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Sedimentology and coastal dynamics of carbonate pocket beaches: the Ionian-Sea Apulia coast between Torre Colimena and Porto Cesareo (Southern Italy)

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ABSTRACT - This study focuses on a section of the Apulia Ionian-Sea coastline, between Torre Colimena and the town of Porto Cesareo, where pocket beaches of different size and shape are found. The larger pocket beaches comprise individual coastal systems which include coastal-plain, dune, beach and shoreface facies. Absence of sediment-delivering rivers, local production of bioclastic debris from a carbonate factory, and low volume and thickness littoral prisms are the main characteristics of these pocket systems. The coastal sediments are predominantly bioclastics ranging from coarse to fine, medium-fine, and very coarse sands on the foreshore, upper shoreface, and lower shoreface, respectively. The foreshore and upper shoreface sediments as well as the size of the backshore deposits vary according to the degree of coastal exposure to the seas, coming between west and southeast directions.
Coastline urbanization and tourist activities have developed extensively during the last 40 years, and most of the erosional signatures have clear connections with nearby human disturbance. Dune degradation related to human activities together with aeolian processes, wave action and a low sediment production from carbonate-factory source are the factors responsible for beach and dune erosion during last years. Our topographic survey and sedimentological data indicate that most of the beaches have natural attributes conducive to flooding during marine storms. The substrate topography controls the size and shape of the study pocket beaches, the spatial arrangement of the coastal deposits and the hydraulic and sedimentary processes. Nearshore rip circulation occurs in most of these beaches.

Keywords: Carbonate pocket beaches; Sedimentology; Coastal dynamics; Porto Cesareo; Ionian Apulia coast.

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1. INTRODUCTION

A beach is the product of three basic factors, i) waves, ii) sediments, and iii) substrate morphology, although other factors interact at different spatial and temporal scale, e.g., tide, biotic components, chemical processes and climate (Short, 1999). Briefly, beaches are wave-deposited accumulations of sediment that occur between wave base and innermost limit of wave action (Cowell et al., 2003 a, b; Anthony, 2009). They are supplied through different processes that are strictly dependent on the local depositional context. Thus, we find beaches that are feed directly by terrestrial sediments (e.g. deltaic coasts), others supplied laterally by the longshore sediment drift (e.g. strandplain coasts) and others formed by local sediment inputs (e.g. cliff coasts, biogenic reef coasts). Depending on the type of coastline and its exposure to dominant winds and waves, beaches vary considerably in length and width, ranging from the extended ocean beaches to those developed within narrow embayments, the so called pocket beaches.

Pocket beaches are the subject of our study. They form along an articulated coastline whose orientation with respect to dominant sea conditions control sedimentary processes and local hydrodynamics. The scientific literature regarding these beaches is quite rich (Yasso, 1965; O' Rourke and Le Blond, 1972; Silvester et al., 1980; Short, 1985; Hsu and Evans, 1989; Hsu et al., 1987, 1989, 2008; Yamashita and Tsuchiya, 1992; Roy et al., 1994; Wind, 1994; Short et al., 1995; Moreno and Kraus, 1999; Klein and Menezes, 2001; Simeoni et al., 2012; Pranzini et al., 2013).

In Italy, many pocket beaches occur along the Apulia Ionian-Sea coastline, a microtidal coast rather fragmented in a series of small embayments varying in size from hundred of meters to few kilometres and characterized by the absence of sediment-delivering rivers. In fact a very small hydrographic network drains the mainland, and most of the rainfall infiltrates into the ground resulting in a sub-surface circulation which is manifested by several freshwater springs and an intricate network of karst cavities that often is present along the coast. Due to the lack of terrestrial sediment inputs, these beaches are fed mainly by local sediment sources, especially by indigenous production of bioclastic carbonate detritus (Caldara et al., 1998).

Our study focuses on a sector of the Apulia Ionian-Sea coast, between Torre Colimena and the town of Porto Cesareo, where pocket beaches form relatively small individual coastal systems which generally include dune and coastal-plain zones (Fig. 1). This coast is of high environmental and economic value. In fact, its beauty attracts an omnipresent recreational activity during summer upon which a large part of local economy is based. Three Sites of Important Communities (SIC: Torre Colimena, Palude del Conte - Dune di Punta Prosciutto, Porto Cesareo) and a marine protected area (Porto Cesareo) make precious this coast, which however shows the effects of the human disturbance. Although the coastal plain zones were reclaimed in the autarchic period, major human constructions occurred during the last 30-40 years, when tourist activities and coastline urbanization have grown exponentially. At the present time, dune and beach erosion, risk of marine inundation during storms, and shoreline retreat are the main issues of concern for the local and regional governance. Some interventions for dune restoration has occurred in recent times and more decisive actions are seriously considered. The coast is managed mostly by regional monitoring plans (PRC, 2006).

Within this defined framework, the present work aims to: (i) provide an objective morphological and sedimentological description of these pocket beaches, (ii) better define their present morphodynamics and processes governing sediment dispersal from sources to sediment sink zones (iii) identify environmental hazards and fragilities that may cause reduction in the value and use of the coast, and (iv) define directions for coastal governance towards possible remedies.

2. GEOLOGICAL SETTING

The Apulia region, where the study area is located, is part of the Apulian platform which constitutes the mostly undeformed foreland area of both the Apennine and Dinaric orogens (Fig. 2A). The basement of this platform is constituted by Variscan crystalline rocks upon which a

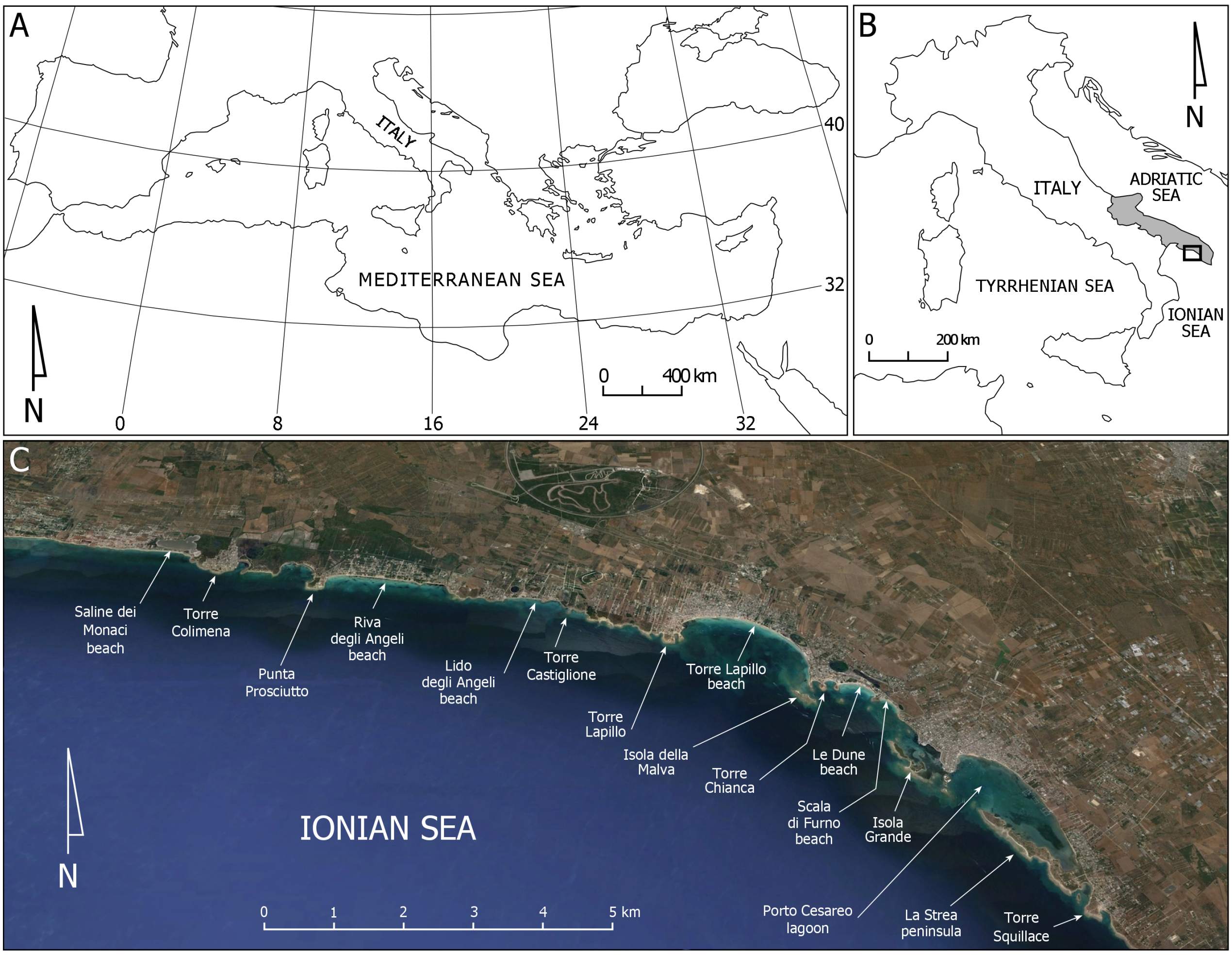

Fig. 1 - Location of the Apulia region (gray in B). The square indicates the sector of the Taranto Gulf where the study area is located. C) Detail of the study area.

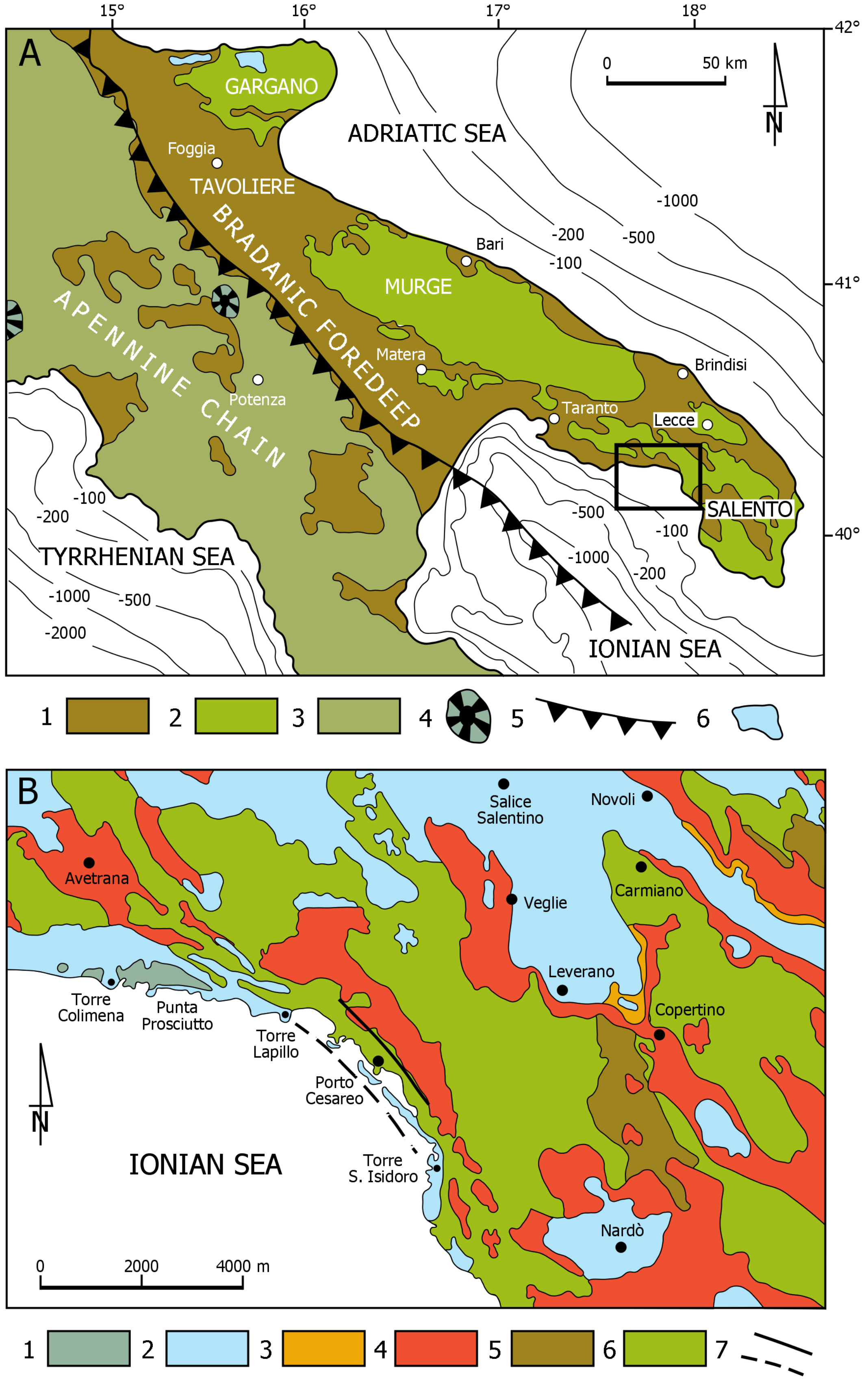

Fig. 2 - A - Simplified geological map of the Apulia region: 1) Plio-Quaternary deposits; 2) Meso-Cenozoic limestones; 3) Apenninic chain units; 4) Volcano; 5) Thrust front; 6) Coastal lakes. B - Geological map of the study area. 1) Middle-Upper Pleistocene to Holocene alluvial and coastal deposits; 2) Middle-Upper Pleistocene marine terraced deposits; 3) Lower Pleistocene clay and silty clay deposits (Argille subappennine); 4) Middle Pliocene- Lower Pleistocene calcarenites (Calcareniti di Gravina); 5) Burdigalian- Lower Messinian carbonate deposits (Pietra leccese and Calcareniti di Andrano); 6) Upper Turonian- Maastrichtian platform carbonate succession; 7) Faults.

3-5 km thick Mesozoic carbonate succession occurs. This latter is in turn discontinuously covered by thin Tertiary and Quaternary deposits, mostly represented by bioclastic calcarenitic sediments (Ciaranfi et al., 1988). In general the Apulia corresponds to the most uplifted portion of a WNW-ESE oriented antiform structure which is in turn segmented by several parallel normal faults whose plane plunges both toward the Bradanic Trough to the west and the Adriatic Sea to the east (Ricchetti, 1980). Transfert faults, NE-SW oriented, subdivide the Apulia region into three main structural blocks - the Gargano, the Murge and the Salento blocks - which exhibit different landscapes and tectonic uplift rates varying from 0.40 to 0.20 mm/yr (Ciaranfi et al., 1988; Doglioni et al., 1994). The Apulia Ionian Sea coast experienced uplift rates ranging from 0.31 mm/yr (Taranto area) to 0.02 mm/yr (Gallipoli area) over the last 20 ka (Cosentino and Gliozzi, 1988; Westaway, 1993; Bordoni and Valensise, 1998).

The discontinuous tectonic uplift of the Apulia region started in the Middle Pleistocene (Doglioni et al., 1994). From Middle Pleistocene onward, regional uplift caused the emersion of the entire region. Along the Apulia coastal area the superimposition of Quaternary glacioeustatic sea level changes created several marine terraces composed of abrasion platforms often covered by thin bioclastic deposits (Caldara et al., 1998). In the Salento area, the tracks of at least ten paleoshorelines, ranging in age from 800 to 20 ka, were recognized between 3 and 180 m above present sea level (Boenzi and Ricchetti, 1999; Ciaranfi, 1999).

Upper Cretaceous deposits crop out extensively along the Salento Peninsula both inland and along the coast (Parente, 1994). Such deposits, well studied in terms of stratigraphy (Bosellini et al., 1999) and paleontology (Laviano, 1996 a, b; Parente, 1997; Schlüter et al., 2008), form most of the headlands at the margins of the present pocket beaches along the Salento Ionian Sea coastline (Fig. 2B).

3. MORPHOLOGICAL SETTING

The Apulia region coastline extends for about 865 km and consists of sandy beaches for almost 35% of its length, while the remaining coastline is mostly rocky (Gruppo Nazionale per la Ricerca sull'Ambiente Costiero, 2006). In this region the continental shelf ranges in width from 18 to 60 km in the Adriatic Sea side (shelf break is at 160-200 m depth), whereas is narrower on the Ionian Sea side. Particularly the shelf of the study coast is about 20 km wide and extends up to 100-110 m depth (Fig. 3). Here, the most salient seafloor irregularities concentrate near the coast (5-30 m depth) where two paleocliffs separated by terraces develop parallel to NW-SE oriented tectonic lines (De Pippo et al., 2004a). This shelf is covered mainly by bioclastic sands and, in its inner portion, *Posidonia oceanica* meadows form large patches which are replaced at depth by coralligenous platform deposits (Fig. 4) (Pennetta, 1985). The coastal seafloor consists mainly of Cretaceous carbonate rocks, locally covered by Pleistocene calcarenites and by thin and narrow *algal trattoirs* and modern sand-sized bioclastic sediments (Ambrosano et al., 1986).

The study area lies at an inflection of the coastline resulting in a northern sector oriented E-W (between Torre Colimena and Torre Lapillo) and in a southern sector oriented NW-SE (between Torre Lapillo and Porto Cesareo). In both sectors, the coastline is very irregular due to the morphological variability shown by embayments, headlands and stretches of low rocky coast. De Pippo et al. (2004b) applied a fractal analysis to the contours of this coastline and of the 5, 10, and 30 m isobaths which correspond to the average depths of the edge of submerged marine terraces. The results show that the fractal dimension (D_F) of the coastline (D_F=1.29) is higher than the average value (D_F=1.05) estimated for the entire Apulian coast (D'Alessandro et al., 2006) and is similar to the fractal value of the 5 m isobath (D_F=1.25). This latter value is higher compared the values obtained for the 10 and 30 isobaths (D_F= 1.08 and 0.99, respectively). The Authors conclude that present geomorphological setting is the result of the Plio-Pleistocene tectonics and of the superimposed effects of post-glacial sea-level oscillations and modern coastal morphodynamics (see also De Pippo et al., 2004a).

The study coast is made up of 28.15% of sandy stretches, 61.85% of low rocky sea cliffs, and 10% of anthropic waterfronts. In the northern sector, the beaches (Salina dei Monaci, Riva degli Angeli and Lido degli Angeli) are rectilinear and develop within embayments of varying size. In contrast, the beaches of the southern sector (Torre Lapillo, Le Dune, and Scala di Furno) are located within semi-circular bays, in which small islands (e.g. Isola della Malva

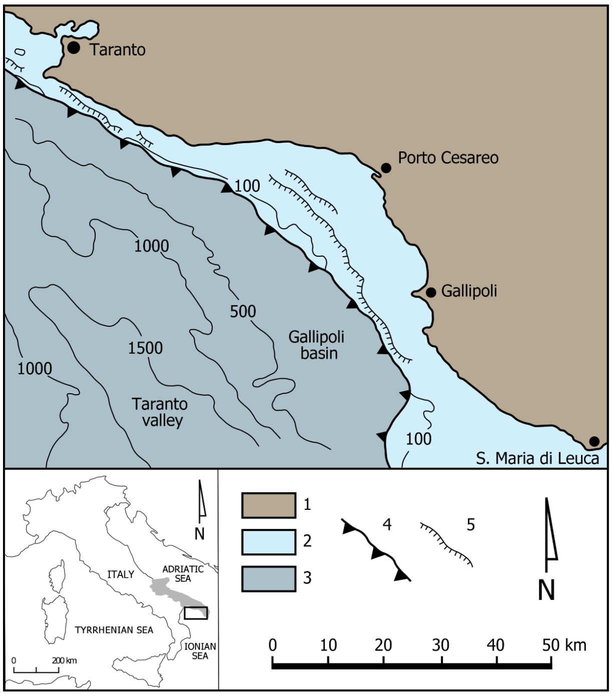

Fig. 3 - Simplified morphological map of the marine sector in front of the study coast (modified from Pennetta et al., 1986). Legend: 1) landmass (Salento peninsula); 2) continental shelf; 3) slope and basin; 4) shelf break; 5) submerged terraces.

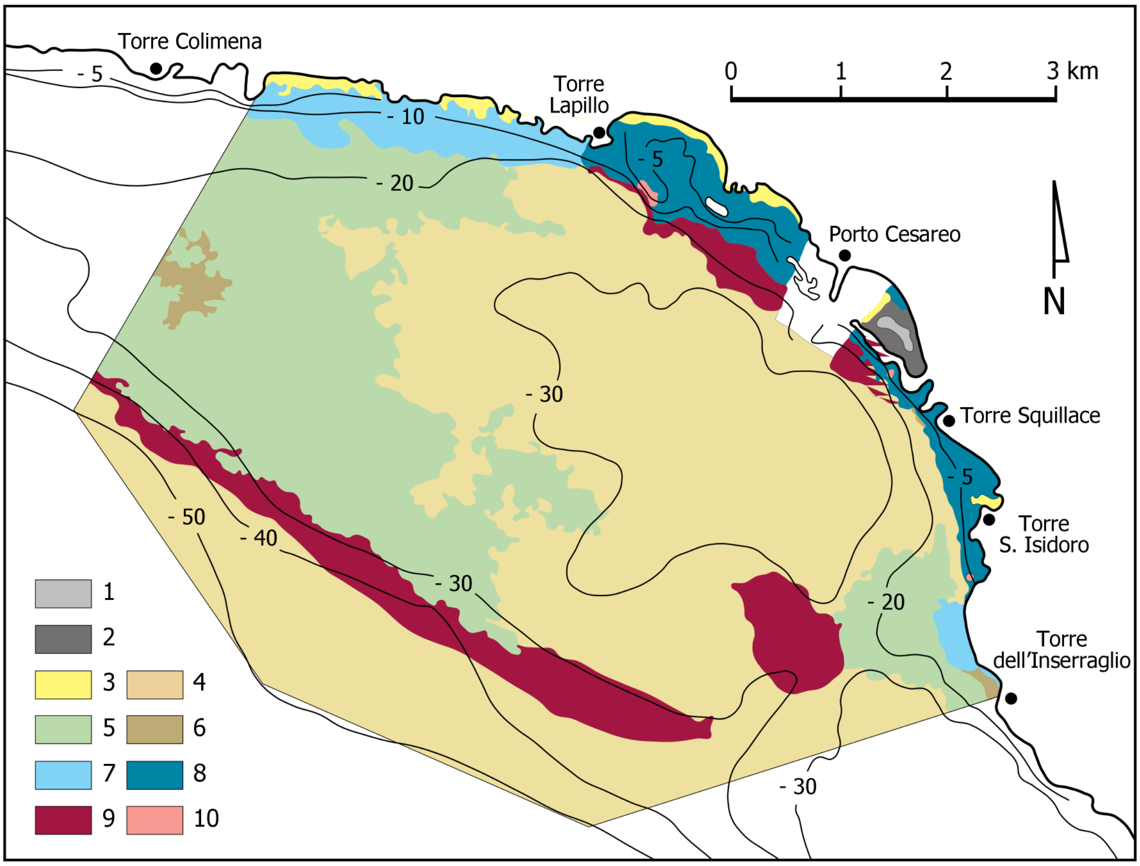

Fig. 4 - Habitats and sediment assemblages in the Marine Protected Area of Porto Cesareo. Legend: 1) Association with *Cymodocea nodosa* on superficial muddy sands in sheltered waters; 2) Biocenosis of superficial muddy sands in sheltered waters; 3) Biocenosis of coarse sands and fine gravels mixed by the waves; 4) Biocenosis of coarse sands and fine gravels under the influence of bottom currents; 5) *Posidonia oceanica* meadows; 6) Facies of dead "mattes" of *Posidonia oceanica* without much epiflora; 7) Biocenosis of infralittoral algae; 8) Overgrazed facies with encrusting algae and sea urchins; 9) Coralligenous platforms; 10) Semi-dark caves. Modified from Area Marina Protetta Porto Cesareo (AMP, http://www.ampportocesareo.it/).

and Isola Grande) and several rocky islets determine further morphologic complexities. South of the Porto Cesareo town a lagoon 800 m wide and 2500 m long is enclosed by a rocky peninsula (La Strea Peninsula) and communicates to the open sea by a main inlet. Figure 5 depicts the southern coastal sector in the Late Holocene (Mastronuzzi et al., 1989). Note the detachment from the mainland of a littoral barrier that has migrated further inland during the final phase of the Holocene transgression. Most of the headlands host medieval watchtowers built originally for defensive purposes (Torre Colimena, Torre Chianca, Torre Castiglione, Torre Lapillo, and Torre Cesarea).

4. DATA AND METHODS

Data used in present study concern: (i) textural and compositional data of coastal sediments; (ii) beach morphology; (iii) coastal bathymetry; (iv) wind and wave climate, and (v) field observations (from 2010 to 2017) with comparative examinations of satellite images. A total of 119 sediment samples were collected along the coast (April 2010): 9 at the foredune toe (and however at the end of the beach), 80 in the swash zone, and 30 on the shoreface zone at about 3, 6, and 10 m depths. All samples, georeferenced by GPS, are aligned along beach profiles defined by a topographic survey. Additional granulometric data of shoreface samples (34), furnished by the Consorzio di Gestione Area Marina Protetta Porto Cesareo, were included in this study.

Classic sedimentological methodologies were employed for the granulometric analyses (Folk, 1980). A column of sieves with size intervals of 1/2 phi was used and resulting data were processed obtaining granulometric frequency curves and statistical indexes (Folk and Ward, 1957). Cluster analyses, based on the individual sediment fractions (%), were used in conjunction with the statistical indexes to identify the main sediment types. The overall sediment composition was determined from microscopic observations on a limited number of representative beach samples (24).

A total of 75 beach profiles, from shoreline to foredune toe and away from each other about 100 m, were surveyed (April 2010) by topographic levelling procedures. Profile morphological parameters were calculated (width, height, slope of the beach and beach volume above the zero-elevation line) in order to appreciate the morphological variability along the beach. Bathymetric data have been provided by Consorzio di Gestione Area Marina Protetta

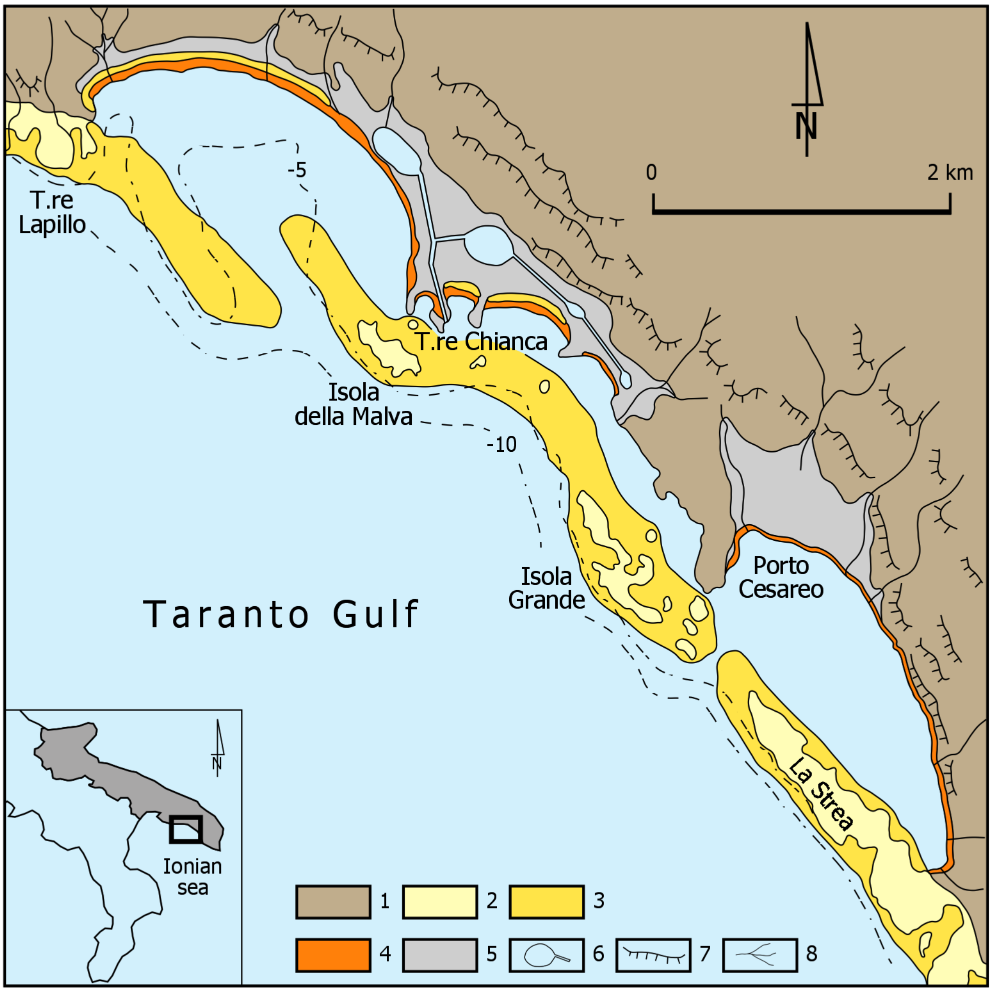

Fig. 5 - Paleogeographic reconstruction during the Late Holocene of the southern sector of the study coast. 1) pre-Holocene sediments; 2) remains of dune ridge; 3) possible configuration of the beach-dune barrier in the Late Holocene; 4) current dunes; 5) marshy deposits; 6) reclaimed areas; 7) pre-Holocene marine terraces; 8) hydrographic network (modified from Mastronuzzi et al., 1989).

Porto Cesareo, and are also included in a scientific report (Boero et al., 1999). Wind data from the Porto Cesareo and Taranto stations (periods December 2006-March 2017) were acquired from the website of Autorità di Bacino della Puglia (AdBP -http://93.51.158.171/web/simop/home), whereas wave climate data were obtained by Petrillo et al. (2014). Photos in this paper are mainly referred to 2010.

5. WIND AND WAVE CLIMATE

The potential wind directions, calculated at the middle of the study coastline (Isola della Malva), are delimited by the azimuths 276°N and 157°N. Within this range, the longest fetches (900-1100 km) are between 162° and 200° N and originate from the northern African coast. Very short fetches (<100 km) occur between 204° and 276° N due to the proximity of the Taranto Gulf western coast (Fig. 6A). As a result, the studied coast is exposed to waves and marine winds from the west, southwest, south, and southeast.

Wind data collected at the Porto Cesareo station during a period of 11 years (from 2006 to 2017) show that winds from the continent, particularly those from N and NNW directions, usually occur ~36%. Winds from the sea, specifically those from the S and SSE, are less frequent (~17%) but have higher speeds resulting in stronger wind strength (Fig. 6B). Looking at seasonal wind data, there is an inverse relationship between the winter and the summer seasons where northern winds become more frequent in winter and less frequent in summer. Data from the Taranto station indicate that NNW and SSW winds are the most recurring ones during the year whereas the SSE winds have a greater wind speed. Northeast winds have low speeds and exert little influence on the coast (Fig. 6C).

Information on wave-induced coastal circulation and wave climate is reported in Petrillo et al. (2014). These authors used a geographical transposition method in order to move the wave parameters collected at Taranto buoy (2006-2013) to the offshore Porto Cesareo coast. As shown in Figure 6D, wave directions are generally between 150°N (15.91%) and 300°N (8.47%), and seas from the south (24.48%) and southeast (15.91%) have the highest frequencies. Significant wave heights range from less than 0.25 m (24.21%), between 0.25-0.75 m (45.50 %), 0.75-1.25 m (17.73%), and 1.25-1-75 m (7.32%). Waves higher than 3 m are rare (0.83%)

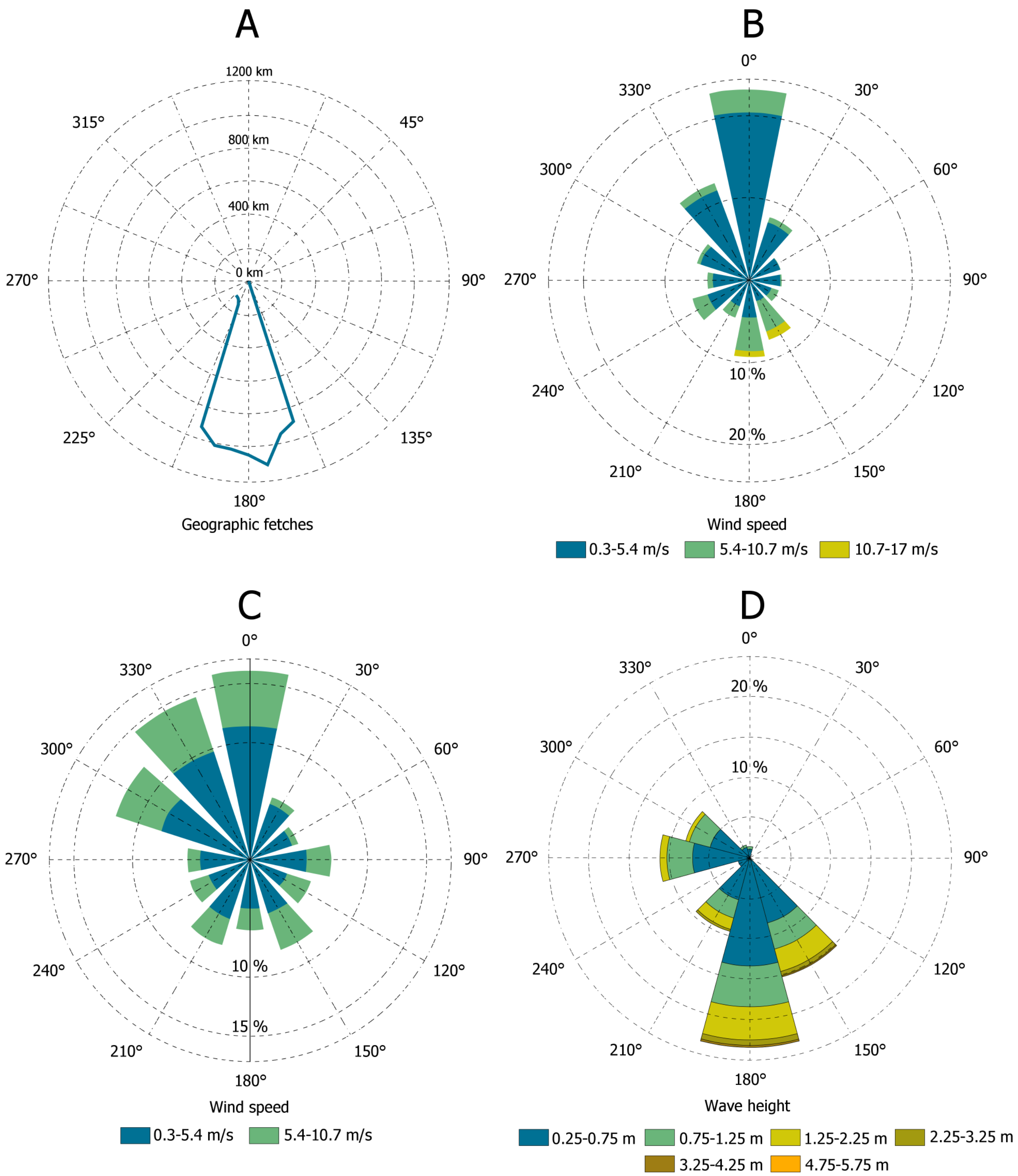

Fig. 6 - A) Polar diagram showing the geographic fetches in the studied coast. B and C), Wind directions and frequencies from the Porto Cesareo (B) and Taranto (C) anemometric stations between December 2006 and March 2017. D) Directional distribution of the significant wave heights off Porto Cesareo (by Petrillo et al., 2014).

and come mainly from the SSE. Waves with a peak period of 3-5 sec (31.89%), and 5-7 sec (21.34%) are the most recurring and those with peak periods lower than 3 sec and higher than 7 sec have frequencies of 6.47% and 16.10% respectively. The highest waves with return periods of 10 and 50 years are respectively estimated to 5.4 m and 6.5 m and the depth of closure is in the order of 7 m depth (Lisi et al., 2010; Petrillo et al., 2014).

6. THE STUDY COAST

6.1. Coastal features, beach morphology, and sediment characteristics

6.1.1. Salina dei Monaci Beach

Coastal features. Located on the western flank of Torre Colimena headland, this beach extends for 1.3 km mostly along the coast of the Salina dei Monaci Natural Park where dune, lagoon, and coastal plain environments are well preserved (Fig. 7A). Here, the mainland sandy barrier narrows gradually towards the headland and the dune field decreases in height and width until it disappears near Torre Colimena. The Pleistocene calcarenite is the substrate upon which the barrier and marshy plain developed during late transgression and present highstand. This calcarenite forms the headland and crops out in places along the beach and continues offshore (Fig. 8A). The calcarenite substrate controls the spatial arrangement of the modern coastal environments. The lagoon basin occupies a low depression and its extension is laterally constrained by the highs at Torre Colimena and at the town of Specchiarica. The Salina dei Monaci lagoon was more extended inland before reclamation and was used for salt extraction until ~1700. In present times, the basin banks are encrusted by salt during summer.

Offshore, the substrate starts to outcrop in shallow water (3-4 m depth) confining the submarine coastal prism near the shoreline (within 100-120 m). So the shoreface zone comprises an upper soft-bottom sandy segment and a lower hard-bottom segment, the former with a concave and moderately steep profile (1-1.2°). Underwater inspections on the lower shoreface area reveal that rocky seafloors are occasionally interrupted by small zones with bioclastic sands forming very thin deposits, often decimetres in thickness. The beach is fully exposed to the dominant southern seas. Their action during extreme storm events is recorded by some imbricated blocks of beach-rock exposed in the western part of the coast (Fig. 8B) (see also Mastronuzzi and Sansò, 2000), and by small washover fans in the lagoon basin near the headland where the littoral barrier is very low and narrow.

Beach morphology. Beach profiles were surveyed from the positions of the shoreline samples (samples and profiles have the same name) up to the foredune toe. They range from short and rectilinear profiles to those long and irregular, the former more frequent along the lateral margins of the shoreline (Fig. 7B). Welded bars are present locally and the ordinary berm crest is generally +0.5 m high. The storm crest, preserved only in the TC4 profile, is at +2 m. Four calculated parameters (see sketch in Figure 7B) were used to summarize the beach morphology and to identify its variations along the coast. Three of them, W (beach width), h (beach high) and Ve (emerged-beach volume) show statistical correlation with each other (W-h: R=0.74; h-Ve: R=0.86; Ve-W: R=0.85) and similar trends along the coast. The highest values of W, h, and Ve occur in the zone of TC4 profile, where the beach deposit (backshore) is well developed and exerts a greater opposition to potential wave attacks on foredunes (Fig. 7B). These values become progressively less pronounced towards the marginal zones (TC1 and TC9). Beach slope (α) ranges between 4°-6° with a peak of 8° near the headland (TC9).

Sediment characteristics. In figure 7A sediments are discriminated by their average size (means-size index) compared to an arbitrary interval-scale of values (common to all the study coastal sectors). Beach samples, poorly differentiated by size, consist of unimodal and well-sorted (σ=0.33-0.52 phi) coarse bioclastic sands (Mz=0.27-0.71 phi), negatively skewed or symmetric (Sk from -0.22 to -0.03), and platikurtic (TC9, near headland), mesokurtic or leptokurtic (Kg=0.78-1.46).

Seafloor sediments are more variable in size, comprising moderately-sorted medium (T1C), coarse (T1D) and very-coarse (T1E) bioclastic sands (Fig. 7A). The graph on the left of Figure 7C records the variations along the shoreline of the three textural indexes (Mz, σ, Sk) that are commonly used to determine sediment transport direction (McLaren and Bowles, 1985; Du et al., 2015). Due to the absence of any real trend in the σ and Sk values, the transport direction is however indefinable. In contrast, the trend of the Mz values indicates westward sediment fining likely connected to a progressive wave-energy decrease along the beach. The prevalent direction of the alongshore sediment transport suggested in AA.VV. (1997) is westward. The graph on the right of Figure 7C shows the grain-size frequency distributions related to the T1A-T1E transect. Note on this graph (i) the quasi-log-normal distribution of all samples that indicates high wave washing processes and (ii) the sediment fining from the lower-shoreface zone of bioclastic production toward the coast.

6.1.2. Pocket beaches between Torre Colimena and Punta Prosciutto headlands

This coastal sector includes three small beaches laterally separated by rocky prominences and externally by a hard seafloor (Fig. 7A). From west to east, the first beach is located at the head of a narrow indentation that is extremely protected from the sea and is used as natural harbour by fishermen. The second beach develops rectilinearly for 450 m and is fully exposed to the sea. Here, beach and shallow seafloor sediments consist of well-sorted coarse (TC10, T2A, T2C) and very coarse (TC11) bioclastic sands that are mostly negatively skewed (Fig. 7A and C). The most coarse, negatively skewed, platikurtic and less sorted bioclastic sand (T2E) was found in the marine zone of bioclastic production. The third beach is located within a small semi-circular bay and its sediment is made up of moderately sorted medium sized sands. The first and third beaches, much less exposed to the sea than the second, show thick accumulations of *Posidonia oceanica* (Fig. 9), and the facing rocky seafloors are dissected by ancient sub-aerial drainage incisions and circular depressions likely connected to paleo-karstic activity. The morphologic profiles (Fig. 7B) highlight narrow beaches (low W values) including poor sediment mass (low Ve values).

6.1.3. Riva degli Angeli Beach

Coastal features. Located between Punta Prosciutto and Punta Grossa headlands, this beach extends for 2.2 km displaying a small prominence in the eastern portion where the Pleistocene calcarenite substrate crops out (Fig. 10A). Inland, there is a low-flat plain that was artificially drained and once occupied by marshy zones. The beach presents a morphodynamic modal stage typical of the intermediate

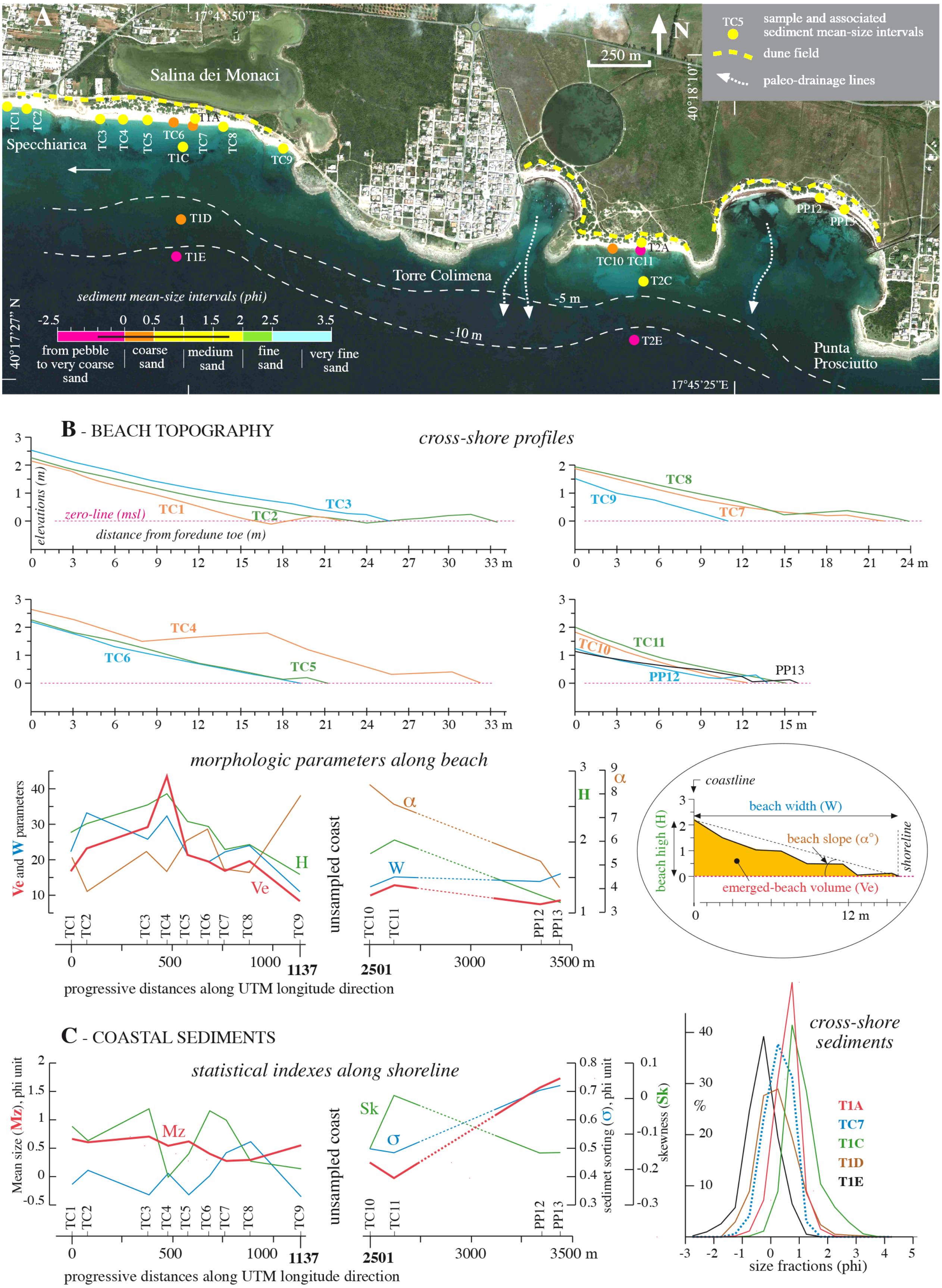

Fig. 7 - The coast near Torre Colimena headland (image by Google Earth, 2009). A) sediment characteristics (Mean-size) referred to the chromatic scale at the bottom left side (black line refers the range of Mean-size values in this specific coastal sector); B) beach profiles (in the same position of shoreline samples) and variations along the beach of their morphologic parameters; C) variations of the grain-size parameters, and sediment characteristics along the T1A-T1E transect. Readers are referred to the text for more details on this figure.

Fig. 8 - Salina dei Monaci beach. A) Emergence of the Pleistocene calcarenite substrate from the thin beach deposit (near TC7 profile). B) Flat Pleistocene calcarenite blocks imbricated during an extreme storm event (between TC2-TC3 profiles).

beaches (Wright and Short, 1984; Short, 1999). In fact cups, crescentic and transverse bars are particularly recurrent in time and rip currents seem to be recognizable in satellite imagery during storm-sea conditions (Fig. 11). The littoral prism ends in shallow water (about -3 m) where the seafloor begins to be predominately rocky. A shoreline advancement occurred in the period 1992-2005 (PRC, 2006), and a prevalent alongshore sediment transport from the margins to the middle of the beach is indicated in AA.VV. (1997).

The dune field is vegetated by Mediterranean scrubs and shows stress effects due to the human pressure. Houses, streets, local blowouts, and several access paths to the beach often interrupt the continuity of the dune vegetation cover (Fig. 12). Especially along these man-made paths, wind erosion, inland sand diffusion and occasional marine floods occur. Clear signals of wave erosion on the foredune face are present in the eastern zone where the beach is very narrow. Wood fencings are used in places to promote eolian

Fig. 9 - The pocket beach west to Punta Prosciutto headland, next to PP13 profile. Note the thick stack of *Posidonia oceanica* (red arrow) partially covering the backshore and completely the foreshore where the calcarenite substrate often crops out. Note also the imbricated blocks (yellow arrow).

deposition (Fig. 12). Despite their positive effects, the overall dune system displays metastable conditions.

Beach morphology. According to the topographic profiles in Figure 10B, this beach can be subdivided into three zones. In the western zone (profiles RA14-RA17) the beach is narrow (15-20 m) and dips regularly seaward showing low berm-crests (+0.5 m) (Fig. 12A). A more complex topography occurs in the central zone (profiles RA18-RA25), where a storm berm-crest (1.5-1.8 m high) often separates the sub-horizontal inner part of the beach from the gently sloping outer part (Fig. 12B). Here beach morphology varies due to the frequent renewal of welded bars and cusps. In the eastern zone (RA26-RA31) the beach is narrow and dips straight seaward (Fig. 12C-D). These three zones are well identifiable by the variations in the morphological parameters (Fig. 10B). The trend of W (beach width), h (beach high) and Ve (emerged-beach volume) indicates that the backshore deposit is more developed in the central beach zone compared to the other two.

Sediment characteristics. In Figure 10A samples are discriminated by their average sediment size (Mz). In particular, beach sediments are largely made up of unimodal, well-sorted (σ=0.32-0.53 phi) coarse and medium bioclastic sands (Mz=0.61-1.97 phi) with mostly symmetric (Sk from -0.17 to 0.13) and mesokurtic (Kg=0.95-1.19) overall distributional shapes. Sediment characteristics are also quite constant along beach (Fig. 10C). Note that σ and Sk values fall into a narrow range of variability (well-sorted and symmetric sediments) and do not show significant trends. Variations of Mz values indicate enrichment in fine sand particles in the western zone where wave energy impact should be lower.

Seafloor sediments consist of two main bioclastic sediment types (Fig. 10A). Type 1 includes upper shoreface sediments (samples 46-49, 51, T3C, T4C), which are made up of moderately sorted (σ=0.42-0.72 phi) medium sands (Mz = 1.31-2.02 phi), mostly symmetric (Sk from -0.03 to 0.13) and mesokurtic (Kg=0.95-1.13). Type 2 sediments occur in the lower shoreface and are constituted either by unimodal, well-sorted, symmetric and leptokurtic coarse sands (T4E, T4D), or poorly sorted, negatively skewed, meso-platikurtic and generally bimodal very coarse sands to fine pebbles (50, T3D, T3E).

The grain size frequency distributions, in figure 10C, show the granulometric variability from beach to sea (samples T3A-T3E and T4A-T4E). These distributions display the differences described above between beach (samples T3A, RA21, T4A, RA30), upper shoreface (T3C, T4C), and lower shoreface (T3D, T4D, T3E, T4E) sediments.

6.1.4. Lido degli Angeli Beach

Coastal features. Lido degli Angeli is a 1 km long pocket beach which is divided into two portions by a rocky prominence (Fig. 10A). The beach is bounded inland by a vegetated dune field which is interrupted by access paths to the beach, beach resorts, and car parks. Despite the protection of wood fencings, wind erosion and inland sand diffusion occur and some episodic and limited marine floods beyond the dunes have been observed. Satellite images from different periods show variations in the beach width near the rocky prominences due to slight rotations of the shoreline depending on wave direction. Cusps, crescentic,

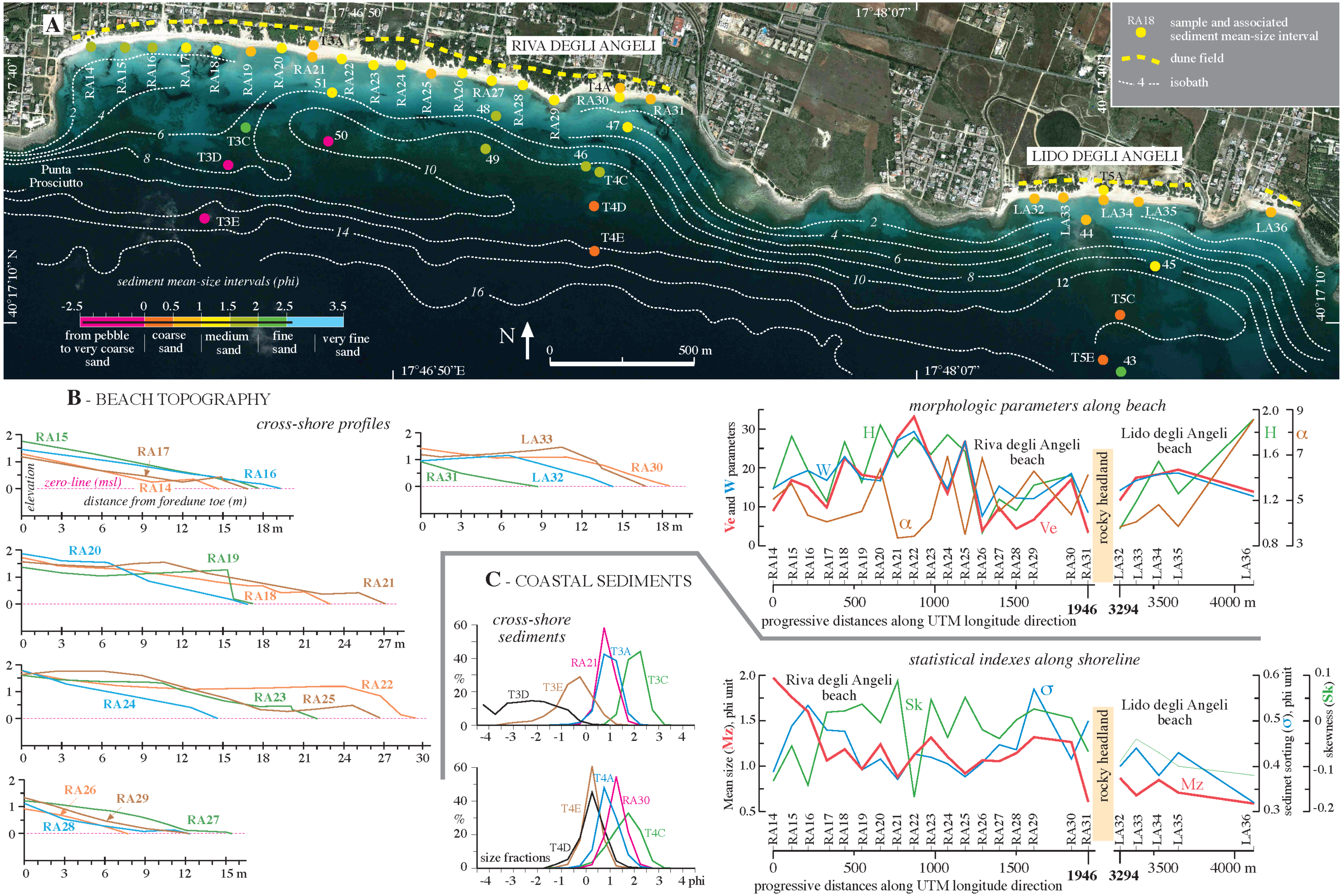

Fig. 10 - Riva degli Angeli and Lido degli Angeli beaches (satellite image from Google Earth, 2009). A) bathymetry and sediment characteristics; B) beach profiles and lateral variations of their morphologic parameters, and C) variations of textural parameters along shoreline and sediment types along two land-sea transects.

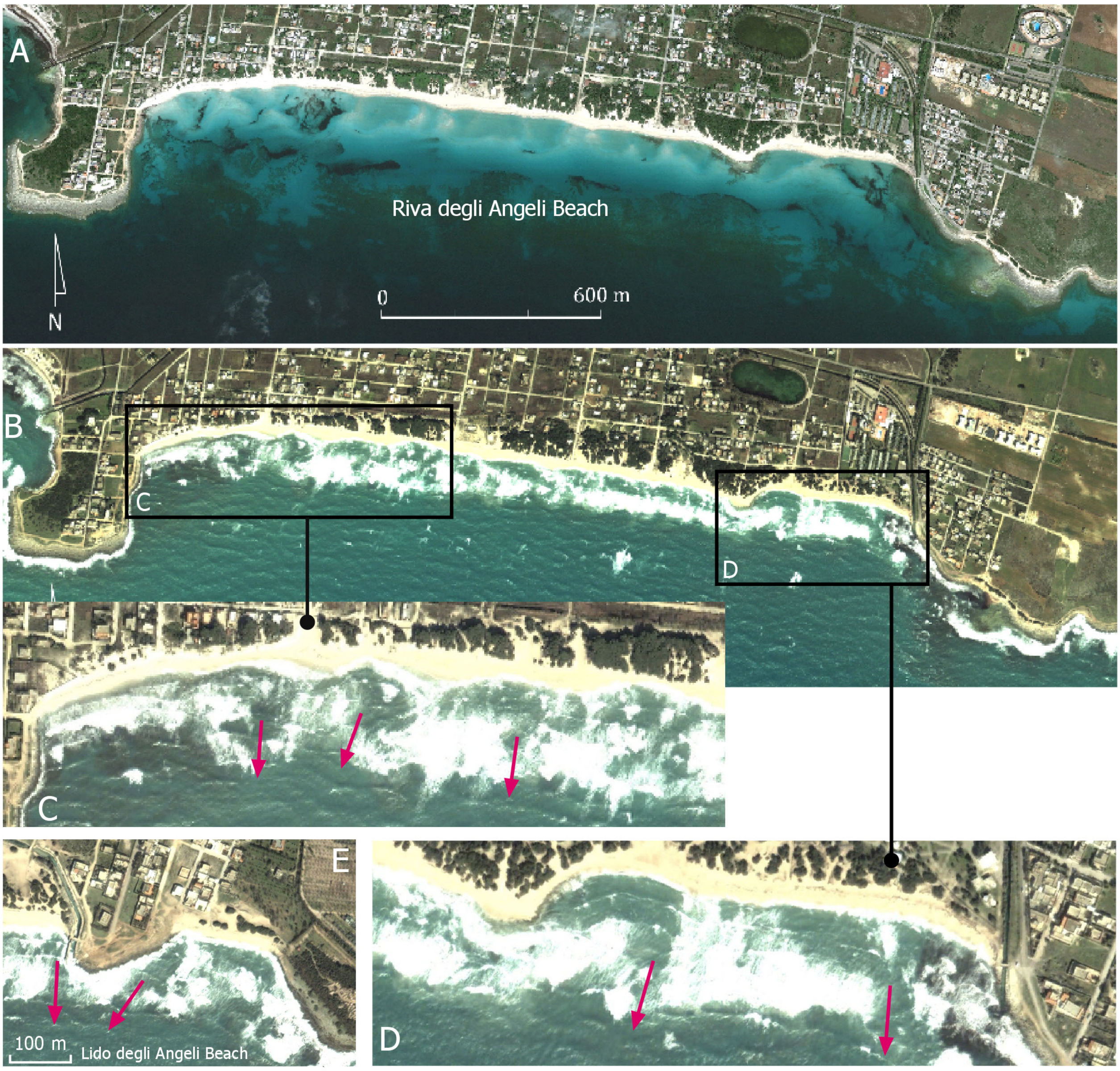

Fig. 11 - Riva degli Angeli beach during calm (A) and storm sea conditions (B). Note the nearshore transverse bars (A), and the break in the incoming wave pattern likely connected to rip currents (C-D). In E, possible headland rips at the easternmost extremity of Lido degli Angeli beach. Satellite images from Google Earth.

transverse bars and rip channels are the most frequent nearshore features (Fig. 11E). In the recent past the shoreline underwent erosion (AA.VV., 1997).

Beach morphology. Beach profiles and related morphological parameters are shown in Figure 10B, and some coastal features can be directly appreciated by the photos in Figure 13. This beach is about 15-20 m wide (LA33, LA34, and LA35 profiles) and narrows near the western headland (LA32) (Fig. 13A-B) and in the eastern zone (LA36) (Fig. 13D). The ordinary and the storm berm crests are about 0.7 m and 1.5 m high, respectively.

Sediment characteristics. Beach sediments are poorly differentiated (Fig. 10A and C) and consist mostly of bioclastic coarse sands (LA32, LA33, LA34, LA35, LA36 samples) which are generally unimodal, well-sorted (σ=0.32-0.49 phi), and prevalently symmetric (Sk from -0.12 to 0.03) or mesokurtic (Kg=1.00-1.14). Along the beach, the sediments tend to become finer and less sorted from west to east (Fig. 10C).

6.1.5. The coast between Lido degli Angeli Beach and Torre Lapillo headland

This coastal stretch extends in a WNW-ESE direction for 2.2 km and is mostly rocky. The few beaches occurring here are very small and consist of a thin veneer of coarse-medium bioclastic sands, which often contains calcareous pebbles deriving from coastal erosion. More inland the Pleistocene rocky substrate is covered by sandy beach deposits probably of Tyrrhenian age (see Cotecchia et al., 1969; Dai Pra and Stearns, 1977; Dai Pra, 1982). Some narrow indentations are present near Torre Lapillo headland and karstic features are quite common.

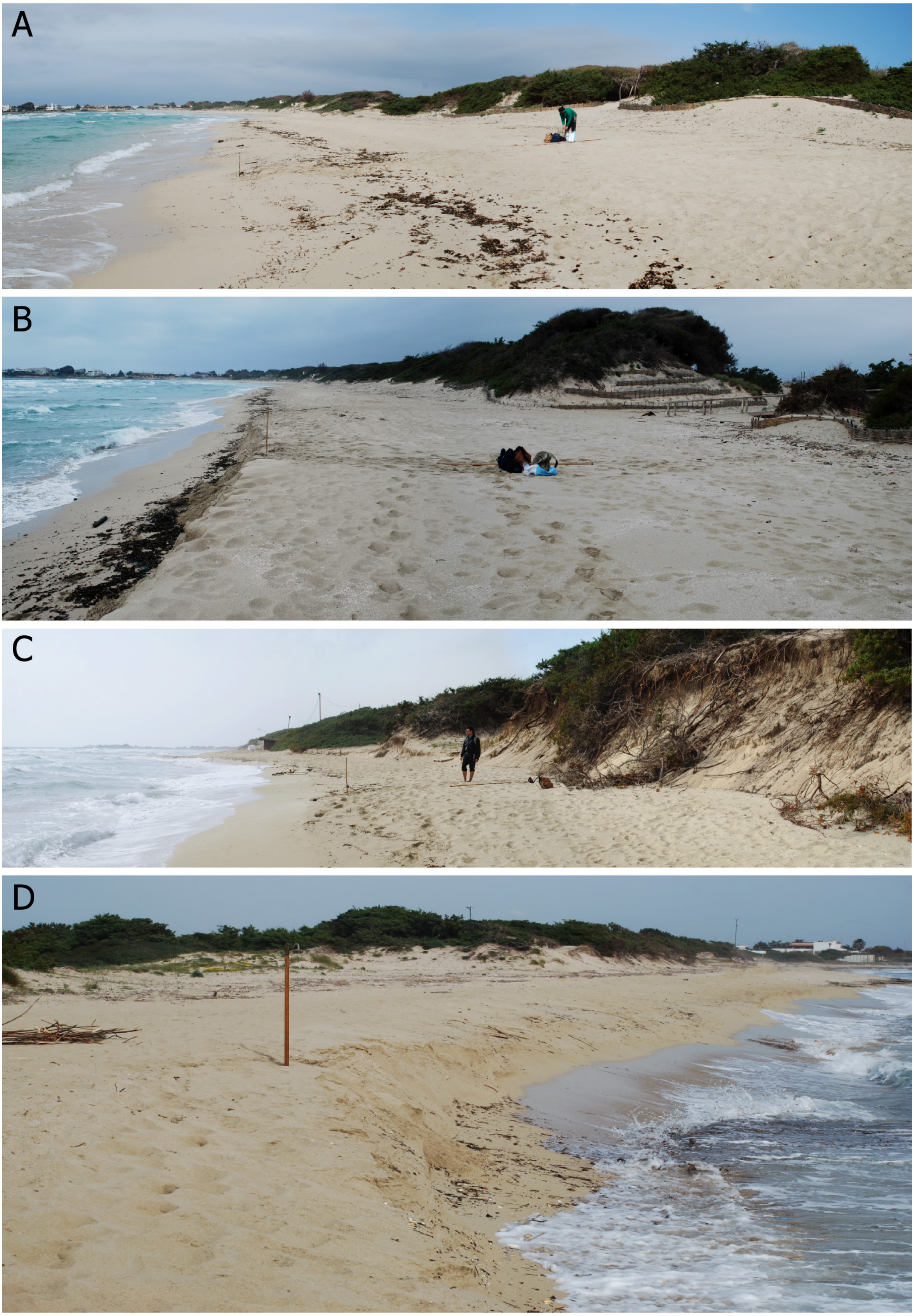

Fig. 12 - Morphological features at Riva degli Angeli beach. A) view of the western zone of the beach (profiles RA14-RA17); B) central zone (profiles RA18-RA25); C and D) eastern zone (profiles RA26-RA31). Note the wood fencings for dune defense and restoration (A), the dune cut connected to an access path to the beach (B), the clear signals of wave erosion in foredune (C), and the erosional scarp on the foreshore (D).

Fig. 13 - Morphological features at the Lido degli Angeli beach. A) Western zone of the beach (photo on profile LA32). B and C) Central zone (profiles LA33-LA34). D) Eastern zone (profile LA36). To note the general degradation of foredunes due to wave-wind erosion and summer recreational activities, the benefits provided by the wood fencings, and the calcarenite rocky cup near profile LA36.

6.1.6. Torre Lapillo Beach

Coastal features. This beach extends for about 3 km along the bay-arc to the east of Torre Lapillo headland (Fig. 14A). This is a coastal stretch that is densely urbanized and where the original dune field, once well developed, was almost totally dismantled. The waterfront contains houses, villas, and several streets connected to the beach. Some beach resorts stretch almost to the shoreline. The beach narrows sharply in its eastern portion where man-made structures have been created to contrast beach erosion by western waves.

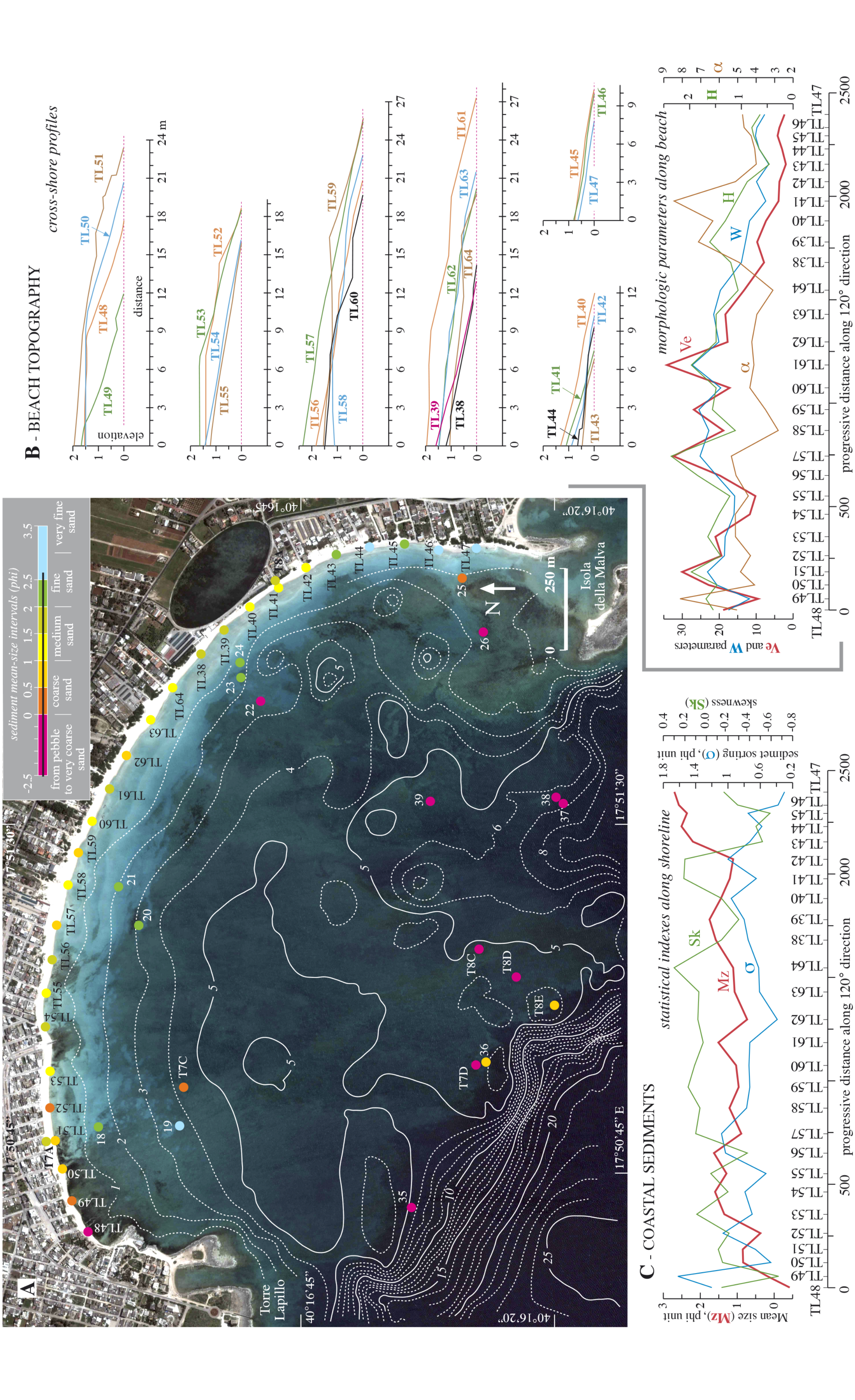

Fig. 14 - The coast of Torre Lapillo bay (satellite image from Google Earth, 2011). A) Bathymetry and sediment characteristics. B) Beach profiles and lateral variations of their morphologic parameters. C) Variations of textural parameters along shoreline.

Within the bay, the seafloor is shallow and displays a terraced morphology with an outer edge at 6-8 m depth along which wave ripples were directly observed (Fig. 14A). The rocky seafloor is constituted by Pleistocene deposits and is patchy covered by modern sediments. Paleokarst features dissect the hard seabed and consist of some circular depressions and small submarine caves that were observed in the eastern part of the bay. External to the terrace edge, the rocky seafloor deepens significantly down to -20 m forming a steep slope, potentially a paleo-cliff.

Beach morphology. The topographic profiles and related morphologic parameters subdivide the beach into a western and eastern zone (Figs. 14B, 15, 16, and 17). Along the western zone (from TL48 to TL64 profiles), the beach is relatively developed in height (h), width (W) and volume (Ve), resulting in average h=1.6 m, W=20.3 m, Ve=20.1 m^3/m. Values higher than these averages occur in the middle of the bay (TL57-TL61) and values lower near the Torre Lapillo headland (TL48-TL49) and down drift of the jetties between the TL53-TL54 profiles. Topographically, most of the beach profiles comprise an inner portion, sub-horizontal or gently sloping inland, and an outer flat portion that dips seawards. The ordinary and the storm berm crests are about 0.5 m and 1.5 m high, respectively.

In the eastern zone (between TL38 and TL47), in contrast, the beach profiles are flat, relatively steep and do not show any defined berm crest. Moreover, the beach narrows and decreases progressively in height towards the eastern bay margin. These variations are recorded by the common trend of W, h, Ve parameters (Fig. 14B). Their low average values (W=10 m, h=0.94 m, Ve=4.8 m^3/m) indicate a low fragility of this beach zone.

Sediment characteristics. In Figure 14A, samples are differentiated by their average sediment size (Mz). Specifically, beach sediments consist mostly of moderately sorted medium sands, negatively skewed or symmetric, and prevalently mesokurtic and platykurtic. Distinctive sediments occur at the bay margins and are composed by either poorly and moderately sorted coarse and very coarse sands (western margin: TL48-TL53), or moderately and well-sorted fine sands (eastern margin: TL43-TL47). These sediments are negatively skewed, leptokurtic or very leptokurtic.

The textural parameters (Mz, σ, Sk) vary along the beach without showing any trend connected to the sediment transport direction (Fig. 14C). Only the Mz values have a general trend (R=0.76, linear interpolation) indicating sediment fining from west to east according to the different exposure of the shoreline to the dominant southern seas.

Marine samples range from fine sands to fine pebbles (Fig. 14A). The finest sediments occur exclusively in the upper shoreface (samples 18, 19, 20, 21, 23, 24) and consist of moderately sorted fine sands, with unimodal, leptokurtic, symmetric or negative-and-positive skew frequency distributions. In contrast, the coarsest samples are found in the lower shoreface (with some exceptions: T7C, 22, 25, 26) and show a greater size variability ranging from coarse sands to fine pebbles. These samples, unimodal (T7C, T8E, 22, 35, 36, 38, 39) or bimodal (25, 26, 37, T7D, T8C, T8D), are moderately and poorly sorted, symmetric and plati-mesokurtic.

6.1.7. The coast between Isola della Malva and Porto Cesareo

Coastal features. This coastal stretch extends up to Porto Cesareo town and includes four adjacent beaches separated by rocky headlands (Fig. 18A). The two westernmost beaches, at the flanks of the Torre Chianca headland, are located between two small coastal indentations exposed to southerly seas (Fig. 19). The near islands of Isola della Malva and Lu Squeiu, made up of Pleistocene calcarenites, provide a further protection for these two beaches. Both are delimited inland by low, scarcely vegetated and discontinuous dune deposits, and seaward by rocky seafloors. The beach deposits overlay the substrate and are very thin and restricted mostly to the emerged portions. Offshore, the bathymetry is very irregular especially facing Isola della Malva.

Further east, Le Dune beach develops for about 800 m and is exposed to the south-westerly and southerly seas (Fig. 20A, B). In summer, this beach undergoes a large tourist impact causing a partial deterioration of the dune field, which has already been compromised by recent urbanization. Some beach resorts are close to the shoreline and dune erosion occurs at the flanks of the corridors leading to the beach. The submerged beach, which extends for about 300 m before it intercepts the rocky seafloor, shows commonly transverse bars and sometimes multiple bars parallel to the shoreline. Satellite images from different periods record the persistence of a large rip-channel (near D69 sample position) whose neck is about 150 m long and 50-100 m wide (Fig. 21). Two minor channels are present at beach margins and could be associated with headland rips. Outside this embayment, an ancient sub-aerial drainage line, perhaps rejuvenated by the main rip current, dissects the rocky seafloor. The beach has a slight Z-shaped form with an increased sediment accumulation on its western extremity.

The Scala di Furno beach extends for 450 m within a small embayment exposed to the westerly and south-westerly seas, having short fetches (about 100 km). The dune field is absent in the northern part of the embayment, and is very spotty and discontinuous in the southern part (Fig. 20C). A flat reclaimed area, occasionally flooded, is present landward the road that was built on the ancient dune field. Also Scala di Furno is a zeta-shaped beach with more sediment accumulation along its northern portion. Nearshore rip circulation occurs in the middle of the embayment and, similarly to the other beaches, the rocky seafloor confines the submerged littoral prism in very shallow water (1-2 m depth).

Further southeast, the low-rocky coast is mostly occupied by the town of Porto Cesareo, whose docks are protected by the Isola Grande (also called Isola dei Conigli by local residents).

Beach morphology. Beach profiles and morphologic parameters are shown in Figure 18B. The pocket beach west of the Torre Chianca headland narrows from the middle

Fig. 15 - Photos (proceeding from west to east) along the western zone of Torre Lapillo beach. A and B) The beach near TL48 and TL52 profiles, respectively. Note the coarse material spread from the substrate cropping out near the shoreline (A), and the uninterrupted sequence of the houses that have replaced the original dune field and that today are very close to the shoreline (A, B). C and D) The beach near TL57 (C) and TL60 (D) profiles, where it widens and some foredunes are discontinuously present.

Fig. 16 - Photos collected along the eastern zone of Torre Lapillo beach. A and B) The beach near profile TL45 in April 2010 (A) and August 2016 (B). Note the disappearance of the beach in this time-interval, and the sandbags used to protect the beach resort (see red arrow) from waves. C and D) The easternmost beach portion at the two flanks of the house near to the shore (see red arrow) in April 2010 (C) and in August 2016 (D).

to the margins and displays a flat morphology without any berm crest relief. At D65 profile, beach width (W) is only 11 m and the emerged beach volume (Ve) is very low (8 m^3/m).

The pocket beach east to this headland tends to widen from east to west. Here beach profiles (D66, D67) have irregular morphology with the ordinary and the storm

Fig. 17 - A and B) Eastern zone of Torre Lapillo beach near TL 38 and TL39 profiles. Here sandbags and wood fences are used to contrast erosion especially in the Bacino Grande bathhouse, very near to the shore. The benefits of this intervention are local and quite limited.

(D66) berm crests about 0.5 and 1.3 m high. Beach width (W) and the emerged beach volume (Ve) are 22 m (D66), 18 m (D67), 20 m^3/m (D66) and 16 m^3/m (D67).

In contrast, Le Dune beach shows a more uniform morphology with the exception of profiles D70 and D73. The first profile is extraordinary extended (W=38 m; Ve = 44 m^3/m) because it includes an inner portion originally occupied by dunes, whereas the second profile is very short (W=11 m; Ve=7 m^3/m) because next to the headland. The other profiles range in width (W) between 19 m and 26 m, and in volume (Ve) between 16 m^3/m and 33 m^3/m. The ordinary berm crest is less than 1 m high and the storm crest, preserved only in zone of D70 profile, is at +1.5 m. Due to the Z-shape configuration of this beach, the profiles D68 and D73 are very different. Among the four examined beach, the Dune beach is the one most developed in terms of volume, width and height (Fig. 18B).

Further south, Scala di Furno is a low volume beach (7 m^3/m, D74; 14 m^3/m, D75; 5 m^3/m, D76) and shows flat and gently sloping profiles ranging in width from 20 m in the middle beach portion (D75) to 12-13 m near the margins (D74, D76).

Sediment characteristics. Sediment size variability is shown in Figure 18A. Beach sediments are made up mostly of unimodal, moderately-sorted (σ=0.47-0.82 phi) medium and fine bioclastic sands (Mz=0.70-2.40 phi), with symmetric or positive or negative skewed (Sk from-0.41 to 0.17) and meso-leptokurtic (Kg=0.90-1.31) frequency distributions.

The variations along the shoreline relative to the sediment size (Mz) seem to be connected to the degree of coastal exposure (Fig. 18C). In fact, the coarsest and finest sediments are respectively present at Le Dune and Scala di Furno beaches: the first beach exposed to the dominant southerly seas and the second to the westerly and south-westerly seas with very short fetches. The trend of the σ values (R=0.76; linear interpolation) indicates sorting becomes poorer proceeding from east to west.

Marine sediments consist mostly of unimodal medium or fine sands and, subordinately (samples 32 and 33), very coarse sands (Fig. 18A). Sediment distributions are moderately sorted, negatively skewed and meso-leptokurtic. Marine sediments became progressively finer proceeding seaward (Fig. 18C).

6.1.8. The Lagoon of Porto Cesareo

6.1.8.1. Open coast

The headland of Porto Cesareo, the inlet channel to the lagoon and the peninsula of La Strea are the main morphological elements of this coastal stretch (Fig. 22A). The headland, made up of Cretaceous carbonate rocks, is occupied by the docks of Porto Cesareo town and is surrounded by shallow seafloors and small islands (Isole Cesaree). The inlet channel, 400 m wide and 3-4 m deep at the entrance, extends seaward down to -10 m whereas

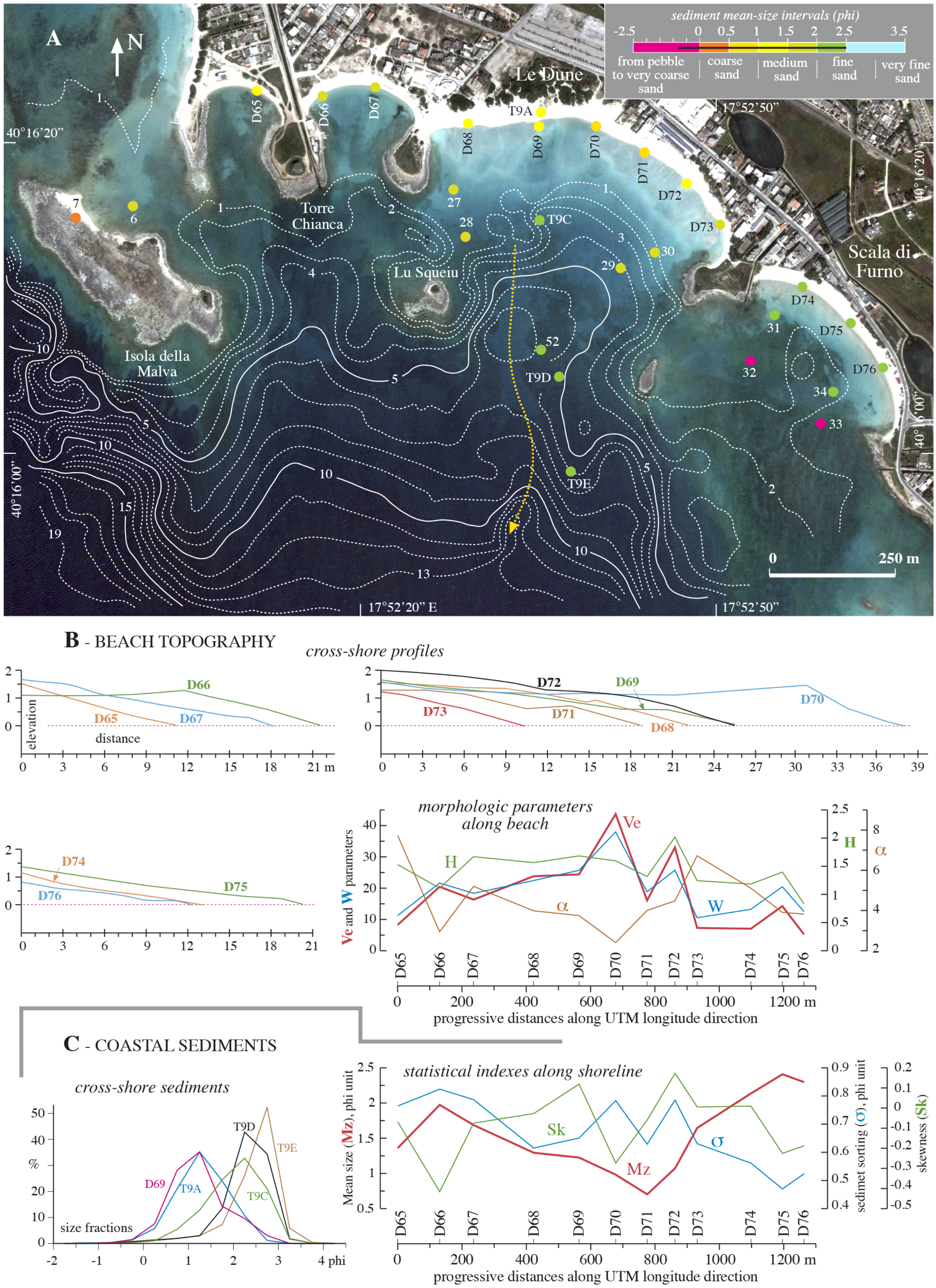

Fig. 18 - The coast between Isola della Malva and Porto Cesareo. A) Bathymetric map and sediment characteristics (satellite image by Google Earth, 2011). B) Beach profiles and lateral variations of their morphologic parameters. C) Variations of textural parameters along the coast.

Fig. 19 - Morphological features of the two pocket beaches to the west (A) and east (B and C) of the Torre Chianca headland.

landward merges with the shallow and flat bathymetry of the lagoonal basin. At the termination of the channel, the seafloor sediment (sample T10E) consists of a poorly-sorted very-coarse sand, very negatively skewed and leptokurtic. This sediment includes fine pebble-sized biogenic detritus forming a secondary mode.

La Strea Peninsula, about 250 m wide and 2 km long, is mostly rocky and mantled in place by thin modern sand deposits. Pleistocene calcarenites overlie the Cretaceous carbonate substrate and form a wide (80-100 m) wave-cut terrace. Modern sediments accumulate at the inner terrace termination, and inland they form occasional small dune ridges. Offshore, the seafloor is mostly rocky due to the presence of the carbonate substrate and, more rarely, of the Pleistocene calcarenites (Viel et al., 1986). Thin algal trottoirs cover in place the rocky seafloor that is locally interrupted by small zones of bioclastic sands (Ambrosano et al., 1986). Seafloor morphology is very irregular, passing from a steep topography near the La Strea coast, interrupted by a terrace (6-9 m depth), to seafloors more gently dipping beyond the 20 m isobath (Fig. 22A).

6.1.8.2. Lagoon basin

The lagoon of Porto Cesareo is a very shallow basin that stretches in NW-SE direction for about 2.4 km with a maximum width of 700-800 (Fig. 22A). The lagoon formed during the end of the Holocene transgression on a substrate depression previously occupied by marshlands

Fig. 20 - View of the western (A) and middle (B) portions of Le Dune pocket beach. Note in western portion, the relatively wide beach and the partial preservation of dunes, only attacked by waves during major southerly storms. In C, view from the south of Scala di Furno pocket beach. Here dunes are substantially absent and the beach is narrow and easy floodable during westerly and south-westerly storm seas.

(Mastronuzzi et al., 1989). Within the lagoon, hydraulic circulation decreases in intensity from north to south. Salt water "pumped" through the entrance during stormy seas, tidal flows and local wind-driven waves are the main controls on sedimentation (Passeri, 1973). Salt-water pumping and tidal flows exert their control mostly along the northern and southern portions of the basin, respectively. Local runoff and several karst-springs feed the basin with fresh water. With the exceptions of the inlet zone, the bottom of the lagoon is flat, sub-horizontal and mostly covered by patchy bioclastic sediments. Rocky outcrops are scattered everywhere, whereas local algal mounds and more extended seagrass meadows are present in the southern basin portion.

Section A-B-C summarizes lagoon morphology and related environments (Fig. 22B). According to the decrease in hydraulic energy, sediments along this section tend to

Fig. 21 - Satellite images of different periods at Le Dune beach (images from Google Earth). Possible rip circulation during a storm event is shown in A. In B-E, changes in time and space of the nearshore bar pattern with persistence of the main rip channel in the middle of the beach.

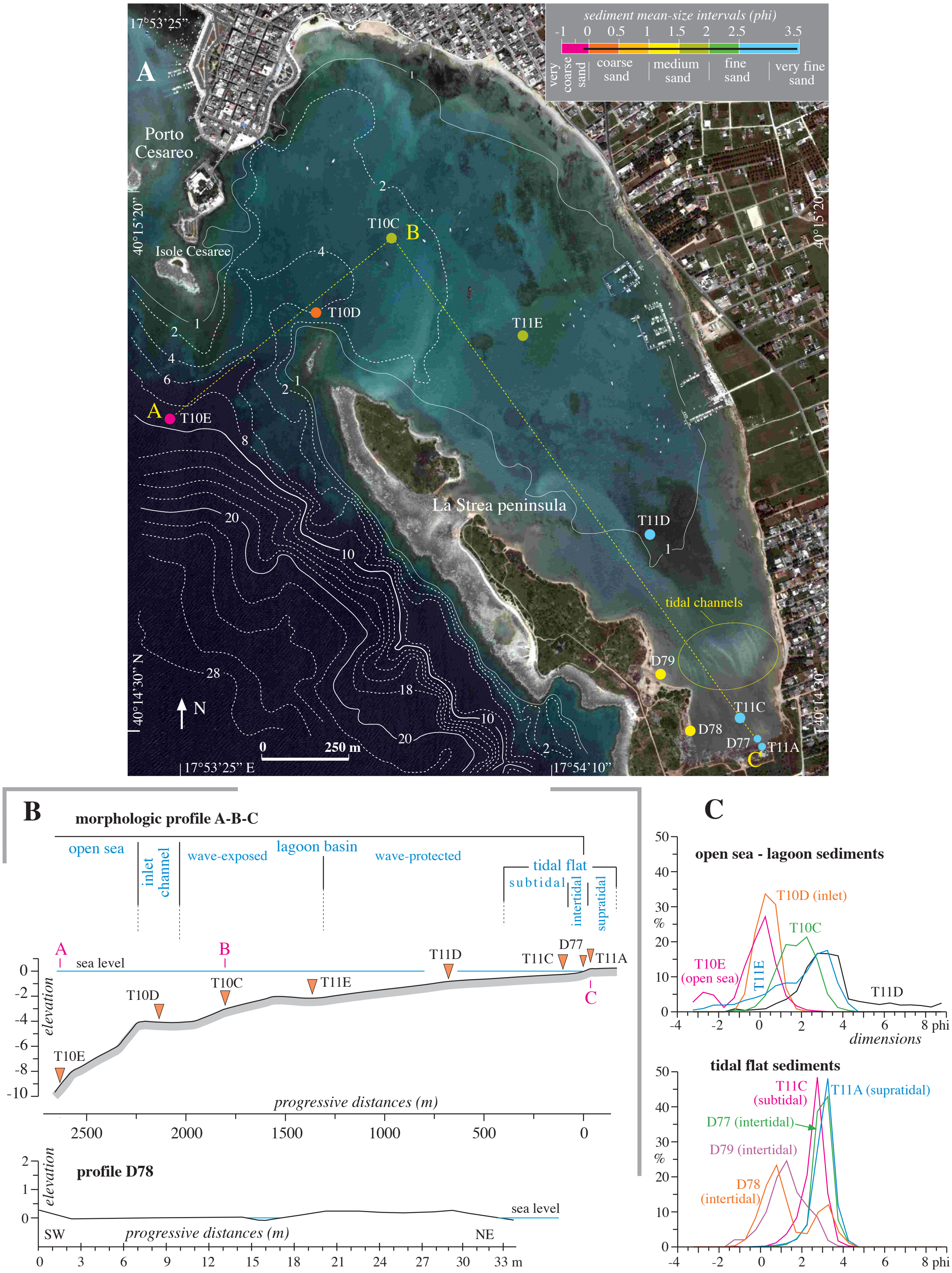

Fig. 22 - Porto Cesareo coastal sector (satellite image from Google Earth, 2011). A) Bathymetry and sediment characteristics. B) Morphologic section (A-B-C), related environments, and topographic profile (D78). C) Grain-size frequency distributions of the collected samples.

become progressively finer from A to B and from B to C. Sediments in (T10D) and facing (T10C) the inlet reflect relatively high-energy conditions. In fact, they consist of well-sorted coarse sands (T10D) and moderately-sorted medium sands (T10C). Proceeding south-east (from B to C), the decrease in energy is accompanied by the mixing of coarse and fine size populations resulting in very-poorly-sorted medium-fine sands (T11E, T11D). Further south, in the tidal flat, sediments (T11C, D77, T11A) lack coarse fractions and comprise well-sorted fine and very fine sands.

Deposition within the Porto Cesareo lagoon is the result of the intermixing of sediment derived from (i) lagoon bioclastic production, (ii) drainage of surrounded terrestrial areas, and (iii) the access through the inlet channel of marine bioclastic particles that spread mostly in the upper and middle part of the lagoon.

6.1.8.3. Lagoon shore

The waves that enter into the lagoon form a beach about 1.3 km long in the northernmost portion of the lagoon shore, densely urbanized (Fig. 22A). This beach, composed of fine and very fine sands, is flat and narrows toward the southeast without showing any submerged bar and external dune features. Further southeast along the mainland shore, some narrow beaches, often interrupted by rocky zones, are present and merge with the tidal flat of the southernmost part of the lagoon. This same pattern also occurs along the opposite shore (La Strea peninsula) where rocky outcrops are more frequent, some of them affected by karst features. In both lagoon shores, sediments become progressively finer toward the southeast changing in colour from yellow to gray. Towards this direction a weak sediment transport might be occur in response to wave diffraction at the lagoon entrance

6.1.8.4. Tidal flat

This environment is exclusive of the southernmost and more protected portion of the lagoon and includes supratidal, intertidal, and subtidal zones (Fig. 23A).

<u>Supratidal zone</u>. This zone manifests as a flat and marshy area locally separated from the intertidal environment by a morphological step about 30 cm high (Fig. 23B) whereas its inner boundary is marked often by substrate outcroppings. This zone differentiates into an upper and lower portion. The former, totally colonized by Salicornia carpets with sporadic grasses such as Ammophila, is crossed by small tidal channels that are only active during heavy rains, highest tides (spring tide) and on the occasion of marine storms causing increasing water level in the lagoon. Small brackish ponds are also present and are fed by rainwater, karst springs, and salt water related to rising groundwater during the highest tides. In the small tidal channels sediments vary from coarse to fine sands often mixed with mud-sized material, and are covered by carpets of desiccated Cyanophyceae algae. Sediments inside and outside the channels are composed of clay, red-soil particles, and quartz grains whose amount decreases towards the lagoon in favor of the carbonate particles.

The lower supratidal portion with well-sorted very fine sands (Fig. 22C, sample T11A) is colonized by halophyte associations as Salicornia, whereas carpets of blue-green algae are present within the small tidal channels (Fig. 23C). This supratidal portion is submerged during the highest tides and the cycle of emersion and submersion leads to the formation of plane-parallel laminated deposits. The laminations vary in colour and can include marine sands, peloids, quartz aeolian particles, and particles transported during the rainy seasons. A black-fetid felt of blue-green algae helps to trap these sediments. Different processes of sedimentation occur in the sinuous tidal channels, where bioclastic sands prevail and are coarser in their deepest part as compared to the banks (Fig. 23D). In the southern lagoon shore of La Strea Peninsula, upper and lower supratidal environments are indiscernible. Here the supratidal zone presents thin laminated deposits with alternations of organic sediments and coarse bioclastic sands probably related to storm events (Fig. 23E).

<u>Intertidal zone</u>. This zone, about 70-100 m wide, is flat, sub-horizontal and crossed by small tidal channels extending into the supratidal environment (Fig. 24 A,B). Intertidal zone is highly affected by bioturbation presenting numerous tracks, burrows and mounds formed by crustaceans (Callianassa) and worms as *Arenicola marina* and *Pectinaria koreni* (Passeri, 1973) (Fig. 24 C,D). Intertidal sediments consist of either a well-sorted very-fine sand (D77) or a poorly-moderately sorted medium sand (D78, D79), the latter found on the southern shore of La Strea Peninsula (Fig. 22C). These sediments are generally agglutinated by algal carpets, consolidated by early cementation, or simply desiccated.

<u>Subtidal zone</u>. With depths shallower than 1 m, this zone extends approximately 400 m from the southern lagoon shore. Morphologically, it is very flat and several submerged tidal channels, about 100 m long, are located on its external portion (Fig. 22A). Sediments are mostly fine and very fine sands, yellow at the surface and dark and fetid just below, with local deposits of coarse sands in the external zones. The infauna is represented by gastropods (e.g. *Cerithium, Conus*), crustaceans (e.g. *Crangon*), annelids (e.g. *Pectinaria*) and lamellibranches (e.g. *Cerastoderma, Venerupis*) (see Passeri, 1973). The subtidal zone shows the presence of a seagrass meadow that has been assigned to *Cymodocea nodosa* (Fig. 24E, F), a plant endemic in the Mediterranean areas (Procaccini et al., 2003) often characterizing the lagoon environments (Short et al., 2007).

6.2. Sediment composition

A total of twenty-four samples, collected mostly in the swash zone, were selected for qualitative compositional analyses. In the coastal area near Torre Colimena headland (Fig. 7) sediment samples (TC1, TC4, TC6, TC9, TC11) are poorly differentiated and consist of yellowish to greyish coarse sands with rounded and well rounded grains displaying polished surfaces. Carbonate bioclasts are dominant and carbonate lithic fragments common. Bioclasts include ordinary shell detritus, gastropods and echinoderm spine fragments, and rare benthic foraminifera (*Elphidium, Quinqueloculina*). Monomineralic quartz and feldspar grains are rare.

In the coastal area of Riva degli Angeli (RA14, RA20, RA24, RA29, RA30) and Lido degli Angeli (LA34, LA36) (Fig. 10), sediment samples are yellowish to greyish medium-coarse sands. The dominant bioclastic fraction includes

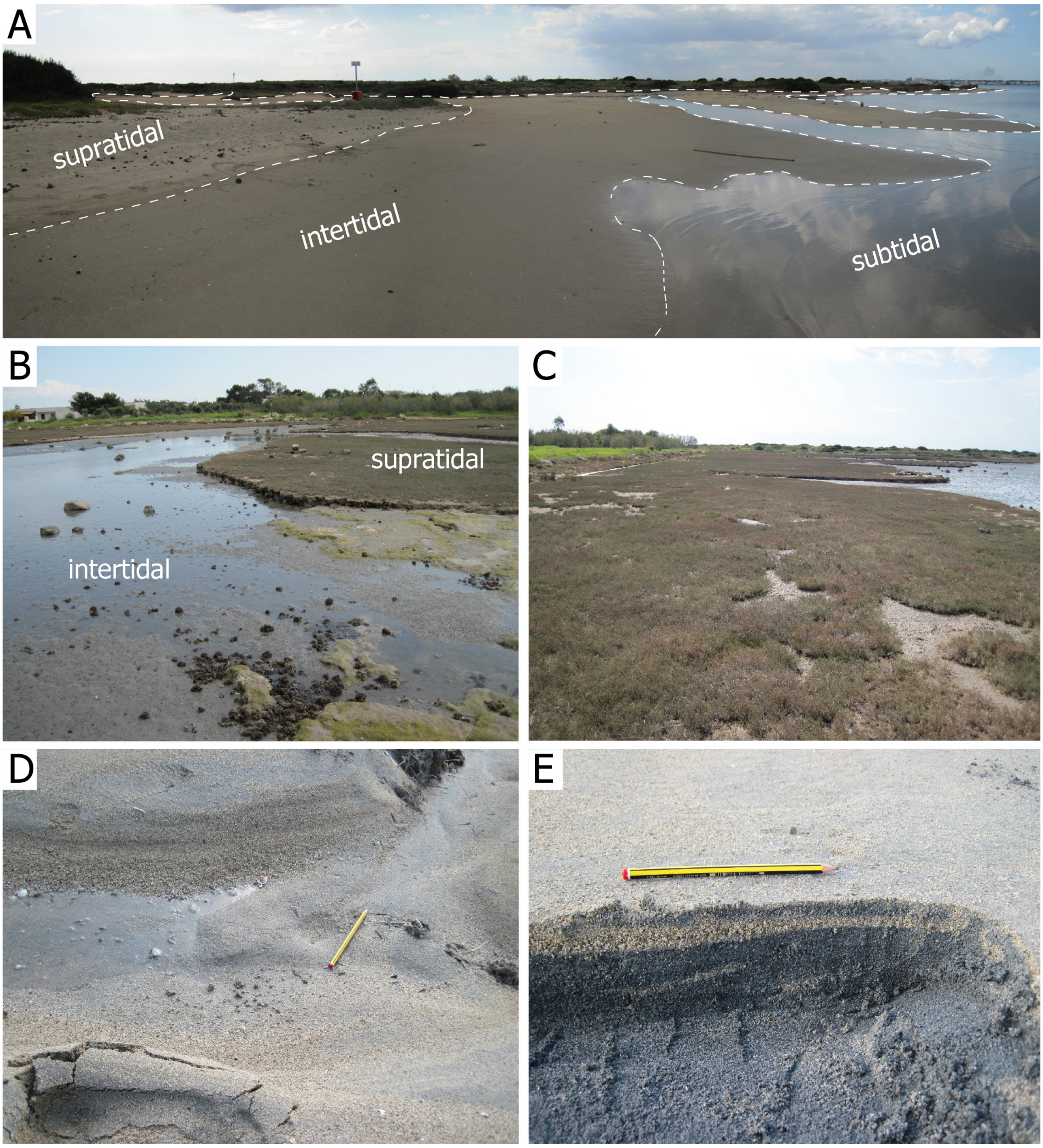

Fig. 23 - A) The tidal flat in the southernmost shore of the Porto Cesareo lagoon. B) Supratidal and intertidal zones delimited by a morphological step. C) Supratidal zone crossed by dry tidal channels. D) Coarse bioclastic sands present in the deepest portion of the tidal channels. E) Coarse bioclastic sandy layers (light colour) formed in the supratidal zone during storm events.

gastropods, echinoderm spines, and a wide variety of benthic foraminifera that survived to abrasion. Foraminifera comprise *Elphidium crispum, Elphidium incertum, Ammonia, Quinqueloculina, Spiroloculina, Peneroplis planatus, and Perenoplis pertusus*. Monomineralic quartz grains occur with a higher frequency when compared to the previous coastal area, and are very well rounded suggesting a history of aeolian transport.

In the Torre Lapillo bay (Fig. 14), beach sands are yellowish to grayish coarser-grained in the western zone (samples TL53, TL58, TL62), and pale-grey fine-grained in the eastern zone (TL38, TL46, TL47). Bioclasts are dominant with minor carbonate and monomineralic quartz grains that increase in the eastern beach zone. Bioclasts include shell detritus, gastropods, sponge spicules, serpulids, benthic and rare planktonic foraminifera, and echinoderm spine fragments. Grains have sharp edges and foraminifera are not as rounded and abraded as the beach sands in the previous two coastal areas. In the western beach zone, benthic foraminifera include *Peneroplis planatus, Peneroplis pertosus, Elphidium*

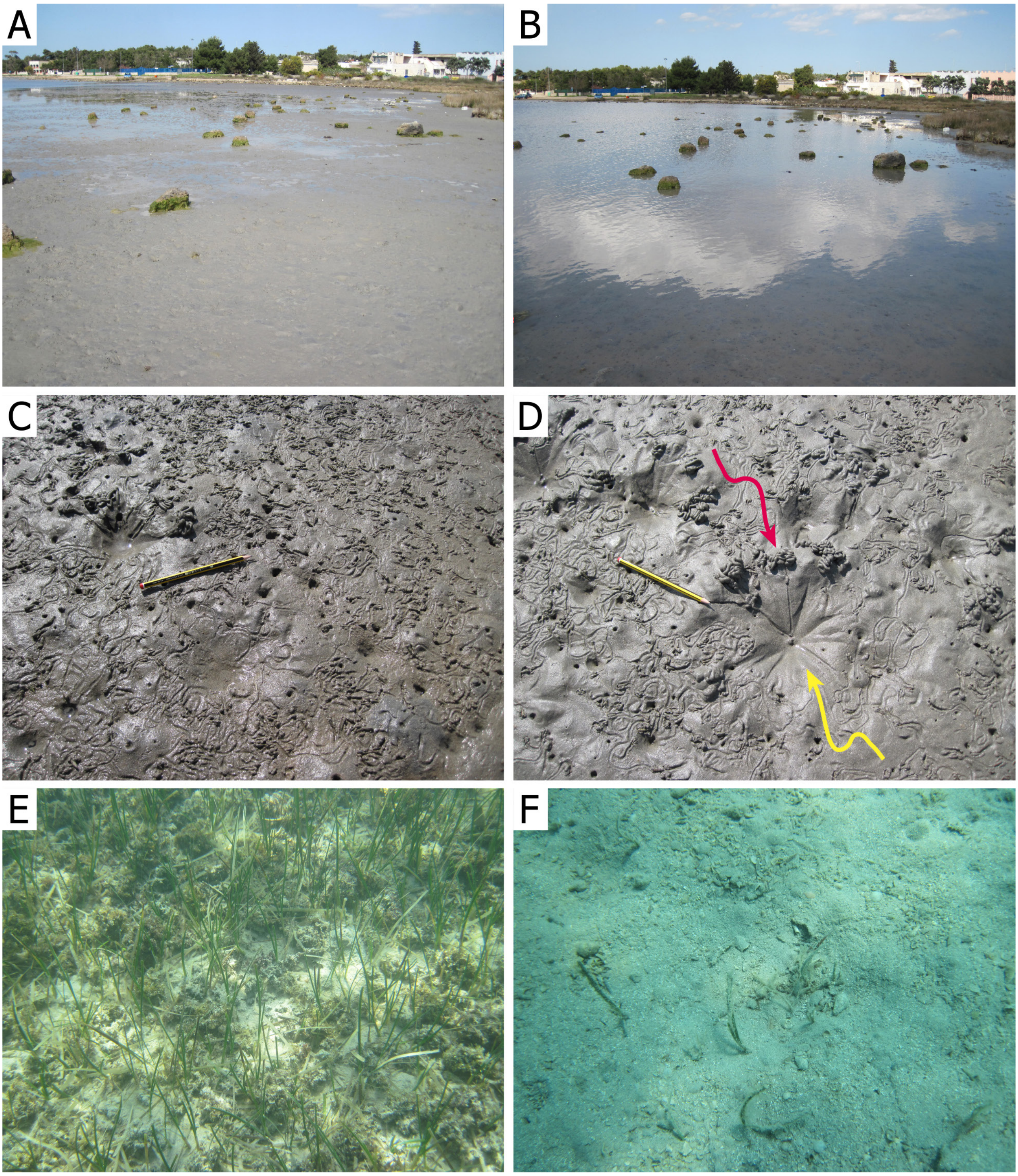

Fig. 24 - The tidal flat in the southernmost shore of the Porto Cesareo lagoon. A, B) intertidal zone during low and high tide. C, D) Bioturbation in the intertidal zone highlighted in low tide conditions. Besides the tracks left by molluscs (probably gastropods), it is noteworthy the mounded topography probably associated to the *Callianassa* activity and the conical depression (conical head shaft of collapsing sediment) due to the ingested sediment extruded at the tail shaft by *Arenicola marina*. E, F) Seagrass meadow assigned to *Cymodocea nodosa* in the subtidal zone (-0,8 m) and in the lagoon basin (-2.2 m), respectively.

crispum, Ammonia, Elphidium incertum, Polymorfina burdigalensis, and *Sorites*. Porcellaneous foraminifera are rare. In the eastern zone Peneroplidae are common and porcellaneous forams include *Quinqueloculina*, and *Spiroluculina*. Other benthonic foraminifera are *Ammonia* sp., Elph*idium crispum, Rosalina, Lachlanella corrugate, Bolivina* sp. and *Reophax*.

Sediment samples collected near Torre Chianca headland (D65, D67), at Le Dune (D69) and Scala di Furno (D75) beaches (Fig. 18) are pale-yellow to pale-grey and consist of moderately to well sorted sands. Bioclasts are dominant and lithic fragments and monomineralic quartz grains common.

Bioclasts and lithic fragments are sub-rounded whereas monomineralic quartz grains subangular. Bioclasts include shell fragments, gastropods, echinoderm spines, ostracods, and benthic foraminfera (*Peneroplis planatus, Peneroplis pertosus, Elphidium crispum, Sorites, Quinqueloculina*). Lithic fragments consist of micritic carbonates and calcarenites.

In the tidal flat of the Porto Cesareo Lagoon (Fig. 22), sediment samples (D77, T11A) consist of greyish very-fine sands. The coarser clasts are lagoonal allochems such as cerastoderma and serpulids. Quartz and carbonate grains are about 50% each with the quartz grains more rounding than the carbonate grains. Sponge spicules and peloids are common. Bioclasts include gastropods and ostracods, and a few porcellaneous forams such as *Quinqueloculina* and *Spiroluculina*, and small *Elphiudium*.

7. RESULTS

7.1 Main Coastal features

Sedimentological and morpho-bathymetric data identify the main cross-shore morphodynamic zones common to all investigated coastal sectors exposed to the sea. Moving from sea to land, they are shelf-transition, lower and upper shoreface, foreshore, backshore, dune, and coastal plain zones (Fig. 25).

The shelf-transition zone, between about 7 m and 20 m depth, is morphologically well defined to the south of Torre Lapillo headland. Here this zone corresponds to a strip of steep rocky seafloor that is externally delimited by terraced morphologies and is dissected by incisions and local small depressions often filled in part by bioclastic debris.

The lower shoreface zone (wave-shoaling dominated) is delimited by the closure depth at about -7 m (Lisi et al., 2010; Petrillo et al. 2014), and is mostly rocky with scattered thin coarse-sand bioclastic deposits. A carbonate factory that is the main sediment source in all the investigated coastal systems occupies this zone.

The upper shoreface zone (wave breaking and surf dominated) is poorly extended everywhere (100-200 m from shoreline) ending at 2-3 m depth. It is on average 5 times narrower than the lower shoreface, and shows well-developed bedforms (symmetrical and asymmetrical ripples) and rhythmic morphologies (cusps, different types of bars) often associated with rip-channels.

The foreshore is only a few meters wide and is often indistinguishable from the swash zone due to the low tidal range (30-40 cm). The foreshore-swash zone increases in slope with wave impact and beach sand size, and shows low-angle cross-laminated sandy deposits.

The backshore zone varies in volume and morphology showing extended irregular cross-shore profiles and short rectilinear profiles in the middle and at the margins of the embayments respectively.

The dune zone varies in elevation and width. Excluding the effects due to human presence, the size of the dune-field deposit tends to increase with the length of beaches and to decrease towards the lateral margin of the beaches.

The coastal plain zone is a lowland area with generally inactive sedimentary processes as a consequence of its reclamation and urbanization.

All the investigated coastal stretches show the following characteristics (Fig. 25): (1) the sediment depocenters are located near the coastline (upper shoreface, backshore, dune zones) rather than within and offshore the lower shoreface zone where bioclastic production occurs; (2) the coastal prisms are underdeveloped in size and in cross-shore extent, especially if compared with the typical siliciclastic prisms in Mediterranean areas; (3) there is a strong control of the substrate morphology i) on the spatial arrangement of the deposits, ii) on their size, iii) on the extent of the carbonate factory area, iv) on the form of the shoreface profiles, and v) on present-time sedimentary processes that occur in a coast only supplied by local sediment sources.

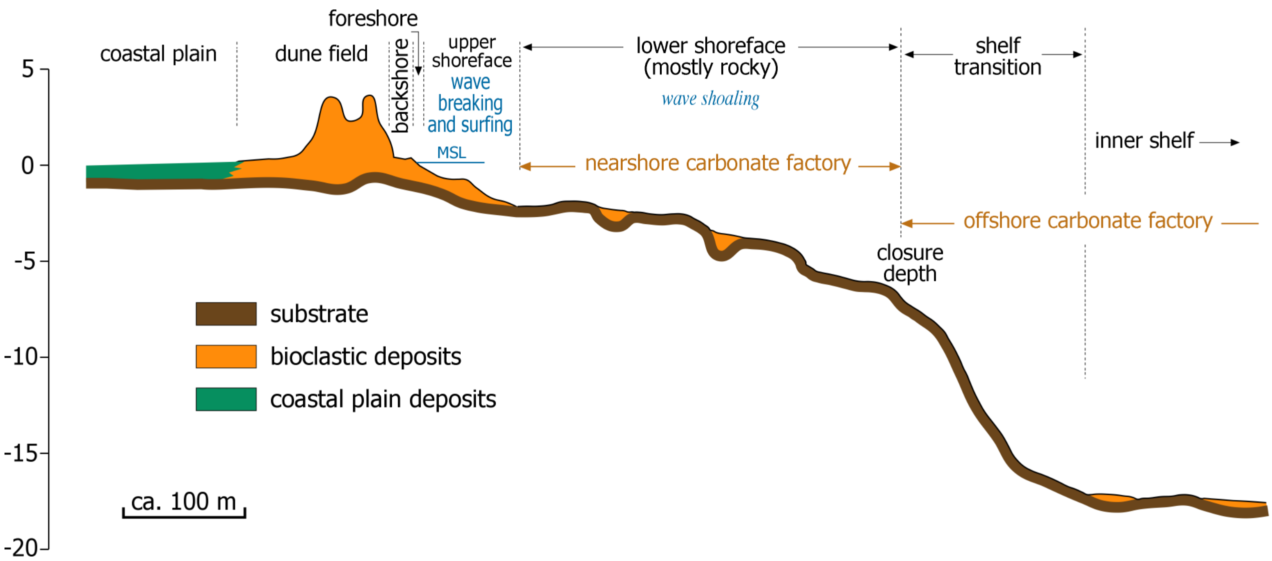

Fig. 25 - Idealized cross-shore profile showing the main morphodynamic zones composing the study coast.

7.2. Sediment types

Figure 26 summarizes the results of an analysis based on: (i) the exam of the grain-size frequency distributions and related statistical parameters of all sediment samples, (ii) environmental considerations emerging from all data used in this study, (iii) results deriving from a cluster analysis. This latter (using Euclidean distance with average linkage method) was performed individually on three pre-selected sets of our samples that were collected in the swash (= foreshore), upper shoreface, and lower-shoreface zones (Groups 1, 2, and 3 respectively: Fig. 26A). The weight percentages contained in the sediment fractions were used as variables. The three clusters (A, B, C: Fig. 26A) for each zone were defined based on the correlation dendrograms.

The lower shoreface zone includes very coarse sediments and their decrease in size from 1A to 1C groups is accompanied by granulometric curves that are disorganized (1A), partially organized (1B) or organized in quasi-lognormal distributions (1C) (Fig. 26A). None of the three sediment groups is distinctive of a single investigated coastal stretch and often all three are randomly present in the same stretch. Local hydraulic conditions and sediment from the supplies carbonate source underlie the granulometric differentiation. Basically, the three sediment groups represent the original debris from this source (group 1A), and sediment from this source that are partially (group 1B) or totally (group 1C) washed by waves.

Upper shoreface sediments decrease in size from 2A to 2C groups, are unimodal, and do not include the coarse-size fractions present in the adjacent lower shoreface carbonate-factory zone (Fig. 26A). These sediments are the product of the selective processes during their nearshore transport. The three sediment groups are ubiquitous in the study coast and differentiate mostly as a function of depth and wave exposure. Basically, upper shoreface sediments become finer with depth and increase slightly in size near the lower shoreface carbonate factory.

Sediments from swash zone are overall unimodal, well and moderately sorted, and decrease in size from 3A to 3C groups (Fig. 26A). The geographic distribution of these three sediment groups shows connections with the degree of coastal exposure (Fig. 26B). In fact the rectilinear beaches of the northern coast (Salina dei Monaci, Riva degli Angeli and Lido degli Angeli beaches), particularly exposed to prevalent southern winds and waves, contain coarse and mid-size sediments (group 3A, 3B). Coarse sediments (group 3A), in particular, are exclusively at Salina dei Monaci beach, and at the beach to the east of Torre Colimena headland. In contrast, in the protected embayments of the southern coast (Torre Lapillo Bay and Torre Chianca area) fine and mid-size sediments prevail (group 3B, 3C). Specifically, fine sediments (group 3C) are present in the most protected eastern zones of the Torre Lapillo Bay. In the Torre Chianca area the distributions of the sediment groups are also related to the exposure of the individual beaches. In fact different sediment types occur at Le Dune (3B) and Scala di Furno (3C) beaches, the second protected from the dominant southern seas.

7.3 Beach topography and coastline fragility

The fragility of the natural (foredune) and anthropic coastline elements depend on the physical opposition exerted by the facing backshore deposit, and on level and type of the incipient forces or occurrences such as storm-sea events, periods of negative sediment imbalance and rising in sea level. Within this framework, the backshore sediment development was used as an indicator of the potential fragility of the coastline in adverse conditions. The degree of backshore development was defined by the morphologic parameters (Ve, W, h) of the beach topographic profiles. Three classes of backshore development were adopted using the beach sediment volume (Ve) as primary discriminator to define class limits. These classes (A<10 m^3/m; B=18.5-10 m^3/m; C>18.5 m^3/m) were arbitrarily defined by dividing the Ve bin data population by 1/3 (e.g. class-limits of 10 and 18.5 m^3/m correspond to 33.3 and 66.6 percentiles). Appropriate W (beach width) and h (beach high) values were associated to the Ve class-limits by the equations of the two regression lines in figure 27A. Based on field observations, the following levels of potential fragility are assigned to these classes: class A, critical conditions with a needed of systematic interventions where this class is present with continuity along coast; class B, average critical conditions with presence of evolutionary risks; class C, low critical conditions.

The geographic distribution of the three classes is shown in figure 27 B,C. Class A is present at the margins of some beaches, in relationship of some local rocky outcrops, at the head of small coastal indentations (east to Punta Prosciutto and Torre Chianca headlands) and along the eastern zone of Torre Lapillo Bay where, from the date of our topographic survey (2010), beach recession dramatically occurred and is still active. The high fragility of class A zones is well evident in photos (Figs. 9, 12C and D, 16, 17, 19A, 20C). Contrary to class B that is discontinuously distributed, class C identifies the zones most exposed to the dominant seas, where constructive long-term wave-processes created robust backshore deposits that confer today a relatively low fragility to the coastline. Class C zones (some visible in the photos: Figs. 8B, 12B, 15C and D, 20A) correspond to the beaches, or to their most exposed portions, of Salina dei Monaci, Riva degli Angeli, Lido degli Angeli, Torre Lapillo and Le Dune.

7.4. Shoreline behaviour: a test at Torre Lapillo Beach

The degree of the instability of a shoreline in response to an eventual variation of the sediment budget is an important aspect that needed to be understood in the coastal management. This aspect was explored through the modelling of five cases of beach evolution virtualized by a coastal behaviour oriented model, the Random Shoreface Translation Model (RanSTM) (Cowell et al., 1995, 2006; Tortora et al., 2009). This model, based on a principle of sediment-mass conservation, predicts the morphological effects due to a shoreface profile that translates on pre-existent seafloor and terrestrial topography according to a defined input set of environmental parameters, invariant with the exception of the sediment input-output in our

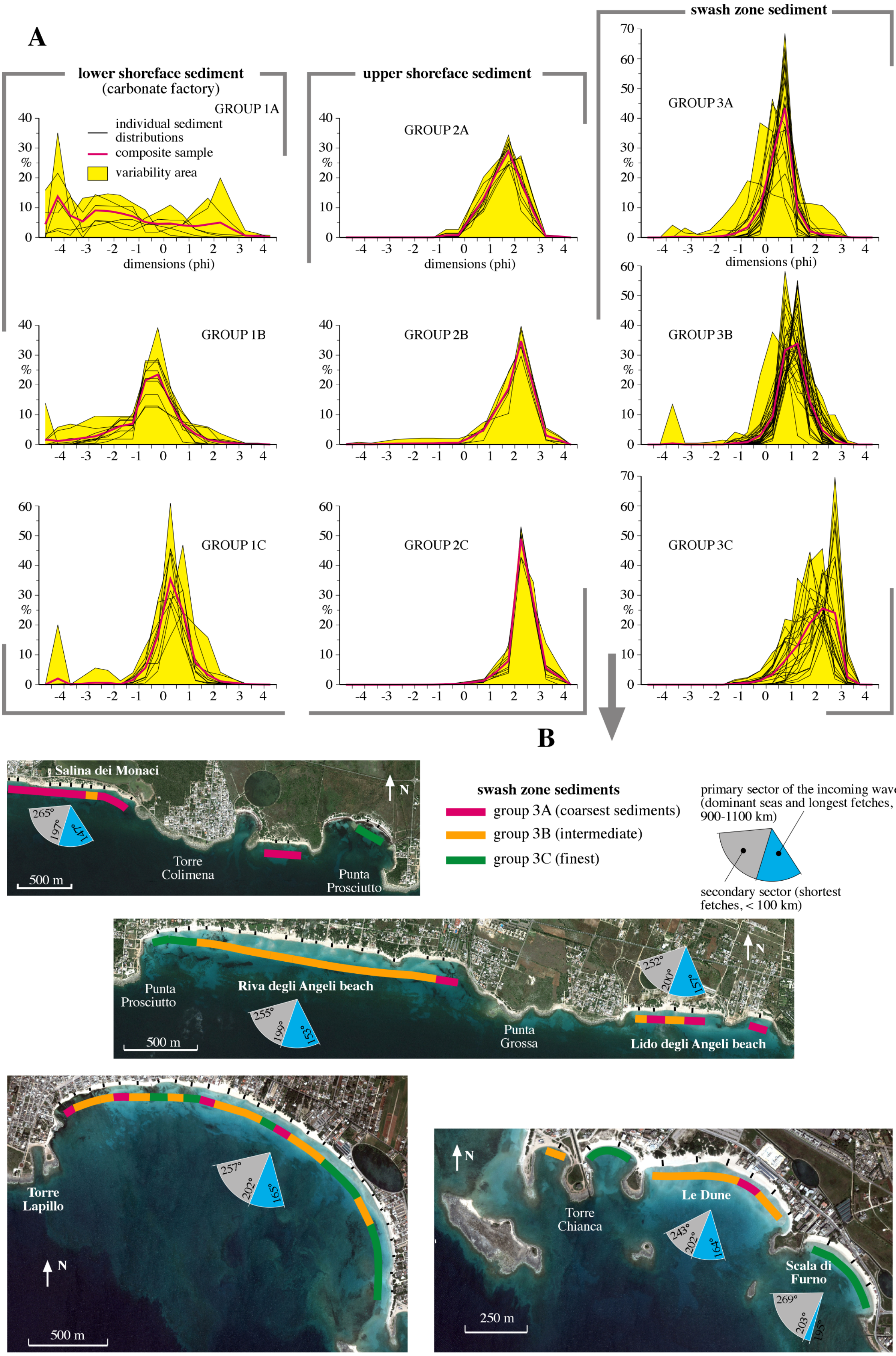

Fig. 26 - A) Sediment characteristics of the groups resulting from a cluster analysis carried out individually on lower shoreface, upper shoreface and swash-zone sediments. B) Geographic distribution of the groups related to the swash-zone sediments.

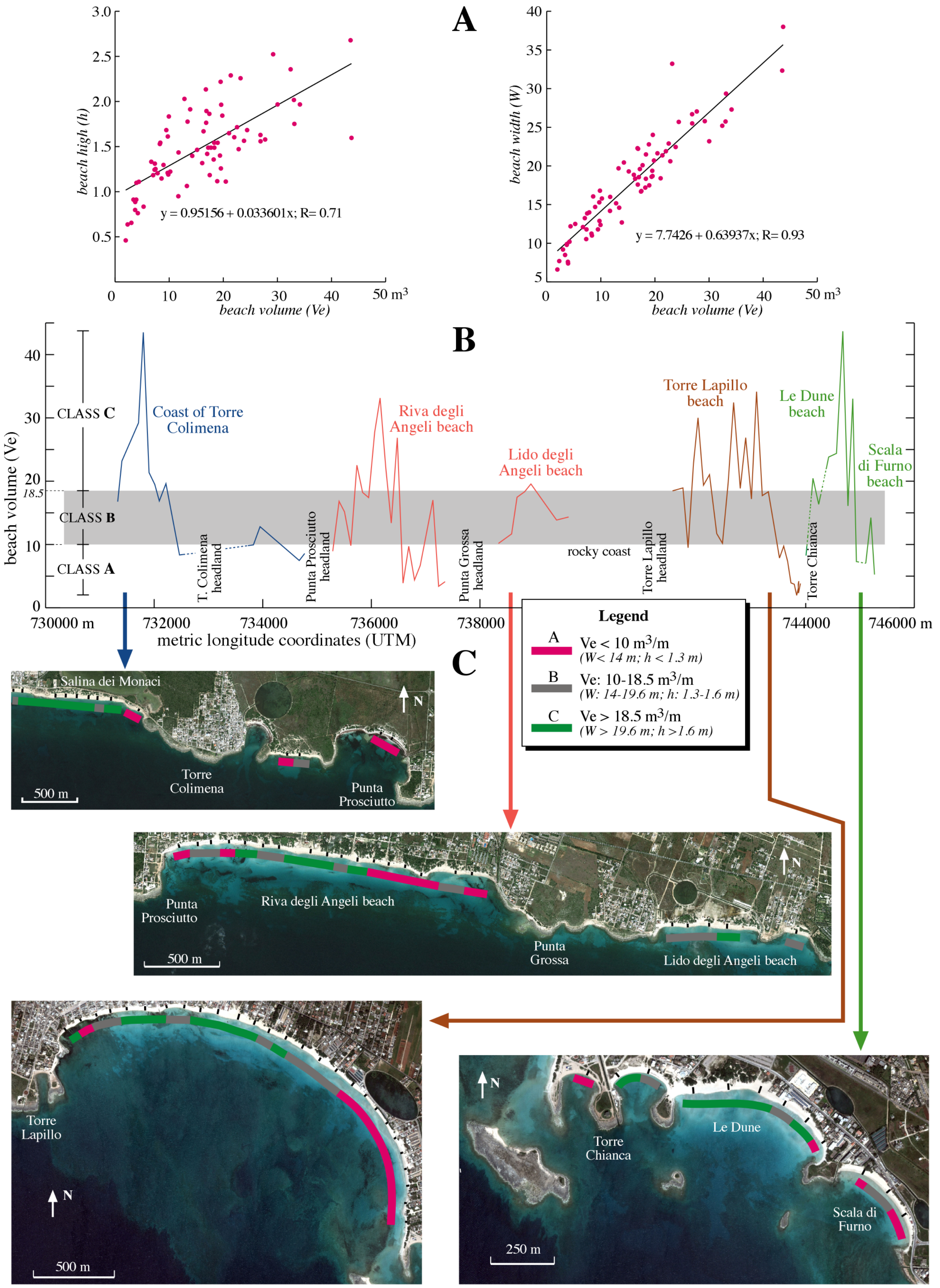

Fig. 27 - Development of the backshore deposit as an indicator of the coastline fragility. A) Correlations of the morphological parameters (Ve versus h; Ve versus W) related to the width (W), height (h) and volume (Ve) of the beach. B) Variation along the study coast of the beach volume parameter (Ve). C) Distribution in map of the three classes of backshore development connected to the degree of coastine fragility.

experiments.

The pre-existent profiles used for cases A, B, D (Fig. 28) represent an average of the topo-bathymetry in the middle of Torre Lapillo Bay (between TL60 and TL64 positions; Fig. 14), whereas pre-existent profiles for cases C and E were arbitrarily reconstructed with the intention to represent a generic beach with a healthy sediment volume. Each pre-existent profile includes the translating shoreface portion, defined as active profile. In the case A and B the active profile is externally delimited by the termination, very near to the coast, of littoral prism at Torre Lapillo beach. Each case has involved 1000 repetitions of the simulation process to evaluate the shoreline changes resulting from a wide range of sediment amounts in input or output (a repetition for an individual amount). In the graphics (Fig. 28 A-E), the active profiles (before translation) are marked in red and the resulting predicted profiles from 1000 translations appear as condensed within a blue band.

The first three simulations involve common amounts of negative sediment supplies applied (Fig. 28 A-C): to the present profile at Torre Lapillo bay (simulation in A); to this profile lowered (by 1.5 m) on the inner extremity to imitate an eventual further natural or anthropic dune dismantlement (in B); and to an idealized profile related to a well-developed littoral prism (in C). The graph in figure 28F couples the sediment amounts imposed as input with the resulting shoreline retreats. Data in this graph indicate that beach recession at Torre Lapillo bay (case A) accelerates in the event of further dune dismantlement (case B) and is about twice as much as that in the generic high-volume healthy beach (case C). The different responses of the three shorelines are related to the sand volume contained in the littoral prisms, and to the extent of the shoreface profiles from which the sediment subtraction per unit length (= inland translation) depends on. The high shoreline instability at Torre Lapillo bay (cases A, B) is an aspect that should also concern the other low-volume beaches of the study coast. Note in figure 28F the wide range of sediment amounts in output applied to the simulations. Looking to the recent past shoreline changes at Torre Lapillo beach, the results below the negative threshold of 150 m^3/m seems to be more pertinent for a projection at this beach in the future 50 years.

The two other simulations evolve by positive sediment supplies (Fig. 28 D,E). The shoreline at Torre Lapillo beach (Fig. 28G, case D) results very sensitive advancing four times more than the generic beach with a healthy sediment volume (case E). This extraordinary advance is particularly important for eventual nourishment actions at Torre Lapillo beach, where small amounts of sands (in our tests considered equal in dimension to the native sediments) should promote remarkable prograding effects. For example, fill-volumes of 100 m^3/m and 50 m^3/m determine 67 m and 38 m of shoreline advance (see depositional surfaces x and y in figure 28D), against 17 m and 9 m for the generic healthy beach (Fig. 28G). Low fill-volumes (on the order of 60-70 m^3/m) are recommended to avoid the burial of the carbonate factory habitat. A similar high nourishment performance could regard the other beaches of the study coast as well.

7.5. Sediment dynamics

For a generic embayment of the study coast, figure 29 shows a scheme of the sand dispersal governing the sediment budget. This latter depends (i) on sediment amounts supplied by local sources (lower shoreface carbonate factory and subordinately foredune and headland erosion), and (ii) on sediments, lost or gained, that cross in opposite directions the cross-shore (coastline and closure-depth line) and the lateral boundaries of the embayments. In this view, the scheme intends to represent our closed or semi-closed coastal systems in which sediment inputs from local sources and sediment outputs involve small amounts. The sediment dispersal is generalizable as follows: (1) prevalent cross-shore sediment transport; (2) weak longshore sediment transport confined within the embayments and often converging in the middle of them; (3) nearshore rip circulation with rips extending in some cases up to the lower shoreface and more rarely beyond its termination; (4) moderate or null lateral sediment interchanges with adjacent coastal sectors; (5) presumable offshore sand dispersion during storm events; (6) enhancement of sand diffusion by wind to the mainland due to human interferences on the coast. This last point seems to be crucial today considering the natural low sediment recharge from the main carbonate-factory source. In this regard, none of the investigated beaches shows evidence of progradation or health conditions. Contrary a metastable equilibrium (or a disequilibrium in some cases) prevails almost everywhere and the excess of sand lost inland should be the main cause.

In the study areas, the overall sediment dynamic is strongly conditioned by the morphology of the coast and by its orientation with respect to the potential directions of the incoming waves (between west and southeast directions). In this regard, the northern coast (north of Torre Lapillo headland), relatively straight and exposed to the south and south-easterly dominant seas, is more inclined than the southern coast to promote: lateral sediment interchanges with adjacent areas in lower shoreface zones, offshore sand diffusion, and cross-shore sediment transport. These dominant seas trigger a weak longshore transport of sand that, despite the reduced prominence of the headlands, is always confined within the individual embayments. Rip currents contribute to the bidirectional sediment transport between beach and shoreface zones.

By contrast, the two bays of the southern coast (Torre Lapillo and the area of Torre Chianca headland) are completely closed to the lateral sediment interchanges and, albeit less exposed to the sea, are affected by the entire potential sector of wave provenience (between west and southeast directions). In these bays also the seas with short fetches (from the west and south-west) have effects on the longshore sediment transport and cause beach erosion (eastern zone of Torre Lapillo beach, Scala di Furno beach). At the Torre Lapillo bay the net longshore sediment transport is from the margins to the middle of the beach (AA.VV., 1997) whereas, further south, is westward (Le Dune beach) and northward (Scala di Furno beach). In both the bays wave diffraction and refraction greatly influence the sediment

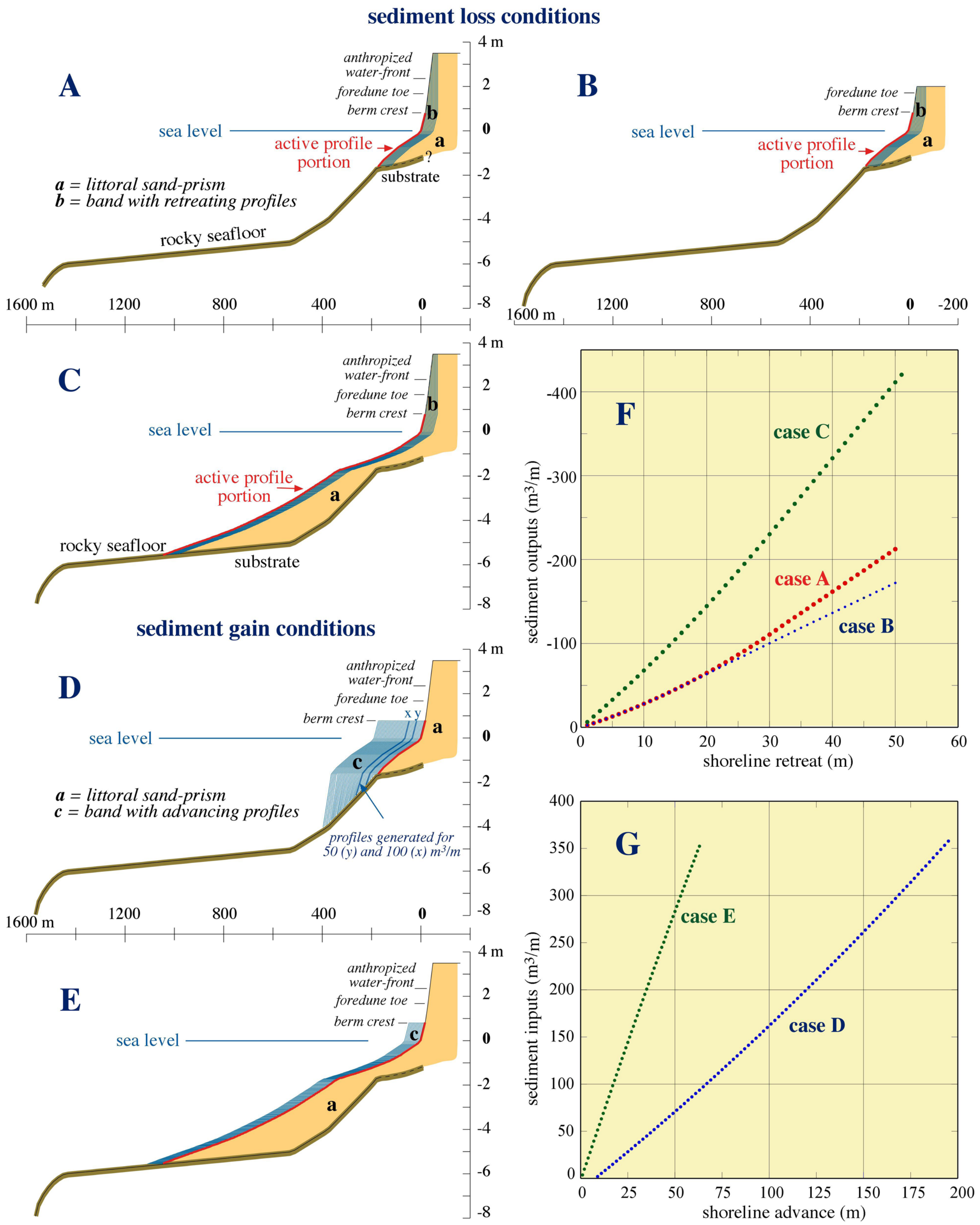

Fig. 28 - A-E) Cases of morpho-stratigraphic evolution by the Random Shoreface Translation Model in order to test the response of the shoreline to eventual changes in sediment input and output. F and G). Synthesis of the results by coupling sediment amounts imposed as input in the simulations and the obtained shoreline changes.

dispersal. In the southernmost bay a relevant seaward drainage of water occurs in stormy conditions and causes different types of energetic rips (and perhaps downwelling currents) that can bypass the shoreface.

Geologically, the investigated coastal systems are considered as unfed and in the fossil sedimentary successions they should be recognizable mainly by: sediment composition (mostly bioclastic), sediment size (from very

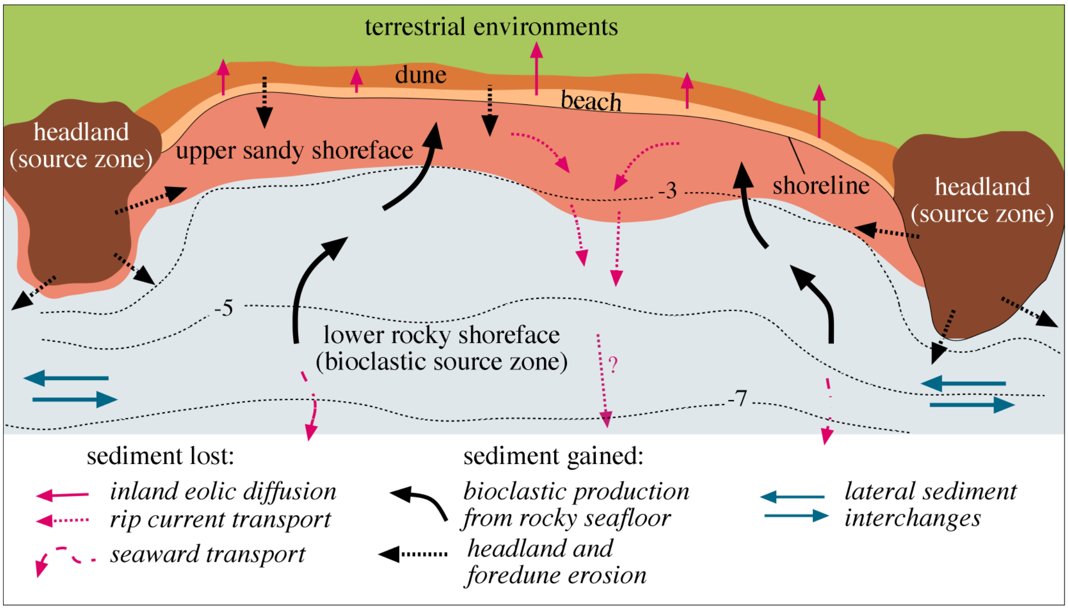

Fig. 29 - Scheme showing the sediment dispersal in a generic embayment of the study coast.

coarse to fine sands), strong lateral variability of the facies, and very low preservation potential resulting in deposits (when present) with metric thicknesses.

8. CONCLUSION

Short mainland pocket beaches and stretches of low rocky coast alternate in the microtidal coastal region examined. Here modern depositional environments have developed within embayments and narrow coastal indentations with significant control imposed by the underlying irregular substrate. This substrate, made up of Pleistocene or Mesozoic sedimentary deposits, crops out today subaerially on the rocky coastal stretches and ubiquitously in shallow water regions of rocky seafloors. Beach-dune deposits above the substrate are very thin (2-5 m) and the submerged beach ends in water depths of 2-3 m where a rocky seafloor interrupted by patchy bioclastic accumulations begins. A general lack of terrestrial sediment inputs and the presence of autochthonous bioclastic sedimentation from productive rocky seafloors are further distinctive characteristics of the examined coast.

Regional geology and tectonics control coastline orientation resulting of a northern area (west-east oriented) and a southern area (northwest-southeast oriented), the former being more exposed to the most intense and frequent seas from the S and SE. Excluding smaller segments of coastline extending for a few hundred meters, the beaches in the northern coastal area are straight, fully exposed to the southern seas, and made up mostly of coarse bioclastic sands. Particularly, Salina dei Monaci beach is a part of a well-preserved littoral system along which the wave-energy impact is high and the alongshore sediment transport occurs westward. Lido degli Angeli beach is typified by nearshore rhythmic morphologies associated with rip-current circulation. The same circulation occurs also at Riva degli Angeli, a retreating beach with a dune field degraded through anthropogenic effects. In contrast, beaches of the southern coastal area develop within bays, have bioclastic sediments ranging from coarse to fine sands, and show in general a higher degree of human interferences. This last aspect relates especially to Torre Lapillo bay whose original dune field has been replaced by an urbanized waterfront, and the shoreline is retreating. Further east, Le Dune and Scale di Furno beaches are typified by nearshore rip circulation and by their zeta-form shorelines established in response to the oblique direction of the incoming southern seas. Beaches are also present in the northern part of Porto Cesareo lagoon whereas tidal flat environments have developed in the more protected southern portion.

Along the study beaches hydraulic and sedimentary processes mainly depend on the shape and size of the embayment in which they are located. In a broad sense, all are pocket beaches (aside from the beaches within the lagoon of Porto Cesareo) since they form small individual coastal units closed or semi-closed alongshore to sediment interchanges, and locally supplied by biogenic sediment production and, to a lesser extent, by headland and foredune erosion. In such systems potential sediment losses involve: (i) offshore dispersion by waves (ii) potential sediment dispersion beyond the headland boundaries during storm events, (iii) physical abrasion and probably chemical dissolution of the bioclastic material, and (iv) inland sediment transport via wind processes. Under natural conditions, low amounts of sediment input and output seem to be one of the main peculiarities of these beaches.

Scattered signatures of marine and aeolian erosion are ubiquitous. Erosion scarps in foredune and beach deposits, loss of the dune vegetation cover as well recurrent damage to the urbanized coast and beach resorts are widely evident. Data on shoreline evolution are quite controversial: a general retreat trend is reported in AA.VV. (1997) whereas retreating, advancing and stable conditions alternate along the coast in Piano Regionale delle Coste (PRC, 2006). Both reports agree that Torre Lapillo bay contains the shore most affected by erosion. Our topographic survey indicates that all beaches have natural attributes conducive to flooding during marine storms and that these attributes are being currently exacerbated.

Coastline urbanization and tourist activities have developed exponentially during the last 50 years and most of the erosion signatures present today along the coast have clear connections with nearby human disturbance. Human impact varies from low to medium-high in degree and tends to increase with proximity to Porto Cesareo town. It is highest on those beaches whose original dune field was degraded in part (Lido degli Angeli, Riva degli Angeli) or almost in total (Torre Lapillo bay) by urbanization. Here the natural sediment interchanges between dune and beach cannot occur as in the past. Specifically, supply of dune sand to the beach is insufficient or absent and, in the reverse direction, sands eroded on the beach by wind are mostly dispersed into the urbanized area or further inland. A persistently enhanced exportation of sands beyond the inland boundary of the coastal system occurs today with consequent negative sediment imbalance. With the present invariant conditions a further degradation of these beaches is therefore not excluded. Similar phenomena, but to a lower degree, occur also in the non-urbanized coastal stretches where the impact of the recreational activities is however high. Here, access paths to the beach, dune degradation by wind erosion, and reduction of the dune-field vegetation cover also due to the trampling by bathers seem to be the main causes of the sediment loss to the mainland by aeolian diffusion.

Even if the future outlook depends on several unpredictable variables, an aspect to be considered carefully, especially in the vision of the global warming effects (IPCC, 2013), is the level of sensitivity of the analyzed beaches to any environmental change that might be aggravated by human impact. In this respect, concern mostly relates to effects due to the (i) reduced volumes and thickness of the beach-dune deposits, (ii) reduction of the natural functioning of the dune-field in releasing sands (iii) and weak supply from local sources with consequent no compensation of any eventual increase in sediment lost outside of the system. These three factors act in different ways but all together confer to these beaches a modest protection against storm-waves, marine flooding and periods of negative sediment imbalance. A further concern is the exacerbation of the shoreline retreat occurring in some beaches because of the acute sensitivity of low-volume coastal system to sediment loss. Our tests using the RanSTM model (Cowell et al., 2006) show that equal negative sediment imbalances cause shoreline retreat at Torre Lapillo bay that are almost two times greater compared to a hypothetical beach possessing a healthy sediment volume. Such tests also predict an acceleration of the shoreline retreat if further destruction or degradation of dune-fields occurs. Strong sensitivity to any type of environmental change and a weak defence against adverse conditions are aspects of these beaches to be considered carefully in their present and future management.

How to strengthen geomorphic resilience of the coast is the current problem. Dune stabilization and rehabilitation techniques for contrasting aeolian erosion and inland sand dispersal seem to be urgent requirements for most of the beaches. In case of the beach-dune nourishment choices, the use of nourishment material similar to the native sediments (bioclastic) is strongly recommended to maintain the extraordinary beauty of these beaches. Some proposals to recover sands from ephemeral accumulations near the shoreline should be rejected as unreasonable (the quarried zone is within the nourished area). A pilot nourishment intervention followed by post-fill monitoring seems to be the most prudent solution before applying this technique extensively. Our tests at Torre Lapillo bay, even if very preliminary regarding nourishment actions, indicate that small sand volumes can provide a significant accretion of the shoreline. Small sand nourishment volumes are also suggested to avoid the burial of the rocky seafloor by sediment, and the consequent loss of rich habitat. A final recommendation concerns the safety of swimmers. In fact the rip currents are quite common in the nearshore zone (see also Huntley et al., 1988; Hartmann, 2004), but they are never identified by signage and little known even by local residents. Cases of drowning are not so rare in study coast and information from local governance on beach hazards is desiderable.

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