IMPACT OF CLIFF EROSION ON MARINE SEDIMENT COMPOSITION - INDICATION OF LOCAL COASTLINE EVOLUTION (VRGADA ISLAND, CROATIA)

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Abstract – Surface sediment along the carbonate-bordered eastern Adriatic is highly carbonaceous material, composed largely of biogenic skeletal material. Local outcrops of soft-rock material such as Eocene flysch and Pleistocene sandstones may locally change the composition of the surface sediment cover. Highly erosive coastal cliff developed in Pleistocene sediments on the Vrgada Island gave rise to the idea that local seabed surface sediment may reflect the composition of the cliff sediment.

Preliminary results of sedimentological analyses showed that sediment samples collected on both sides of the cliff contain material eroded mostly from the eastern side of the cliff. Subsequent longshore drift caused by dominant waves likely sort fallen material, transporting its finer fractions to the northern side and further into the sea.

Introduction

Eastern Adriatic coast is a primary karstic transgressive coast, mostly built of Mesozoic carbonates (over the 90 % of the coast length). Eocene flysch is represented by approx. 6 % in length, while other usual younger soft rocks are Quaternary clastics [1]. Surface seabed sediment along the eastern Adriatic coast is mainly composed of mixed carbonate-siliciclastic sandy sediment, where carbonates are generally of biogenic origin. Biogenic particles originate from a typical temperate assemblage of carbonate secreting marine invertebrate, with molluscs, foraminifera, bryozoans and red calcareous algae being the most common [3, 4]. The deposition of recent biogenic carbonates is enabled due to the scarce terrigenous supply resulting from the karstic relief on which poor network of karstic rivers has been developed. Their sediment input is low, and sediment material supplied to the sea usually remains at river mouths. The exception is the Neretva River, an allogenic karstic river which discharges a large quantity of particulate sediment into the Adriatic compared to other Croatian coastal rivers.

In general, the mineral composition of the non-carbonate component in the surface sediment points to the Eocene flysch as one of the main sources of the siliciclastic material. Flysch outcrops are being eroded in the coastal zone by the denudation processes and wave abrasion, while surface flysch lithology underlying karstic river beds contribute to its particle load. According to [3], much of the siliciclastic component has been found in very fine sand and mud fractions. Locally, other types of lithologies such as Pliocene and Pleistocene sands and sandstones may affect the composition of surface seabed sediment. One such example is deposit sequence on the Vrgada Island situated in the middle of the Croatian coast (Fig. 1).

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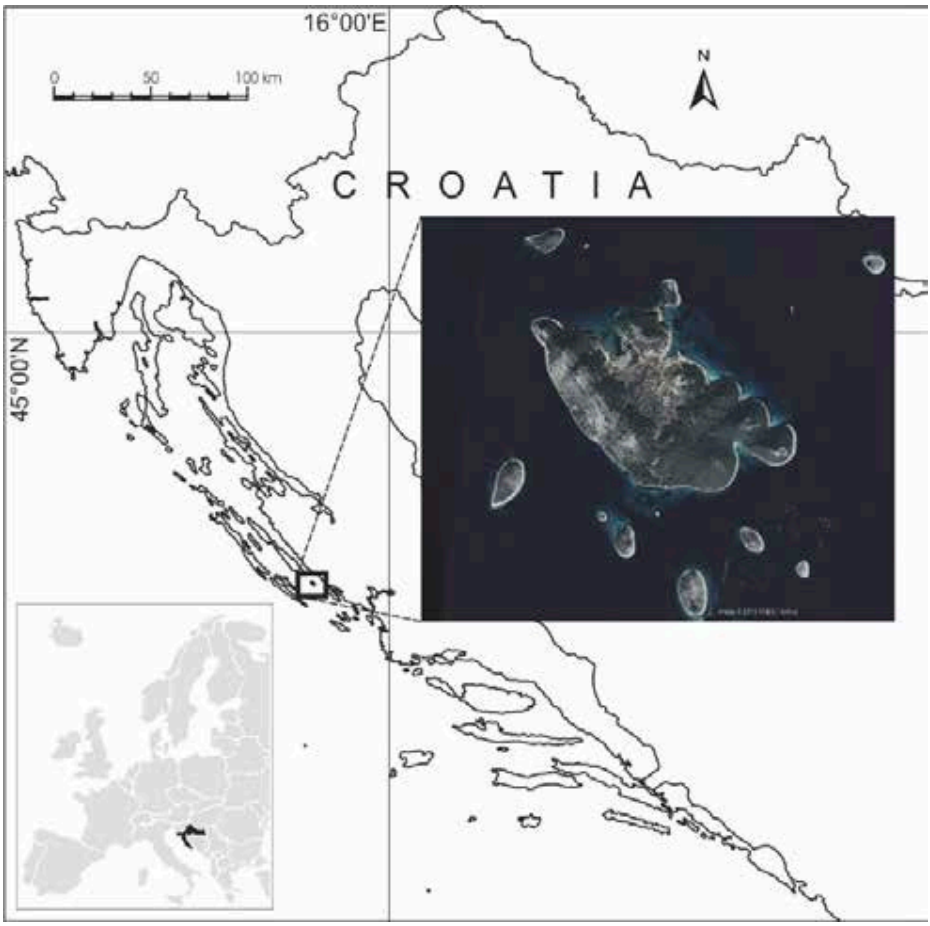

Figure 1 - Location map of the Vrgada Island along the Eastern Adriatic coast.

Vrgada Island is composed mostly of Cretaceous limestones, however, in its NW part Pleistocene sediments crop out in several places [4, 5, 6]. The most attractive appearance of this soft-rock depositional succession is the coastal cliff (Fig. 2). Together with beaches and other typical coastal processes, cliffs are rare forms along the Eastern Adriatic, due to the prevailing carbonate lithology along the coast. Thus, it is expected that local erosion of soft-rock cliffs may influence the composition of the surface marine sediment.

The aim of this work is to examine this claim trough classical sedimentological analyses of marine sediment. Furthermore, it is expected that results of sediment characteristics may point to the direction of sediment transport along the coast, in front of each cliff side.

Study site

The ~15 m thick soft-rock depositional Pleistocene succession on the Vrgada Island is a triangle-shaped coastal cliff subjected to the coastal erosion (Fig. 2). The evidence of ongoing coastal erosion is especially visible on its eastern side in form of weathered material on the cliff toe, numerous vertical cracks (observed during the fieldwork), and trees with bare and exposed roots. Its eastern sub-vertical side is exposed to waves of two most dominating winds: *Bura* (*Bora*) and *Jugo* (*Sirocco*) and, as shown on Fig. 2.

The northern part is less steep and overgrown with pine trees, so the true cliff form is partially hidden (Fig. 2). This section of the coast experiences mild north-western wind (*Maestral*) operating mostly during the summer. Both sides of the cliff are fronted by the narrow sandy beach, a rare type of the beach along the Croatian coast.

Figure 2 - Eroding coastal cliff on the Vrgada Island; view from east (left photo) and from north (right photo).

Materials and methods

In total, ten surface marine sediment was collected along two profiles, almost perpendicular to both sides of cliff faces: six on the eastern and four on the northern side, following the depth gradient up to 25 m (Fig. 3).

Sediment samples were dried, weighed, and wet sieved using the 7 standard sieves of 1 mesh phi. Sedigraph was used to analyze fractions < 0.063 mm. Sediment classification was done after [7]. Carbonate content was calculated according to the volumetric measurement of CO_2 evolved after each sample being treated by 1:1 diluted HCl acid, using the Scheibler apparatus.

Coarse-grained fractions (gravel to very fine sand) of each sediment were examined using a stereomicroscope for quantitative identification of marine skeletal grains and grains supplied after cliff erosion.

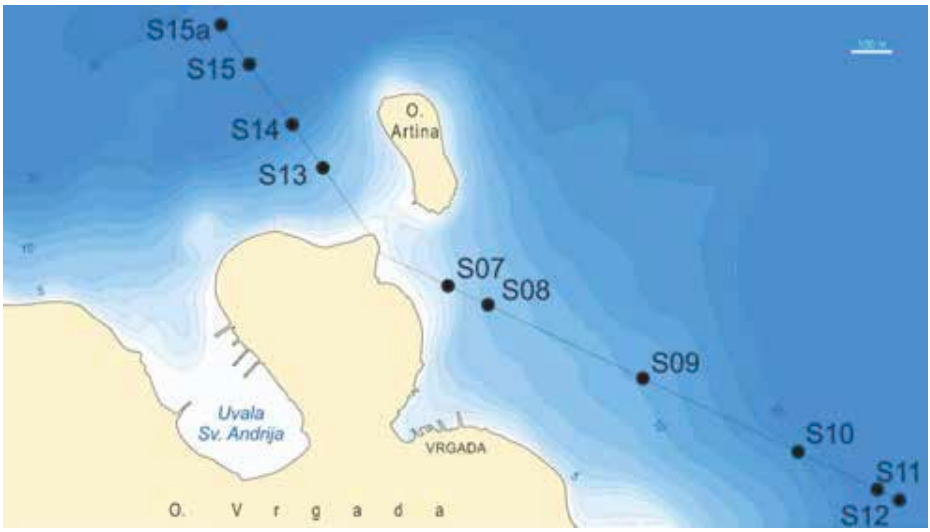

Figure 3 - Locations of sediment sampling along both profiles. Uvala = bay.

Results

All relevant results are shown in Table 1. Six samples on the eastern side were characterized as sands: the first two collected closest to the cliff (S07 and S08) are gravelly sands with the mean size of 608 and 705 μm, respectively, while the rest are gravelly muddy sands, with Mz varying between 157 and 240 μm. Their carbonate content ranged between 78 % and 88 % with no obvious trend observed. Microscopic examination showed that the shallowest three samples (S07-S09) contained a higher amount of coarse grains resulting from cliff erosion, while the other three (S10-S12) contained mostly marine carbonaceous sediment.

Table 1 - Surface sediment characteristics.

Sample:	Sediment type (after Folk, 1954):	Carbonate content (%):
S07	gravelly sand	78
S08	gravelly sand	84
S09	gravelly muddy sand	80
S10	gravelly muddy sand	82
S11	gravelly muddy sand	80
S12	gravelly muddy sand	79
S13	gravelly muddy sand	35
S14	gravelly muddy sand	51
S15	gravelly mud	47
S15a	gravelly mud	38

Samples collected on the northern side of the cliff are more fine-grained than the previous ones; they are characterized as gravelly-muddy sands (S13 and S14) with Mz of 60 μm and 97 μm respectively, and gravelly muds (S15 and S15a) with Mz of 43 and 28 μm respectively. Their carbonate share was consistently lower (35÷52 %) compared to samples along the eastern profile. Microscopic examination showed the dominance of particles derived from the cliff, and in many cases, quartz recognized as dominant.

Discussion

Cliff on the Vrgada Island is a rare example of cliffs in soft rocks along the Eastern Adriatic Coast. According to [4], much of the siliciclastic material forming the cliff was supplied from the Eocene flysch basins in the hinterland. There is also an indication that some of the material probably deposited from volcanic eruptions during Pleistocene. Soft-rock cliffs are more prone to weathering and slope processes in general, compared to tectonic cliffs in carbonates, characteristic of southern coasts of many Croatian islands [1].

Both sides of the cliff are fronted by a sandy beach. This sandy character is less obvious along the eastern part due to the material constantly falling from the cliff; thus, the beach along the eastern side contains more gravel. The shallowest two samples S07 and S08 on the eastern part are at the same time and coarsest samples in the set. Much of these fractions contained coarse-grained material fallen from the cliff, as shown by microscopic examination. However, their carbonate content is rather high (Table 1), higher compared to the average of 61 % for the surface sediment of the Eastern Adriatic given by [1]. The amount of carbonate in these coarse fractions are the results of more resistant tube-like carbonate concretions [4]. Moreover, the shallowest samples are constantly reworked by waves, therefore, their coarseness is probably a result of the wave action. Sample S09 showed approx. the same quantity of cliff and marine material, while in samples S10-S12 marine component dominates.

Beach on the northern side shows its truly sandy character, without gravitationally lowered material, as can be seen in the Fig. 2. Marine sediment samples follow the same pattern: they contain less gravel and more fine sand and mud, mostly silt (not shown in Table 1!). Carbonate component in these samples are much lower (sometimes up to 50 % lower; Table 1) compared to samples from the eastern side, and is lower than 61 %, the average for the Eastern Adriatic [2]. As shown by [2] and [3], much of the fine sand and silt fractions along the Eastern Adriatic generally contain a higher amount of quartz grains. Therefore, it is likely that sediment samples along the northern profile off the northern side of the Vrgada cliff collect more quartz grains, as confirmed by the microscopic examination. In general, preliminary results of classical sedimentological analyses presented here showed that there are differences in sediment composition between two seabed sections in front of the two cliff sides on the Vrgada Island.

Considering a higher carbonate content and overall coarseness of the sediment, one could conclude that the sediment in front of the eastern part of the Vrgada cliff is a typical highly carbonaceous and coarse eastern Adriatic seabed cover, described by [2]. However, the fact is that the higher coarseness degree and higher carbonate amount, in this case, result from the material fallen from the cliff, where material kept in surface sediment is largely composed of cliff carbonate concretions. On the other hand, material deposited in front of

the northern cliff segment (more protected from strong winds and waves, and covered by vegetation) was much more affected by the material eroded from the cliff, containing less carbonates and more quartz grains derived from the cliff. The mechanism of such differences in sediment composition and sediment distribution has been ascribed to the joint action of intensive cliff erosion on the eastern side and north-westward longshore drift caused by dominant waves. Waves approaching from the east are induced by *Bura* and *Jugo*, both typical for the winter season. Besides wave action during which wave notches may develop (as observed during winter fieldwork), the occurrence of *Bura* gusts approaching the cliff face almost in shore-normal direction may mimic hammer beat along with a beat sound effect. This action weakens segment by segment of the cliff face, accelerating its erosion. The synergy of such events with before mentioned wave action, usual slope processes, and natural affinity of soft rocks to be mechanically eroded may lead to the massive cliff erosion observed in the case of Vrgada Island.

Once eroded, material from the cliff is being sorted along the eastern side, leaving generally coarse-grained fraction on the beach and on the shoreface. Fine-grained fraction on the other hand is being transported further and eventually distributed along the northern side of the cliff. Indeed, as shown in the Fig. 2, beach on the northern side of the cliff is mostly covered by sand. Since being fine-grained, this sand may easily be withdrawn into the sea and finally be deposited on the seabed. However, in order to corroborate this hypothesis, additional measurements focused on the beach morphology and beach dynamics are currently being conducted.

Acknowledgements

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