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Variety of physical-chemical characteristics of Holocene sediments from the middle Adriatic Sea (Croatia)

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Grain size, organic matter and carbonate content were analyzed in 5 Holocene sediment cores from the middle Adriatic. Fine-grained, non-carbonate particles settling prevailed in the investigated area. The differences among the stations were influenced by location and hydrodynamic conditions at the sampling sites, by the weathering of the surrounding areas partly under anthropogenic influence and the presence of the remains of the organisms with carbonate skeleton. Even though the east Adriatic coast is mostly carbonate, at the stations near the east Adriatic coast, the presence of the Eocene flysch deposits results in the lower carbonate content (40.27-48.88%) in the sediment with the predomination of silt-sized particles (33.12-56.83%). At the station near Vis Island the sediment is mostly carbonate (67.36-76.5%), with the highest sand content (67.07-70.63%). The source of this sediment are the skeletal remains of the organisms which lived on the seabed, the pre-Holocene sediments and the carbonate rocks from surrounding islands. At the deepest station located closer to the west Adriatic coast clayey particles prevail (52-70%), while carbonate content is low (31.7-40.5%). These clayey particles are the result of the erosion in the Alps and the Apennines. These particles have been supplied to the Adriatic Sea mostly by rivers, and subsequently redistributed by the sea current, which carries them along and off the west coast.

Key words: sediment, grain size, organic matter, carbonates, Holocene, Adriatic

INTRODUCTION

Adriatic Sea is semi-enclosed part of the Mediterranean Sea (Fig. 1). In general, the western Adriatic coast is characterized by low, sediment-loaded coasts, while east part is karstic, steep and rocky. Holocene sediments along the west coast were more investigated than those along the east coast (PIKELJ *et al*., 2009).

Along the west (Italian) coast there is a significant supply of terrigenous particles by rivers, but coastal sands represent a relatively narrow belt. A part of the sand was reworked during the late Pleistocene - early Holocene transgression (VAN STRAATEN, 1970). Sea currents that flow along the Italian coast to the southeast distribute the terrigenous particles and deposit them in a belt parallel to the coast (GOUDEAUA

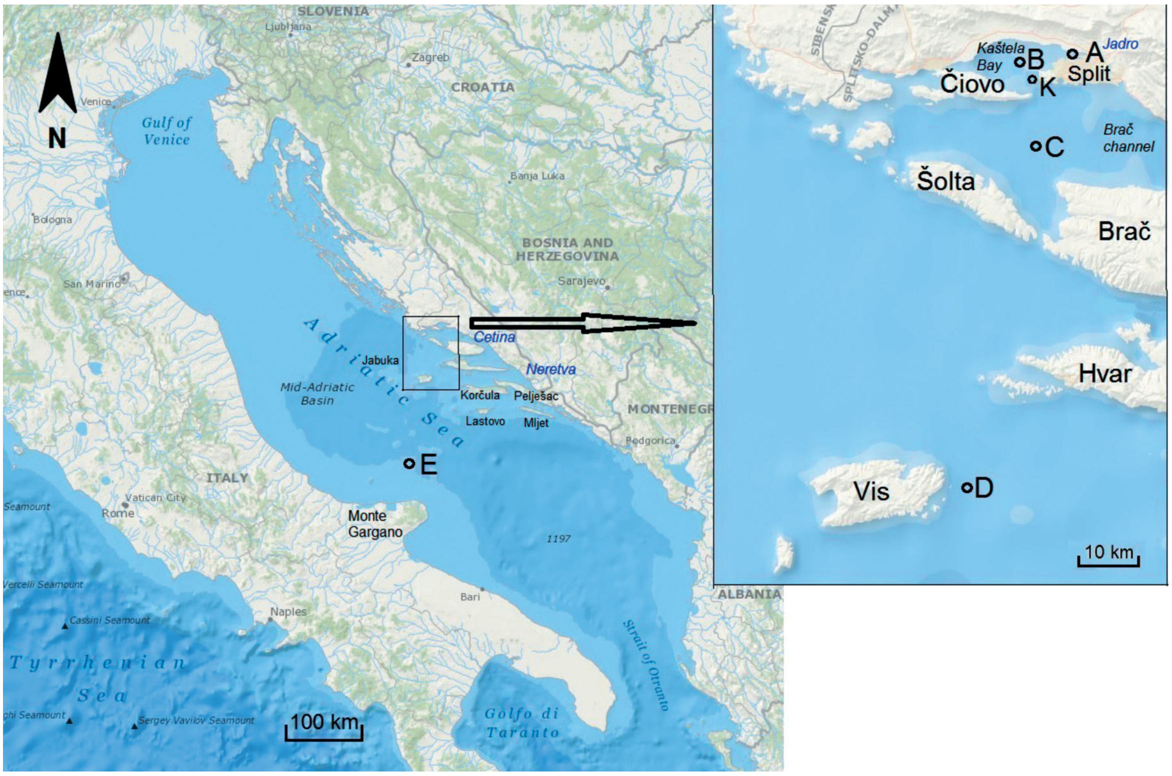

Fig. 1. Investigated area with sampling stations

et al., 2013). Coastal sand grade into mud belt as a result of energy environment decrease and depth increase. The establishment of the present sea level in the Holocene formed such a facies relation.

The Croatian east Adriatic coast is mostly composed of Mesozoic and Paleogene carbonates. Less prevalent are the Eocene flysch deposits covering approximately 6% of the coast (PIKELJ & JURAČIĆ, 2013). In the middle part of the east Adriatic coast is located only one considerable zone of the flysch deposits longitudinally facing the sea from Kaštela Bay to the river Neretva mouth (PIKELJ & JURAČIĆ, 2013). Namely, as a consequence of the Dinaride geotectonic, the thick Eocene flysch bed was thrusted against the Mesozoic carbonate rocks that prevail along the Eastern Adriatic coast (HERAK, 1986). The east Adriatic coast as well indented, causes changes in sedimentation at shorter distances (PIKELJ et al., 2009, ŠKRIVANIĆ & MAGDALENIĆ, 1979). Modern rivers along the east coast usually create estuaries and transport different quantities of various mineral particles (carbonates, clay minerals, quartz and feldspar), which usually settle at the rivers' mouth (CUKROV *et al*., 2007, JURAČIĆ & CRMARIĆ, 2003; SONDI *et al*., 1995; JURAČIĆ & PROHIĆ, 1991; BENAC & ARBANAS, 1990). The interventions in the environment (deforestation, construction of various buildings etc.) because of anthropogenic influence are getting more and more important issue, especially in the coastal area.

The middle part of the Croatian coast with larger islands differ according to geomorphology (GIORGETTI & MOSETTI, 1969). Sea belts (i.e. channels) among the islands are relatively wide with maximal depth between 50 to 80 m with smooth sea bottom. Area covered with fine-grained particles forms an entire continuous muddy cover parallel to the coastal zone and at the same time protected by barrier islands. It is relatively closed and well protected area, especially in the central and deepest parts of the channel, where, according to the structure of sediments, intensive dynamics of benthic layers of sea water is missing (ALFIREVIĆ, 1964). The area dominated by coarse-grained sediment is outside the insular zone (ALFIREVIĆ, 1964).

Kaštela Bay with surface of 61 km^2 is located in this area. Kaštela Bay is the largest bay in the central part of the Croatian coast (Fig. 1). In the second half of the 20th century the area of Kaštela Bay became one of the most densely urbanized and industrialized coastal areas. Uncontrolled disposal of urban and industrial waste waters into the sea in the mid-eighties, made Kaštela Bay one of the largest and most widely known areas of contamination in the Mediterranean region (MARGETA & BARIĆ, 2001; KUŠPILIĆ *et al.*, 2009). The situation has improved since 1991 as a result of the closure of many industrial plants and the redirection of sewerage to the Brač Channel in 2004 (BOGNER *et al.*, 1998; KUŠPILIĆ *et al*., 2009; UJEVIĆ *et al.,* 2010). Transport of sediment toward the bay is controlled by prevailing circulation, which is mostly induced by local winds (BEG PAKLAR *et al*., 2002).

In the Adriatic, two environments of sediment deposition can be distinguished. First belongs to the nearshore and offshore, while second belongs to the deeper parts of the sea floor. At the peak of the last glaciation, 18,000 years ago, the sea level was about 125 m lower than today, the Island of Jabuka Pit and the south Adriatic basin were covered by the Adriatic Sea. The wide area of the Adriatic nearshore and offshore represented mainland which was supplied by clastic sediments by rivers as well as the sea depressions by mud and considerable quantities of turbidites. Due to strong winds, the river material was reworked and considerable quantities of aeolian sand and loess were deposited, too (MARKOVIĆ-MARJANOVIĆ, 1972; WACHA *et al.,* 2011; PAVELIĆ *et al*., 2011, 2014; BABIĆ *et al*., 2013; WACHA *et al.*, 2016). After late Pleistocene - early Holocene transgression, the sea covered the land and established new depositional conditions. Sedimentation of silt commenced in the offshore area, while sand deposited in the narrow coastal belt, i.e. nearshore, has gradually covered older alluvial sands. Due to insignificant sediment supply, large bottom surface still represents alluvial sand reworked by marine processes or rocky bare bottom.

Sediment cores investigation indicates the possible occurrence of changes during sedimentation. Investigation in different area points out the source of sediment. In order to determine differences in sedimentation we chose five coastal stations in the central part of the east Adriatic from Croatian to Italian coast. Obtained results of grain-size analysis, organic matter and the carbonate content in sediment indicate if the source of the particles is the same in the study area and if changes occur during sedimentation.

MATERIAL AND METHODS

From Croatian to Italian coast, we choose 5 stations (Fig. 1). Stations A and B are located in Kaštela Bay, whereas station A is placed near mouth of river Jadro and station B in the middle of the Bay. Station C is located in the channel between the islands (Čiovo, Šolta and Brač) and the mainland. Near Vis Island is located station D, while station E is located 23 km from Monte Gargano Peninsula (Table 1, Fig. 1).

Sediment was sampled using a gravity UWITEC Korer, 9 cm in diameter (Umwelt und Wissenschaftstechnik, Mondsee, Austria) in January and February 2010. The first 10 cm of sediment cores was divided into 1 cm thick sub-samples. For the sediment sample length greater than 10 cm sediment cores were divided into 2 cm thick sub-samples. Sub-samples were stored in plastic bags, frozen at -20° C, and freeze-dried.

The grain-size of the sediment samples was determined by sieving (>0.063 mm) and hydrometering (<0.063 mm) according to Cassagrande (STRMAC, 1952). The hydrometering method is based on the density measurements of suspension in sediment samples, which depends on settling velocity of suspended particles during 48 hours. The obtained density values were used to determine grain-size and to generate of cumulative granulometric curves. WENTHWORTH (1922) size class was used for particles size. The content of gravel (>2 mm) and sand (0.063-2 mm) particles was determined by sieving. The content of silt (0.004- 0.063 mm) and clay (<0.004 mm) particles was determined from the cumulative granulometric curves, constructed toward to the results of grain-size analysis. Sediment type was

*Table 1. Date of sampling, depth and location of sampling station with core length and number of sub samples (n). *Samples were taken using van Veen grab*

Station	Date of sampling	Depth (m)	φ (N)	Λ (E)	Core length (cm)	n
A	24.02.2010	20	43°31.941	16°27.34	16	13
B	24.02.2010	35.4	43°31.283	16°22.85	20	15
C	24.02.2010	74.8	43°26.083	16°22.856	20	15
D	28.01.2010	102	43°0	16°20	5	5
E	29.01.2010	112	42°8.32	16°10.26	16	13
B	17.03.2009	35.4	43°31.283	16°22.85	*	
K	18.03.2009	25	43°30.363	16°23.808	*	

Table 2. Obtained ranges, average±st.dev. and U (expanded measurement uncertainty) for sediment at two stations. n-number of determined samples

Station	B			K		
(%)	n	Range Average±st.dev.	U	n	Range Average±st.dev.	U
Gravel	15	0.01-0.42 0.12±0.11	0.08	10	0.16-0.57 0.33±0.13	0.15
Sand	15	0.71-0.97 0.85±0.09	0.04	10	21.87-25.37 23.24±1.00	0.74
Silt	15	42.96-51.43 46.86±2.41	3.53	10	49.06-53.74 51.52±1.70	3.69
Clay	15	47.6-56 52.16±2.37	3.52	10	22.20-26.20 24.92±1.29	3.13
Organic matter	20	6.24-8.12 7.25±0.47	0.07	15	3.20-4.12 3.73±0.28	0.09
Carbonate	18	34.99-42.11 38.65±2.14	0.51	15	59.30-68.60 64.47±2.17	0.47

determined according to the classification by SHEPARD (1954). Equivalent size particle values were read off from cumulative curve at 5, 16, 25, 50, 75, 84 and 95% and grain-size parameters (Mz-mean size, So-sorting, Sk-skewness, Kg-kurtosis) were calculated according to FOLK & WARD (1957).

The organic matter content was determined by H_2O_2 treatment of the samples at 450°C for 6 hours. The loss of weight after this treatment was attributed to the organic matter content (VDOVIĆ *et al*., 1991). The carbonate content pronounced as $CaCO_3$, was determined as weight loss after the treatment with 4M HCl (LORING & RANTALA, 1992).

In March 2009 at stations B and K (Table 1 and 2) sediment (0-15 cm) samples were taken using van Veen grab in order to perform the measurement uncertainty analyses (ZAMBERLIN *et al*., 2005). In the 1st Inter-calibration Exercize for Grain Size Analyses in sediment, Synthetic report, June 2012 bias was satisfactory with one exception: the one values for clay (<0.002 mm) content was questionable (Z=2.050).

Program STATISTICA 12 was used for statistical analysis (StatSoft Inc., 1984-2013; http://www.statsoft.com). Non–parametric Sperman rank order correlations were used to assess the influence among all determined parameters (gravel, sand, silt, clay, carbonate and organic matter content, grain-size parameters: sorting, skewness, kurtosis, mean size, median), while principal component analysis (PCA) separated parameters in a few factors.

RESULTS

Grain size analysis

The results of grain-size analysis showed that weight percent of gravel particles ranged from 0 to 27.57 (Table 3) were the least represented. The highest (station A 5.83 ± 7.85%) and lowest gravel content (B 0.17 ± 0.19%; C 0. 26 ± 0.21) of the cores were obtained at eastern stations (Fig.1 and Table 3). Sand content had the widest range, from 0.69 to 70.63% (10.69 ± 17.88%) (Table 3) with the highest content at the station D (68.62 ± 1.65%). Silt content ranged from 1.28 to 56.83% (Fig. 1 and Table 3). The highest average silt value was determined at the station A (50.74 ± 6.57%) and the lowest at the D station (3.16 ± 1.61%). The widest ranges were determined at stations A (33.13 to 56.83%) and E (14.18 to 37.46%), while the narrowest range was at the station D (1.28 to 4.82%) (Table 3). Clay content ranged from 19.00 to 70.00% (Fig. 1 and Table 3). The highest average clay particles content (63.31 ± 4.80%) was determined at the station E located near Italian coast (Fig. 1 and Table 3).

According to Shepard's classification the most frequent type of sediment was clayey silt, followed by silty clay (Fig. 2). The other sediment types (sand, sandy clay, clayey sand and the mixture) were less represented.

Table 3. Ranges (min and max values) and average ±st.dev. for obtained parameters at investigated stations (Mz-mean size, Md-median, So- sorting, Sk-skewnes, Kg-kurtosis)

Station Parametars: Range Average±st.dev	A	B	C	D	E
Gravel (%)	0.63-27.57 5.83±7.85	0.00-0.80 0.17±0.19	0.09-0.75 0.32±0.25	4.52-7.20 5.53±1.12	0.65-11.02 2.75±3.23
Sand (%)	3.12-9.30 5.16±1.52	0.69-1.69 1.21±0.23	3.90-6.65 5.32±0.73	67.07-70.63 68.62±1.65	7.83-20.88 11.09±3.84
Silt (%)	33.13-56.83 50.74±6.57	45.51-54.17 49.85±2.48	43.32-52.74 49.93±2.35	1.28-4.82 3.16±1.61	14.18-37.46 22.85±6.16
Clay (%)	30.00-51.00 38.27±5.23	45.00-53.00 48.77±2.46	41.50-50.00 44.43±2.14	19.00-24.50 22.70±2.17	52.00-70.00 63.31±4.80
Mz (µm)	2.19-37.59 8.18±10.08	2.19-3.56 2.93±0.41	2.67-4.24 3.58±0.37	42.69-55.68 48.04±5.33	1.59-5.65 2.94±1.27
Md (µm)	3.64-17.95 7.08±3.46	3.28-5.15 4.19±0.52	3.91-5.92 5.12±0.54	125.00-159.32 146.47±17.66	2.02-3.64 2.46±0.45
So	2.60-6.19 3.38±1.11	2.44-2.65 2.56±0.06	2.73-3.09 2.85±0.09	4.24-4.76 4.44±0.19	2.87-4.45 3.43±0.58
Sk	-0.35-0.37 0.12±0.23	0.23-0.35 0.30±0.04	0.16-0.35 0.23±0.04	0.45-0.49 0.48±0.02	-0.34-0.05 -0.12±0.14
Kg	0.64-2.11 1.38±0.51	0.85-1.07 0.97±0.08	0.85-1.19 1.02±0.09	0.96-2.76 1.99±0.86	0.83-2.19 1.54±0.35
Organic matter (%)	7.29-9.00 8.07±0.54	5.89-8.86 7.23±0.92	5.35-7.46 6.53±0.61	3.04-3.60 3.40±0.22	5.25-6.81 6.26±0.41
Carbonate (%)	46.31-48.88 47.79±0.80	40.27-44.43 42.29±1.44	43.96-48.85 46.93±1.45	67.36-76.50 73.52±3.55	31.70-40.50 34.77±2.32

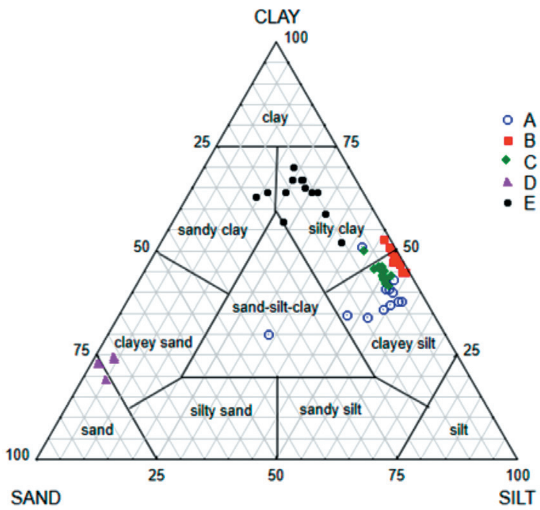

Fig. 2. Sediment type according to Shepard's classification for all sub-samples at investigated stations

The results of grain-size analysis showed that the mean size (Mz) at investigated stations was in the range from medium clay to coarse silt (1.59 to 55.68 μm) (Table 3). At station D the highest Mz was determined (48.04 ± 5.335 microns), and the values at other stations were similar. The widest range was determined at near coast station A (2.19 to 37.59 microns) with varying gravel content. Median (Md) were in wider range than Mz, from coarse clay to fine sand (2.02-159.32 μm) (Table 3). As for Mz, highest values were at station D (146.47 ±17.66 μm).

In the investigated area prevails very poorly sorted sediment, ranging from very poorly to extremely poorly sorted (2.44 to 6.19) (Table 3). The best sorted sediments were at the stations B (2.56 ± 0.056) and C (2.85 ± 0.091), while the least sorted sediment was at the station D (4.44 ± 0.193) (Table 3). Skewness values (Sk) were in range from very negatively (-0.35) to very positively skewed (0.49). At the station D throughout the depth of the core curves are very positively skewed (0.45 to 0.49), while at the station A was recorded the widest range of values from very negative to very positive skewed (from -0.35 to 0.37). In investigated stations prevails positive and very positive skewed curve, indicating that at the investigated sites, coarse grained fractions in sediments prevail (Table 3).

Distribution of grain size fractions in samples of marine sediments shows that mesocurtic curve (0.90 to 1.11) prevail, followed by very leptokurtic curve (1.50 to 3.00) and leptokurtic curves (1.11 to 1.50) (Table 3). At most stations prevalent material was distributed around at one grain size interval. As for the kurtosis of the curve, the widest range of values was determined at the station A (0.64 to 2.11), while the narrowest range was at the station B (0.85 to 1.07).

Carbonate and organic matter

Carbonate content in sediments at the investigated stations ranged from 31.7% (station E,

*Table 4. Correlation matrix between parameters (statistically important correlations P<0.01 are marked with bold letters and P<0.05 are marked with *), n=61*

	So	Sk	Kg	Mz	Md	Gravel	Sand	Silt	Clay	Org. matter
Sk	-0.16									
Kg	**0.47**	-0.27*								
Mz	**0.44**	0.30*	0.23							
Md	0.14	**0.34**	0.12	**0.77**						
Gravel	**0.77**	-0.05	**0.58**	**0.47**	0.23					
Sand	**0.83**	-0.22	**0.51**	0.31*	0.02	**0.62**				
Silt	**-0.60**	0.00	-0.18	0.10	**0.39**	**-0.36**	**-0.63**			
Clay	-0.14	**-0.34**	-0.12	**-0.79**	**-0.99**	-0.24	-0.03	-0.40		
Org. matter	**-0.36**	-0.06	-0.13	-0.03	0.16	-0.10	**-0.49**	**0.61**	-0.19	
Carbonate	0.17	0.30*	0.05	**0.68**	**0.87**	0.18	0.08	0.26*	**-0.88**	0.08

*Table 5. Factors separated with PCA (separated parameters in factor are marked with bold letters and * marked parameters attributes to factor)*

Variable	Factor (1)	Factor (2)	Factor (3)
So	0.20	0.41	**0.84**
Sk	**0.80**	0.12	-0.09
Kg	-0.02	0.56*	0.43
Mz	0.68*	0.55	0.45
Md	0.69*	0.68	0.18
Gravel	0.11	0.02	**0.97**
Sand	0.56	**0.79**	0.19
Silt	0.01	**-0.92**	-0.29
Clay	**-0.91**	0.08	-0.27
Org.matter	-0.27	**-0.86**	0.07
Carbonate	**0.91**	0.31	0.13
Expl.Var	3.68	3.56	2.28
Prp.Totl	0.334	0.324	0.207

12-14 cm) to 76.5% (station D, 1-2 cm) (Table 3). The highest average value of carbonate was observed at deeper station D located near Vis Island (73.52 ± 3.55%), ranging from 67.36 to 76.5%. Meanwhile, the lowest values (34.77 ± 2.316%), with a range of 31.7 to 40.5% were determined at the deepest station E. Carbonate values greater than 50%, were determined only at the station D (Table 3).

The organic matter content in marine sediments at the investigated stations ranged from 3.04% (station D, 2-3 cm) to 9.00% (station A, 0-1 cm) (Table 3). The highest proportion of organic matter in the sediment was found at the near coast station A (8.07 ± 0.55%), while the lowest proportion of organic matter at station D near Vis Island (3.40 ± 0.22%). The average content of organic matter decreases going from station A to D. However, the organic matter content at station E is higher than content obtained at station D, and lower than content at stations A, B and C.

Statistical analysis

Correlation coefficients suggest that the organic material accumulates in fine-grained particles mostly silt sized (Table 4). Positive correlation between sorting and particle sizes of gravel and sand indicates that poorly sorted sediment contains coarse particles.

In order to establish segregation of different influences to parameters (So; Sk; Kg; Mz; Md; content of gravel, sand, silt and clay particles, as carbonate and organic matter), PCA were used. The proportion of variance was statistically important (86 %) and components were divided into three groups affected with grain size (Table 5).

DISCUSSION

The Adriatic Sea represents a submerged karst relief, and appeared after the last glaciation as result of sea level rise (STIPANIČEV & MILJUŠ, 1986). According to eustatic curve (STANLEY, 1995), the deepest station E flooded about 17,000 BP, and the shallowest station A before 7,500 BP. Flooding at different periods has led to changes in the environment and also affected the sedimentation of particles over time.

Although at the investigated stations dominate the clay particle size (<4 µm) according to mean size (Mz) dominated fine silt (13.15 ± 7.91 µm). However, obtained correlation of Mz with a carbonate, and negative correlation with particle size clay (Table 4) indicates the accumulation of carbonate in the silt-sized particles.

Content of gravel particles varies at different stations, and depends primarily on the presence of biogenic particles, but also of mechanical weathering of the surrounding rocks on land. The highest share and the widest range of gravel in the sediment was determined to shallower station A, suggesting influx of large particles of terrigenous origin (from the surrounding coastal areas) and presence of skeletal remains mostly of vertebrates. PCA separate factor 3 indicates to occasionally occurrence of gravel particles as a result of terrigenous input or biogenous origin.

Sand content in the eastern coastal area (stations A, B and C) was the lowest (Table 3). Slightly higher sand content at E station in the west part of the sea affects reworking from shallow coastal areas. The highest proportion of sand particle size determined at the station D probably dates from the period before and during the flooding of this part of the Adriatic Sea. According to AMOROSI & ZUFFA (2011) allogenic factors such as: tectonic exhumation, physical and chemical rock breakdown, change in sediment flux, change in source/basin physiography, shelf colonization by organisms, generation of chemical grains and volcanism, and interaction between them, play a decisive role in dictating sand distribution. One of the source of sand grains could be particles from mechanical weathering of nearby mainland (BOROVIĆ *et al.,* 1977). Namely, outcrops of Pleistocene aeolian sand are found on the neighboring Vis, Hvar, Mljet, Lastovo islands and Pelješac peninsula (PAVELIĆ *et al*., 2011, 2014; BABIĆ *et al*., 2013; WACHA *et al*., 2016). These sands are predominantly carbonates, and indicate that the Dinarides as the source area (PAVELIĆ *et al.,* 2011, 2014). The dimensions of the area covered by dunes on Hvar Island indicate an existence of a dune field, as part of possible coastal desert environment during the Pleistocene along the eastern Adriatic coastal belt (PAVELIĆ *et al*., 2011, 2014). The other source of the Pleistocene calcareous sand are Neretva and Cetina Rivers which also today supply sand to the Adriatic Sea (PAVELIĆ *et al*., 2011; 2014). However, the eastern part of the Vis Island was built mainly of Upper Cretaceous layered limestone with dolomite lenses (BOROVIĆ *et al.,* 1977) and it could be a source of carbonate particles. Today, part of sediment grains originates from the skeletal remains of organisms which are mostly carbonate.

The increased proportion of silt and clay at the stations along the eastern coast of the Adriatic, except at station D, is result weathering of carbonates and mostly flysch deposits as well as the Pleistocene loess which occur along the eastern Adriatic coast as small arosional patches (MARKOVIĆ-MARJANOVIĆ, 1972). Weathering of carbonate rocks is mostly chemical, while flysch deposits, which consist of layers of marl and coarse grained particles, and loess, are physical producing greater amount of fine-grained particles which enter to the sea. Natural weathering and impact of human activities especially in coastal areas (making roads and other buildings as well as the excavation of the flysch deposits) lead to introduction of different size parcels into the marine environment. Stations A and B are located in Kaštela Bay where is the mouth of river Jadro with three cement factories. Prevailing of fine-grained particles is in agreement with before obtained data for stations A and B (ALFIREVIĆ, 1980; BOGNER *et al.,* 1997; BOGNER *et al.,* 1998; BULJAC *et al.,* 2011; BULJAC *et al*., 2016) as well as station C (ALFIREVIĆ, 1964). Established negative correlation between the So and silt particles indicate the origin of the silt particles from the same source (Table 4). However, along the western coast of the Adriatic where is located station E, is a significant influx of rivers particles. Sediment is redistributed under the influence of southward current as well as wind–driven waves resulting in formation of muddy belt parallel to the coast (FAIN *et al.,* 2007; CATTANEO *et al*., 2007). The west Adriatic coast mud belt ended at the south-eastern part of the Gulf of Taranto containing approximately 80% material from Northern Adriatic (GOUDEAUA *et al.,* 2013). Established insignificant negative correlation between clay and other particles (gravel, sand and silt), probably indicates different origins.

Sorting of sediment indicates the origin of the sediment particles. Investigated area is dominated by a very poorly sorted sediment which indicates the presence of different grain size fractions and the different origin of sediment particles (FOLK, 1974). The poorest sorted sediment is at station D, with the highest proportion of sand (Table 3), indicating a biogenous and terrigenous origin of sediment particles. Skewness and kurtosis of the cumulative granulometric curves indicates that in the study area sediment larger particles prevailed distributed around a one-grain size.

The highest proportion of organic matter is determined at the station A located in semi-enclosed east part of the Kaštela Bay, formerly heavily polluted. Sediment resuspension occurred during the winter and became source for suspended matter and organic matter which is consequently settled to the other part of Bay

(UJEVIĆ *et al.,* 2010). At the station B primary production increased in the 1980s as a result of anthropogenic nutrient loading and global climatic changes, i.e. high North Atlantic Oscillation index. A drop was recorded in the period from 2005 to 2007 (NINČEVIĆ GLADAN *et al.*, 2009). At the stations A, B and C most abundant particles were silt. There was a significant correlation between organic matter and silt-sized particles with negative correlation to sand (Table 4) indicating accumulation of organic matter with fine-grained particles. Fine-grained particles have larger surface area what influences the organic bulk composition. Higher proportion of organic matter into a fine-grained particles, was established in the eastern part of the Adriatic coast (UJEVIĆ *et al*., 1998; BOGNER *et al*., 2004; BOGNER *et al*., 2005; MATIJEVIĆ *et al*., 2008). At station D primary production is lower than at station B (MARASOVIĆ *et al.,* 2005). Primary production along the west Adriatic offshore, where is located station E, is influenced by land-derived nutrients which promote phytoplankton growth. Sedimentary dynamics such as reworking, reoxidation and resedimentation as result of Ekman veering influences process decomposition of reactive (algal) organic components in surface sediment (TESI *et al.,* 2007). The refractory organic carbon delivered by the rivers, especially in partially degraded soil fraction, is more efficiently accumulated and preserved on surface sediments on labile marine and estuarine phytoplankton detritus (HEDGES & OADES, 1997). Older sediments may contain much higher proportion of terrestrial organic matter as a result of the efficient and selective degradation of the algal fraction (TESI *et al*., 2007). North from Monte Gargano Peninsula, the surface sediments are highly influenced by terrigenous material, which is dominated by soil-derived organic matter (TESI *et al*., 2007; GOUDEAU *et al.,* 2013).

Obtained carbonate contents indicate that only at the station D deposition of carbonate particles predominates, while at the other four stations are deposited mostly non-carbonate particles (Table 3). However, along the east coast higher carbonates content were determined than on the west coast (FAGANELI *et al.,* 1994; DE LAZZARI *et al.,* 2004). Established negative correlation between carbonate and clay, and obtained the lowest carbonates content and the highest proportion of particles of clay on the station E indicate different, mostly non-carbonate origin of the clay particles as result of the Alps and the Apennines weathering. This explains sedimentation at station E and separation of Factor 1 in PCA (Table 5). Similar carbonate contents at stations in Kaštela Bay (A, B and D) were obtained earlier as for station in Brač Channel located NE from D (BULJAC *et al.,* 2011; BOGNER *et al.,* 2004). Along the middle part of the east Adriatic coast between islands, muddy sediments prevail (ALFIREVIĆ, 1964) influenced by lower carbonate sedimentation. However, the correlation with the significance of $p<0.05$ between carbonate and silt particle indicates their similar origin. Particles can be of biogenic and terigene origin.

A statistically significant correlation between the proportion of carbonate and silt particle size, Mz and Md and higher silt particles content at stations A, B and C, refers to the origin of these particles (Table 4). Carbonate particles in their origin may be allochthone caused by weathering of rocks on land, while autochthone were produced by the indigenous organisms. The carbonate content in sediments usually depends on the amount of shells of marine organisms, since they secrete their skeletons which are mostly made from carbonates. The other source are the carbonated stones and flysch deposits where marls contain 20-80% of calcite (TIŠLJAR, 1994) as well as clay. Factor 2 explain sedimentation at stations A, B, C and D as result of east coast weathering. The differences between the stations are the result of differences in the underlying areas, according to a certain geographical location of these stations and hydrodynamic conditions on them, the presence of organisms with calcareous skeleton and anthropogenic influence.

CONCLUSIONS

Differences between stations resulted in geological and sedimentological characteristics of the weathered areas, geographical location and hydrodynamic conditions, the presence of organisms with calcareous skeleton and anthropogenic influences.

At near east Adriatic coast stations (A, B and C) sediment with silt particles predominated as result of flysch deposits especially marl weathering, and probably of loess weathering.

Sediment at station D (near Vis Island) probably dates from the period before (aeolian and river brought sand) and during the flooding of this part of the Adriatic Sea. At present time the source of sand grains could be particles from physical weathering of nearby mostly carbonate mainland and skeletal remains of organisms which lives in seabed.

The deepest station E is under the influence of western Adriatic coast currents which carry particles which are results of the Alps and the Apennines weathering. Depth and distance from the Italian coast influence prevailing of clay mostly non-carbonate particles.

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Promjene fizikalno-kemijskih karakteristika holocenskih sedimenata iz srednjeg dijela Jadrana (Hrvatska)

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SAŽETAK

Veličina zrna, udio organske tvari i karbonata određeni su u 5 jezgara holocenskih sedimenta iz srednjeg Jadrana. U istraživanom području prevladava taloženje sitnozrnatih i nekarbonatnih čestica. Na razlike između postaja utječe njihov geografski položaj i hidrodinamički uvjeti na njima, mehaničko trošenja okolnog područja djelomično pod antropogenim utjecajem ali i prisutnost ostataka organizama s karbonatnim skeletom u sedimentu. Iako je istočna obala Jadrana uglavnom karbonatna, na postajama u blizini istočne obale, prisutnost eocenskih flišnih naslaga smanjuje udio karbonata (40,27-48,88%) u sedimentu, a prevladavaju čestice veličine mulja (33,12-56,83%). Na postaji u blizini otoka Visa sediment je uglavnom karbonatan (67,36-76,5%), s najvećim sadržajem čestica veličine pijeska (67,07-70,63%). Porijeklo ovog sedimenta su skeletni ostaci organizama koji su živjeli na morskom dnu, pre-holocenski sedimenti i čestice nastale trošenjem karbonatnih stijena okolnih otoka. Na najdubljoj postaji koja se nalazi blizu zapadne obale Jadranskog mora prevladavaju čestice veličine gline (52 - 70%), a udio karbonata je nizak (31,7-40,5%). Ove glinene čestice su nastale erozijom Alpa i Apenina, a u Jadransko more su dospjele rijekama, te su morskim strujama pretaložene duž zapadne obale.

Ključne riječi: sediment, veličina čestica, organska tvar, karbonati, Holocen, Jadran