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Variable sources of beach sands of north Adriatic islands: examples from Rab and Susak

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ABSTRACT

The composition of beach sands from the Islands of Rab and Susak (northern Adriatic) has been studied in order to determine how individual beaches are supplied with detritus. The beaches on both islands are composed of quartz dominated siliciclastic sand, with subordinate carbonate content. Three end-member heavy mineral assemblages have been identified among the studied beach sands, each one associated with a specific source rock: (1) a garnet dominated assemblage and (2) a zircon, rutile and tourmaline dominated assemblage on Rab Island, as well as (3) an assemblage dominated by unstable minerals on Susak Island. Sands from individual beaches contain one of these specific assemblages or display a mixing of two varieties. The end-member assemblages are very comparable with those of Eocene and Pleistocene sediments which crop out on the two islands, identifying them as the principal sources of detritus. Cretaceous and Eocene carbonate rocks, although present to a considerable extent in the study area, have shown to be a negligible source of sandy material. Thus, the supply of detritus to the beaches is primarily controlled by erosion of siliciclastic rocks in the immediate or nearby hinterland.

Keywords: beach sands, sediment supply, framework composition, heavy minerals, Rab, Susak, Croatia

1. INTRODUCTION

Analysis of framework composition and heavy mineral assemblages are commonly used tools for delineating provenance of both ancient and recent sediments (WELTJE & VON EYNATTEN, 2004; GARZANTI & ANDO, 2007). In particular, many studies have employed such methods to determine sources of detritus and reconstruct supply pathways by which coastal areas are supplied with sand (e.g. GILES & PILKEY, 1965; GANDOLFI et al., 1982; CLEMENS & KOMAR, 1988; POTTER, 1994; MARCHESINI et al., 2000; SABEEN et al., 2002; GARZANTI et al., 2002, 2003; CASCALHO & FRADIQUE, 2007). Beaches represent a delicate coastal environment, one that is easily subject to destructive processes if an imbalance is created between the supply of detritus and erosion (KOMAR, 1998). In the European Union, comprehensive coastal investigations have shown that its coastal beach environments are experiencing increased erosion due to lack of sediment, attributed primarily to human activity (SALMAN et al., 2004). Given the rising pressure from development, the coastal environments of Croatia can be expected to become more and more vulnerable to such processes in the future. A better understanding of how beaches are supplied with sandy material is crucial when considering the protection and management of such environments, which is essential if their aesthetic, recreational and economic values are to be preserved.

With the above notions in mind, we have conducted a comparative beach sediment study on the Islands of Rab and Susak, located in the Kvarner region of the NE Adriatic (Fig. 1). To date our research on beach sands from Rab Island has shown that considerable variability exists in their heavy mineral compositions (BABIĆ et al., 1997; CRNJAKOVIĆ et al., 1998; LUŽAR-OBERITER et al., 2005; LUŽAR-OBERITER, 2006). In the current study, data has been obtained from

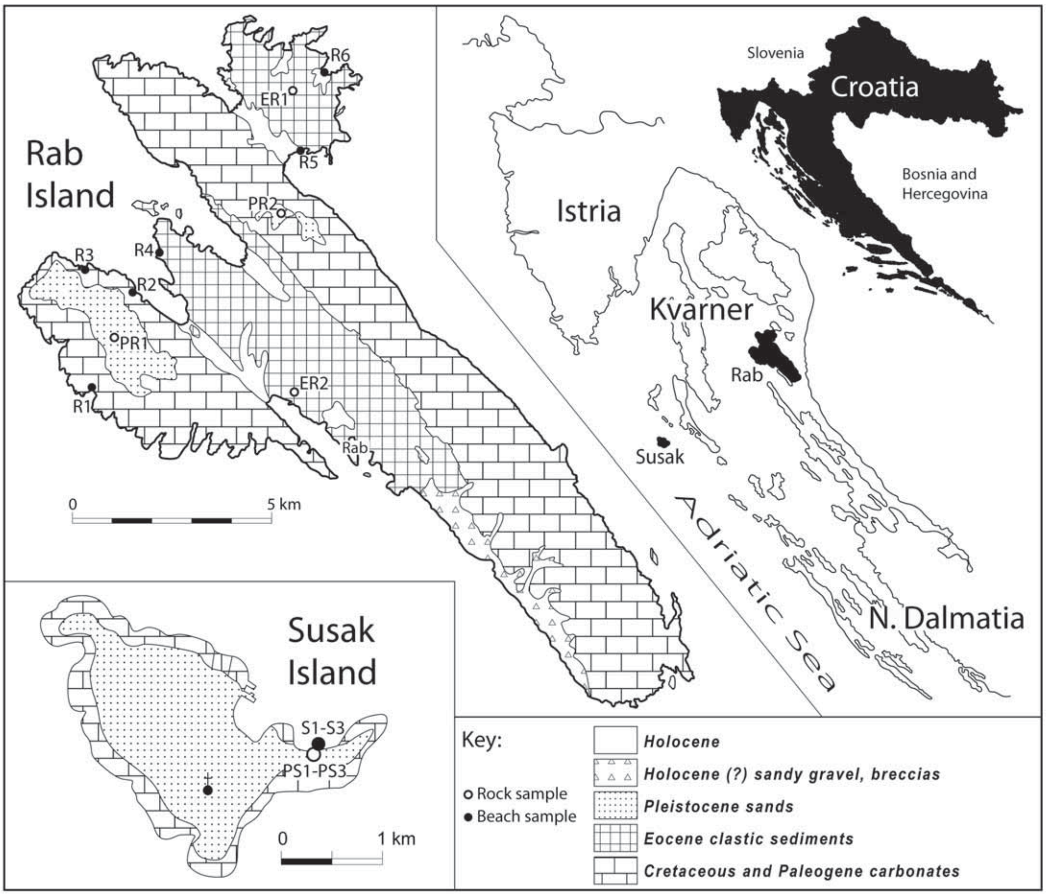

Figure 1: Maps of the study area with marked locations of the analyzed samples. Basic lithologies are simplified after MAMUŽIĆ (1962, 1968) and MAMUŽIĆ et al. (1969, 1973).

both modern beach sands and ancient rocks from both islands, which we use to document the presence of three end-member heavy mineral assemblages and more precisely define the relationships between individual beaches and their source(s) of sand (MIKULČIĆ PAVLAKOVIĆ et al., 2006).

2. MATERIAL AND METHODS

Six separate beaches have been chosen from various bays on Rab Island, while for the smaller Island of Susak, the beach in Bok bay has been selected as a representative location (Fig. 1). Samples of beach sands were taken from the foreshore of each beach (Samples R1 to R6 and S1 to S3). To identify the sources from which the individual beaches are supplied with detritus, potential source rocks which crop out on the islands were identified and sampled. These included Eocene sandstones (Samples ER1 and ER2) which are ubiquitous on Rab Island (Fig. 1), as well as Pleistocene sediments from both islands (Samples PR1, PR2, PS1 to PS3).

Thin sections were produced from both hard rock and disaggregated sand samples. For disaggregated samples, which included beach and Pleistocene sands, the material was first artificially cemented with epoxy. Thin sections were inspected under a polarizing light microscope to determine framework composition.

All samples were treated with 3% hydrochloric acid to remove carbonates. Rock samples were crushed prior to acid treatment, for which only fragments larger than 1mm were used. Carbonate content was calculated from the weight difference before and after acid treatment. Obtaining heavy mineral concentrates was performed by gravity separation with bromoform (MANGE & MAURER, 1992), using the 0.05–0.125 mm size fraction after sieving. Heavy mineral proportions were determined by ribbon counting 300–400 grains in each sample. We have chosen to display these results as proportions of three groups of heavy mineral species, which have been determined to best express the differences between our studied samples: 1) garnet, 2) zircon, tourmaline and rutile (ZTR), and 3) other transparent grains.

3. RESULTS

3.1. Ancient Rocks

In the two Eocene sandstone samples from Rab Island angular to subangular quartz predominates among the framework grains. The remainder of the siliciclastic component is made up mostly of rounded chert grains. Feldspars, mica and other lithic fragments (pelitic, quartzite type, quartz-feldspar aggregates) also occur. The measured carbonate content in these two samples is 35% and 48%, (Table 1) most of which is present in the form of matrix.

The Pleistocene sands of Rab Island are largely dominated by monocrystalline quartz grains, along with rarer chert, commonly with a limonitic coating. Other lithic fragments are brown limonitized finegrained clasts. Feldspars are rare. Unlike in the Eocene sandstones carbonate is almost completely absent (1–4%), in these sands.

The samples of Pleistocene sand from Susak Island contain 16–34% carbonate (Table 2) which is present as grains of micritic or microsparitic limestone. Rare mosaic grains with large crystals or individual larger carbonate crystals were identified as probable dolostones. The siliciclastic component is mostly quartz, along with lithic fragments, feldspars and mica. The lithic fragments are aggregates of mica and quartz, epidote or zoisite, or may be entirely composed of sericite. Micro-quartzite and chert fragments are much rarer.

Heavy mineral assemblages from the analyzed rock types which crop out on the two islands demonstrate obvious dissimilarities (Tables 1 and 2). Eocene sandstones from Rab Island are characterized by the dominance of garnet and a low proportion of ZTR (66% and 11% in average, respectively). The analyzed Pleistocene sands from Rab Island have a much lower garnet content together with a high proportion of ZTR (5% and 63% in average, respectively). The Pleistocene sands of Susak Island demonstrate yet a third compositional type with low garnet and low ZTR content (17% and 4% in average, respectively), while the bulk of the heavy mineral fraction is made up of unstable minerals, mostly amphiboles and epidote/zoisite.

Table 1: Carbonate content and proportions of specific heavy mineral groups in samples of beach sands (R1–R6), Eocene sandstones (ER1, ER2) and Pleistocene sands (PR1, PR2) from Rab Island. ZTR = zircon+tourmaline +rutile; OT = other transparent heavy mineral grains.

Sample	Locality	% $CaCO_3$	% ZTR	% Garnet	% OT
R1	Planka	9	67	13	20
R2	Vardarika	6	62	12	26
R3	Valafta	9	52	18	30
R4	Gonar	4	34	41	25
R5	Crnika	4	32	42	26
R6	Saramić	9	11	72	17
ER1	Lopar	35	13	72	15
ER2	Palit	48	9	60	31
PR1	Kalifront	4	63	6	31
PR2	Fruga	1	62	4	33

Table 2: Carbonate content and proportions of specific heavy mineral groups in samples of beach sands (S1–S3) and Pleistocene sediments (PS1–PS3) from Susak Island. ZTR = zircon+tourmaline+rutile; OT = other transparent heavy mineral grains.

Sample	Locality	% $CaCO_3$	% ZTR	% Garnet	% OT
S1	Bok	28	3	15	83
S2	Bok	66	5	25	70
S3	Bok	26	2	10	88
PS1	Bok	22	4	12	84
PS2	Bok	16	5	26	69
PS3	Bok	34	4	13	83

3.2. Beach Sands

All the beach sands analyzed from Rab Island are predominantly composed of siliciclastic material, and contain only a small amount of carbonate. Those from the Kalifront peninsula (samples R1, R2, R3; Fig.1) are clearly dominated by quartz, along with rarer chert grains. Lithic fragments of weathered quartz sandstone occur occasionally. Feldspar is almost completely absent. Carbonate grains do occur (6–9% carbonate), but these are primarily shell fragments of recent organisms. Only rarely are they detrital carbonate grains of a somewhat larger grain size than the siliciclastic material. On the Lopar peninsula (samples R5 and R6), quartz also dominates the beach sands. Lithic fragments are fairly common and are mostly chert grains, along with occasional fragments of Eocene sandstone. Other rarer fragments are quartzite types, phylitic or quartz-feldspar aggregates. Carbonate grains are rare (4–9% carbonate), and consist of recent shell fragments and redeposited foraminifera (*Nummulites*) from the Eocene sandstones. Sample R4 (Fig. 1) is comparable in framework composition to samples R5 and R6 described above.

The siliciclastic component in the beach sands from Bok bay on Susak Island is almost identical to that of the Pleistocene sand present on the island. Only the amount of mica varies significantly due to hydraulic sorting. The carbonate content in two of the beach sand samples is similar (26% and 28%) to that of the Pleistocene sands. However, the third sample contains a considerably higher proportion of carbonate (66%). This excess carbonate comes from shell fragments of recent organisms, mostly foraminifera.

Heavy mineral assemblages of various beach sands from the two studied islands show major differences. In the beach sands from Rab Island, the variations in the proportion of garnet relative to ZTR are most conspicuous. Among the individual beaches of Rab Island, the garnet content varies between 12% and 72%, while the ZTR vary from 11% to 67% (Table 1). A higher proportion of garnet relates to a lower proportion of ultrastable minerals, and *vice versa*. Among the other heavy minerals encountered are epidote/zoisite, Cr-spinel, pyroxenes, staurolite and kyanite, the proportions of which do not differ significantly among the studied samples. Unlike those of Rab Island, the beach sands from Susak Island demonstrate relatively low amounts of garnet and ZTR (12–26% and 4–5%, respectively), and instead contain a very high proportion of unstable minerals, mainly amphiboles and epidote (Table 2).

4. DISCUSSION

Analysis of thin sections reveals a strongly dominating siliciclastic component in the composition of the studied beaches on Rab Island. Although Cretaceous and Eocene carbonate rocks cover a large area of the island, they obviously play a negligible role in supplying sandy material to the studied coastal areas. Indeed, the carbonate material that is present in the sands is more commonly composed of recent shell fragments or redeposited foraminifera than detrital carbonate grains. Even most of the carbonate which makes up a considerable proportion of the Eocene sandstones, (up to 48%), does not arrive on the beaches which contain a maximum of 9% carbonate. This is probably because most of it is present as matrix in the sandstones, and is lost during weathering. Furthermore, this also excludes coarse grained Quaternary sediments, (Holocene after MAMUŽIĆ et al., 1973), common on the SE part of the island as a source of material for the beaches included in this study, as they contain predominantly detrital carbonate fragments. Instead, Eocene sandstones and Pleistocene quartz sands are the obvious dominant sources of detritus, which is reflected in the general similarity between their framework components and the grain composition of the beach sands. Lithic fragments identified in some of the beach samples, are an additional indicator of these source rocks.

The general similarity in the dominant framework components between the Eocene and Pleistocene source rocks on Rab Island does not allow for a more precise evaluation of the contribution each of these sources makes to a specific beach. In this regard, a comparison of heavy mineral assemblages showed to be a much better indicator. The consistent variability in the garnet versus ZTR proportions in heavy mineral assemblages of the studied beaches indicates the derivation of these sands. While the garnet-rich and ZTR-poor beach sands (Lopar peninsula), closely resemble those of Eocene sandstones, the beach sands rich in ZTR and poor in garnet (Kalifront peninsula) are comparable to those of Pleistocene sands (Fig. 2). These relationships suggest that some beaches are supplied exclusively from Eocene rocks (e.g. Saramić – R6), some from Pleistocene sands (e.g. Planka – R1), while other beaches receive detritus from both sources (e.g. Gonar – R4 and Crnika – R5). This is consistent with the previously proposed view on the provenance of the Rab beach sands which was based on the study of only three beach samples (CRNJAKOVIĆ et al., 1998), and a similar conclusion has been reached for the northern Dalmatian coast (PAVIČIĆ et al., 2000), where analogous rocks were identified as important sources of detritus for beach sands.

The beach sands from Susak Island show almost identical compositions to those of the analyzed Pleistocene sands on this island, both in framework components and heavy minerals (Fig. 3). Such a conspicuous similarity results from the large coverage of Pleistocene sand (Fig. 1) which is characterized by a homogenous composition throughout the island (MUTIĆ, 1967; BOGNAR et al., 1983; CREMASCHI, 1990; MIKULČIĆ PAVLAKOVIĆ, 2006). Furthermore, considering that the carbonate content in the beach sand has been attributed to shells of recent organisms, the carbonate rocks on Susak Island represent a negligible source of sandy material to Bok bay.

The heavy mineral assemblages of the Susak beach sands are considerably different from those of Rab Island (Tables 1 and 2). Consequently, we have identified three end-member heavy mineral assemblages in the beach sands of the two islands: 1) garnet dominated assemblage from Rab Island, 2) ZTR dominated assemblage from Rab Island and 3) assemblage dominated by unstable minerals from Susak Island. These correspond to the heavy mineral assemblages of the three studied ancient rock types from the two islands: 1) Eocene sandstones, 2) Pleistocene sands of Rab Island and 3) Pleistocene sands of Susak Island, respectively (Fig. 4). Consequently, we have shown that studying the heavy mineral assemblage of beach sand allows the assessment of the contribution each source rock makes to a specific beach.

The substantial variability of beach sand compositions detected across a relatively short distance of shoreline, as witnessed on Rab Island, allows us to conclude that the supply of detritus to the beaches must be primarily controlled by erosion of siliciclastic sediments in the immediate or nearby hinterland. Other possible supply paths such as longshore transport or a derivation from a more distant source are obviously less significant in this area.

In the bottom sediments surrounding Rab Island, ŠKRIVANIĆ & MAGDALENIĆ (1979) determined sand dominated by quartz along with heavy mineral assemblages with

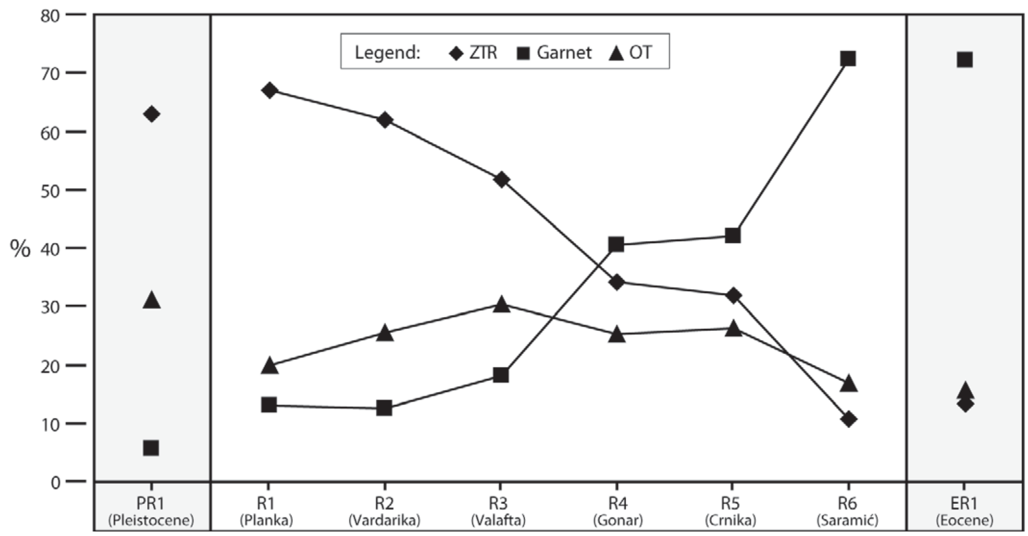

Figure 2: A comparison in the proportions of ZTR, garnet and other transparent grains among different beach sands from Rab Island (R1–R6). Results from a Pleistocene sand sample (PR1) and an Eocene sandstone sample (ER1) are added for additional comparison. ZTR=zircon+tourmaline+rutile; OT=other transparent grains.

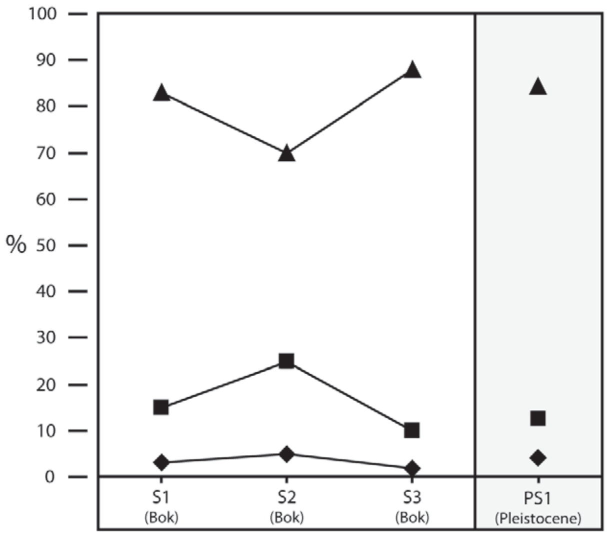

Figure 3: A comparison of the proportions of ZTR, garnet and other transparent grains among different beach samples from Susak Island (S1–S3). Results from a Pleistocene sand sample from Susak Island (PS1) are added for additional comparison. See legend in Fig. 2.

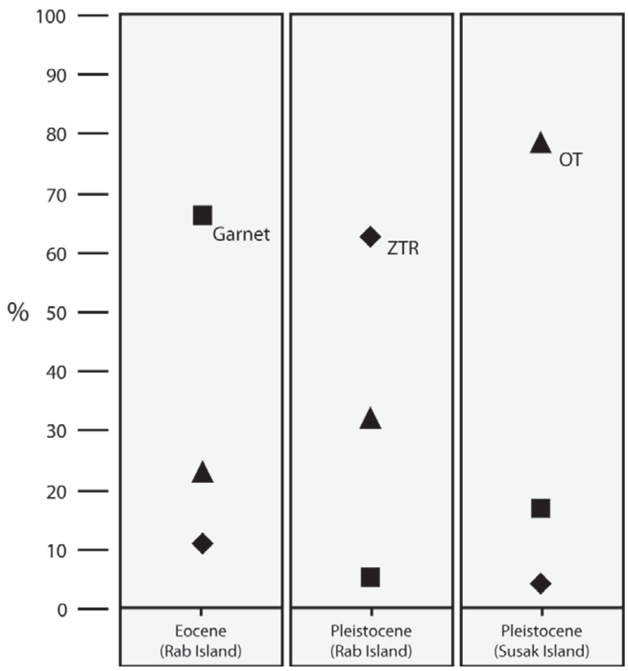

Figure 4: A comparison of the average ZTR, garnet and other transparent mineral proportions among the three different source types. See legend in Fig. 2.

increased amounts of zircon and garnet, which is similar to the framework composition and dominant heavy minerals we detected in the studied beaches on the island. This suggests that the supply of sand material from Eocene sandstones and Pleistocene sands probably extends to the bottom sediments of the surrounding seaways. Similarly, heavy mineral assemblages analogous to those of the Pleistocene sands on Susak Island can be found in the bottom sediments of the northern Adriatic (PIGORINI, 1968), including the western part of the Kvarner region (ŠKRIVANIĆ & MAGDALENIĆ, 1979).

The source areas and the natural transport directions of beach sands from the Islands of Rab and Susak have been successfully assessed using framework composition and heavy mineral assemblages. Since haphazard construction can potentially cut off vital sediment supply paths and disrupt the beach sediment budget, which eventually leads to sediment deficit and coastal erosion, we propose that the information derived from this and other similar coastal studies should be taken into account when planning future development along the relevant coastline. In our continuing research we are extending our study area to embrace a greater coverage of the Croatian coastline, including other Islands as well as the mainland.

5. CONCLUSIONS

This study has shown that the studied beach sands of the Islands of Rab and Susak are made up primarily of siliciclastic, quartz dominated detritus. Carbonate particles are mostly a minor component. Three end-member heavy mineral assemblages, each related to a different source rock, have been identified in the studied beaches: 1) a garnet dominated assemblage and 2) a zircon, rutile and tourmaline dominated assemblage on Rab Island, as well as 3) an assemblage dominated by unstable minerals on Susak Island. Intermediate compositional types of beach sands result from the mixing of detritus supplied from two sources. Consequently, erosion of siliciclastic sediments in the immediate or nearby hinterland, specifically Eocene sandstones and two varieties of Pleistocene sands, has a primary role in providing the studied beaches with sandy material, while longshore transport or derivation from a distant source are much less significant. Meanwhile, the carbonate, where present, is more commonly derived from shells of recent organism's than from eroding Cretaceous and Eocene carbonate rocks.

Furthermore, for the studied area, the heavy mineral assemblage of sand from a specific beach allows the successful identification of its specific source rock(s).

We propose that the conclusions derived from this study should be taken into account when planning future development of the relevant coastline.

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