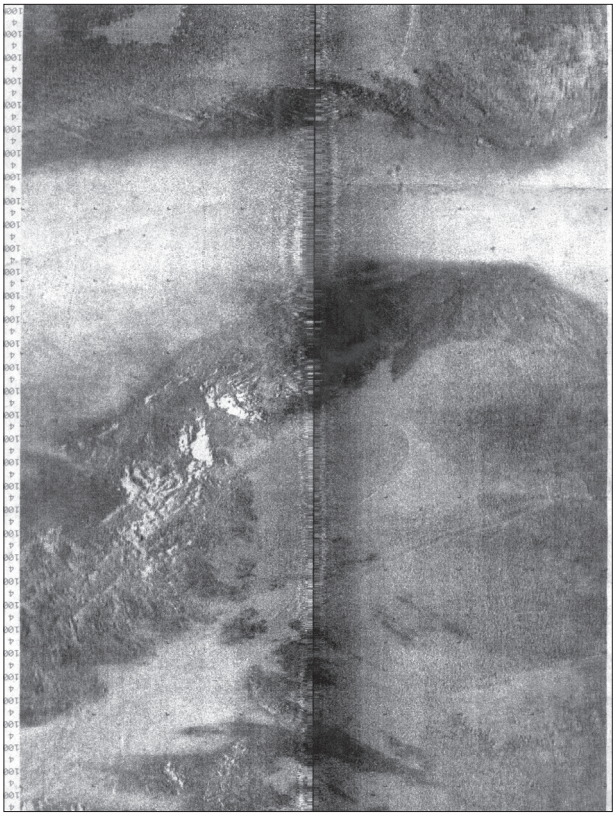

Figure 2. Side scan sonar of the PaleoKrka valey in the Šibenik Channel between coast and Zlarin Island. Channel depth is 40 m and paleocanyon is 70 m deep. Hrvatski Hidrografski institut, 1993.

Coastal karst phenomena include marine lakes, karst estuaries, coastal and submarine springs, submarine caves etc. All of them are a consequence of a former karstification and subsequent rapid sealevel rise since Last Glacial Maximum (LGM), approximately last 19.000 years. During LGM (30.000 to 19.000 aBP the sealevel was 120 to 130 m below present sealevel (Lambeck et al, 2002), and aeral and subsurface karstification took place. *Surface watercourses* cut their valleys into the carbonate bedrock forming canyons that can be traced deep below present sealevel (*e. g.* PaleoKrka River canyon in the Šibenik Channel — fig. 2) or river valleys up to 150 km seaward (PaleoNeretva and PaleoCetina — Sikora et al, 2014).

Well known examples of *drowned dolines* today connected to the sea at sea level are Veliko jezero and Malo jezero in the Mljet National Park at Mljet Island (Vuletić, 1953; Sondi & Juračić, 2010). There are few other *marine lakes* (inland lakes filled with seawater coming through karstified underground. *e. g.* the Mir Lake on Dugi Otok Island (Fig. 3) or Zmajevo oko near Rogoznica (Surić, 2002).

Figure 3. Marine lake Mir on the Dugi Otok Island. Photo by: D. Petricioli.

Figure 4. Vrulja in the Vrulja Bay below Biokovo Mountain. The internationally accepted term vrulja for submarine spring originates from this particular submarine spring. Photo by: K. Pikelj.

Figure 5. Speleothems in the drowned Y-cave, Brbinjščica, Dugi otok Island, Photo by: D. Petricioli.

Important and interesting hydrogeological phenomena are the submarine springs (*vruljas*) and *coastal springs*, which are well-known in coastal karst and are rather common along the EAC. The most remarkable ones are located in front of intensively karstified mountains (*e. g.* Biokovo Mountain; Fig. 4). Vruljas are considered to be former land and/or coastal karstic springs, which were established during the sea-level lowstands in glacial periods, and by sealevel rise, they were converted into submarine springs. However, some vruljas may seasonaly convert into marine estavelles (Surić, 2002).

Along the EAC there are more than 230 registered submarine and partially drowned speleological objects (caves, pits, anchialine caves) and most of them have been explored (Surić et al, 2009). These forms are excellent evidence of the sea-level changes, since most of them contain speleothems—typical chemical sediments that precipitate only in subaerial conditions and only subsequently submerged and overgrown by marine biota. These speleothems along the mainland and islands coasts are useful proxies for the sea-level change reconstructions in the Adriatic and the Mediterranean region. Furthermore, speleothems have been proven as a useful paleoclimatic record (Fig. 5) (Surić and Juračić, 2010; Surić et al, 2004, 2005, 2010). The deepest known speleothems found within the submerged EAC karst are those at -71 m from Brač Island (Garašić, 2006) although the sea-level during

Figure 6. Modra špilja on Biševo Island. Partially drowned cave. Light entrance through the opening below sea-level (https://www.plavi-svijet.org/cime-se-bavimo/nasi-projekti/centar-modra-spilja-bisevo).

the LGM was up to 130 m lower than present. However, deeper karstification was probaly possible during the Messinian Salinity Crisis (~6Ma BP), when the sea level in the Mediterranean was estimated to be more than1500 m lower than today (Mocochain et al, 2009; Surić and Juračić, 2010). All these and other karst peculiarities along the eastern Adriatic coast seem to be a very promising background for development of geotourism.

INITIATIVES FOR ESTABLISHMENT OF GEOPARKS ALONG THE ADRIATIC COAST

The organised effort to establish geoparks was promoted by UNESCO Division of Earth Sciences in 1996 in order to protect geological heritage, and European Geopark network was established including ten countries. At the moment it includes 74 geoparks from 26 countries (including Papuk geopark from inland Croatia) (European Geoparks, 2019).

The UNESCO Global Geoparks label was established on 17 November 2015, expressing governmental recognition of the importance of managing outstanding geological sites and landscapes in a holistic manner. At the end of 2018 there were 140 Global Geoparks in 34 countries (UNESCO, 2019).

The UNESCO geopark concept recognizes the relationship between people and geology and the ability of a geoheritage site to serve as a focus for economic development. This concept agrees closely with trend for integration of science and culture whilst recognizing the unique importance of the physical landscape. Therefore uniting geoconservation with tourism can lead to protection of unique geoheritage features, scientific research, broad environmental education and the enforcement of local tourism-based economic development. Such a year-long tourism concept is called geotourism. Few iniatives for establishment of geoparks were raised on different locations along the Adriatic coast: Dugi otok Island (Juračić & Petricioli, 2004), Rab Island (Geopark Rab, 2019) and Vis Island (Geopark Vis, 2019). The most advanced initiative is the Vis Archipelago Geopark, which should include the island of Vis and the adjacent islands of Biševo, Sveti Andrija, Brusnik, Jabuka and Palagruža. This is very attractive area of the Adriatic, formed from the oldest and the youngest rock formations. Parts of the Vis archipelago (Brusnik and Jabuka islets) are built from igneous rock, that is unique in the Adriatic and are easily distinguished from other Adriatic islands which are built predominantly of sedimentary carbonate rocks. However, very scenic are blue cave at Biševo Island (Fig. 6), and Green cave on Ravnik Island.

CONCLUSION

The drowned karst phenomena (drowned canyon-like river valleys, drowned dolinas, vruljas and caves), along with unique physical landscape with numerous islands are excellent basis for improving tourism into green year-long geotourism that should be sustainable and should not exceed the caring capacity of the environment.

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