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Grain size and compositional trends of sediments from *Posidonia oceanica* meadows to beach shore, Sardinia, western Mediterranean

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Abstract

Inputs of biogenic carbonate sediment from *Posidonia oceanica* seagrass meadows to four beaches of the Sinis peninsula (Sardinia, western Mediterranean) were evaluated.

Beach and continental shelf sediment samples were analysed for grain size distribution and composition, biogenic vs. siliciclastic, in order to identify the provenance of beach sediments and sediment transport pathways. Seabed mapping was carried out in order to identify the distribution of meadows and sediment deposits offshore.

Shelf sediments were collected in unvegetated sites and in *P. oceanica* meadows. Sediments from unvegetated sites were coarse sands and gravel, mainly siliciclastic (biogenic carbonate content is 3–7%). Sediments from *P. oceanica* meadows were coarse sand, mainly biogenic (carbonate contents varying between 60 and 90%).

Beach sediments showed bimodal grain size distribution (59% of samples) resulting from mixing of coarser siliciclastic with finer biogenic materials in variable proportions. Biogenic carbonate contents in beach sediments range from 0 to 90%, reaching the highest values in offshore samples.

Analysis of grain size and compositional trends from shelf to beach sediments highlighted that the latter originate from two different sources: erosion of granitic outcrops, providing the siliciclastic component, and export of sediments from *P. oceanica* meadows, providing biogenic material. *P. oceanica* meadows also influence shore by contributing towards maintaining the beach sediment budget.

Keywords: sediment; grain size; texture; *Posidonia oceanica*; biogenic sediments

1. Introduction

Several works have highlighted relationships between seagrass ecosystems and coastal sedimentation (e.g. Fonseca, 1996; Madsen, Chambers, James, Koch, & Westlake, 2001). In particular, concerning the Mediterranean, an important role in controlling coastal sedimentary processes has been attributed to the seagrass *Posidonia oceanica* (Boudouresque & Jeudy de Grissac, 1983; De Falco, Ferrari, Cancemi, & Baroli, 2000), a marine phanerogam endemic to the Mediterranean basin and widespread along its coasts in a bathymetric range from the surface to 30–40 m depth in clear waters (Pergent, Pergent-Martini, & Boudouresque, 1995).

Jeudy de Grissac and Boudouresque (1985) observed that the sediments collected inside the *P. oceanica* meadows in different Mediterranean sites showed a high percentage of biogenic carbonate due to the fauna—e.g. gastropods, foraminifers, and bivalves—associated with the ecosystems. Biogenic sediment production and trapping of fine particles (<63 μm) by leaves (Gacia, Granata, & Duarte, 1999) gives rise to the construction of a fibrous structure, termed a 'matte', made up of a network of roots, rhizomes and sediments which,

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growing vertically, elevates the seabed (Boudouresque & Jeudy de Grissac, 1983). The structure effectively reduces wave energy, thereby affecting the composition of bottom sediments. Jeudy de Grissac and Boudouresque (1985) highlighted that *P. oceanica* thus influences the geomorphology of sandy shores. In particular, its leaves attenuate waves, reducing energy to beaches, and the matte structure reduces the slope of the submerged seabed. Dead leaves are also frequently thrown up on beaches, especially during winter, forming 'banquettes' which protect beaches from erosion (Jeudy de Grissac, 1984). Meadow regression may involve increases in energy and seabed slope, altering shore profiles (Jeudy de Grissac & Boudouresque, 1985). This mechanism has been considered responsible for beach erosion in the Côte d'Azur (Jeudy de Grissac & Boudouresque, 1985). In our study area, the Sinis Peninsula (western Sardinia, western Mediterranean), this mechanism probably has little relevance, as the upper bathymetric limit is 200–500 m from the shoreline and at a depth of about 10 m. Matte thickness is also low (50 cm) and the matte substrate is rocky. These characteristics mean that possible meadow regression cannot substantially alter the seabed slope. Instead, more attention has to be turned to the relationships between *P. oceanica* meadows, as source area of biogenic carbonate sediments, and sediment beaches. Although several studies have been devoted to show that *P. oceanica* meadows can influence the stability of sandy shores, the role of *P. oceanica* meadows as possible source area of biogenic carbonate sediments supplied to beach areas is still largely unknown.

The aim of the present study was to evaluate the contribution of biogenic carbonate sediments from *P. oceanica* meadows to four beaches of the Sinis Peninsula. To reach this goal, seabed mapping was carried out in order to identify the distribution of the meadows and of sediment deposits offshore. The composition of continental shelf sediments, from *P. oceanica* meadows and from unvegetated sites, was analysed and compared with the composition of beach sediments in order to identify the provenance of beach sediments. Moreover, grain size trends between shelf and beach sediments and along beaches were analysed to evaluate trends of sediment transport and depositional processes, by investigating the variability of statistical moments of grain size distributions (McLaren & Bowles, 1985; Muzuka & Shaghude, 2000; Pyökäri, 1996).

2. Study area

The study area is located in western Sardinia, western Mediterranean (39°0.55 lat N; 8°0.25 long E) (Fig. 1). It is close to Tharros, one of the most important Phoenician and Roman archaeological sites in Sardinia, and is part of the 'Sinis Peninsula and Mal di Ventre Island' Marine Protected Area, established in 1997 by the Italian Ministry of the Environment. The coastal area is studded by rock formations, which range in age from Neogene to Recent: Miocene marl and limestone, aeolian and marine sandstone, and Quaternary dune ridges. The geological setting of the Sinis Peninsula includes a Neogene sequence of volcanic and marine sedimentary rocks with small Pliocene plateau basalts. The Palaeozoic granite basement outcrops on the island of Mal di Ventre and along the continental shelf, whereas Pliocene basalts outcrop on the continental shelf, on Capo Catalano (Fais, Klingele, & Lecca, 1996; Marini & Murru, 1977).

Prevailing winds along the Sinis Peninsula during the year are mainly from the north-west (mistral) and are light or moderate, sometimes rising to gale force during winter. In autumn–winter, the south-western libeccio is also important, with variable fetches (Pinna, 1989). These strong winds expose the study area to very high waves, among the highest in the Mediterranean (ISDGM & ECMWF, 1993).

Water depth is less than 20 m between the island of Mal di Ventre and the Sinis Peninsula, becoming deeper in the southern zone (Fig. 1). The seabed of the Sinis area has rocky outcrops, sediments and *P. oceanica* meadows. Meadow distribution is influenced by substrate morphology with a matte, 50 cm thick, on rock, at the deepest depth limit (30 m). The meadow is continuous between Mal di Ventre and the coast, and extends off the Sinis Peninsula coast from Cape Mannu to Cape San Marco (Fig. 1). Several inter-matte channels occur inside the meadow, with associated bioclastic sediments (Tursi, Cocito, Costantino, & Orrù, 1992).

The Sinis coastline is characteristically a system of beaches and rocky spurs. The four main beaches analysed here are, from north to south: Mari Ermi (Er) ~1.5 km long; Is Arutas (Ar) ~0.6 km; Maimoni (Ma) ~1.6 km; and San Giovanni (Sg) ~1 km.

The site is ideal for evaluating the contribution of biogenic carbonate sediments to beach shore sedimentation, because of the lack of terrigenous supply, due to the absence of riverine discharges.

3. Methods

The seabed was mapped by image analysis (Pasqualini, Pergent-Martini, Clabaut, & Pergent, 1998) of the set of aerial photos dated 2000, using Multiscope software. Image analysis was verified by an in situ survey by divers along four transects (one for each beach), perpendicular to the coastline, for a distance of about 700 m. In order to characterise the structural features of *P. oceanica* meadows, in situ measurements of shoot density (number of shoots m^{-2}) were performed (8–10 replicates) using a 40 × 40 cm quadrat (Pergent et al., 1995).

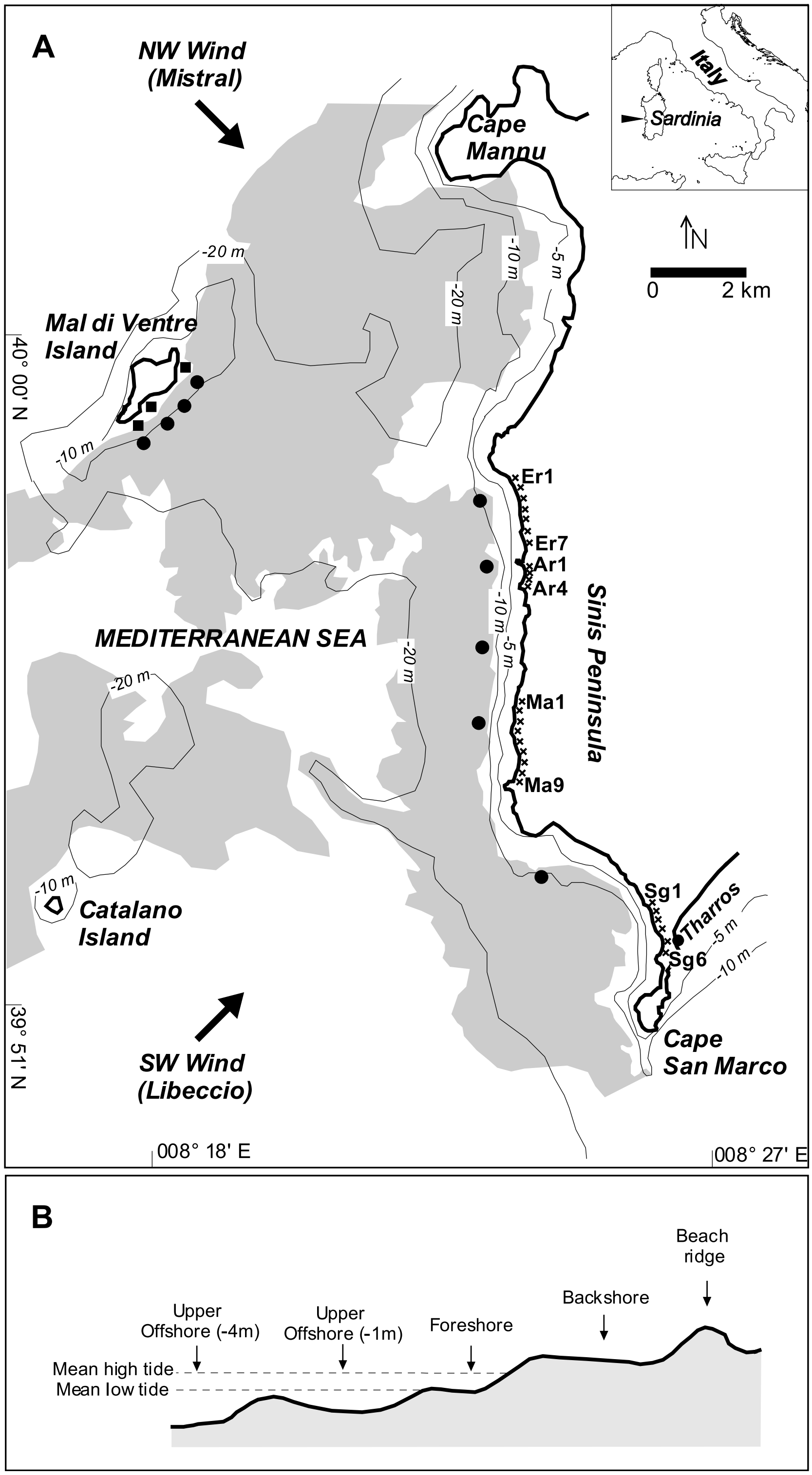

Fig. 1. (A) Location map of study area, showing depth contours and sampling sites. Beach abbreviations: Er, Mari Ermi; Ar, Is Arutas; Ma, Maimoni; Sg, San Giovanni. (×) Beach transects; (■) unvegetated continental shelf sediments (UN-SH); (●) *Posidonia oceanica* sediments (Po-SH). Shaded area = *P. oceanica* meadow distribution (from Tursi et al., 1992). (B) Schematic beach transect showing location of sampled points.

Sediment samples were collected between March and June 2001 from the four sandy beaches (Fig. 1). Twenty-six transects, spaced 200 m apart (100 m in Ar beach), were made normal to the shoreline and numbered from north to south. Seven transects were sampled on Er along a distance of 1.2 km (over 1.5 km). The last 0.3 km southward were not sampled due to a coverage of *P. oceanica* dead leaves stored in banquettes. Four transects (spaced 100 m) were sampled on Ar along a distance of 0.4 km (over 0.6 km); the last 0.2 km northward were not sampled, because thin strata of sand were interbedded in a body of sandstones. Both Ma (nine transects along 1.6 km) and Sg beaches (six transects along 1 km) were sampled.

Three samples were collected from each transect, one from the beach ridge, one from the backshore, and one from the foreshore. Samples from the upper offshore were also collected where possible (presence of sediments instead of rocky outcrops), i.e. in 12 transects (five on Er, three on Ar, two on Ma, two on Sg). On beach ridges, samples were collected at the bottom of the seaward slope. On backshores, samples were collected midway between beach ridge and berm; on foreshores, they were collected midway between upper shoreface and lower shoreface. In upper offshore areas, samples were collected at water depths of 1 and 4 m.

Twelve shelf sediment samples were collected by divers, nine inside the matte of the *P. oceanica* meadows and three in unvegetated sites near the granitic outcrop of Mal di Ventre island (Fig. 1). Sediments were sampled with PVC pipes (10 cm length, 5 cm diameter). Sediment cores were thoroughly washed with distilled water and oven-dried at 80 °C for 12 h. Cores were subsequently sub-sampled and analysed for grain size distribution and carbonate contents. A total number of 107 samples were analysed.

Grain size analysis was performed by dry sieving for the coarser fractions (<1 phi) and laser analysis (Galai Cis 1 laser system, liquid flow mode) for finer sands. Analysis of the finer samples under the binocular microscope showed a great abundance of biogenic components. Quantitative size analysis are rarely attempted using the standard methods for detrital carbonate sediments because carbonate grains tend to break easily (Lewis & McConchie, 1994), therefore the laser system was used to overcome this problem.

The laser systems allow to analyse the fraction <600 μm, its upper detection limit, with a resolution of 5 μm. The liquid flow controller (Galai LFC-101) analyses the size of suspended particles flowing through a cell scanned by a laser beam. About 2 g of sediments was suspended in 1 l of distilled water, inside a tank with mechanical stirring and connected to an ultrasound system. The suspension is pumped by a peristaltic pump into the cell scanned by the laser beam.

Carbonate contents ($CaCO_3$ dry wt%) were determined by dissolution in hydrochloric acid (1 M HCl) for 4 h. After filtering through Whatman GF/C filters, the residue was dried and weighed.

Statistical parameters of grain size distributions (mean, sorting, skewness) were computed using the momentum method (Blott & Pye, 2001; Lewis & McConchie, 1994).

Data on grain size (expressed at 0.5-phi intervals) and percentages of carbonates were processed by means of multivariate analysis to assess if carbonate contents were related to a specific grain size range. Q-mode factor analysis (FA) was applied as an exploratory technique to identify different sediment populations that could be related to the carbonate content. Syvitski (1991) highlighted that the Q-mode FA of grain size frequency distributions can be an effective method of dissecting mixture of sediment sources, even if the accuracy of results decreases with increasing complexity. One fundamental problem in the FA is that grain size data suffer from the problem of the constant sum, i.e. components of data expressed as percentages are not free to vary independently and it is inevitable that induced correlation will arise (Syvitski, 1991). To avoid this problem, data were ranked to obtain comparable units of variables and to represent outliers. FA was performed to find the directions of maximum variance of data (Korhonen & Siljamäki, 1998; Le Maitre, 1982; Swan & Sandilands, 1995). Results were then used to order data in one or two dimensions and interpret them as influencing factors. Ranks of data values were used as input data, principal component as extraction method, and normalised VARIMAX as factor rotation.

Based on the results of FA, the linear correlation between carbonate content and the cumulative percentage of grain size data expressed at 0.5-phi intervals was evaluated.

4. Results

4.1. Field observations and seabed mapping

Along Er beach, from transects 1 to 7 (north to south), the beach ridge was built up of alternating layers of dead *P. oceanica* leaves and sand. The same stratified structure was also observed on Ma beach, close to transect 4, where the backshore had a berm created by storm waves and incipient dune formation. Both had alternating layers of dead *P. oceanica* leaves and sand (Fig. 2a,b). Wide areas of Er and Ma beaches were covered with *P. oceanica* banquettes.

Fig. 3 shows an image analysis map of the seabed off the beaches. Three units were identified: (1) rocky outcrops, (2) sand deposits, and (3) *P. oceanica* meadows.

Near the coastline, from 0 to 5 m depth, the seabed is mainly rocky sandstone. Unconsolidated deposits occur south of Er and Ma beaches; they are also found along a very narrow band off Ar beach and a very wide one off Sg beach. The upper bathymetric limit of *P. oceanica* meadows is always discontinuous and cannot clearly be determined, but it has a progressive increase in seabed coverage, which becomes continuous between 5 and 10 m depth.

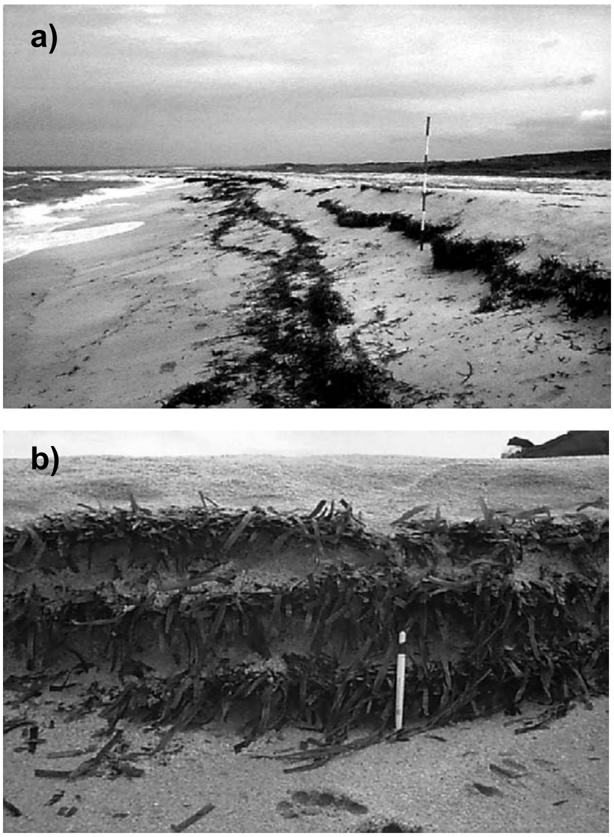

Fig. 2. (a) View north from transect 4 on Ma beach. Berm due to storm waves and incipient beach ridge are built up of alternating layers of *P. oceanica* leaves (black) and sand (white). (b) Close-up of berm, showing *P. oceanica* leaves and sand sediments in layers.

The meadows form a matte ~50 cm thick on sandstone and bio-constructions formed of encrusting corallinaceous algae and bryozoa. Bio-constructions are known to grow in the sciophilous environment typical of the rhizome layer in dense *P. oceanica* meadows. In such meadows, the leaves reduce light penetration, favouring the growth of corallinaceous biotic communities (Peres & Picard, 1964). Meadow density is 478 ± 28 and 378 ± 58 shoots m^{-2}, at 5 and 10 m depth, respectively. These data classify the meadow at the boundary between normal and sub-normal density, according to Pergent et al. (1995), who classify *P. oceanica* meadows on the basis of variability of shoot density with depth. Thick layers of sand occur inside the inter-matte channels and cavities, a few metres wide, which have developed inside the meadows.

4.2. Continental shelf sediments

Shelf sediments collected in unvegetated sites near Mal di Ventre island (UN-SH, Fig. 1) were mainly siliciclastic, with biogenic carbonate contents varying from 3.1 to 7.1%. Grain size ranged between coarse sand and gravel, with mean grain size ranging from −0.85 to −1.67 phi, sorting from 0.66 to 1.26 phi, and Sk from 0.61 to 3.41. Shelf sediments collected inside the matte of *P. oceanica* meadows were mainly biogenic with carbonate contents varying from 60 to 90%. These sediments are coarse sand, with mean grain size ranging from 0.29 to 1.12 phi, sorting from 0.68 to 1.36 phi, and Sk from 0.60 to 2.71.

4.3. Beach sediments

Beach sediment sizes range from medium-fine sand to pebbles, very coarse sand and pebbles being most common on the northern side of Er and Ma beaches and all along Ar beach, and medium-fine and coarse sand on the southern side of Ma and Sg beaches.

A large number of samples are bimodal (59%) collected from the foreshore to the beach ridge, and 83% of the upper offshore samples. Of the 21 samples collected from Er beach, 14 have bimodal grain size distributions, but only seven are unimodal. On Ar the 12 samples collected show unimodal distributions; on Ma, 13 out of a total of 26 samples have bimodal distribution; the rest are unimodal. On Sg beach, the 18 samples collected have bimodal distribution.

Bimodal samples show modes at −1 and 4 phi for 10 vs. 14 of Er samples, 0.5 and 2 phi for 6 vs. 15 of Ma samples, and 15 vs. 18 of Sg samples; unimodal samples have modes at −1.5 or −1 phi for 6 vs. 7 of Er samples, 12 out of 12 of Ar samples, and 9 vs. 13 of Ma samples.

Mode distributions on the upper offshore showed that most samples (15 out of 18) have bimodal distribution, with modes at different positions in the four beaches. Of the eight Er samples, six have bimodal distribution, but only two unimodal. On Ar beach, two of the three samples have bimodal distribution; on Ma and Sg beaches, all samples (three on Ma, four on Sg) are bimodal.

Mean grain size values (Fig. 4) in Er beach increase from north (~−1.5 phi) to south (~−1 to 1 phi) and from foreshore to upper offshore (up to ~4 phi). In Ar beach, the mean grain size is coarse (~−1 phi) for all samples, without any trend either from north to south or along the transects. In Ma beach, values increase from north (~−1 phi) to south (up to ~2 phi) for beach ridge and backshore samples, and from foreshore to beach ridge. In Sg beach, the mean grain size is finer (~0.5–2 phi) and quite constant from north to south, becoming finer from foreshore to beach ridge, with the exception of transects Sg1 and Sg2. Upper offshore samples are the finest (~3 phi). Sorting (Fig. 4) varies from well sorted to very poorly sorted for Er beach, from well to moderately well sorted for Ar, from well to poorly sorted for Ma, and poorly sorted for Sg. Both sorting

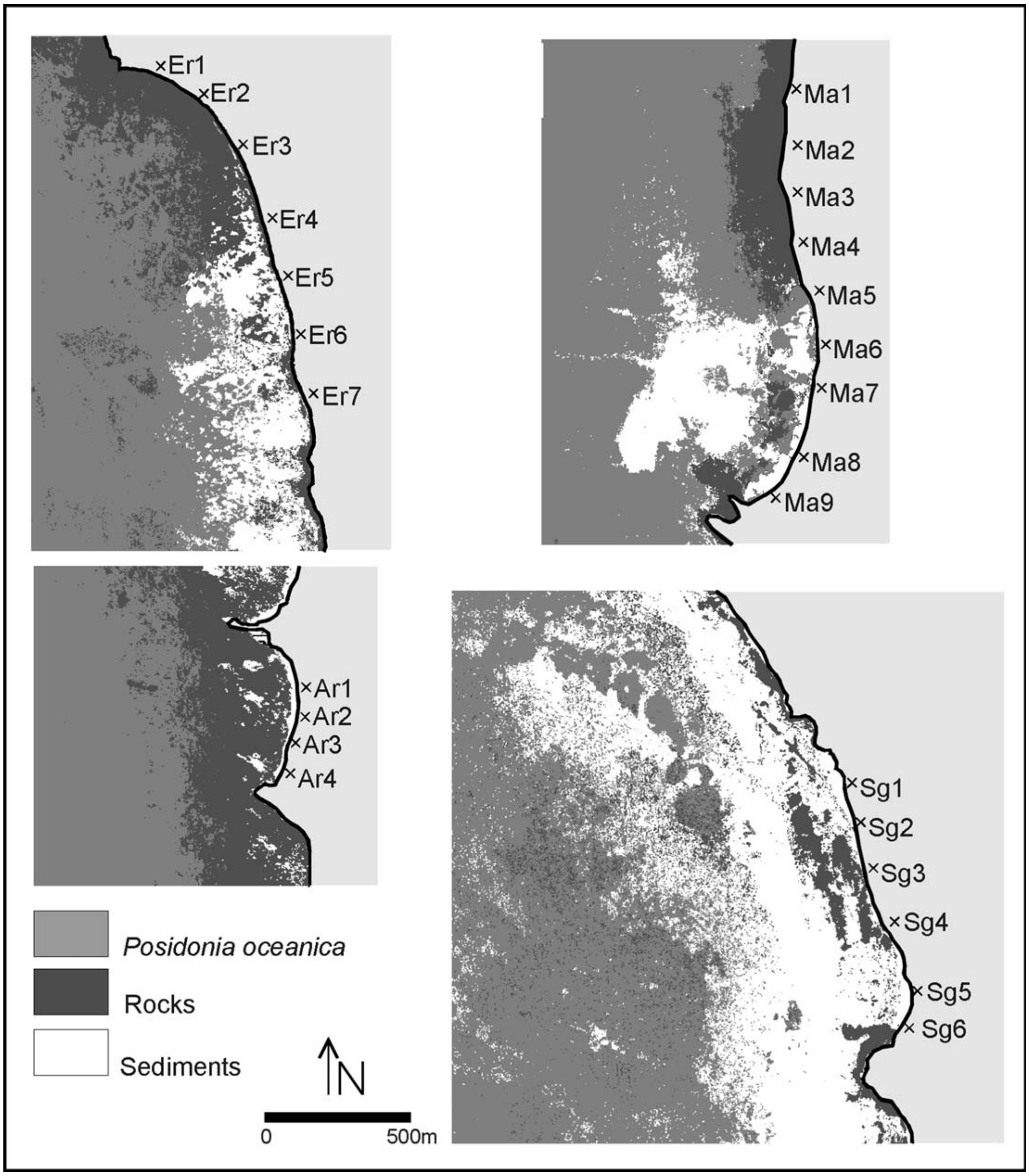

Fig. 3. Seabed maps showing distribution of *P. oceanica*, sediments and rocky outcrops along analysed beaches (image analysis).

and mean values show similar trends, increasing from north to south in Er and Ma and being constant along Ar and Sg. Skewness shows great variability (Fig. 4), both from north to south and along the transects in Er beach, ranging from very coarsely skewed in upper offshore samples, to very finely skewed. In Ar beach, skewness is quite constant both from north to south and along the transects ranging from near symmetrical to very finely skewed. Skewness shows great variability both from north to south and along the transects in Ma beach, ranging from coarsely skewed to very finely skewed. Sg beach samples show high variability of skewness along the transects, from near symmetrical to very finely skewed, without any trend from north to south.

Carbonate contents were measured in foreshore and upper offshore samples (Fig. 5). In Er beach, carbonates show an increase from north to south (0–25%) in foreshore samples, reaching their highest values (~60%) in the upper offshore. Ar beach samples are completely siliciclastic. In northern Ma beach (Ma1–Ma3) sediments are siliciclastic, whereas variable amounts (3–53%) of carbonates are found in the southern sector of the foreshore, reaching ~70% in upper offshore samples. In Sg beach, carbonates range from 30 to 60% in the foreshore, reaching 90% in upper offshore samples. Microscopic analysis showed that the biogenic carbonates are composed of fragments of bivalves, echinoidea, foraminifers and gastropods, and other, not clearly classifiable biogenic fragments.

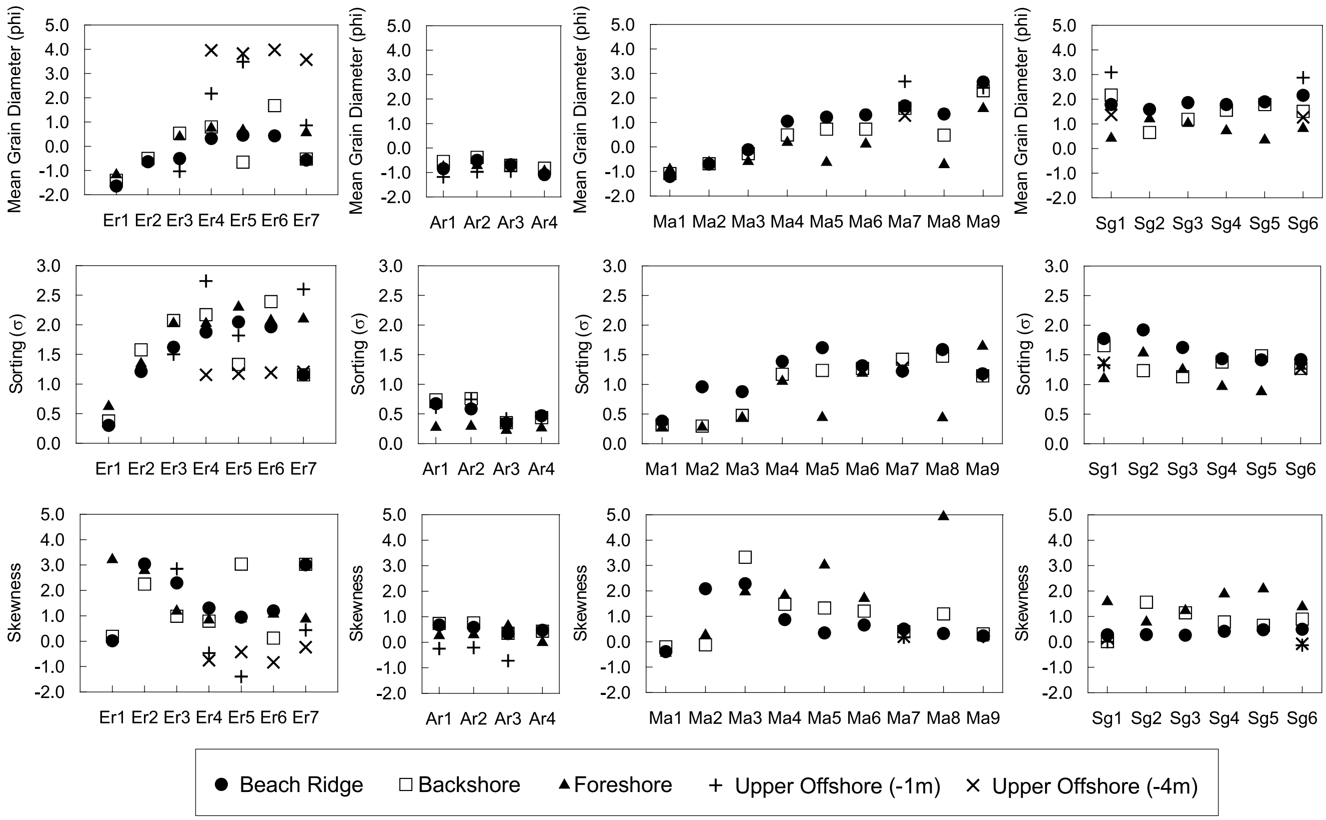

Fig. 4. Variations in mean grain size, sorting and skewness along transects of four beaches: north (Er beach) to south (Sg beach).

4.4. *Texture and composition relationships*

Relationships between carbonate contents and grain size were evaluated by Q-mode FA. Treatment was applied to grain size distribution from foreshore samples from the four beaches and percentages of carbonates. Three factors were extracted. Table 1 shows the factor score matrix, indicating the percentage of information explained by each factor. Three factors explain 93.2% of the variability. Factor 1 (65.8%) shows the relationship between finest grain size distribution and percentage of carbonates, and represents the finest biogenic sediments. Factor 2 (18.9%) is mainly representative of the siliciclastic coarse sands. Factor 3 (8.5%) is mainly representative of the siliciclastic very coarse sands and gravel. The results of FA showed that sediment composition is related to grain size.

Following a procedure similar to the one suggested by Konert and Vanderberghe (1997), the correlation coefficient (R) and the slope were calculated to assess the relationships between carbonate content and cumulative size classes and to identify the grain size interval that best separates biogenic and siliciclastic sediments.

Fig. 6 shows the trend of R and slopes for the various grain sizes. Values between −0.5 and 0.5 phi give the best correlation (range 0.92–0.97), with slope between 1.17 and 1.33. This grain size interval separates two sediment types constituting the beaches: the coarsest siliciclastic, and the finest mainly biogenic.

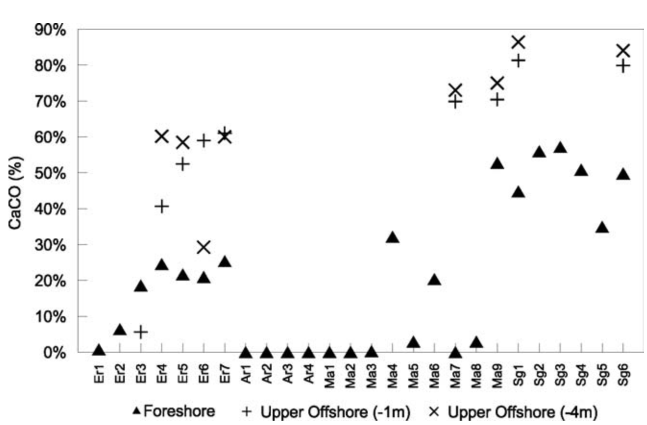

Fig. 5. Carbonate contents measured in foreshore and upper offshore samples in four beaches.

4.5. *Grain size trends of siliciclastic and biogenic sediments*

Grain size trends between marine and beach sediments (foreshore and offshore) were analysed by evaluating the variability of grain size distributions of coarser siliciclastic and finer biogenic sediments from the shelf to the beach.

Table 1
Q-mode factor score matrix

Variable	Factor 1	Factor 2	Factor 3
Carbonate (%)	0.88*	0.14	0.41
<−2 phi	−0.17	−0.08	−0.92*
−2	−0.31	−0.19	−0.91*
−1.5	−0.52	−0.16	−0.78*
−1	−0.85*	0.00	−0.32
−0.5	−0.69*	0.64	−0.03
0	−0.13	0.96*	0.12
0.5	0.32	0.88*	0.25
1	0.83*	0.41	0.14
1.5	0.94*	0.08	0.28
2	0.95*	0.06	0.28
2.5	0.94*	0.07	0.30
3	0.95*	0.01	0.27
3.5	0.94*	−0.16	0.24
>4 phi	0.91*	−0.26	0.10
Percentage of variance explained by each factor	65.8	18.9	8.5
Cumulative percentage variance	65.8	84.7	93.2

Variables with asterisks characterise each factor.

The two modes recognisable in several samples can be separated at grain size class 0 phi. Separation between the modes was made when the two parts (finer and coarser) of grain size distributions were subdivided by a minimum frequency values of <1%. In this way, two grain size distributions, referring to biogenic and siliciclastic populations, were obtained after normalisation to 100%. This procedure was applied to Er samples and to three Ma foreshore samples (Ma4, Ma6 and Ma9), which showed a clear separation between the two modes.

It was not possible to separate the two modes for Sg foreshore samples, because the two populations overlapped. Ma and Sg offshore samples, which showed carbonate contents varying from 70 to 90% were considered representative of the finer biogenic sediment

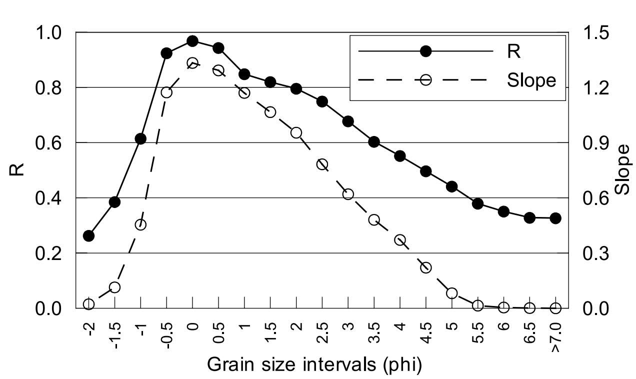

Fig. 6. Relationships between carbonate contents and grain size. *Y*-axis (right): slopes of relations between cumulative grain size classes and carbonate contents. *Y*-axis (left): associated correlation coefficients.

group, and Ar samples were only composed of coarser siliciclastic sediment.

The statistical moments (mean, sorting, Sk) describing the shape of the grain size distribution of the biogenic and siliciclastic populations were computed, and were averaged for each beach. The moments of the siliciclastic populations were compared with those of unvegetated shelf sediments (UN-SH), mainly siliciclastic. The moments of biogenic populations were compared with those of *P. oceanica* (Po-SH) matte sediments, mainly biogenic (Fig. 7).

The grain size trend of siliciclastics showed that beach sediments are finer, better sorted and more negatively skewed compared with UN-SH. The trend along the beaches showed an increase in mean grain size of the siliciclastic population from north (Er) to south (Ma); sorting and Sk did not show any trends.

The grain size trend of biogenics showed that beach biogenic sediments are finer, less well sorted, and more negatively skewed than *P. oceanica* matte sediments. No trend was observed along the beaches.

5. Discussion

The characteristics of beach sediments on the Sinis Peninsula show distinct patterns related to: (i) the geology of adjacent coastal rocks; (ii) *P. oceanica* meadows; (iii) coastal orientation; and (iv) directions of predominant and prevailing winds and waves. The shore sediments showed marked bimodality on grain size distribution, very poor sorting, and great variability in skewness. Bimodality may be attributed to the mixing of the two different populations, coarser siliciclastic and finer biogenic. Muzuka and Shaghude (2000) also observed that the presence of shell fragments produced bimodality along the Msasani beach (Tanzania).

The shelf sediments of unvegetated sites (UN-SH, Fig. 1) may be considered as the result of erosion of the Paleozoic granitoid basement outcropping on the island of Mal di Ventre and along the continental shelf (Marini & Murru, 1977). The hypothesis that beach siliciclastic sediments originate from this deposit is supported by the grain size trends of siliciclastic populations (Fig. 7), according to sedimentological literature, which stresses that changes in grain size distributions can be used to predict the direction of transport (Gao & Collins, 1992; McLaren, 1981; McLaren & Bowels, 1985). Beach siliciclastic sediments are finer, better sorted and more negatively skewed than their source material, denoting sediment transport from the marine area to the beaches (Gao & Collins, 1992; McLaren, 1981; McLaren & Bowels, 1985). Grain size trends along the beaches showed that siliciclastic population become finer from north (Er) to south (Ma), and are interpreted as due to increasing distance between source and deposition areas.

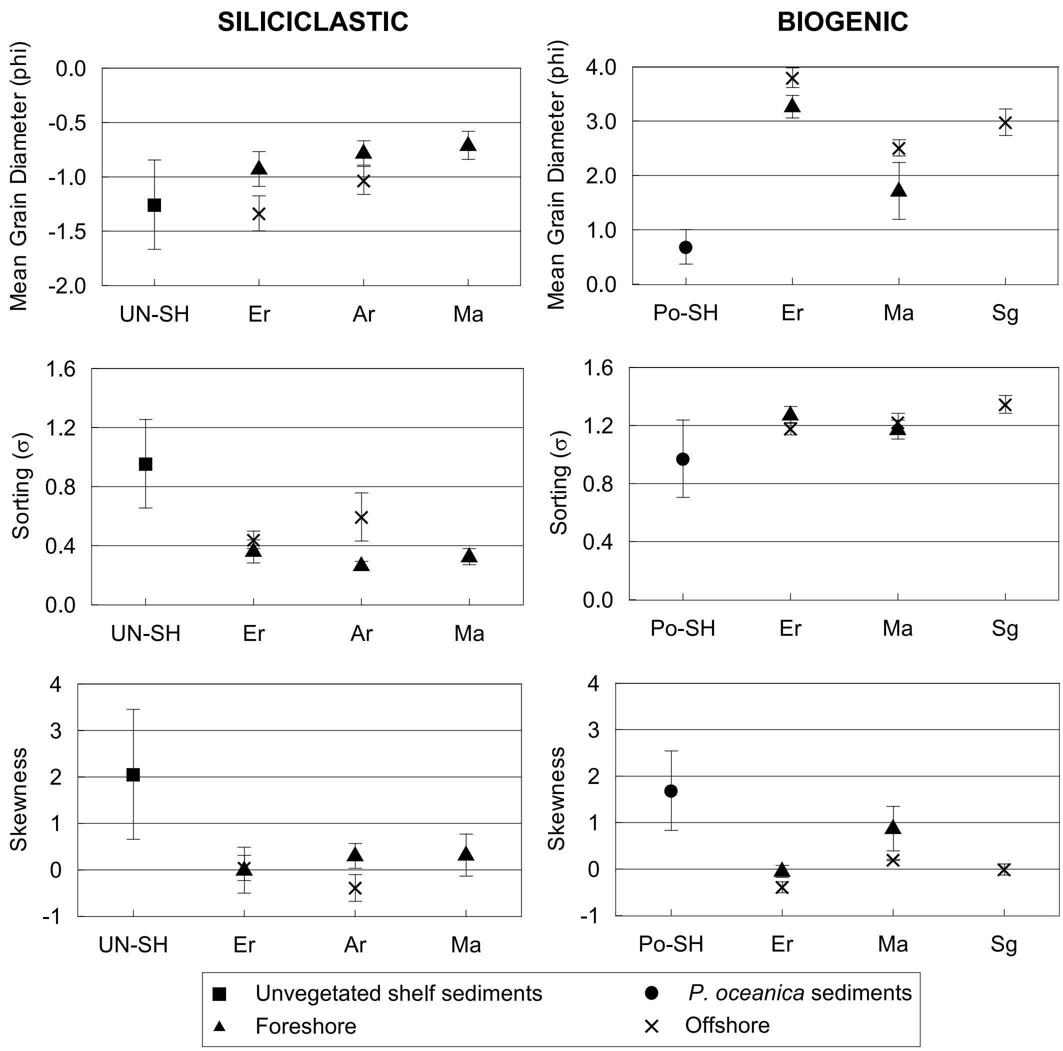

Fig. 7. Mean values of statistical moments of siliciclastic and biogenic sediments. Left: comparison between unvegetated shelf sediments (UN-SH) and siliciclastic population of beaches; right: comparison between *P. oceanica* shelf sediments (PO-SH) and biogenic population of beaches.

The *P. oceanica* meadows are viewed as the source area of biogenic carbonate sediments—a hypothesis supported by analysis of shelf sediments collected inside the *P. oceanica* matte (Po-SH, Fig. 1), mainly composed of biogenic sediments. Qualitative observations of the shelf and beach sediments, made by binocular microscopy, identified fragments of molluscs (bivalves, gastropods) echinodea and foraminifers in the biogenic fraction. This association was highlighted by Jeudy de Grissac and Boudouresque (1985) as typical of *P. oceanica* meadow sediments.

The mechanism whereby sediments within seagrass meadows reach beaches may be related to the growth dynamics of the meadows at their upper bathymetric limit, in the model proposed by Boudouresque and Jeudy de Grissac (1983). Severe hydrodynamic conditions favour the formation of inter-matte channels inside the meadows. *P. oceanica* laterally re-colonises these channels with alternating erosion/colonisation cycles (Boudouresque & Jeudy de Grissac, 1983). The study area is characterised by such hydrodynamic conditions, due to its severe exposure to waves (ISDGM & ECMWF, 1993). These conditions may favour the formation of the inter-matte channels observed inside the meadows. The channels are covered by sediments deriving from matte erosion which may be transported outside the upper limit of the meadows offshore and from there to the emerging beaches. This hypothesis is supported by the composition of beach-offshore sediments, which have higher contents of biogenic carbonates (up to 90% in Sg offshore samples). Seabed mapping showed that offshore sediments are distributed in the southern sectors of Er and Ma beaches and extended offshore of Sg beaches (Fig. 3). High percentages of biogenic carbonates in foreshore sediments are found in the southward sector on Er and Ma, in the entire Sg beach (Fig. 5), while foreshore sediments are siliciclastic in the sectors where offshore sediments are absent or only present in the form of very narrow bands (north Er, Ar, north Ma).

Grain size trends of the biogenics showed that beach biogenic sediments are finer, less well sorted, and negatively skewed with respect to *P. oceanica* sediments (Fig. 7). This trend does not follow that of particle size distribution for sediments undergoing transport and deposition proposed by McLaren (1981) and McLaren and Bowels (1985), who found that deposits are better sorted than their sources. However, McLaren (1981) also acknowledged that mechanical breakdown of grains during transport may cause anomalous trends. In the Sinis coastal area, transport of biogenic sediments from meadows to beaches probably involves changes in the size of single grains, due to mechanical fragmentation. Carbonate skeletons may also be affected by microboring (Perry, 1998)—another factor which may also contribute to their fragmentation. Fragmentation produces a decrease in the grain size of biogenic particles, but does not select grains and does not improve sorting.

Over the last 20 years, there has been an increasing interest in the role of seagrass meadows in the coastal sedimentary processes highlighting the role of the meadows in controlling the grain size and composition of sediment associated to the plant (De Falco et al., 2000; Gacia et al., 1999; Jeudy de Grissac & Boudouresque, 1985). However, no evidence was found for the relevance of seagrass meadows in the beach shore sedimentation. This study showed that *P. oceanica* meadows may influence Sinis shores with the input of biogenic sediments which contribute towards maintaining the sediment budget. This budget can be influenced by fluctuations in the production of fauna with carbonate skeletons associated with *P. oceanica* meadows and by changes in the removal rate of biogenic sediments outside the meadows.

6. Conclusions

1. The shore sediments of the Sinis Peninsula result from mixing of coarser siliciclastic and finer biogenic sediments. The highest percentages of biogenic sediments were found in offshore samples, reaching ~90% in those of Sg beach. The highest percentage of biogenics in the foreshore were also found in Sg beach (~40–60%).
2. *Posidonia oceanica* meadows were found to be the source area of biogenic carbonate sediments. Biogenic sediments move from meadows to beaches and are trapped in limited sectors (South Er, South Ma, Sg). Grain size trends between meadow source area and beaches showed that beach sediments are finer, less well sorted, and more negatively skewed than those of source. Mechanical fragmentation of biogenic grains appears to be an important process along the Sinis coast.
3. *Posidonia oceanica* meadows influence Sinis shores by contributing towards maintaining the sediment budget. Changes in the production and removal rate of biogenic debris from *P. oceanica* meadows may influence the sediment budget of the sandy shores of Sinis.

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