

Characterization of the fine-grained fraction in the surface sediment of the eastern Adriatic channel areas

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This paper presents results of a study conducted to provide detailed characterization of fine-grained fraction in the selected surface sediment sampled along the eastern Adriatic Sea. The studied fraction was dominated by silt-sized material and composed of carbonate particles (both of biogenic and terrigenous origin), biogenic silica and terrigenous siliciclastic particles. Both components, biogenic and terrigenous were deposited in recent and sub recent conditions. The knowledge about mineral and granulometric composition and the origin of fine-grained particles is essential for understanding sedimentological processes. The obvious complex composition of the fine-grained fraction should be taken into account when environmental studies are to be carried out.

Key words: fine-grained fraction, origin of carbonates and siliciclastics, eastern Adriatic, channel areas

INTRODUCTION

Grain size is an important abiotic factor affecting physical, chemical and biological processes in sediments. Therefore, grain size is the first property to be measured in sedimentological studies. It indicates the provenance of the sediment particles, gives the information of particle transport, sorting and deposition and it has been used for discrimination between depositional environments and facies (e.g. EL-ELLA & COLEMAN, 1985; HALFAR *et al.*, 2004). In oceanology, particle grain size measurement is being used for number of reasons: e.g. to describe the sediment itself (geology), to characterize water masses transport (physics) and to use obtained data for further studies such as organism distribution (biology) (KRANCK & MILLIGAN, 1991).

Coastal waters are one of the most endangered marine environments, in which accumulated sediment acts as a sink for organic and inorganic pollutants. There is a general understanding that elevated concentration of organic and inorganic contaminants in sediment coincide with higher proportion of fine-grained (or mud) fraction (<63 μ m) (WINDOM, *et al.*, 1989; BARBER II *et al.*, 1992; MIKAC *et al.*, 2006; RUBIO *et al.*, 2000; ILIJANIĆ *et al.*, 2014). Grain-size analysis of sediment is thus the first descriptive parameter in many geochemical and biological studies as well.

Fine-grained fraction comprises silt (4-63 μ m) and clay (<4 μ m) particles. The mineral composition of silt-sized particles in shelf deposits is usually similar to the fine sand. In the finest end of their range, silt-sized particles

behave much like the clay-sized particles, sharing their similar mineral composition (SEIBOLD & BERGER, 1996; STEVENS *et al.*, 1996). Much of the clay fraction in shelf environments is composed of clay minerals (*e.g.* smectite, illite, chlorite, kaolinite). Clay mineralogy in marine sediments is widely used to define sediment provenance, distribution and dispersal pathways (TOMADIN, 2002; LIU *et al.*, 2010). Surface properties of clay minerals such as high specific surface area give fine-grained fraction capability to adsorb various substances, both organic and inorganic, influencing thus the geochemistry of sediment (VDOVIĆ & JURAČIĆ, 1993; FELJA *et al.*, 2016). It is thus clear that, not only grain size, but mineral, biological and geochemical composition of the finest sediment fraction should be also taken into account in comprehensive environmental studies. Many of them conducted in the Adriatic Sea have examined fate of the pollutant in bulk marine sediments, omitting thereby the detailed composition and origin of the fine-grained fraction (*e.g.* MARTINČIĆ *et al.*, 1989; VDOVIĆ & JURAČIĆ, 1993; UJEVIĆ *et al.*, 2000; ILIJANIĆ *et al.*, 2014).

According to PIKELJ (2010) the eastern part of the Adriatic Sea is defined as non-tropical carbonate-siliciclastic shelf significantly influenced by *in situ* biogenic carbonate production, mostly found in coarse-grained (>63 µm) fraction. Siliciclastic component is thus presumed to reside mostly in fine-grained fraction. The objective of this preliminary study was to provide the insight into the grain size and mineral composition and overall role of mud fraction of the selected surface sediment collected in the channel areas along the eastern Adriatic shelf. Only sediments from the channel areas were chosen for this preliminary study since contained greater amount of fine-grained fraction compared to those from the mainly shallower outer shelf.

MATERIAL AND METHODS

Study area

The eastern Adriatic Sea and the adjacent coast are characterized by highly tectonized (folded and faulted) karstic relief. Its submer-

sion during the Pleistocene-Holocene sea-level rise helped to develop one of the most indented coasts in Europe with the second largest archipelago within the Mediterranean, distinctive by numerous drowned coastal karst landforms (VLAHOVIĆ *et al.*, 2005; SURIĆ & JURAČIĆ, 2010; PIKELJ & JURAČIĆ, 2013). The hinterland of the eastern Adriatic is dominantly built of Mesozoic carbonates (limestones and dolomites) prone to karstification. A subordinate rock assemblage in the coastal area is the Eocene flysch (assemblage of marl, siltstone, sandstone, and carbonate breccia in alternation) with associated deposits (Pleistocene sands) (see detailed geological setting in VLAHOVIĆ *et al.*, 2005, JURAČIĆ *et al.*, 2009; PIKELJ & JURAČIĆ, 2013 and PIKELJ *et al.* 2015). Consequently, most streams and rivers are small, and terrigenous sediment supply is low and of local relevance. The flysch and associated deposits are found largely on the hinterland coast (CGS, 2009), while analogous outcrops are less distributed on islands (LUŽAR OBERITER *et al.*, 2008). Their weathering is aided by rare and ephemeral surface flows (BENAC *et al.*, 2013), by marine abrasion (PIKELJ *et al.*, 2014) and episodically by the direct denudation after heavy rains (seen during the fieldwork). Thus, studied channel areas are characterized by generally low terrigenous supply within the recent hydrodynamic conditions. Furthermore, these areas are protected from the deposition from the west, due to the both, outer island chains and prevalent cyclonic circulation (JURAČIĆ *et al.*, 1999; STECKLER *et al.*, 2007).

Analyses

Sediment samples analysed in this study were sampled for the purpose of a wider regional sedimentological study (PIKELJ, 2010). Selected surface samples were collected from the broad geographic area from the Kvarnerić to Elafiti archipelago (Fig. 1) covering various sampling depths and having various grain size properties. Bulk samples were analyzed for grain size (Table 1) by wet sieving for the coarse-grained (sand and gravel) fraction and by using a sediment particle size analyzer (Micromeritics Sed-

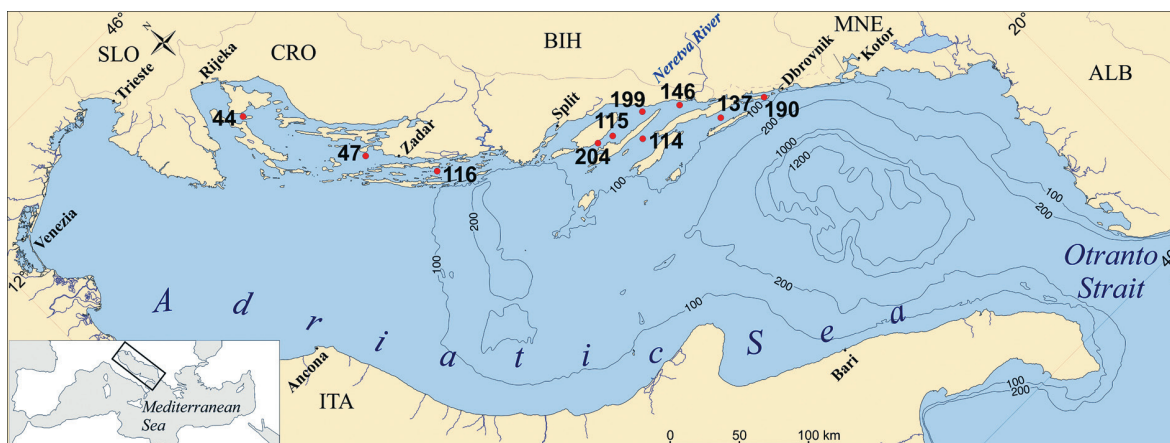


Fig. 1. Location map showing sampling locations. Location names and sampling depths are given in Table 1

iGraph 5100) for the fine-grained (<63 μm , silt and clay) fraction. Sediment texture was determined according to the classification of FOLK (1954). Mineral composition was determined by X-ray diffraction (Philips X-Pert PRO instrument, equipped with vertical goniometer, Cu-tube (40 kV, 40 mA) and graphite monochromator). Previously separated fine-grained fraction (passed through a 63-micron-mesh-size sieve) of selected samples was further analyzed in this study. The carbonate content of the fine-grained fraction was determined using gas volumetry, by

measuring carbon-dioxide evolved after acidification of 300 mg of homogenized mud with 1:1 diluted HCl. The semiquantitative mineral composition of fine-grained fraction subsamples was determined through X-ray diffraction in the same manner as bulk sediment. Symbols for identified minerals were used following KRETZ (1983). Smear slides of mud subsamples were prepared following nannofossil preparation techniques (BOWN, 1998) and examined using the Reichert Zetopan microscope (320-1600 \times magnification, oil immersion objective) by PP

Table 1. Sampling locations, sampling depths and grain size characteristics of the selected bulk sediment samples (PIKELJ, 2010)

Sample No:	Sampling location:	Sampling depth (m):	Gravel (%):	Sand (%):	Mud (%):	Silt (%):	Clay (%):	Sediment class (after FOLK, 1954):
44	Sjeverna vrata	66	0.1	8.1	91.8	51.0	40.8	mud
47	Vir Sea	62	0.8	35.8	63.4	43.2	20.2	slightly gravelly sandy mud
114	Korčula Channel	65	1.8	21.8	76.4	46.9	29.5	slightly gravelly sandy mud
115	Hvar Channel	82	0.2	84.1	15.7	9.4	6.3	muddy sand
116	Middle Channel	75	3.5	72.7	23.8	19.0	4.8	slightly gravelly muddy sand
137	Mljet Channel	80	0.1	9.5	90.4	29.1	61.3	mud
146	Neretva Channel	35	0.2	1.5	98.3	46.5	51.8	mud
190	Lopud Strait	57	12.5	43.8	43.7	17.2	26.5	gravelly muddy sand
199	Hvar Channel	47	2.0	66.2	31.8	15.7	16.1	slightly gravelly muddy sand
204	Hvar Channel	70	0.3	55.1	44.6	39.4	5.2	muddy sand

and XP light in order to define their content. Calcareous nanoplankton and microplankton species were identified and biostratigraphically considered following: PERCH-NIELSEN (1985), PUŠKARIĆ (1988), BOWN (1998), and <http://www.nannotax.org> (accessed: September, 2012).

RESULTS AND DISCUSSION

Grain size, carbonate content and mineral composition

The original bulk sediment grain size properties of selected samples showed that the texture of bulk surface sediment varies greatly, from muds, slightly gravelly sandy muds, gravelly sandy muds to slightly gravelly muddy sands, gravelly muddy sands and muddy sands (Table 1). The fine-grained fraction was dominated by silt in 6 samples (44, 47, 114, 115, 116, 204), clay dominated slightly in 2 samples (146, 199), while major difference in favour of clays was found in only 2 samples (137, 190) (Table 1, Fig. 2). According to PIKELJ (2010), much of the siliciclastic material in surface sediment along the eastern Adriatic appears to reside in the fine-grained fraction. It was thus expected that the carbonate content will be significantly lower in the mud fraction compared to the bulk sediment (56% in average). However, average carbonate share in mud fraction was only slightly lower and was ~ 47 %. The amount of carbonates determined was still considerably high for nine of ten samples, while one sample (44) showed even higher carbonate share in the fine fraction compared to the bulk sample.

Similar percentage and minimum differences were found in samples 47, 137, 146 and 204, while the major difference in percentage and decreased carbonate share was found in samples 114, 115, 116, 190, and 199 (Table 2). This variability was in part the result of the sampling locations locally influenced by vicinity of the local source of siliciclastic material. The Neretva River input accounts as the main source of siliciclastic material in the area of the Hvar, Korčula and Neretva Channels, supplying the area with quartz, plagioclase, feldspars and clay minerals, as well as with detrital calcite and dolomite (JURINA *et al.*, 2013; FELJA *et al.*, 2016). The erosion of flysch deposits facing the sea in the zone stretching from the Kaštela Bay to Ploče was suggested as an additional source (PIKELJ & JURAČIĆ, 2013). The typical minerals assemblage in flysch deposits in the Adriatic zone includes quartz, calcite, dolomite, clay minerals (illite, chlorite, montmorillonite), feldspar, micas (muscovite and biotite) and accessory heavy minerals such as garnets, tourmaline, zircon, rutile, apatite and chromite (MAGDALENIĆ, 1972; TOŠEVSKI *et al.*, 2012). Mineral composition and distribution of mineral phases in analyzed fine-grained fraction showed the presence of minerals characteristic for flysch: quartz, calcite, dolomite, chlorite, plagioclase, muscovite and rutile (found only in one sample) (Table 2). The similarity of mineral assemblages between mud fractions implied similar or the same sources of detrital material. In case of the sediment sampled distant from the Neretva River and the Kaštela-Ploče flysch zone, where occurrences of flysch outcrops are sporadic, only minor

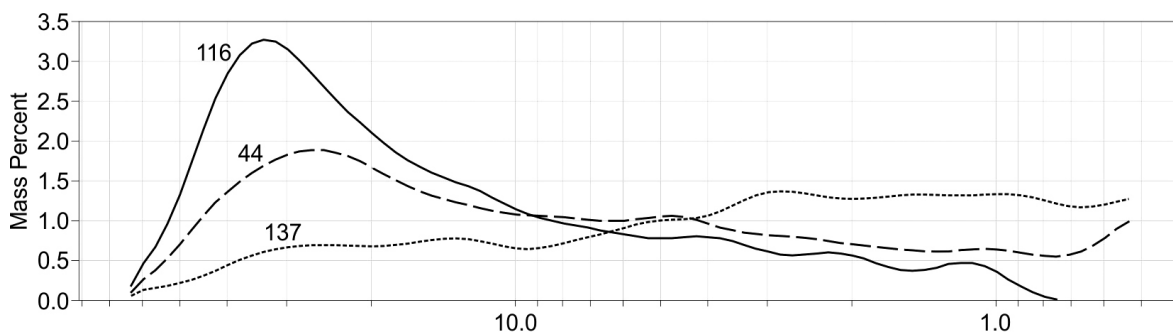


Fig. 2. Particle size distribution curves of selected fine-grained fractions obtained by sedimentograph

Table 2. Carbonate content and mineral composition of bulk sediment (PIKELJ, 2010) and the studied fine-grained fraction

Sample No:	Sampling depth (m):	Carbonates (%) in bulk sediment (PIKELJ, 2010):	Carbonates (%) in mud (this study):	Mineral composition* of bulk sediment (PIKELJ, 2010):	Mineral composition* of mud (this study):
44	66	48.5	52.1	Cal, Qtz, Cal-Mg, Ms, Pl, Amp, Dol	Cal, Qtz, Cal-Mg, Dol, Ms, Pl, Chl
47	62	48.6	45.2	Qtz, Cal, Cal-Mg, Arg, Dol, Amp	Qtz, Cal, Dol, Cal-Mg, Arg, Ms
114	65	57.4	43.4	Cal, Cal-Mg, Qtz, Arg, Dol, Ms, Chl, Pl	Cal, Qtz, Dol, Cal-Mg, Arg, Amp, Pl, Chl, Ms
115	82	67.8	52.9	Dol, Qtz, Cal, Cal-Mg, Arg, Pl	Cal, Qtz, Dol, Cal-Mg, Arg, Ms
116	75	76.6	62.9	Cal, Cal-Mg, Arg, Qtz, Ms, Px	Cal, Qtz, Rut, Cal-Mg, Arg
137	80	31.9	26.3	Qtz, Cal, Cal-Mg, Chl, Ms, Pl, Dol	Qtz, Cal, Cal-Mg, Pl, Chl, Ms, Dol
146	35	34.6	34.5	Qtz, Cal, Cal-Mg, Chl, Ms, Dol, Pl	Qtz, Cal, Dol, Pl, Ms, Chl, Cal-Mg
190	57	51.9	34.1	ND**	Qtz, Cal, Dol, Cal-Mg, Chl, Ms, Pl
199	47	66.3	45.5	ND**	Qtz, Cal, Dol, Cal-Mg, Ms, Chl, Pl, Arg
204	70	76.2	72.2	ND**	Cal, Qtz, Dol, Cal-Mg, Arg

*The minerals in the order of decreasing abundance. **ND: not determined. Abbreviations of identified minerals (after KRETZ, 1983): Cal-calcite, Qtz-quartz, Arg-aragonite, Ms-muscovite, Pl-plagioclase, Dol-dolomite, Amp-amphibole, Chl-chlorite, Px-pyroxene, Rut-rutile. Symbol Cal-Mg was used for magnesian calcite.

amount of siliciclastics might be directly eroded by surface processes. The seabed itself was thus considered as a possible source of flysch-derived material, since channels and some bays are submerged synclines with troughs built in the Eocene flysch (BENAC *et al.*, 2008; PIKELJ *et al.*, 2009; PIKELJ & JURACIĆ, 2013). Bearing in mind the tendency of flysch to rapid weathering when wetted and dried (TOŠEVSKI *et al.*, 2012), the above consideration suggests that weathering of presently submerged flysch outcrops could have occurred under the subaerial erosion during the last sea-level stand. Furthermore, SIKORA *et al.* (2014) presented the reconstruction of paleo-riverbeds of the Cetina and Neretva Rivers during the lowered sea-level, according to which flat river valleys and accumulations were formed, filling thus the exposed recent seabed in the modern offshore channel areas with terrigenous

sediment material. Both, coastal erosion and river sediment flux suggest recent and subrecent time of deposition of detrital sediment material found on the recent seabed surface, as already suggested by PIKELJ *et al.*, 2009 and PIKELJ, 2010.

Mineral composition of siliciclastic component found in analyzed sediments partially overlapped with loess and loess-like deposits found along the coast and on islands along the Eastern Adriatic (DURN *et al.*, 1999; MIKULČIĆ PAVLAKOVIĆ *et al.*, 2010; PAVELIĆ *et al.*, 2011). As far as the Northern Adriatic is concerned, loess originated from the ancient alluvial plain of the Paleo-Po River and its tributaries during the low sea-level stand (DURN *et al.*, 1999; MIKULČIĆ PAVLAKOVIĆ *et al.*, 2010). On the other hand, the Dinarides are considered as the source of the aeolian deposits on the Hvar Island (PAVELIĆ *et al.*, 2011). A certain quantity of aeol-

lian sediments probably deposited in the channel areas as well, under the same conditions during the low sea-level stand. As shown by MIKULČIĆ PAVLAKOVIĆ *et al.* (2010) and PAVELIĆ *et al.* (2011), aeolian sediment from both source regions contained amphiboles (among other minerals), which could explain their finding in samples 44 and 47 in the Kvarner Region and in the sample 114 from the Korčula Channel (Fig. 1). Furthermore, enhanced runoff during the early Holocene pluvial (KALLEL *et al.*, 2004) might additionally transport this sediment to the study area where deposited as river-borne sediment. This is supported by reconstructions of paleoriver flows given in SIKORA *et al.* (2014) and PAVELIĆ *et al.* (2011). Denudation of aeolian deposits might further supply the study area by siliciclastic material under the modern high sea-level stand.

As far as detrital calcite and dolomite are concerned, it is more likely that these carbonates originate from the flysch, already loaded with older carbonate lithoclasts, instead of widespread Mesozoic carbonates, more susceptible to dissolution.

By comparing the mineral composition of mud fraction with that of the bulk sample, similarity in mineral composition has been observed (Table 2). The main variation is visible in the abundance of mineral phases which probably arises from partitioning of mineral abundances between grain size fractions during the transport, deposition and diagenesis (Table 2). This segregation may depend on the provenance supply and thus the original bulk sediment composition, physical properties of particles, hydrodynamic conditions, as well as the stage of particle breakdown (in case of skeletal debris) and the size of crystallites produced (DEBENAY *et al.*, 1999; ACHARAYA *et al.*, 2008).

Beside the calcite and dolomite, carbonate minerals identified include magnesian calcite and aragonite in various abundances (Table 2). As previously mentioned, the dolomite is of detrital origin as well as a part of calcite. Considering the high contribution of biogenic particles to formation of surface sediment veneer in the eastern Adriatic (PIKELJ, 2010; PIKELJ & JURACIĆ,

2014), it is obvious that part of the calcite in the fine-grained fraction derives from skeletal debris. Remnants of many of calcite secreting organisms, such as molluscs, foraminifera, ostracods, barnacles, coccolithophores *etc.* (SEIBOLD & BERGER, 1996) were found in the bulk sediment (PIKELJ, 2010). Magnesian calcite was indentified in all samples, while aragonite was found in six of them (Table 2). Both, Mg-calcite and aragonite are defined as biogenous, since no favourable conditions for their inorganic precipitation exist in the study area (BURTON & WALTER, 1987; FLÜGEL, 2004). The exception is occasional precipitation of inorganic aragonite ("whiting events") in the semi-enclosed marine lakes on the Mljet Island (SONDI & JURACIĆ, 2010). Aragonite and Mg-calcite skeletons and/or skeletal fragments of molluscs, bryozoans, foraminifera, red algae, echinoderms, ostracods, corals and sponges were indentified in coarse-grained fraction of investigated samples (PIKELJ, 2010).

Nature of the biogenic particles

Analysis of the smear slides revealed that fine-grained fractions abound with particles of biogenous origin, including calcareous nannoplankton, juvenile foraminifera, various calcareous skeletal debris, diatoms, sponge spicules, radiolarians and silicoflagellates (Fig. 4). The first three groups contribute to the rather high carbonate content in analyzed <63 µm fraction. Moreover, this result supports the interpretation that part of carbonates is of biogenic origin.

Calcareous nannoplankton was represented by remnants of coccolithophores, mostly in form of coccoliths (Fig. 3). In all samples a total of thirty-four species were recognized, ranging in age from the Middle Jurassic to the Holocene (Fig. 3). The same stratigraphic distribution of calcareous nannoplankton around the Jabuka Islet was recently reported by PIKELJ *et al.* (2015). The assemblage of fossil species characteristic for the Eocene was found in all analyzed samples. It was thus concluded that these species were eroded from the most widespread Eocene deposits: Eocene flysch. This is in accordance

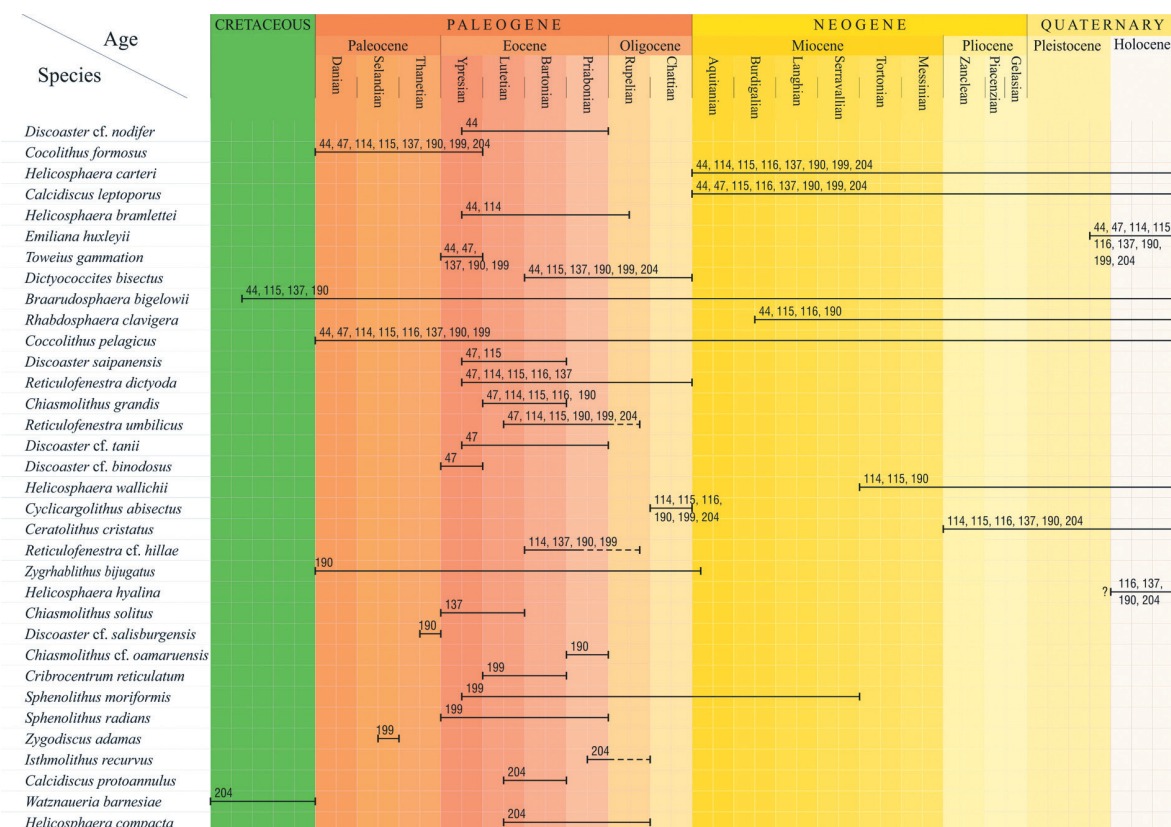


Fig. 3. Stratigraphic distribution of identified calcareous nannoplankton species in the studied fine-grained fractions. Sample numbers are indicated above/below the distribution line

with the interpretation that the siliciclastic component of the fine-grained fraction together with detrital carbonates comes from the flysch. Only one calcareous nannoplankton species found (*Watznaueria barnesiae*) dates from the Jurassic (Fig. 3). Similar as for the detrital carbonates it is more likely that this species was twice redeposited: from the Mesozoic carbonates into the Eocene flysch and from the Eocene Flysch to the surface sediment of the eastern Adriatic.

The species ranging from the Paleocene to the Oligocene (or Paleocene-Eocene and Eocene-Oligocene) were presumed to be eroded mostly from the flysch, since deposits of Paleocene and Oligocene age are scarce along the coast. The age of species stretching from the Neogene to Holocene in age is not easy to impose. However, due to the restricted occurrence of the Miocene and Pliocene deposits along the coast (CGS, 2009), we presume that most of them are of the Pleistocene age or

Holocene. In case of species such as *Emiliana huxley*, it could have been deposited during the Pleistocene and Holocene (Fig. 3). It can be thus concluded that studied fine-grained fraction of the surficial sediment contains recent and subrecent (Pleistocene) biogenous particles, as well as older particles, recycled and redeposited several times.

Tropical carbonate muds are widely known to be produced by disintegration of green algae such as genus *Halimeda* and by the biologically induced direct precipitation of inorganic carbonates (FLÜGEL, 2004 and reference therein). Formation of carbonate mud was recorded in various non-tropic environments as well: on the temperate shelf of south-eastern Australia (BLOM & ALSOP 1988), in temperate and high latitudes all over the Europe (FARROW & FYFE, 1988) and in the NW Mediterranean (FORNOS & AHR, 2006). In all given cases the carbonate mud was considered to be derived from biodegradation,

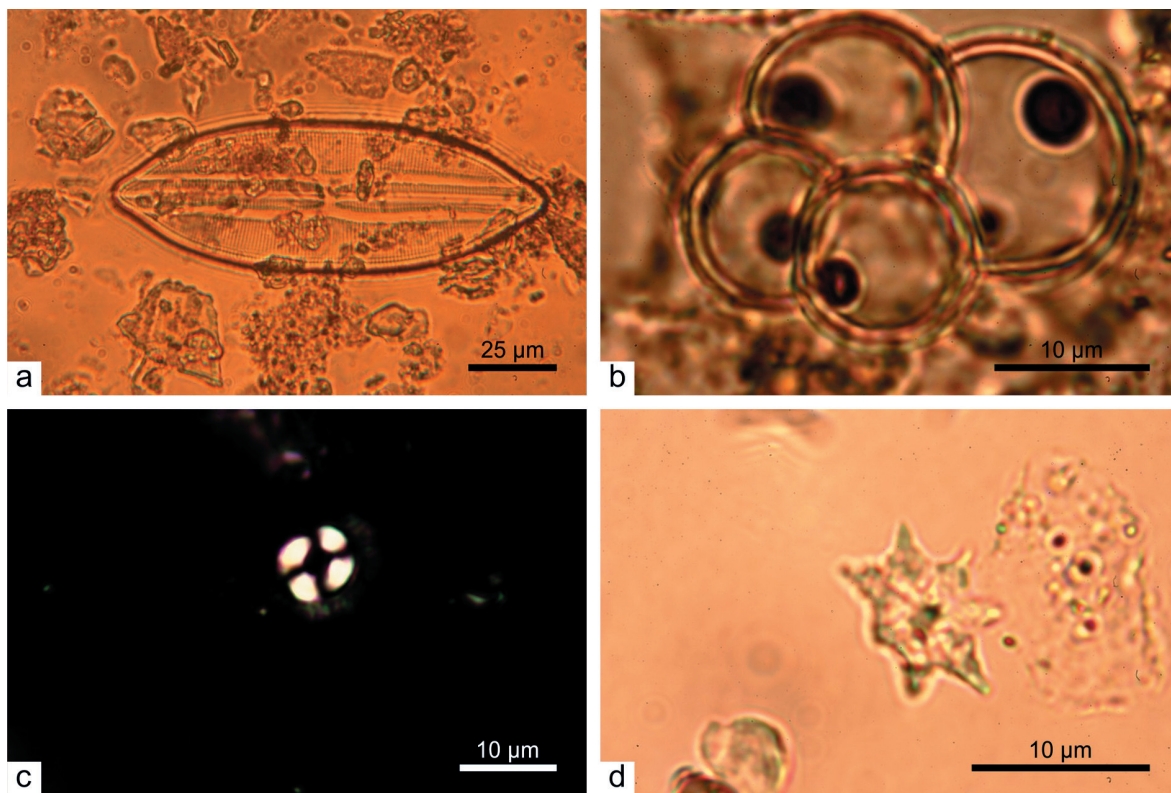


Fig. 4. Images of selected biogenic particles found in the studied fine-grained fraction: a) biogenic debris with diatom *Navicula hennedy* Smith 1856 (sample 115; presumably passed through 63 μ m mesh size by its intermediate or short axis); b) juvenile foraminifer in biogenic debris (sample 199); c) *Coccolithus formosus* (Kamptner, 1963) Wise 1973; (sample 44); d) *Discoaster saipanensis* Bramlette & Riedel, 1954 (sample 47)

physical disintegration and maceration of macro-skeletal components and from accumulation and disintegration of pelagic components (e.g. nannoplankton). As previously mentioned, rare cases of inorganic carbonate precipitation out of tropics may occur in restricted and stressed environments (SONDI & JURACIĆ, 2010). By showing the high average (~ 47 %) of carbonate content found in the fine-grained fraction, this study put the eastern Adriatic on the list of environments of typical non-tropical mud production. Based on the here obtained results and previous related studies (FARROW & FYFE, 1988; PIKELJ *et al.*, 2015), we presume that biologically and physically caused disintegration of coarse skeletal material as a leading process in the formation of carbonate mud in the eastern Adriatic. Furthermore, it is aided by accumulation of calcareous nannoplankton, not only of recent species, but also by sedimentation of reworked fossil (zombie) species. Physical and chemical fragmentation and

alteration of carbonate grains (destructive diagenesis) in non-tropical shelf realms is mainly controlled by carbonate skeletal assemblage and sedimentation rate. The selective destruction may thus result in biased sedimentary record, while the low sedimentation rate leaves carbonate grains exposed to destruction in the taphonomically active zone (SMITH & NELSON, 2003). Due to their rare and local cementation (NELSON & JAMES, 2000), non-tropical carbonate (or mixed carbonate + siliciclastic) sediments may thus remain unlithified for a long time and eventually result in weakly cemented deposits in sedimentary record, as shown by ANDRE *et al.* (2003).

Non-carbonate biogenic remnants are the last component found in the studied mud (Fig. 4). Its contribution was recorded only during the smear slide analysis, but not by XRD, due to their amorphous nature. Yet, this biogenic silica increases number of components to already

rather complex composition of the studied sediments.

The fine-grained fraction of sediments tends to be enriched in metals and organic carbon owing to clay minerals due to their physical and chemical properties (*e.g.* cation exchange capacity and specific surface area) which are usually found in the finest size fractions. In contrast, carbonate minerals are often associated with coarse-grained fraction and generally act as diluents of metals (VDOVIĆ & JURACIĆ, 1993; RUBIO *et al.*, 2000; ALOUPI & ANGELIDIS, 2001). The bulk sediment of the study area is generally described as coarse grained (PIKELJ, 2010; Table 1). Furthermore, this study revealed that the average carbonate share in the fine-grained fraction was only slightly lower compared to bulk sample. This finding thus implies that much of the carbonate fine-sized particles derived from the *in situ* produced carbonate bioskeletons. This mechanism of destructive diagenesis is typical for non-tropical carbonate shallow water realms (NELSON & JAMES, 2000; SMITH & NELSON, 2003). Moreover, when found together with carbonates in coastal sediment, quartz and feldspars enhance its diluting effect (WINDOM, *et al.*, 1989). This mineral assemblage (carbonates, quartz, feldspars) was commonly found in the studied fine-grained fraction, while only one clay mineral found (chlorite) was subordinate (Table 2). It is thus important to be aware of detailed characteristics of fine-grained fractions when environmental studies are to be carried out.

CONCLUSIONS

Results presented here showed that examined fine-grained fraction (<63µm) in the surface sediment collected in the channel areas of the eastern Adriatic Sea were mainly dominated by silt fraction and contains both, carbonate and non-carbonate component. The carbonate share of mud (~47%) is slightly lower compared to amounts of carbonates in the bulk surface sediment (56%) and consists of calcite, dolomite, Mg-calcite and aragonite. Dolomite and a part of calcite were considered to be land-derived, mostly from the Eocene flysch. The other part

of calcite was of biogenous origin together with Mg-calcite and aragonite. The production of carbonate mud in the studied area was enabled by biological and physical degradation of various skeletal particles abundant in the coarse-grained fractions.

One part of biogenous carbonate fine-grained particles was derived from the Eocene flysch, as confirmed by the age of the identified calcareous nannoplankton and this is the second implication of flysch being one of the sources of studied sediment. The third indication of flysch-derived material deposited in the study area was the mineral composition of the siliciclastic component in which quartz, chlorite, plagioclase, and muscovite dominated. Together with other non-carbonaceous minerals, amphibole found in the analyzed sediment indicated that one part of the siliciclastic component probably derived from the loess deposited along the eastern Adriatic. Beside the non-carbonate terrigenous component, analyzed fine-grained fraction contained a certain amount of non-carbonate biogenic particles, including diatom, silicoflagellate, radiolarian and sponge remains. In general, terrigenous sediment input from the Croatian part of the Adriatic coast provided by coastal erosion and river discharge in the modern conditions is rather low. It is thus suggested that similar processes could supply the recent seabed with terrigenous material in the subaerial conditions during the lower sea-level stand.

The knowledge about mineral and granulometric composition and the origin of fine-grained particles is crucial for understanding sedimentological processes (*e.g.* cementation). Furthermore, fine-grained sediment particles are recognized as a sink for many contaminants discharged into coastal waters, while their behaviour and the fate are strongly affected by the characteristics of the sediment, other than grain size. It is thus important to be aware of the complex nature of the studied fine-grained (<63 µm) fraction when environmental studies are concerned, not only in the eastern Adriatic, but also in other complex depositional environment. Finally, a highly needed study of clay mineral assemblage composition and distribution in sed-

iments along the Eastern Adriatic should add to our understanding of its origin complexity.

ACKNOWLEDGEMENTS

This work was supported by the Project No. 119-1191152-1169 funded by the Croatian Ministry of Science, Education and Sports and the MEDIAS (MEDIterranean Acoustic Surveys - assessment of distribution and abundance of

small pelagic fish; previous PELMON project) funded by the Croatian Ministry of Agriculture (previous Ministry of Agriculture, Fisheries and Rural Development). We wish to thank Darko TIBLJAŠ for the help during laboratory work (XRD) and Robert KOŠČAL for the technical support in figure preparation. Special thanks to Goran DURN for his helpful suggestions and to two anonymous reviewers.

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Received: 12 July 2016
Accepted: 22 August 2016

Karakterizacija sitno-zrnaste frakcije površinskog sedimenta u kanalskom području istočne strane Jadranskog mora

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SAŽETAK

Ovaj članak prikazuje rezultate istraživanja provedenih kako bi se detaljnije okarakterizirala sitno-zrnasta frakcija u odabranim uzorcima površinskog sedimenta uzorkovanih na području istočnog dijela Jadranskog mora. U sitno-zrnastoj frakciji generalno prevladava materijal veličine praha, a cjelokupna se frakcija sastoji od karbonatnih čestica biogenog i terigenog porijekla, biogenog opala i terigenih siliciklastičnih čestica. Obje komponente, biogena i terigena, taložene su u recentnim i subrecentnim uvjetima. Poznavanje granulometrijskog i mineralnog sastava sitno-zrnaste frakcije osnova je razumijevanja sedimentoloških procesa, a njegovu očitu kompleksnost bi svakako trebalo uzeti u obzir pri istraživanjima kakvoće morskih okoliša.

Ključne riječi: sitno-zrnasta frakcija, porijeklo karbonata i siliciklastita, istočni Jadran, kanalsko područje