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Characteristics of Pleistocene aeolian – alluvial sediments of the northern coastal cliff of Vrgada island (Adriatic sea, Croatia)

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Abstract:
Aeolian-alluvial deposits on the northern part of Vrgada Island were investigated in order to interpret deposition mechanisms and environmental conditions. Preliminary results of basic sedimentological analyses of 49 samples allowed distinguishing 3 facies along the cliff.

Keywords:
Aeolian, Alluvial, Pleistocene, Cliff, Adriatic sea

1. Introduction

Various types of rocky coasts represent about 80% of the world's shorelines (TRENHAILE, 1987), including both hard and soft rocks. The Croatian coast consists predominantly of Mesozoic and Cenozoic carbonates as they cover over 90% of its surface (PIKELJ & JURAČIĆ, 2013). Eocene flysch and other less resistant sedimentary rocks and rock assemblages, including Pleistocene sediments occupy approximately only 6% of the coast (PIKELJ & JURAČIĆ, 2013). Pleistocene sediments on the Adriatic islands usually cover small surfaces and form vertical outcrops whose thickness rarely exceeds 10 m. They are represented by various types of sediments which include gravel, sand, loess like sediment and sandy silt deposited in subaqueous and subaerial environments. In the northern Adriatic loess-like sediment

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intercalated with sand on Susak Island is well described and dated (CREMASCHI, 1990; WACHA *et al.*, 2011). Pleistocene sands occur on several Adriatic islands including Vrgada Island situated in the northern part of the Adriatic.

The erodible cliff material on the Vrgada Island are analysed in order to get the insight in depositional mechanisms and environment, paleo-climate and characteristics of the sedimentary basin which evolved in the coastal belt dominated by high-relief mountains composed mostly of carbonates.

2. Materials and methods

The study area is a coastal cliff located on the northern part of Vrgada Island. The cliff is located in a small, east oriented bay and viewed from the air has a mild, semi-circular shape. It is elevation spans from 0.5 m a.s.l. to 13 m a.s.l. The lateral range of the cliff from southern to northern tip is approximately 60 m. This 12.5 m thick sediment succession was found to be deposited on the limestone bedrock (largely Upper Cretaceous) which can be seen in the southern part of the bay. Fieldwork included sampling, measuring sediment thickness, defining lithology, GPS positioning, defining colour of sediment and photographing. Various horizons and facies were recognized and described. Depending on the horizon diversity, sampling was carried out and the frequency was 0.25 m. A total of 49 samples were taken for sedimentological analyses.

Grain-size analyses combined wet sieving and the pipette method. Heavy mineral gravity separation using bromoform was performed on the 0.063-0.125 mm calcite-free fraction of seven selected samples. Qualitative and quantitative analysis of the heavy mineral fractions were based on 300–350 grains counted per sample and were conducted using a polarizing light microscope (MENGE & MAURER, 1992). The carbonate ($CaCO_3$) content was calculated from the weight difference before and after cold hydrochloric acid (5 %) treatment for each of the seven samples that were also used for heavy mineral analysis.

Quartz grains were examined using a scanning electron microscope (SEM) in order to inspect the shape of the grains and observe grain surface morphology in detail. Previously extracted LMF of 7 samples were chosen for scanning electron microscopy. More than 70 different grains were photographed from which the best photographs that show complete quartz grains were selected. Microscopy was performed within magnification range of X350 - X3500. The classification method and implemented terminology for quartz grain surface textures and shapes used in this study was done according to MAHANEY (2002).

3. Results and discussion

The studied sediment succession was deposited on top of carbonate bedrock and paleosol (*terra rosa*). Sand and silt dominates in all samples with average values of 34,77 % for silt and 58,69 % for sand. Samples from the upper part of the succession contain significant percentage of gravel showing almost regular cycles of high and low percentage of gravel. Contrary, the middle and especially lower part of the outcrop contain significant percentage of clay content, with maximum of 24% of clay recorded at the lowermost sample.

The uppermost 3 m of the outcrop, which is represented by 13 samples, is sand dominated, significantly bioturbated and abundant in carbonate concretions. Bioturbations stretch in the form of vertical, tubular features throughout the zone. This zone is defined as facies A. In this facies we observed two cycles of decreasing in gravel percentage from the top to bottom.

Facies B is represented by the next set of 17 samples, characterized by an almost regular interchange of sand and gravel layers. Gravel deposits in this facies are present in the form of channels and layers. Individual gravel clasts are 1-3 cm in length and dominantly angular with a smaller percentage of sub-rounded ones. Both, sand and gravel layers in this facies are horizontal to sub horizontal.

The lowermost 19 samples (facies C) are dominated by silt-sized particles, with sand and clay making up a maximum of 25%, while gravel was found to make up less than 5% throughout this facies. The lowermost sample is the most fine-grained, with the maximum percentage of clay (24%) and up to 54% of silt. This facies consist of sub horizontal to horizontal layers of silt and sand. The high clay percentage is probably a redistribution of the paleosol on which the sediment was deposited.

Changes in colour of the sediment layers were observed throughout the outcrop. Using Munsel colour chart we distinguished almost regular change in facies A, B and top of the facies C. Colour change is in range from 5YR 5/8 to 7.5YR 5/6. Other variations in colour, but not represented in many layers include 5YR 5/6, 2.5YR 4/8, 2.5YR 3/6 and 7.5YR 4/4 (yellow – red). Lowermost part of the facies C is represented by yellowish red coloured sediment, 5YR 5/8.

Heavy mineral analysis showed that samples from the upper part of the Vrgada cliff section are dominated by garnet which regularly constitutes more than 50% of the heavy mineral fraction, along with zircon, spinel, augite, titanite, tourmaline and rutile, each making up about 5-10%. Samples from the lowermost part of the section contained conspicuously high amounts of green clinopyroxene (>50%), possibly of volcanic origin (PIGORINI, 1968; POUCLET *et al.*, 1999). Mineral assemblages found in the samples clearly indicate that the siliciclastic material was derived from the erosion of local source rocks found in the area of northern Dalmatia, primarily Eocene sandstones (PAVIČIĆ *et al.*, 2000). Considering that these rocks are presently not exposed on Vrgada or any other surrounding islands, the material was probably transported to the studied location during times when the sea level was considerably lower. The absence of epidote/zoisite and hornblende indicates that northern Italian rivers which otherwise supplied most of the Quaternary sediments of the northern Adriatic (PIGORINI, 1968;

MIKULČIĆ-PAVLAKOVIĆ *et al.*, 2011), could not have contributed material deposited in the study area.

Carbonate content in the samples varied from 2.5% in the lowermost sample to 72.9% in the uppermost sample, giving a mixed character to the studied deposits. The nature of carbonate grains needs to be further investigated in order to determine its source(s).

All scanned and photographed quartz grains from the Vrgada outcrop were sand-sized particles (>63 µm). In all of the seven samples angular grains dominated. Their share was over 60% of the total number of grains in the samples. Around 5% of grains were very angular or sub-angular. Rounded and well-rounded grains maked up to 5%. Over 70% of the grains in all samples were of low sphericity. On most grains conchoidal fractures and V-shaped percussion marks were visible. Conchoidal fractures were detected in over 50% of the grains in the samples. A small number of grains showed conchoidal fractures that are nearly the size of the length of the longer axis of the grain, while the majority of grains had conchoidal fractures with 1/3 of that dimension. V-shaped percussion marks were visible on only 3 individual grains. The size of these surface micro textures is in the range of 2–5 µm. They are usually clustered on smooth, flat surfaces of grains in groups that consist of 3 to 5 marks. About 10% of all grains displayed sets of parallel striations. The length of striation marks on average was between 15 and 20 µm and sets consisted of 5 to 6 striations on average. Upturned plates are observed on more than 10% of grains.

Conchoidal fractures which are present in most grains, are the product of glacial and aeolian transport of silt and sand. Smaller number of grains has so called V-shaped percussion marks on their surfaces that occur as a result of the bouncing and collision between grains in the process of saltation. They can also be the product of the same process in rivers and streams with high water energy (MAHANEY, 2002.). A small number of grains had visible sets of parallel striations which indicate the process of glacial abrasion of grains under the pressure of ice. Combination of these surface textures on quartz grains indicates a short transport of sediment no matter which mechanism (alluvial or aeolian) was dominant.

4. Conclusions

The preliminary results presented here point to the complex origin of the studied sediment on the Vrgada Island. It appears that two major depositional forces may have formed the sediment: alluvial and aeolian. Three (3) different facies are identified and described in this outcrop. Top facies A according to grain size distribution represents deposition in a high energy water environment. Facies B can be attributed to lower water energy but with some exceptions which are represented with gravel lenses in sand. Lower facies C displays stronger aeolian influence which is represented in the dominance of fine grained particles (silt and clay) and low percentage (approx. 5%) of gravel. Sediment colour variations in facies A and B are probably due to postsedimentation, chemical processes. On the other hand, the red colour at the bottom of the facies C is the result of grain size distribution and the presence of clay minerals. Heavy mineral analysis indicates that the sediment was supplied from local sources. This was confirmed by SEM analysis indicating short transport of quartz grains. Since the similar sediment is observed on the island of Artina, located north west from the cliff and on the coast between Pakoštane and Draga villages, located north-north west from the cliff, it is to be assumed that the sediment that forms the cliff on the island of Vrgada is part of the sub regional sedimentary body. Unlike the southern Dalmatian islands where karst traps located in the inner part of the island were important factor in the preservation of sediments (BABIĆ *et al.*, 2013), on the island of Vrgada sediment is preserved at shore line.

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