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COASTAL PROTECTIONS IN TYRRHENIAN CALABRIA (ITALY): MORPHOLOGICAL AND SEDIMENTOLOGICAL FEEDBACK ON THE VULNERABLE AREA OF BELVEDERE MARITTIMO

ABSTRACT: BELLOTTI P., CAPUTO C., DAVOLI L., EVANGELISTA S. & PUGLIESE F., *Coastal protections in Tyrrhenian Calabria (Italy): morphological and sedimentological feedback on the vulnerable area of Belvedere Marittimo*. (IT ISSN 0391-9838, 2009).

This study provides with the results of a morphological and sedimentological study carried out along the coast of Belvedere Marittimo (Tyrrhenian Calabria, Southern Italy). From 1873 to 1955 the coast has been overall stable, even if local erosion occurred. As from the end of the '50s this area underwent erosion processes, which greatly have increased during the following years. In order to check the severe erosion of the shoreline, and to minimize the risks coming from it, several kinds of coastal engineering structures, like breakwaters, seawalls and groins, have been constructed during the time all along the considered coast.

The specific aim of the present study has been to single out the evolutionary trend of the shore, and to define the sedimentological characteristics of the bottom and the morphology of the seafloor up to –15 meters. Moreover, underwater observations of the structures allowed an evaluation of the present conditions. The analysis of the shoreline changes occurred between 1873 and 1955, showed an overall beach stability. Later on the erosion processes, already active at the end of the '50s, enlarged becoming particularly strong for some areas during the period between 1955-2002. Depth surveys by echosounder and local direct observations allowed an investigation of the morphological features of the submarine coastal area. The seafloor up to –15 meters shows a regular pattern, except for local articulations near Capo Tirone. Moreover, for a sector of the northern part of the studied area, where a larger number of groins, seawalls and breakwaters were present, the comparison between depth data prior to the engineering structures and data following it, has been carried out. The result allowed a singling out of accumulations and erosion areas, as well as the marked influence that the structures have on the local sedimentary dynamics.

The sedimentological analysis of 108 bottom samples taken at –15, –10, –5, –2 and 0 meters, and the cluster analysis of phi percentage, showed two main clusters: the first includes samples of fine and medium-fine sand, medium sorted with symmetric grain size distribution; conversely, the second includes coarse sand, usually pebbly, few or poorly sorted, with negative skewness. Morphological changes that occurred on the seafloor and spatial sediment distribution in the area defended by engineering structures show that sediments lying behind these structures tend to flow away from the seashore, mainly because of frequent western waves.

KEY WORDS: Morphology, Sedimentology, Coastal engineering structures, Calabria, Italy.

RIASSUNTO: BELLOTTI P., CAPUTO C., DAVOLI L., EVANGELISTA S. & PUGLIESE F., *Protezione costiera della Calabria tirrenica, Italia: variazioni morfologiche e sedimentologiche indotte nell'area vulnerabile di Belvedere Marittimo*. (IT ISSN 0391-9838, 2009).

Questo lavoro presenta i risultati di uno studio morfologico e sedimentologico effettuato lungo un tratto di litorale della Calabria tirrenica, situato nel territorio del Comune di Belvedere Marittimo. Il litorale è stato complessivamente stabile dal 1873 al 1955, anche se localmente interessato da lievi fenomeni erosivi che a partire dalla fine degli anni '50, si sono diffusi e fortemente intensificati. Per tentare di arginare il marcato arretramento della linea di riva e mitigare i rischi da esso derivante, sono stati necessari vari e diffusi interventi di difesa. Pertanto, il litorale in esame risulta attualmente caratterizzato, per gran parte della sua estensione, dalla presenza di numerose opere di difesa di varia tipologia realizzate in periodi diversi.

L'obiettivo del presente studio è stato quello di determinare la dinamica della spiaggia emersa e di definire le caratteristiche morfologiche e sedimentologiche dei fondali fino a una profondità di 15 metri. Osservazioni dirette effettuate sui fondali hanno consentito anche di valutare lo stato delle opere di difesa. Lo studio della variazione della linea di riva ha evidenziato fra il 1873 ed 1955 una complessiva stabilità degli arenili; successivamente i fenomeni di arretramento, già attivi verso la fine di questo periodo, divengono più diffusi e in alcuni tratti particolarmente accentuati nell'intervallo di tempo compreso fra il 1955 e il 2002.

L'indagine sulle caratteristiche morfologiche sottomarine dell'area costiera, effettuata attraverso campagne batimetriche e osservazioni dirette, ha evidenziato un andamento abbastanza regolare delle isobate con la eccezione di locali articolazioni in prossimità di Capo Tirone. Inoltre, dal confronto fra i dati di profondità rilevati precedentemente alla realizzazio-

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ne delle opere, sono state identificate le aree in accumulo e quelle in erosione ed è emersa la marcata influenza delle opere sulla dinamica locale. Lo studio delle caratteristiche sedimentologiche, effettuato attraverso l'analisi di 108 campioni prelevati alle isobate –15, –10, –5 e –2 metri e sulla battigia, e la loro elaborazione statistica hanno consentito di raggruppare i campioni in due supergruppi principali; il primo corrisponde a campioni di sabbia fine e medio-fine, moderatamente classata e a distribuzione simmetrica. Il secondo, invece, rappresenta sabbie grossolane, generalmente ghiaiose, poco o moderatamente classate e con asimmetria negativa. Inoltre, a conferma di quanto dedotto dalle variazioni intervenute sui fondali, la distribuzione areale dei sedimenti nella zona protetta dalle opere, evidenzia un parziale movimento verso il largo dei materiali presenti nella zona retrostante le opere stesse, prevalentemente ad opera dei mari regnanti occidentali.

TERMINI CHIAVE: Morfologia, Sedimentologia, Opere di difesa costiera, Calabria.

INTRODUCTION

The erosion of the today's coasts intensely occurs in many countries with man made coastal structures (Chapman & *alii*, 1982; Frihy, 1988; Hequette & Barnes, 1990; Nordstrom, 2000). In Italy this process concerns 42% of the total of beaches (Caputo & *alii*, 1989; G.N.R.A.C., 2006); in particular, Calabria is the Italian region more in crisis, with 43% of its beaches in retreat (D'Alessandro & *alii*, 2002). Studies conducted on eroding coastlines subjected to defensive interventions on a stretch of the Tyrrhenian Calabria coastline are taken into consideration. This particular strand has included erosive phases since the beginning of the XX century (Bossolasco, 1939), wherein defensive interventions have been repeatedly conducted with different methodologies, more than anywhere else in Italy.

The coastal stretch, in the Belvedere Marittimo (Cosenza) municipality, is part of the Tyrrhenian boundary of the Catena Costiera, north of the tectonic line of Sangineto. The Catena Costiera is formed by a series of complex tectonic units (Dietrich & Scandone, 1972) that spans between the Triassic and the Paleogene. Along the considered Tyrrhenian slope, a Tortonian-Messinian sedimentary succession rests, with transgressive contact, on some of the aforementioned units (Perrone & *alii*, 1973). This succession, deformed by a double system of folds with axes NW-SE and NE-SW and beginning its development in the Messinian (Cesarano & Turco, 2002), is constituted by intervals with different lithologies. The calcarenitic interval of this succession crops out, along the littoral in observation, at Capo Tirone and at Punta S. Litterata. In the other zones the connection with the littoral takes place through Plio-Quaternary sediments formed by the reworking of the deposits from the same Miocene succession.

The analyzed coastline extends for approximately 4 km between the stream mouths of Vallecupo, in the north, and Soleo, in the south (fig. 1). On the whole, the Calabrian beaches, according to surveys done on the rest of the Italian littorals, entered into erosion at the end of the '50s; a referable process and to an extent caused by man's influence. The sector under investigation, instead, shows local erosion in the period between 1913-1938 (Bossolasco, 1939). Following this, starting from the end of the '50s, nearly all possible defensive structural typologies have been put into effect; not only for the protection of the

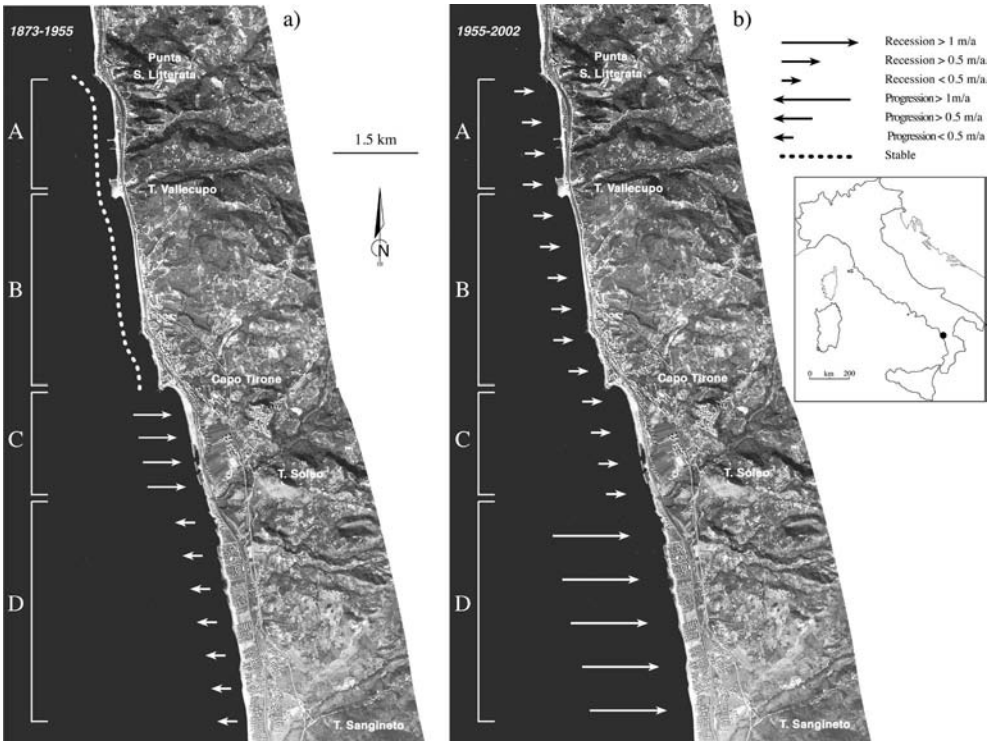

FIG. 1 - Coastal area location and evolutionary trend of the coast between Punta S. Litterata and the mouth of the Torrente Sangineto, from 1873 to 1955(a) and from 1955 to 2002 (b).

sandy shores, but above all for the defense of the infrastructures built very close to the beaches and in particular, the railway and the coastal roads. Another unquestioning peculiarity of the coastal stretch in investigation has been the nourishment by deposits of heterometric quarry material, which for the Calabrian region is a practice still little used. This littoral represents one of the coastlines where the erosive crisis has turned out to be amongst the most evidently noticed in the Calabrian territory, and though presenting a modest longitudinal development. It highlights all the characteristics of a sample area where it has been possible to: analyze and monitor the functionality of different protective interventions that have been carried out over the past 40 years; evaluate the more significant morphological variations that have intervened since the early '50s, the period preceding the defensive interventions; and, identify the sedimentary dynamics.

METHODS

The evolution of the emerged beach, in particular the displacement of the shoreline, has been reconstructed by comparing topographic maps produced by IGMI (Istituto Geografico Militare Italiano) over the last 130 years. For the older period (1873-1955), the scarcity of reference points, didn't allow a rigorous comparison between the diverse shorelines; thus, only a general delineation was possible. For the more recent period (1955-1995) a quantitative assessment of the areal variations of the beach has been made, utilizing different georeferenced aerial photographs (flights from 1978, 1984, and 1995) that were formed to the scale of 1:25000 and superimposed by the interpolation of at least three control points; the most recent shoreline was surveyed in the spring of 2002 by using GPS.

The morphology of the seafloor has been reconstructed on the basis of the depth data recorded using echosounder, and GPS. The echosounding of the seafloor, between the Soleo and the Vallecupo streams to a depth of –15 meters, were made in May and September 2002; echosounding courses, transverse and almost parallel to the shoreline, were made for a length of about 30 km (fig. 5a).

On the basis of the detected data, integrated with the obtained depths from the nautical chart of the IIMI (Istituto Idrografico della Marina Italiana; scale 1:100000) for depths more than 15 meters, as well as topographical data, the seafloor of the entire Belvedere Marittimo coast has been determined by kriging method (Davies, 1986).

For an evaluation of the state of the coastal engineering structures along the coastal stretch north of Capo Tirone, various dives were made, in which direct observations of the condition of the protective structures. A series of measurements with subaqueous instruments were also completed. In particular, the depth measurements were made with two different digital depth finders, and where possible, using a metric tape with a plumb line.

Sedimentological characteristics were derived from grain size analyses of 108 samples collected with a grab at isobaths –15, –10, –5 and –2 meters, and manually from the shoreline. Locally, because of seafloor vegetation or the presence of rocks, the collection of samples was impossible. The analysis was made by means of dry-sieving with dimensional classes of phi/2 (Folk &Ward, 1957) and the size data were processed with the «Clustan Graphics 5» program (Wishart, 2000). In order to identify some groups of grain size resemblance, «the euclidean distances» as proximity measure, and «average linkage» as a clustering method were utilized.

GEOGRAPHICAL AND PHYSICAL CHARACTERISTICS OF THE COASTAL BELT

The study coast is trending nearly N-S, so that it is open to waves incoming from western quarters. A general outline of the wave-climate concerning this coast was made by taking into account data recorded by the wavemeter of Cetraro, operating since 1999 (ISPRA-Istituto Superiore per la Protezione e la Ricerca Ambientale). Data processing and evaluation of closure depth were kindly provided by Prof. Aminti (Università di Firenze; personal communication). This elaboration points out that, during the 1999-2001 period, waves were incoming almost always from 240° to 300°, so that the coast was, and still is, exposed to these waves. Moreover the depth of closure is evaluated at 6.39 meters.

The geomorphological outlines, and in particular the variations of the shoreline during the last 130 years, refer to the coastal tract comprised between Punta S. Litterata (Diamante) and the Torrente Sangineto. The shoreline has the characters of a N-S trending beach interrupted by the Punta S. Litterata and Capo Tirone juts.

The coastal mountainsides to the north of Capo Tirone, formed of marly-clayey lithotypes, are incised by sizeable terraces; those located at a height of 30 and 50 m are wider and better preserved with surfaces dissected by deep fluvial cuts, and they are influenced by widespread solifluction processes. The shores located at the bottom of these slopes record modest sizes, with a maximum extension of 20 m. To the south of Capo Tirone the coastal plain of Belvedere Marittimo opens up and stretches up to the mouth of the Torrente Sangineto. The coastal belt is characterized by the presence, just south of Capo Tirone, of a terraced surface («i Monti») located between 50 and 60 m (fig. 9); the slope delimitating the terrace is deeply and extensively incised by a series of gullies; the material produced by the progressive retreat of the cliff, masks the terrace below which is found at 20 m. To the south of this terrace the coastal plain slightly extends because of the more evident supplies of the Soleo and Sangineto streams; the shores record variable width comprised between 15 and 50 m. In particular, the Torrente Soleo dismembers and dissects the «i Monti» terrace, and deposits a sizeable alluvial fan just before flowing into the sea. The Torrente Sangineto is the only watercourse of the studied area with a fair catchment basin and an alluvial plain 200-300 m wide.

Therefore, the coastal area object of this study is on the whole characterized by terraces cut by small streams that

feed the beach. Terraces didn't show morphological modifications during the last decades.

The beaches bordering the slopes, on the contrary, show an evolution, which implies that such important modifications occurred during the last century; through the cartographical and photogrammetric documents, a description of the variations of the shoreline over time was reached. In particular, the segment comprised between Punta S. Litterata and the Torrente Sangineto mouth recorded a general stability between 1873 and 1955 (fig. 1a). This littoral stretch, as well as the majority of the Calabrian coast, between the middle of the XVIII century and the beginning of the XX century, wasn't very populated; the main town was located on a rise and the residents were mostly farmers, whereas a little group of fishermen was found along the nearby littoral (Gambi, 1965). Moreover, because of the construction of the coast road in 1810 and the railway in 1890, the coast of Belvedere Marittimo registered an increase of urbanization. At the beginning of the XX century, in front of the railway station (just south of Capo Tirone) the shore had a maximum size of 150 m, whereas to the north of Capo Tirone the beach was narrower, around 75-50 m (D'Alessandro & *alii*, 1987). Between 1925 and 1940 the coastal road connecting Sapri to Reggio Calabria was terminated; consequently, the urbanization of the coast and the first erosional processes began. The railway connections were developed, and thereafter a real boom arose in the construction of tourist facilities on the coastal belt; and as a consequence, the coastal erosion phenomenon. Initially the erosional crisis affected the coast between Capo Tirone and the Torrente Soleo (tract C - fig. 1a) where an approximate 1 m coastal retreat was registered on average every year. In particular, near the old Belvedere Marittimo town, the beach at some spots retreated 100 m (Bossolasco, 1939).

A more widespread erosional process characterized the period between 1955 and 2002 (D'Alessandro & *alii*, 2002): stretches already in crisis during the previous period kept on registering coastline retreating, but other areas also showed an evident reduction of the shore surface (fig. 1b). The stretch comprised between Punta S. Litterata and the Torrente Vallecupo includes an exceptionally marked retreating coastline, especially at the stream outlets, causing linear reductions of the beach for more than 50 m. Between the Torrente Vallecupo and Capo Tirone, wherein an overall stability was registered between 1873 and 1955, the shoreline has shown (over the last 50 years) an average retreat of 0.5 m/a. Along an area close to the north of Capo Tirone, where the maximum retreat occurred, the beach disappeared and the road around the promontory was destroyed by the waves. Even the stretch comprised between Capo Tirone and the Torrente Soleo registered erosion. This stretch, after a critical phase occurred between 1873 and 1955, was of a considerable size during the 80's; in the last few years a renewal of the retreating processes has been observed, of which the most significant one is located near the Torrente Soleo outlet (C stretch).

The stretch between the Soleo and the Sangineto streams, which is the southernmost part of the examined coastline (D stretch), has registered, over the last 50 years, a linear retreat (on average more than 1.5 m/a); along the southernmost part of this tract, the beach has noticeably retreated with maximum linear values of about 50 m (fig. 1b). It is remarkable that along this stretch of coastline there are numerous habitations and tourist structures, that at the present time, are by now close to the shoreline, and therefore, in danger. On the whole, the examined stretch recorded, after a long period of overall stability between 1873 and 1955, a strong erosional crisis in the time period comprised between 1955 and 1978; afterward, during the 80's, it followed a progradational process that, only partially, restored the extent of the shore. In the last few years, a renewal of the retreating processes has been taking place. These have almost cancelled the progradational processes recorded before.

The serious and widespread erosional processes that have affected the examined littoral over the last 40-50 years have often caused highly dangerous conditions for the infrastructures and the peoples activities located in areas close to the beach. Damages and dangerous situations have occurred during sea storms to many facilities such as buildings, roads, tourist structures and seaside resorts, which all exist in great quantities close to the beach (fig. 1).

In order to try to restrain the pronounced coastal retreating and minimize the dangers connected to it, numerous coastal engineering structures have been made by the operators interested in the problem (Italian Railways and Maritime Coastal Engineering Office). Therefore, the examined littoral is at the present time mostly characterized by the presence of many different protective structures.

One of the first coastal engineering structures, made around the end of the 50's, consisted of the construction of three parallel breakwaters for the defense of a coastal stretch (sector C), located a little to the south of Capo Tirone (fig. 2). Afterwards, these protections needed restoration: at first, necessary works were carried out in 1967 when the breakwaters were totally reconstructed as a consequence to the heavy damages caused by sea storms.

These initial coastal protections marked the beginning of a series of intervention along most of the examined coastal belt, especially during the 70's and 80's; in fact, this is the period in which the erosion along the littoral of Belvedere Marittimo was more intense. The priority in the construction of the coastal defense structures has been the urgency of protecting facilities directly under the influence of sea storms, following a logic sequence of urgent measures; as a consequence, the coastal engineering structures most of the time only solved local problems, while causing negative effects on contiguous areas. In reality, the littoral stretch extending from Punta S. Litterata to around 1 km to the north of Capo Tirone has been the object of a systematic coastal protection project of the Italian Railways. This was part of a bigger coastal protection project set up at the beginning of the 80's, aimed at the protection of the railway network located along the Calabrian coastal areas more affected by marine erosion. In many occasions sea storms locally caused considerable damages to the railway and, sometimes, the critical conditions made the railway

FIG. 2 - Building of the first engineering structures facing the littoral of Belvedere Marittimo. End of the '50s.

connection between Sicily and the north along the Tyrrhenian side temporarily unusable (Guiducci & *alii*, 1993). The types of intervention were chosen on the basis of a study carried out using auxiliary research on site and mathematical models (Piro, 1987).

In the Belvedere Marittimo area the coastal tract involved in the protection stretches for a little more than 2 km, from around 500 m to the north of the Torrente Vallecupo outlet to about 1 km to the north of Capo Tirone (Sectors A and B); along this tract, in which the railway is located in the proximity of the shore, between the beginning of 1985 and July of 1986 a protection structure was built. This consisted of 14 detached breakwaters and 3 groins. Concerning these three structures, two are situated at the extremities of the considered tract, whereas the third one is located at the Vallecupo outlet. Four breakwaters have been built between the northernmost groin and the intermediate one, whereas the remaining ten have been positioned on the southernmost tract. All the structures were built using rocks of different size (from 50 to 1000 kg) and they were positioned on a layer of *tout venant* poured on the seafloor.

During the setting up of the northernmost groin, 110 m long, serious damages occurred to the housing facilities because of sea storms. Thus, it was considered appropriate to extend the protecting structures to the northernmost portion of sector A, until Punta S. Litterata. Therefore, the Maritime Coastal Engineering Office, in collaboration with the Italian Railways, built four more parallel breakwaters made of rocks. Still along this littoral tract, further coastal engineering structures were built in urgency following the serious damages occurred to the residences at the end of the 80's because of sea storms. These interventions consisted of the repairing, reconstruction and rebuilding (with technical corrections) of a 330 m long riprap. To note, in particular, in the carrying out of this intervention, but also in the setting up of other protecting structures, a geotextile made of a warp of polyethylene monofilaments and of a weft of polypropylene multifilaments was put at the base. Furthermore, a sand nourishment (approximately 14000 m^3) with grain size comprised between 1.5 and 8.5 mm was deposited in the area just in front of the structure.

To the south of the littoral tract related to the intervention of the Italian Railways (southern part of sector B) some coastal protections are found. Here, during the 80's, some detached breakwaters were built in the attempt to stem the evident erosional process that, in addition to causing the disappearance of the ample beach, destroyed the littoral road and damaged the town. Further protections built afterwards, some coastal adherent engineering structures in the area just to the north of Capo Tirone, do not seem to have diminished erosion along this coastal tract (fig. 3).

Even in the southernmost sector (D sector), where numerous housing facilities are near the shore, the conditions of the coast are highly degraded. The maximum retreating rate (50 m) of the entire coast examined in this paper was recorded here. The pronounced erosional process caused a shift of the shoreline in many points close to the buildings during the 80's and 90's. This situation required several interventions for the protection of the facilities under the destructive action of the sea. The first protecting structures were built around the end of the 70's, but it was during the course of the 80's and 90's that numerous detached breakwaters were built in the continuous rim of coastal stretch; moreover rubble has been placed locally for protecting buildings. Even in this case the sequence of the

a

b

FIG. 3 - The coast close to the north of Capo Tirone during the '60s (a) and in 2002 (b).

interventions, that consisted of the repairing and reinforcement of old structures and the placement of new protections, was determined on the basis of the urgency of protecting the buildings threatened by the sea storms. These coastal engineering structures mostly consist of artificial concrete blocks with variable dimensions, generally between 1 and 8 m^3.

Recently, within a project aimed at the nourishment drawn up by the Province of Cosenza, in collaboration with the Maritime Coastal Engineering Office of Reggio Calabria, two more experimental interventions were executed at Belvedere Marittimo (Papalino, 2008). Despite this intervention, the coast to the north of Capo Tirone in May of 2008 was again showing erosion (fig. 4).

SEAFLOOR AND RECENT STATE OF THE COASTAL ENGINEERING STRUCTURES

The seafloor reconstruction carried out through the surveyed data is shown by the course of the bathymetries down to 20 m water depth in fig. 5b.

FIG. 4 - The beach to the north of Capo Tirone in May 2008.

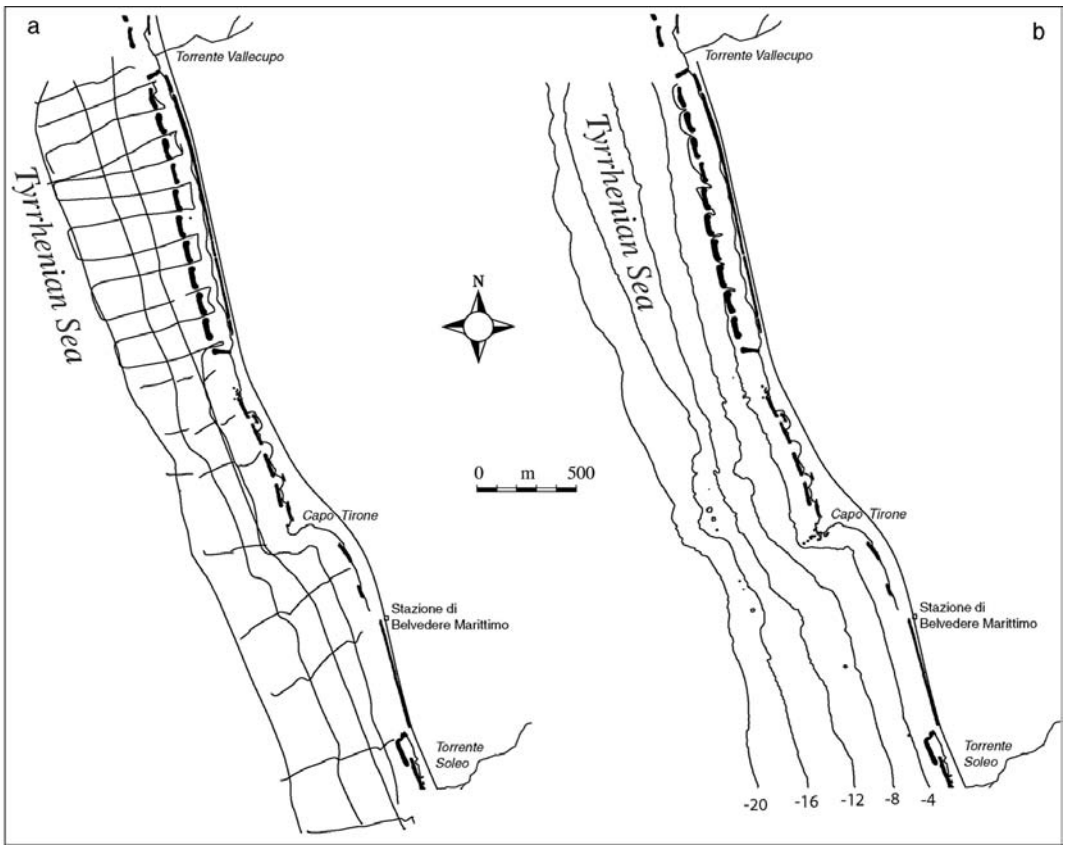

FIG. 5 - Echosounder tracks (a) and bathymetry (b) between the Vallecupo and Soleo river mouths.

The seafloor is characterized by a quite regular morphology, except for local articulations in the zone near Capo Tirone; moreover, in the zone in front of the structures and for the lower depths, because of the jagged pattern of the isobaths, the evident influence of the coastal engineering structures along the entire coastal stretch extending between the Torrente Vallecupo and Capo Tirone can be observed. The variations of the seafloor over time have been deduced by comparing depth data previous to the implementation of most of the coastal engineering structures, taken from the Maritime Coastal Engineering Office of Reggio Calabria, with those surveyed in this study. Considering the inevitable approximations due to diverse depth survey methods, two depth grids have been estabilished, and, on the basis of the compared differences, it has been possible to see morphological changes of the seafloor that occurred between 1980 and 2002.

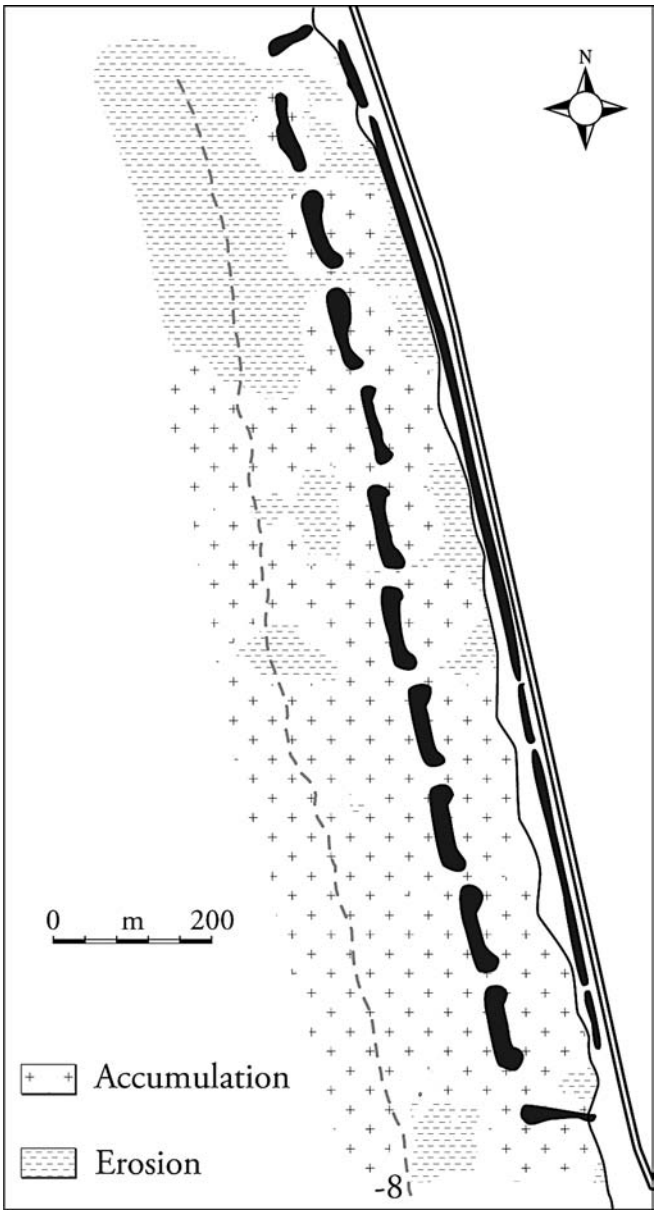

FIG. 6 - Seafloor erosion and accumulation at the railway protecting structures.

This analysis was carried out on the coastal stretch corresponding to the defensive interventions on the railway line to the north of Capo Tirone. From this analysis (fig. 6) a widespread erosion phenomenon of the seafloor in the more northern part of the area has been noticed; corresponding especially to the sea bottom seawards of the first three damaged detached structures. This erosion could not be quantified because compared data were not homogeneous. The negative variation of the seafloor pertains also to the zone behind the breakwaters, due to reduced efficiency of damaged breakwaters during sea storms. More to the south a prevalence of build up phenomena is noticed, with the exception of the zone corresponding to the groin to the south, where there are newly evident erosion phenomena on the seafloor. These modifications are connected to prevalent sea waves coming from west.

Corresponding to the parallel breakwaters, situated to the north of Capo Tirone, direct observations and depth measurements have been carried out on both the external and internal sides. On the basis of these observations it was noticed that the two northernmost breakwaters were seriously damaged by the wave action (fig. 7) and the material on the top was displaced to their base. Moreover, a partial spill of inert materials was observed in correspondence with the openings of the structures (fig. 8); this is also confirmed by the grain size analysis of the sediments at the seafloor. This phenomenon mostly occurs during conditions of high energy wave motion. In fact, the wave motion, over the breakwaters, causes currents (in the openings between the structures) that are responsible for the transport of sediments towards the open sea. Furthermore, in the majority of the structures, the central area is characterized, on the open seaside, by a shallower depth with respect to the two extremities.

SEDIMENTOLOGICAL CHARACTERISTICS

On the basis of the dendrogram obtained from the cluster analysis, six similarity clusters have been defined, whereas five samples cannot be grouped. The six clusters are tied together at a superior hierarchical level in two principal supergroups: the first one contains the majority of the samples and is comprised of groups A, B and C; while groups D, E and F comprise the other supergroup. The grain size characteristics of the groups and their planimetrical distribution are reported in fig. 9.

SUPERGROUP 1

Group A – is formed by 13 samples of very fine sand, moderately sorted with symmetrical distribution, and is principally spread out along the –15 m isobath in the areas to the north and to the south of Capo Tirone.

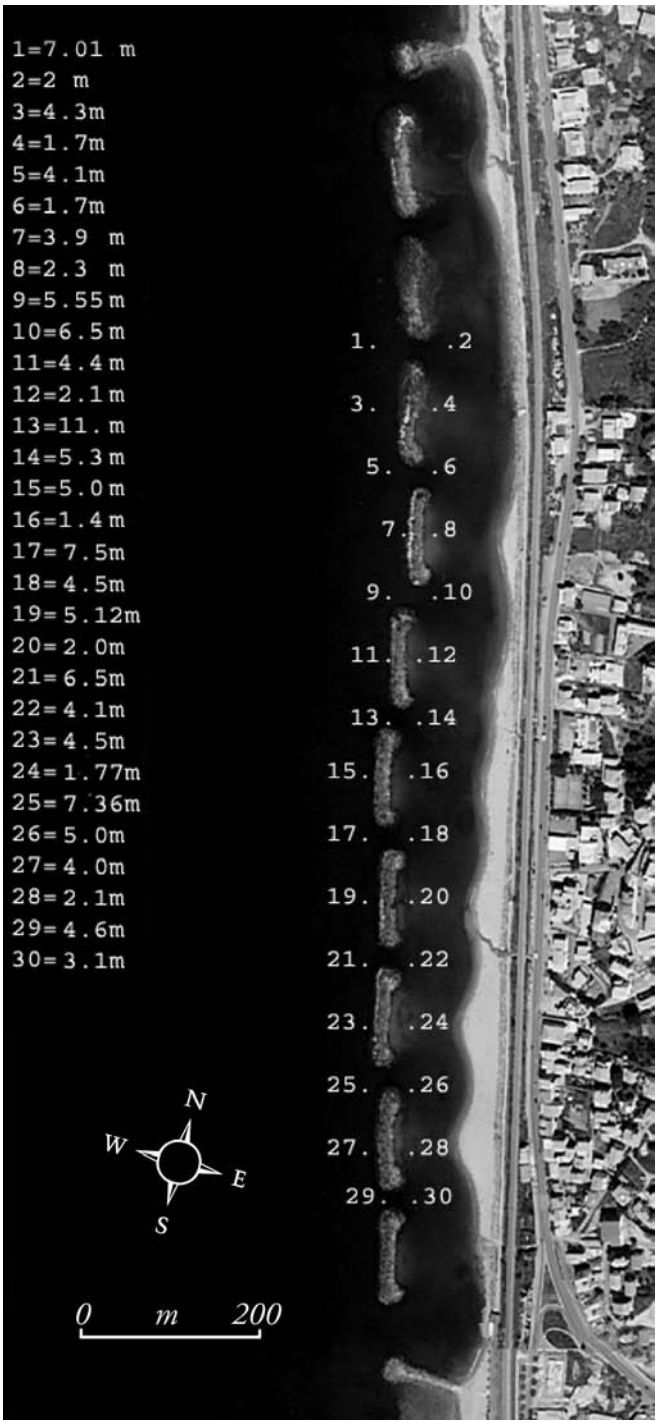

FIG. 7 - Depths measured close to breakwaters.

Group B – comprises 26 samples of medium-fine sand, moderately sorted and with a symmetrical distribution. It is present everywhere along the –10 m isobath; in the vicinity of Capo Tirone it is spread out even to –15 m, whereas along the southern coastal stretch, it comes back to the proximity of the shoreline. In the Belvedere Marittimo area, wherein the detached structures were developed, samples of this group are present on the outside border of the same protections.

Group C – consists of 26 samples of medium sands moderately sorted and with a symmetrical distribution. It is prevalently present in: the inside of the area protected by the detached structures; in the adjacent areas of their external border; and, in the tracts not defended by the detached structures. It is mostly found around –5 meters.

Samples outside the group – this group deals with two samples withdrawn: one on the shoreline in the protected area a little to the north of Capo Tirone; and the other on the –2 m isobath close to the external border of the first breakwaters south of the cape.

SUPERGROUP 2

Group D – is comprised of 14 samples of very gravelly coarse sands, poorly sorted, and with a negative skewness. It is present at the shoreline and in the neighboring sea bottom to the north of Capo Tirone, and in particular, in the areas protected by detached structures.

Group E – is composed of 21 samples of slightly gravelly coarse sand, slightly sorted with a negative skewness. It's present to the north of Capo Tirone: in the inside of the protections, and in some openings between the breakwaters and external sea beds close to the breakwaters. To the south of Capo Tirone the sediments of this group are almost exclusively present close to the shoreline.

Group F – represents only three samples of the shoreline, which are not contiguous to each other, and is comprised of coarse sands, moderately sorted with a negative skewness. This group therefore, is not represented in the design inasmuch as it does not have a spatial distribution.

Samples outside the group – this group deals with two samples of the shoreline: one of them taken from an area immediately to the south of Capo Tirone; and the other taken from the protected area to the north of the promontory. A third sample was taken on the -2 m isobath on the inside of the area protected by the detached structures, to the north of Capo Tirone.

The grain size characteristics suggest that the sediments of supergroup 1 are probably those in normal sedimentation in the area; distributed somewhat in belts parallel to the shore following a normal horizontal gradation (fig. 9). These sediments, comprised exclusively of moderately sorted sands, could come to the coastal sector in observation from water courses that cross them or from neighboring littoral sectors. They would be sorted and put in place by common wave motion and by the associated littoral currents. The presence of the sediments of group B

FIG. 8 - Detail of the seafloor close to a breakwater.

in the seafloors close to the shore, to the south of Capo Tirone, suggest that this is a zone with less energy because it is protected by the cape itself.

The sediments of supergroup 2 present a significant incidence of coarse material; in part from the sediment runoff of the Vallecupo and Soleo streams (and of other local minor water courses) and in part from the pouring of artificial deposits carried out for the nourishment of some littoral stretches in the zone to the north of Capo Tirone (material with D_{50}, comprised between 1.5 and 8.5 mm). The action of the waves on these materials is probably greatly reduced, at least for the coarser fractions that undergo limited displacements only during strong storms. The minor sorting in respect to the samples of supergroup 1 and the negative skewness seem to confirm this hypothesis.

The distribution of the groups of supergroup 2 shows that in the area protected by detached structures, the coarser sediments (group D) remain confined between the structures and the shoreline; whereas, the shore protected by structures in the north close to Capo Tirone, the sediments reach the –5 m isobath (fig. 9). The sediments of group E, finer in respect to those of group D, are found a lot inasmuch as the inside as the outside of the detached structures, apart from being present in proximity to the shore in the areas protected by Capo Tirone.

CONCLUSIONS

The littoral of Belvedere Marittimo, on the whole, showed a stability of the shorelines between 1873 and 1955; however, it is remarkable that in this time the sector between Capo Tirone and the Torrente Soleo started to enter into a crisis and the erosion process at the end of the 50's was already so great that building the first wave breakers as defensive measures was necessary. In the period from 1955 to 2002, there was a more general erosive process that came about; especially in the sector found between Punta S. Litterata and the Torrente Vallecupo, but also on the shore found between the Soleo and Sangineto streams which have registered the highest retreat rates. Along the sector that extends from Capo Tirone to the Torrente Soleo, coastal protections have contained, at least in part, the erosive processes that seem to have recovered vigour in the last few years of the considered period.

The morphological variations of the seafloor that took place between 1980 and 2002 in the area of the detached structures to the south of the Torrente Vallecupo, highlight a mild and more widespread accumulation not exactly evaluable. The northernmost detached structures constitute an exception, where an extensive erosional process prevails, connected mainly to conditions of high energy of waves. In these conditions a transport of inert materials towards the open sea occurs and, at times, deep incisions also occur in the openings between the structures. This is also confirmed by the grain size data and by the subaqueous observations: in fact, a displacement of coarse sediment through the openings directed towards the open sea is recorded, even if the structures seem to be able to usually retain material with Mz <–1 phi (D50 ≈ 2.5 mm). Their efficacy is much lower for the sediments with Mz > 0 (D50 ≈ 1 mm). In proximity to the structures to the north of Capo Tirone the displacement of sediment mainly happens in a SE direction and in

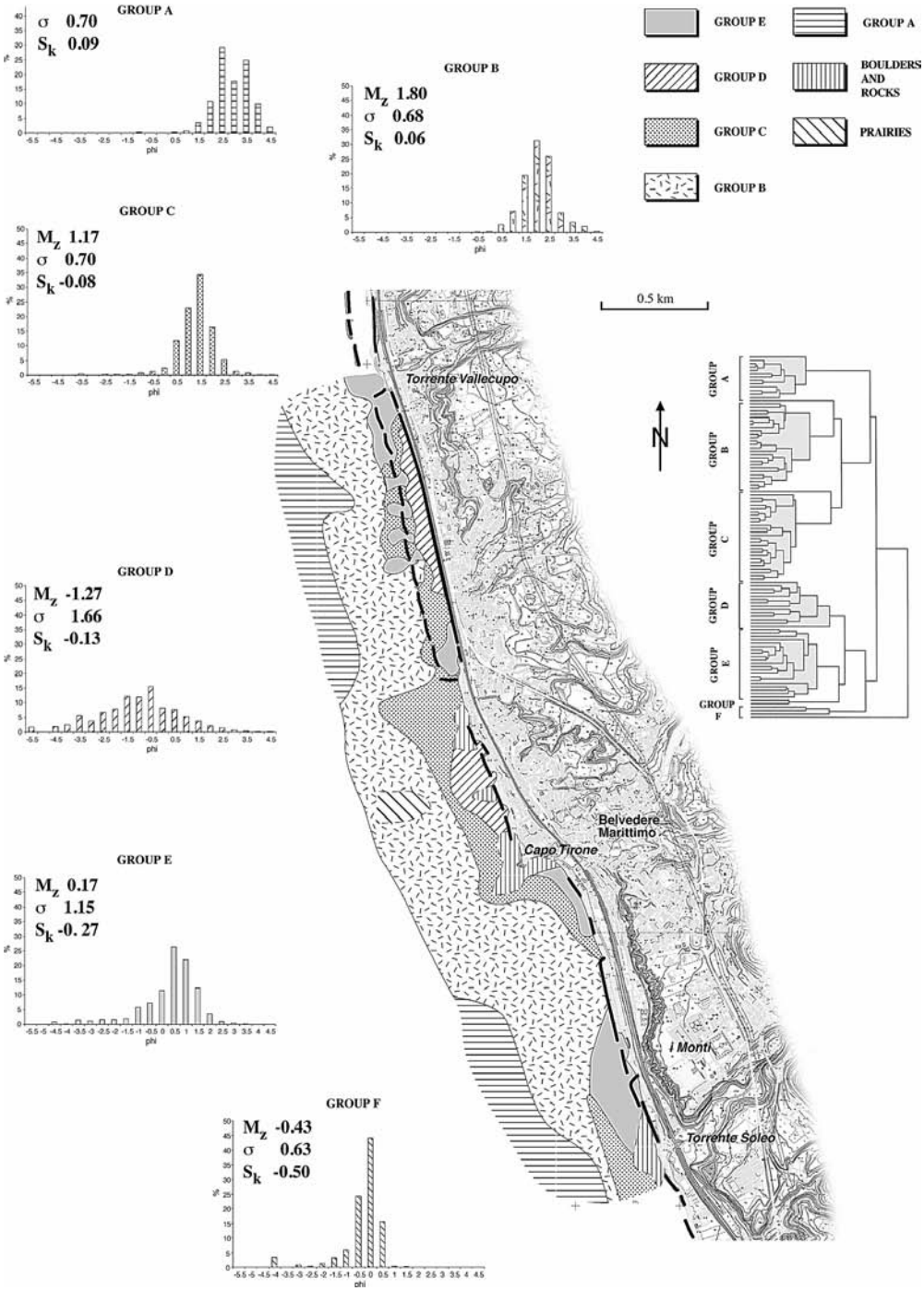

FIG. 9 - Grain size characteristics and areal distribution of sediments along the study area.

part, transversally to the coast, towards the open sea. This can be related to the waves coming from west as shown by the analysis of wave climate recorded by the wavemeter of Cetraro.

The coastal engineering structures that have been built were numerous and diversified: some of them followed the urgency to limit damages to some important facilities, others were carried out using engineered plans. The «rigid» protections caused an enhanced mobility of the seafloor with a major deepening to the openings and the areas just in front of the structures, producing local partial damages. The few nourishments did not entirely attain the expected objectives because they were not sufficiently weighted and protected. The attempt that is being put into effect provides, in fact, a mixed intervention, on which a continuous and adequate monitoring will be necessary in order to define the best «combination» of the two coastal engineering systems.

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