Geogr. Fis. Dinam. Quat.
29 (2006), 71-81, 7 figg.

ISABEL AROZARENA LLOPIS (*)

FACTORS IN THE DEVELOPMENT OF ROCKY COASTS BETWEEN LERICI AND TELLARO (GULF OF LA SPEZIA, LIGURIA, ITALY)

ABSTRACT: AROZARENA LLOPIS I., *Factors in the development of rocky coasts between Lerici and Tellaro (Gulf of La Spezia, Liguria, Italy)*. (IT ISSN 1724-4757, 2006).

The evolution of rocky coasts has been described by several Authors as the result of different interacting factors, referred to as littoral forces, either internal (tectonics, volcanism, seismicity) or external ones (atmospheric, hydrospheric, biospheric and cryospheric). Rocky coasts between Lerici and Tellaro (Gulf of La Spezia, eastern Liguria, Italy) present some features that are intermediate between shore platforms and plunging cliffs. Four types of profile have been identified; they have near-horizontal to steep surfaces, often showing an almost vertical step in the seaward margin. These forms were initially interpreted as wave-cut platforms suspended at different heights from sea level by simple eustatic oscillations. In this work, a polygenetic origin is proposed for these forms, in which tectonics, weathering, wave action and inheritance are all involved.

KEY WORDS: Rocky coast, Shore platform, Inheritance, Weathering, Structural control, Liguria, Italy.

RIASSUNTO: AROZARENA LLOPIS I., *Fattori nello sviluppo delle coste rocciose tra Lerici e Tellaro (Golfo della Spezia, Liguria, Italia)*. (IT ISSN 1724-4757, 2006).

In questo lavoro si affronta il tema dell'evoluzione delle coste rocciose che i diversi Autori hanno interpretato in modo differente attribuendola ad agenti diversi, endogeni ed esogeni.

Le coste rocciose fra Lerici e Tellaro (Golfo della Spezia, Liguria) presentano alcuni caratteri intermedi fra quelli delle piattaforme litorali e delle falesie. Sono stati identificati 4 profili tipo, rappresentati dalla combinazione di superfici più o meno inclinate spesso limitate da uno scalino verticale al margine marino. Queste forme sono state identificate nel passato come piattaforme di abrasione marine sospese a diverse altezze sul livello del mare in conseguenza di semplici oscillazioni eustatiche. In questo lavoro si propone un'origine poligenetica di queste forme, nella quale sono coinvolte, eredità morfologiche, tettonica, alterazione meteorica, azione del moto ondoso.

TERMINI CHIAVE: Coste rocciose, Piattaforma litorale, Eredità, Alterazione meteorica, Controllo strutturale, Liguria, Italia.

(*) *Dipartimento di Scienze della Terra, Università di Pisa, Via Santa Marta 53 - 56126 Pisa (Italy).*

INTRODUCTION

According to Trenhaile (1987), the variability of cliff profiles found in nature is witness to the numerous factors and processes that determine the morphology and evolution of rocky coasts. One of the most famous debates regarding rocky coasts focuses on the relative responsibility of marine and meteoric agents, respectively, in the erosion and backwearing of the coasts, especially in the formation of shore platforms.

There have been different names for the features today called shore platforms; the term «wave-cut platform» (Barrel, 1920; Longwell & *alii*, 1969; Lee & Focht, 1976) was attributed assuming that platforms are the product of exclusively wave action. The same occurs in the case of the term «abrasion platforms» (Johnson, 1919). Other terms are «surf benches» (Bell & Clarke, 1909) or «old hat platforms» (Bartrum, 1916); most of them have a genetic meaning and all of them attempt to descrive subhorizontal or slightly seaward dipping surfaces. The problem with this terms is basically genetical due to the lack of knowledge about their shaping processes; because of this it is advisable to use descriptive terms as «shore platform» (Threnhaile, 1987).

Authors such as Edwards (1941,1951), Sunamura (1977 a,1991) and Trenhaile (1987) have defended wave action as the main modelling agent. Others, like Bartrum (1916, 1935), Wentworth (1938, 1939) and Hills (1949) have proposed subaerial weathering as the main agent. Nevertheless, in some old works (Bell & Clark, 1909; Bartrum & Turner, 1928; Bartrum, 1935; Jutson, 1939; Mii, 1962) and in some newer ones (Kirk, 1977; Sunamura, 1991; Stephenson & Kirk, 2000 a and b) a probable combined action of both factors is put forward.

In particular, different researchers have noted that weathering processes (and the relative rock weakening) together with the inheritance of relict landforms (related to times with a sea-level similar to today's) represent important agents and controlling factors respectively, in the development of rocky coast landforms (Stephenson & Kirk, 2000; Blanco Chao & *alii*, 2003; Dickson & *alii*, 2004). The different intensity that characterizes the action of each factor in a given coastal tract determines the main morphological characteristics and provides information about evolutionary development (Cortemiglia, 1993). In this case study, due to the morphological variability between areas with the same lithology or same wave action exposition, it is necessary to find other factors and controls that could determine local differences. These factors can be weathering, tectonic structure and fracture's pattern of rock masses and, finally, inheritance of relict landforms. The aim of this work is to identify the factor or factors involved in the shaping of shore platforms and to recognize active agents modelling the coastal area at the present time.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING OF THE STUDY AREA

The study area is located in the easternmost part of the rocky ligurian coasts, within the Gulf of La Spezia. The Gulf is limited by two promontories characterized by complex folding concordant with main Appenninic compressive structures. The gulf is a tectonic basin or graben stretching NW-SE (Federici, 1987).

Paleozoic-triassic rocks outcrop on the eastern promontory belonging to the Tectonic Unit of Massa, uncomformably overlain by tectonic breccias (Brecce di Lerici and Maralunga), wich are overthurst by a lacunose and non metamorphic Tuscan Nappe, known as the Lerici-Tellaro Unit. Rocks belonging to this unit are, from bottom to top, Coregna Dolomites, La Spezia limestones and, finally, Monte Castellana dolomites (Carta Geologica d'Italia, 1:50.000, Foglio 248 «La Spezia»).

Five deformational phases have been identified in the area (D_1-D_5, in Storti, 1995). Deformation starting with compression during the Lower-Middle Miocene, (D_1 and D_2), followed by a crustal thinning during the upper Miocene-Pliocene, which caused the opening of the North Thyrrhenian basin (D_3). Progressive evolution of D_3 led to the formation of the Tellaro detachment fault and, eventually, to the formation of the extensional faults during the Pliocene (D_4); these faults are responsible for the horst and graben structure that char-

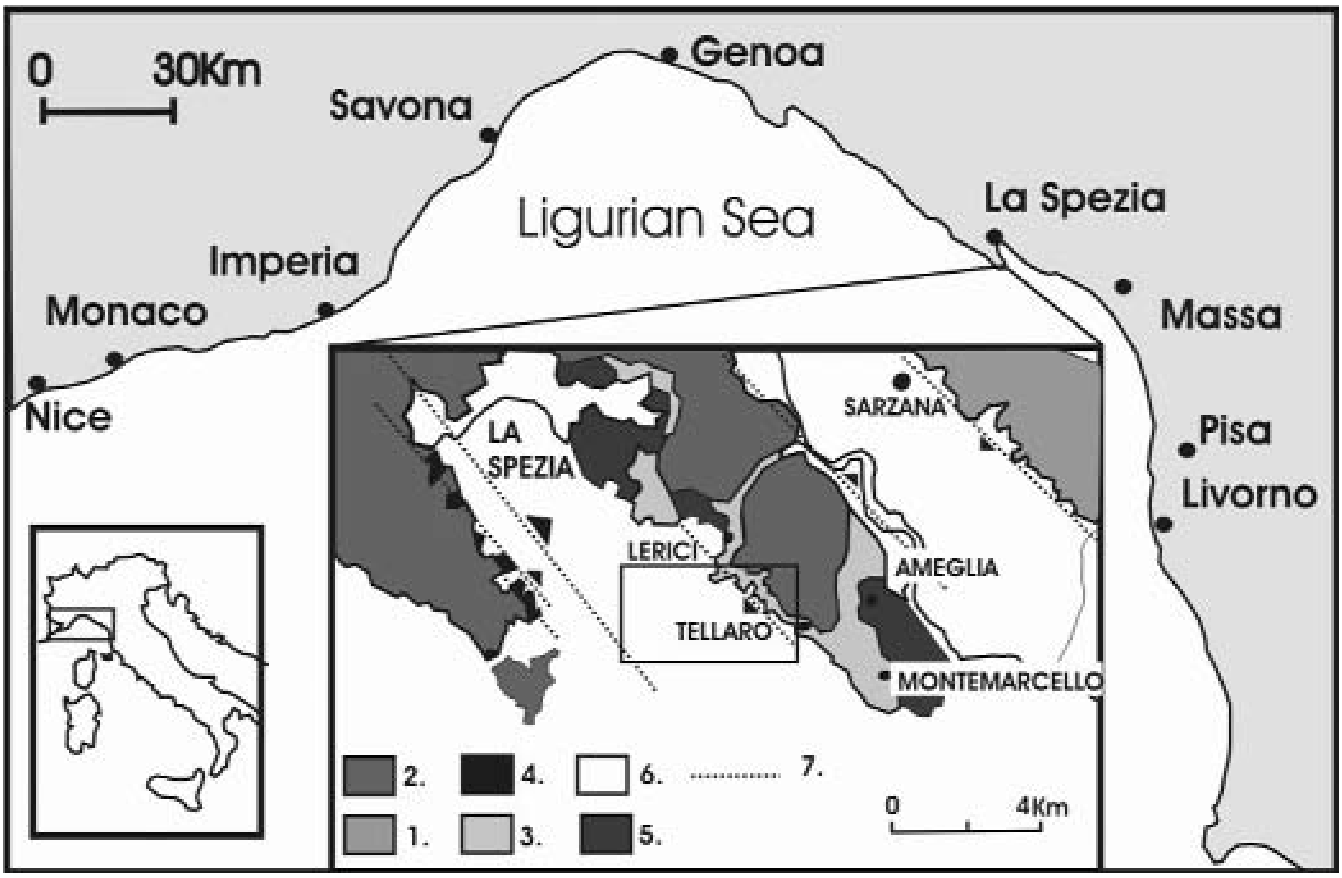

Fig. 1 - Geographical sketch and geological setting of the study area. Legend: 1. Subligurian Unit (Upper Cretacic-Lower Oligocene); 2. Tuscan Nappe (Norian-Lower Miocene); 3 Lerici-Tellaro Unit (Norian-Hettangian); 4. Panigaglia-Portovenere Unit; 5. Massa Unit (Cambrian-Ladinian); 6. Recent deposits (Upper Pliocene-Pleistocene); 7. Main faults and their strike (After Federici & Raggi, 1975).

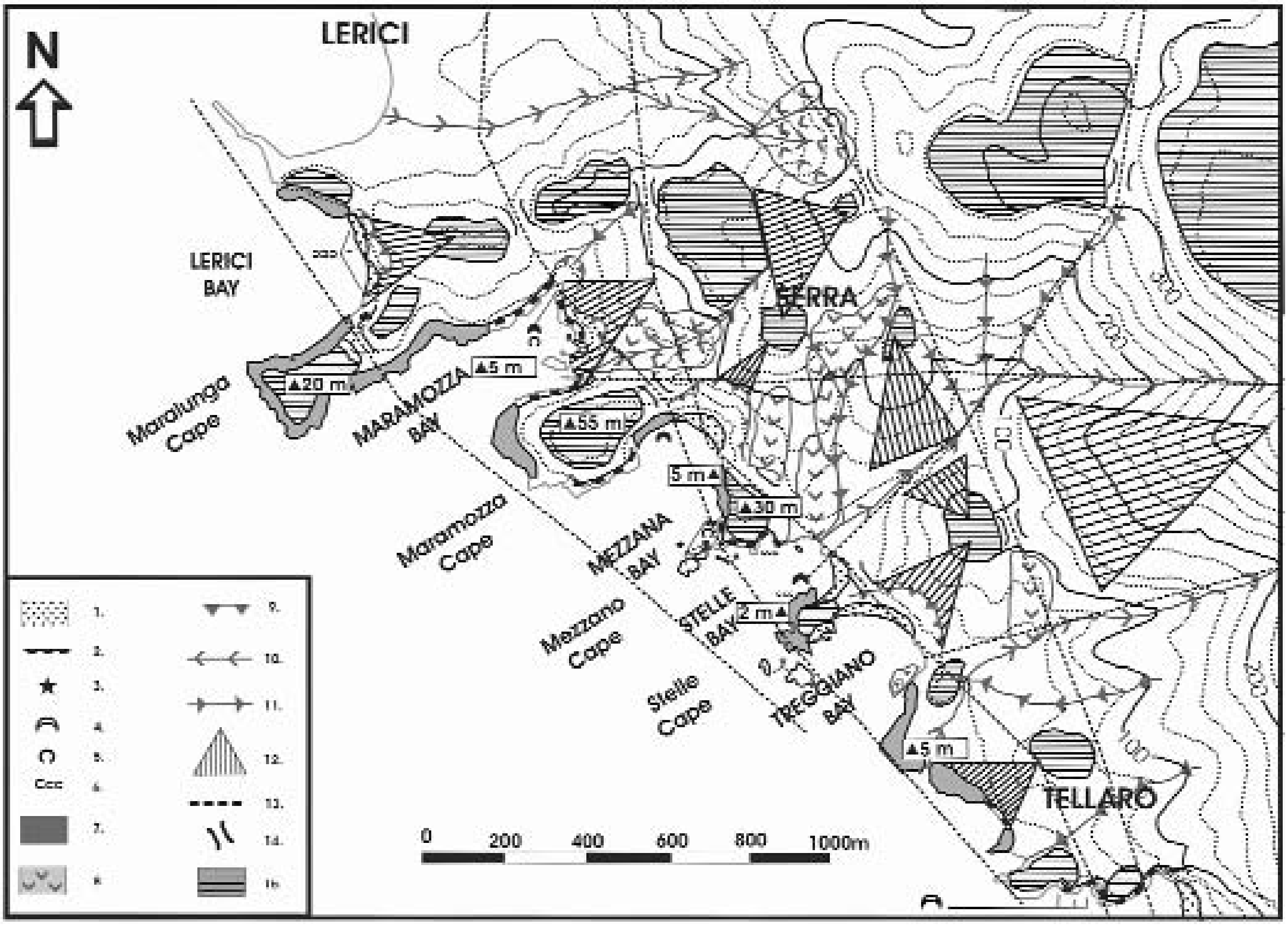

Fig. 2 - Geomorphological map of Lerici-Tellaro coastal area. Legend: 1. beach; 2. plungging cliff; 2. marine stack; 3. marine cave; 4. marine arch; 5. marine notch; 6. shore platform; 7. landslide; 8. lansdlide crown; 9. V-shaped valley; 10. concentrated surficial water groove; 11. triangular slope; 12. fault; 13. seaddle; 14. planated surface.

acterizes the Gulf of La Spezia and River Magra basin (Federici & Raggi, 1975). The latest phase (D_5) reuses the same fault planes of D_4 but with a strike-slip movement (D_5).

The coastline is marked by a series of bays and headlands characterized by a high morphological variability of rocky coastal features. The hillsides of the promontory display several normal faults, which are evident from the presence of triangular slopes located backwards the bays and tectonic saddles located on the inner part of the headlands (fig. 1).

The upper part of the promontory displays several karstic features; dolines and karren, and *terra rossa* fillings (Federici, 1970 and 1987) are frequent in the area. The summits of the promontory are subplanar or slightly rounded and are surrounded by dolines that follow normal and transversal faults parallel to the coast. The transversal faults become evident through the pattern of karstic features and also by means of aerial photograph analysis.

METHODS AND RESULTS

In this section platform profiles are described as four contrasting features. Measurements of topography and bathimetry have been done by means of 1:5.000 topographic maps and 1:30.000 bathimetric maps.

A - Shore platform description

The four platform profiles found in the Lerici-Tellaro coastal area have been found in correspondence to the five headlands that characterize this coastal tract (fig. 2), respectively: Maralunga, Maramozza, Mezzana and Seno delle Stelle, and finally Tellaro (Mezzana and Stelle correspond to the same profile type C).

In addition, other coastal features, such as plunging cliffs, pocket beaches, stacks and arches are also described.

Type A coast

This small platform reaches heights of about 15-20 m. The morphology of the profile, carved in the Maralunga Breccias, is characterized by a 45° dipping surface which, in its seaward margin is cut by a 1-1.5 m high cliff (fig. 3-A). Landwards its profile becomes steeper so it could be defined as an intermediate feature between platform and cliff. The seaward vertical surface gradually becomes a real cliff towards the inner part of the bay, until it replaces totally the platform profile and reaches a height of 15 m. Below sea level, this morphology is vertical and only interrupted by a 1 m wide and 1.5 m deep submerged platform.

This type of rocky coastal profile is typical from the Punta di Maralunga throughout almost its perimeter. The upper slopes of the Maralunga headland show slopes dipping about 15°. Maximum height is 22 m a.s.l. and the upper part of the headland displays a sub-planated surface at an average height of 17 m a.s.l., which has no continuity with the rest of the Maralunga headland, likely caused by the presence of a tectonic saddle.

Type B coast

It is formed almost entirely by a 20° dipping surface with a maximum length (normal to the coast) of 30 m, and

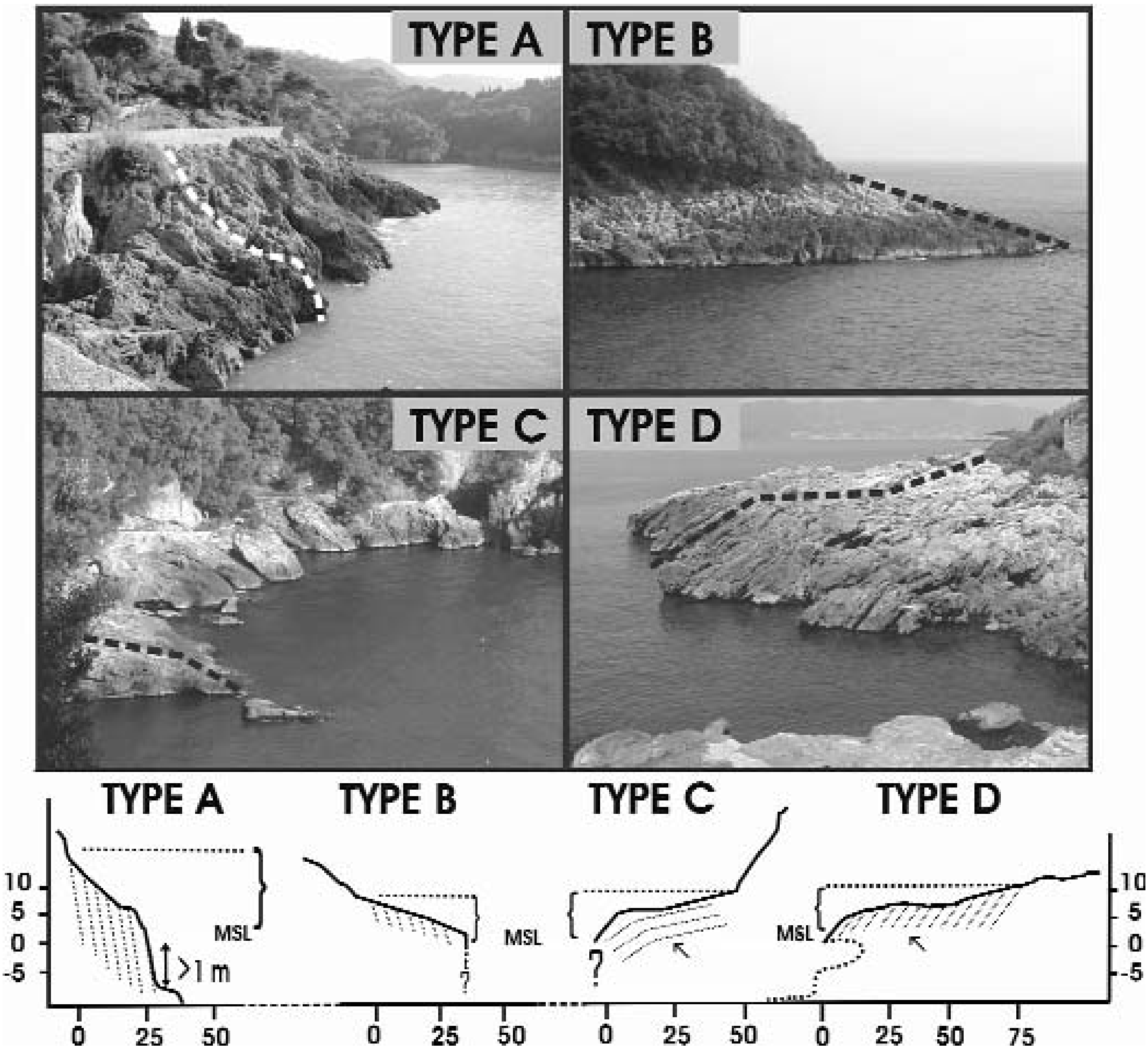

Fig. 3 - The four types of coast analyzed in the text: A. type A coast at Maralunga headland; B. type B coast at Maramozza headland; C. type C at Mezzana headland and D. type D coast at Tellaro. Dashed lines in the profiles sign main discontinuities in the rock mass (fractures or strata).

it is interrupted seaward by the presence of a little vertical escarpment no higher than 1 m (fig. 3-B).

This morphology, characteristic of the most external part of the Punta di Maramozza, becomes more and more vertical towards the inner part of the bay, where it displays a vertical 8 m high cliff. Here, submerged morphology is almost vertical, reaching depths of 15 m approximately. Also in this headland, the Maralunga breccias outcrop and, in the same way as on Punta di Maralunga, give a high roughness to the surface.

The upper part of the Maramozza headland displays dips almost equal to the described profile. The maximum height of the headland is approximately 65 m a.s.l. and the uppermost part also displays a sub-planated surface. This upper part is not continuous landwards; a tectonic saddle between the headland and the rest of the promontory breaks the profile normal to the coast.

Type C coast

This type of profile is characterized by an almost horizontal development with a steeper slope break in the seaward margin. Shore platforms of this type show a vertical cliff on their inner margin affected by gravitational instability and, thus, frequent rock falls (fig. 3-C).

In the case of Mezzana headland, the average height of the platform is near 5-6 m a.s.l., with the slope break at 4 m and the inner margin near 8 m a.s.l. Amplitude of the platform is spatially variable, with a maximum of 30 m and minimum of 8 m. The Monte Castellana dolomites, outcropping at Punta di Mezzano, display strata with subhorizontal dipping and slightly folded, following the landform profile. The hillslope of Punta di Mezzano, from 25 m a.s.l. upwards is characterized by a sub-planated surface between 25 and 30 m a.s.l.. Landslides and rockfalls are also frequent in this headland. The submerged profile is vertical as in the Maramozza headland.

On the other hand, Punta delle Stelle headland displays lower average heights (1.5-2 m a.s.l.), but always with a main horizontal development. This coastal area is quite indented so the amplitude is also variable (20 m approximately). The headland's summit is a subplanated surface at 15 m a.s.l.. Landwards, the headland displays the same type of discontinuity described for the other coastal types, which shows the presence of a normal fault. Below sea level, the platform profile is abrupt, steep and with the presence of sandy bottoms, never shallower than 5 m deep.

Type D coasts

This type of profile displays a subhorizontal surface at an average height of 5 m a.s.l. that becomes a 70° steep surface seawards, and a less steep ramp (40°) landwards. The overall profile can be described as a ramp-flat-ramp morphology (fig. 3-D). All three surfaces show high roughness mainly due to both the intensive folding of the Portovenere Limestones and the development of weathering and karst features. The steep seaward margin of this platform continues below sea level for at least 10 m.

The hillside back standing type D coast shows gentler slopes in comparison with the rest of the analyzed profiles (5° approx.). Depths at the base of the platform are between 8-10 m. In addition, the presence of a submerged void or cave below the seaward margin of the platform is suggested by the means of breakers typology. In figure 3-D, it can be seen the inferred submerged profile with the presence of some kind of void.

B - Coastal slopes

Cliffs are mostly located in the inner part of the bays, sometimes surrounding the margins of pocket beaches. In some cases, platforms that are located in the most external part of the headlands, become gradually cliffs towards the inner part of the bays. This is the case of Maralunga Bay, where both the Maralunga and Maramozza headlands follow this scheme; also the south-eastern hillside of Maramozza headland shows this characteristic. On the Mezzano headland, except for the area where the shore platforms develop, a 25 m high cliff dominates the coastal slope; on the most external part of this headland there is a natural arch and some stacks.

Another interesting landform is found on the type D coasts, near Tellaro village; at a height of 5 m a.s.l., coincident with the flat part of the platform, there is a little relic beach surrounded landwards by a semicircular rocky cliff. The beach deposit is formed of centimetric uncemented rounded pebbles (fig. 7 A and B); the deposit is composed by rounded and calcareous (Portovenere Limestones) centimetric pebbles. It's important to note that the beach deposit is situated inside a semicircular roofless cavity, presumably of karstic origin. The seaward margin of the beach deposit is characterized by the presence of an erosive scar carved on the Tellaro platform. (fig. 7 B) and it's also observed the presence of scattered relics of a likely continental breccia on the cavity walls; this breccia is formed by very angular centimetric pebbles contained in a extremely hard yellowish cement (fig. 7 C). Beach deposit pebbles are limestones from Calcari di Portovenere formation and don't show signs of bioerosion or concrection. Instead, karstic concrections and dissolution cavities are found on the walls that surround the relict beach.

CONTROLLING FACTORS

A - Marine conditions

The study area is affected by SE incoming waves (Libeccio waves). The sector of Maximum fetch lies between 209 (Capo Cavallo, Corse) and 247 (d'Hyeres Islands) and has maximum values of 500 nautical miles (fig. 4). Annual percent frequencies of wind velocity and direction (Beaufort scale) at Palmaria Island (contiguous to the Western Promontory of the gulf), show dominance of NE and SW winds. Offshore wave conditions, given as average percent

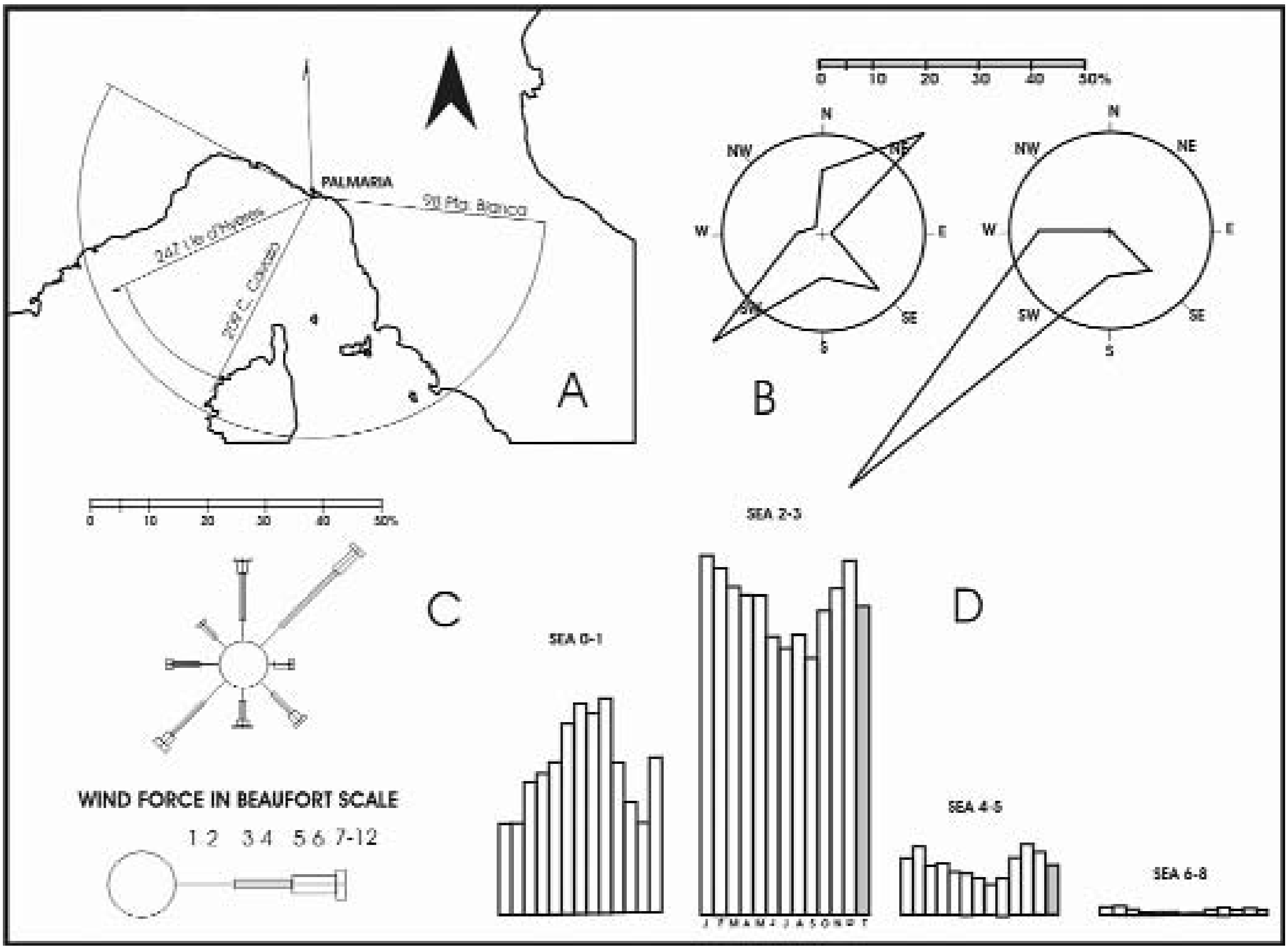

Fig. 4 - Sinthetic sketch of marine and wind data measured in the closest meteorologic station (Palmaria) (data from the Istituto Idrografico della Marina, 1978): A. maximun fetch sectors for the Palmaria station; B. direction of incoming storms: percent frequencies of 6-8 sea force inferred from daily observations relative to an interval of 30 years (from 1930 to 1942 and from 1947 to 1963); C. mean percent frequencies of winds, inferred from three daily observations relative to an interval of 30 years; D. wave conditions in different months of the year: mean percent frequencies inferred from three daily observations relative to an interval of 30 years.

frequencies (measured 3 times a day during 30 years), show dominance of values 2 and 3 (with frequencies about 6, which correspond to bigger wave heights between 0.10 and 1.25 m); values of 4 and 5 (bigger wave heights between 1.25 and 4 m) have an annual percent frequency of about 10 (fig. 4).

With regard to nearshore wave transformations, important refraction of SW incoming wave crests is generated by the presence of Isola di Palmaria at the most external part of the Gulf; refraction makes them reach the coast as southern incoming waves. Furthermore, a mean depth in the Gulf of about 12 m, contributes to an important loss of energy by friction along the wave path. Nevertheless, mean depth at the base of the analyzed landforms is relatively high (5 m); because of this, waves do not easily break exactly on the rocky coast, but often they reflect themselves without breaking.

B - Weathering and karst

Several different types of weathering features have been found on the 4 platform types; (1) deep sub-cylindrical cavities with pebbles at the bottom (giant's potholes) (fig. 5-A); (2) shallow potholes with decimetric to metric diameters, often showing salt precipitates when wet (fig. 5-B); (3) karstic sub-cylindrical cavities sometimes coalescent and/or filled with *Terra Rossa* (fig. 5-C); (4) karstic alveols, which are millimetric to centimetric cavities that cover large areas on the rock surface (fig. 5-D).

At the Maralunga and Maramozza headlands, due to the inherently high roughness of the Maralunga Breccias, water from wave spray and splash tends to stagnate, so favouring the presence of features of type (2). Platforms at Stelle headland show forms of types (2) and (1), where evaporation of water leads to the formation of salt crusts.

It is frequent to find a *karren* like landscape due to weathering and opening of rock joints. Stagnation of water is also favoured at Tellaro as rocky outcrop surfaces are rough due to intense folding and jointing; the main features are those of types (1) and (3). Forms of type (4) are present on all five headlands studied.

C - STRUCTURAL CONTROLS

The eastern promontory represents a structural uplifted block inserted in the Gulf of La Spezia *horst and graben* morphostructure, and shows morphological characteristics that makes this evident. This characteristic becomes more noticeable due to the presence of, at least one high angle normal fault, parallel to the coast. On the top of the hills there are some pieces of relict surfaces spatially linked to karstic features. These relict surfaces have been observed also at different heights along the slope and have been spatially linked to triangular slopes and saddles. The top of the analyzed headlands could be included in this group of «suspended» surfaces (fig. 6).

Shore platforms at the Mezzana and Stelle headlands are carved in Monte Castellana dolomites that lie subhorizontal in both areas. Storti (1995) has noted the presence of a detachment fault at the top of this lithological formation at Punta delle Stelle and below a formation of marls. Evidence of this detachment fault at Mezzano headland and bay was also found in the present field work. The different competence between these two lithological formations, favoured by the subhorizontal dip of dolomites, seems to represent an important control in the morphogenesis of both platforms. The specific agent or agents that eroded the marls differentially with respect to the dolomites could be gravity (landsliding) acting in a scenario very similar to that of today's sea level.

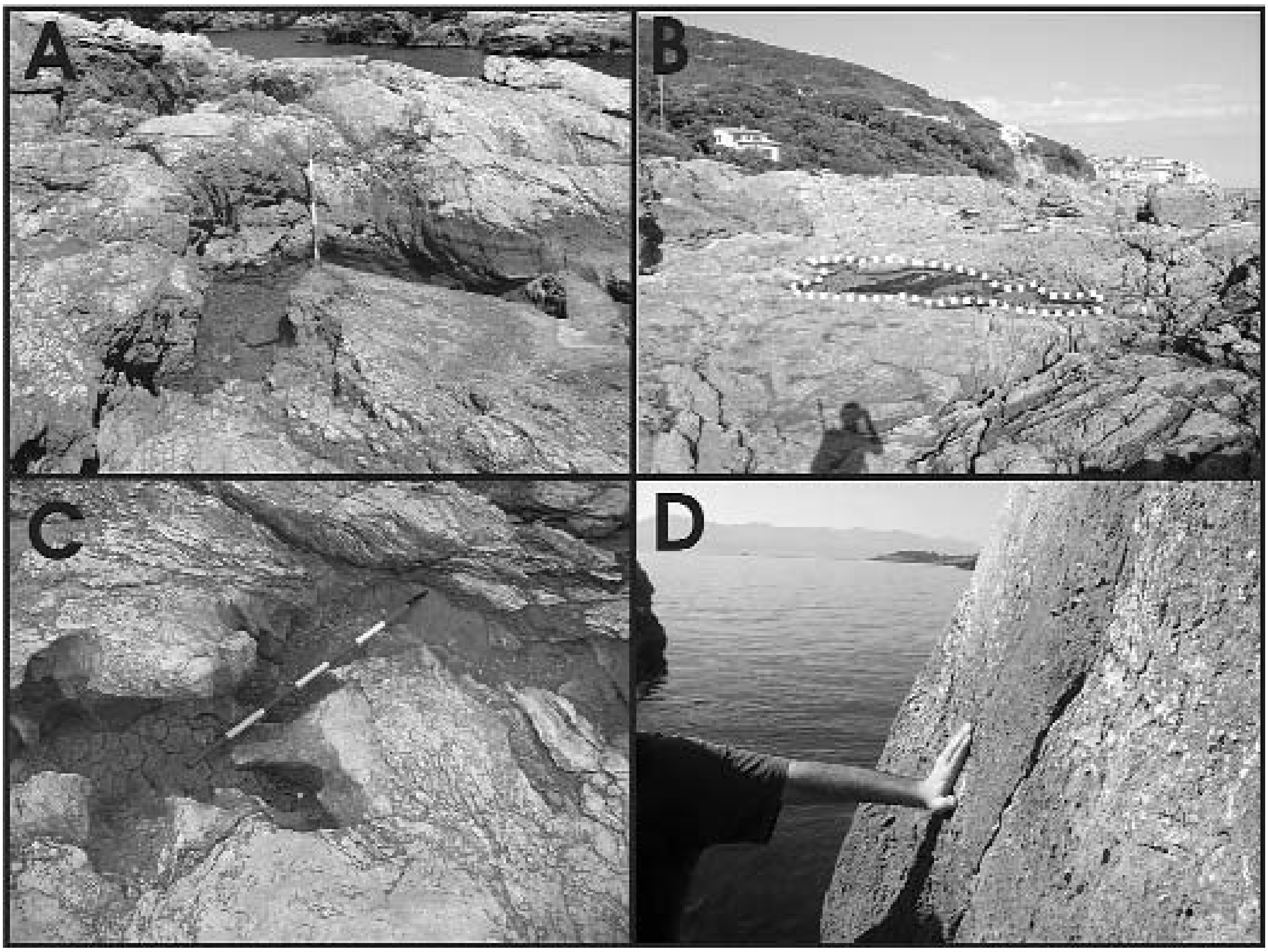

Fig. 5 - Different features of coastal weathering: A. pothole; B. salty rock pools; C. karstic cavities; D. weathering alveoles. Length of scale equal to 1.60 m (each segment equal to 20 cm). A e B are features carved in dolomites (Dolomie del Monte Castellana) and C e D are carved in limestones (Calcari di Portovenere).

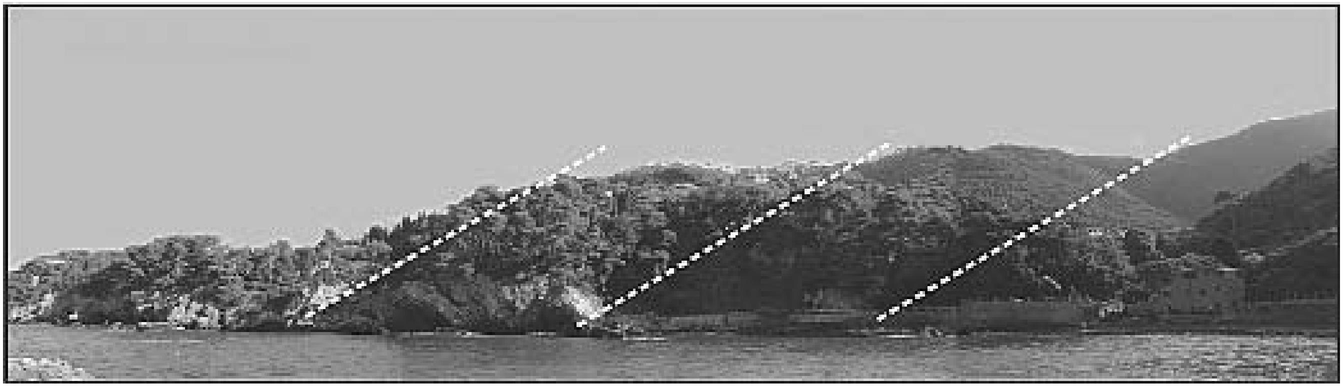

Fig. 6 - Mezzano headland showing the *horst-graben* structural setting of the promontory hillsides: it is a typical stair-like structure displaying three normal faults that leave subhorizontal relic surfaces suspended.

DISCUSSION

Wave action can erode mainly in three ways: abrasion, generation of shock pressures and water hammer pressures. Abrasion needs the presence of sand as an abrasive tool to be an effective agent. To generate shock pressures the entrapment of an air cushion between rock and wave surfaces is needed (Bagnold, 1939; Trenhaile, 1987). As regards generating water hammer pressures, the breaking wave surface should be completely flat and should not entrap air between wave and rock. Trenhaile (1987) stated that, due to the necessity of these strict conditions, true shock and water hammer pressures are extremely unfrequent in real situations while Sunamura (1977 a) stated that the gradient of shore platforms is a function of wave intensity and rock strength.

Davies (1972) suggested that cliff gradients are a function of relative intensity of waves with respect to subaerial processes. The more dominant is wave action, the steeper are the cliffs and thus, when weathering becomes more dominant, slopes begin to show a less steep and concave profile. There are some works in geomorphological literature, mainly in the last years, in which weathering becomes important in the debate on rocky coast erosion; (Stephenson & Kirk, 1996, 1998, 2000 b; Dickinson, 2002 and Trenhaile & *alii*, 1999).

De Pippo & Donadio (1999) have recently proposed a classification of potholes based on morphography but inevitably concerning also their genesis. They recognize the important controlling role of lithology, structure and degree of jointing, karst and also gradient of coastal surfaces. Physical-chemical erosion by marine, meteoric and mixed waters (hyperkarst), climatic conditions, and coastal wave exposure seem to be the main controlling factors in the development of different types of potholes (De Pippo & Donadio, 1999).

With respect to karstic alveols and other coastal weathering features, Mottershead (1993) stated that the main controlling factor seems to be granular disintegration due to salt crystal growth and thermal expansion, favoured by summer temperatures and wet-dry cycles. Also biological contributions have been identified as developmental agents. In fact, the algal content in the waters filling potholes determines pH variations between day and night and between summer and winter (Emery, 1946).

Lowering rates due to this kind of weathering have been calculated by several authors. Emery (1946) calculated a lowering rate of 33 years per centimetre at the limestone coasts of La Joya (California, USA) and he considered this phenomenon as a coastal retreat capable agent.

In this coastal stretch, the platform profiles could remain mixed cliff profiles like those proposed by Davies (1972), formed by a combination of subaerial weathering and wave action. These processes, as wave action does not seem to be active in the present day, would have had much more time to erode and shape the coast, especially if we take into account other periods, for instance the middle and upper Pleistocene (Trenhaile, 1987). Inherited landforms, in this sense, could derive from periods with a slightly higher sea level, as suggested by the presence of a relic beach deposit at 5 m a.s.l. above the Tellaro platform (type D), (fig. 7 A). These facts hold the hypothesis that this cavity was an ancient doline whose roof and external wall were destroyed, presumably by wave action, previously to the deposition of the beach.

Several sea level markers have been found at about 5 m a.s.l. (and also at different heights) in Liguria, most of them being rock terraces without marine deposits, others containing deposits and sometimes fauna that have permitted some datings and correlations. Platforms about 7 m a.s.l at different locations along the coasts of Liguria have been recognized by Issel (1883) and are considered as having formed during the Quaternary. Near the italian-french border Rovereto (1939) identified a 12 m sea level referred to the Tyrrhenian, due to the presence of *Strombus bubonius* fauna, which is a MIS 5.5 marker. Another 7 m high beach deposit with *Strombus bubonius* was found by Isetti & *alii* (1962) elsewhere in Western Liguria and was attributed to the Tyrrhenian. Carobene & Firpo (1994) found two marine terraces near Genova, with their inner margins

Fig 7 - A: relic beach deposit seen from its seaward margin. B: seaward margin of the beach and the erosive scar. C: cemented deposit on the walls of the cavity (continental breccia). Circles in 7 B indicate the position of the cemented deposit on the surrounding walls.

between 7 and 16 m a.s.l.. Federici & Pappalardo (2006) recognized in Eastern Liguria (Lavagna) a marine terrace at 28 m a.s.l. OSL dated to MIS 5.5.

Evidences of MIS 5.5 highstand in Liguria show a different vertical behavior between eastern and western Liguria, with markers slightly uplifted in the eastern area and remaining at eustatic value in the western one (Ferranti & *alii*, 2006). These data, though, are very preliminary; elsewere in the Italian Peninsula, for instance in Calabria (Souhern Italy), the lack of correlation between different sea-level markers along the coast suggests some innaccuracies in the models used to interpret tectonic and eustatic displacements (Pirazzoli & a*lii,* 1997).

The presence at Tellaro of a beach deposit 5 m a.s.l. and the existence of platforms at this height (Maramozza, Maralunga and Mezzana) adds new data for the tectonic reconstruction of the Apennine Chain and the Ligurian coasts. Beach deposit and marine terraces in the study area could represent sea-level indicators; in absence of datings it is possible that these platforms have mainly been developed during MIS 5.5 when the sea level was 6±3 m above the present level (Waelbroeck & *alii*, 2002).

We consider inheritance as the conservation of coastal landforms created during past periods characterized by a sea level similar to the present one, refering their genesis to the same agents described above; wave action, weathering and structural control. However, we can also consider coastal inheritance as the presence of *non marine* relict landforms which are at present sea level, as a consequence of tectonic and eustatic movements. The following explanation shows that both interpretations of inheritance could be applied to the present study area.

Inherited coasts have been described by several authors, mainly in recent years. For instance, Blanco Chao & *alii* (2002, 2003) and Trenhaile & *alii* (1999), in a study on Galician rocky coasts (NW Spain), find outcropping shore platforms partially sealed by periglacial and fluvio-nival deposits.

Total lack of inheritance means that present landforms are still in shaping by active processes since the sea reached its present level. However, in our study area this hypothesis is quite doubtful due to the lack of fresh scars or abraded surfaces on the studied platforms.

The second possible application of the inheritance concept, as mentioned above, implies a non-marine genesis for someones of the forms observed today on the coast. All five studied headlands are the result of extensional tectonics that divided the promontory and cut its slopes and valleys, so creating this headland-bay landscape. Moreover, as evidence of this type of inheritance, subplanar surfaces above the headlands remain as the relic surfaces along the slopes and the top of the promontory, supporting the idea that they all formed within a single unique surface which was successively dislocated by extensional tectonics. In this way, also part of the studied platforms could be remnants of this phenomenon.

CONCLUSIONS

Studying the complex coastal landforms between Lerici and Tellaro it can be stated that rocky coasts are not the result exclusively of present day wave action. Taking this into account, it is necessary to discriminate between controls and specific agents. Structural setting (jointing, dipping, folding), lithological characteristics (differences in hardness) and inheritance are main control factors that create the appropriate scenery and favour the action of active morphogenetic agents. On the other hand, tectonic movements, gravity and landsliding, karst and coastal weathering processes, and wave action, are the main factors that shape the coast.

It is important also to separate relict processes that have shaped the coast in the past from those processes that are currently reworking inherited landforms. At the Maralunga and Maramozza sites, where the whole headland seems to be the result of extensional tectonics, its concave profile suggests interaction between wave action and weathering. At the present day only wave-spray induced weathering and karst seem to be active, so we can easily separate controlling factors from active/inactive agents. Weathering and active wave action could have interacted in a moment when sea level was 5 m above present one, which maybe during the peak of the last interglacial, if we accept that no tectonic movements have occurred since then in the area.

At the Mezzana and Stelle sites, the difference in resistance between lithological formations above and below the subhorizontal detachment fault have conditioned the formation of low dip platforms. Gravity and wave action have acted on this discontinuity, presumably during a past higher sea level period, leading to a significant retreat of the detachment overlying formation (marls). Also in this case, sea level at 5 m above present one could cause erosion at the bottom of the marls.

REFERENCES

BAGNOLD R.A. (1939) - *Interim report on wave pressure research*. Journal of Institut of Civil Engeneering, 12, 202-226.

BARREL J. (1920) - *The piedmont terraces of the Northern Appalachians.* American Journal of Science, 49, 327-362.

BARTRUM J.A.(1916) - *High water rock platforms: a phase of shoreline erosion.* Transaction of the New Zealand Institute, 48, 132-134.

BARTRUM J.A. (1926) - *Abnormal shore platforms*. Journal of Geology, 34, 793-807.

BARTRUM J.A. (1935) - *Shore platforms*. Journal of Geomorphology, 1, 266-268.

BARTRUM J.A. & TURNER F.J. (1928) - *Pillow lavas, peridotites, and associated rocks from northernmost New Zealand.* Transactions of New Zealand Institute, 59, 98-138.

BELL J.M. & CLARKE E. DE C. (1909) - *The geology of the Whangaroa subdivision.* New Zealand Geological Survey Bulletin, 8, 30 pp.

BLANCO CHAO R., COSTA CASAIS M., MARTÍNEZ CORTIZAS A., PÉREZ ALBERTI A. & VÁZQUEZ PAZ M. (2002) - *Holocene evolution on Galician coast (NW Spain): an example of paraglacial dynamics*. Quaternary International, 93-94, 149-159.

BLANCO CHAO R., COSTA CASAIS M., MARTÍNEZ CORTIZAS A., PÉREZ ALBERTI A. & TRENHAILE A. (2003) - *Evolution and inheritance of a rock coat: western Galicia, northwestern Spain.* Earth Surface Processes and Landforms, 28, 757-775.

CAROBENE L. & FIRPO M. (1994) - *Una paleospiaggia tra Voltri e Palmaro (Genova): evidenze sedimentologiche e morfologiche.* Il Quaternario, 7, 123-138.

CORTEMIGLIA GC. (1993) - *Aspetti generali delle morfologia costiera quali basi di riferimento per l'impostazione di una legenda di rilevamento dei relativi morfotipi.* Atti del Convegno: «Linee guida per il rilevamento della Carta Geomorfologica d'Italia 1:50.000», Roma, 1993, 93-116.

DANA J.D. (1849) - *Geology (Putnam, New York).* Report of US Exploration Expedition, 1838-1842, 10, 109-442.

DAVIES J.L. (1972) - *Geographical variation in coastal development*. Oliver & Boyd, Edimburgh, 204 pp.

DE PIPPO T. & DONADIO C. (1999) - *Morphology, genesis and evolution of rockpools along Italian coasts.* Geografia Fisica e Dinamica Quaternaria, 22, 129-141.

DICKSON M.E, KENNEDY D.M. & WOODROFFE D. (2004) - *The influence of rock resistance on coastal morphology around Lord Howe Island, Southwest Pacific.* Earth Surface Processes and Landforms, 2, 629-643.

DICKSON M.E. & WOODROFFE C.D. (2002) - *The development of rock coast morphology on Lord Howe Island, Australia.* Ph.D. Thesis, School of Geosciences, Univ. Wollongong, Wollongong.

EDWARDS A.B. (1958) - *Wave cut platforms at Yampi Sound in the Buccaneer Archipelago.* Journal of the Royal Society of Western Australia, 41, 17-21.

EMERY K.O. (1946) - *Marine solution basins*. Journal of Geology 65, 209-228.

FEDERICI P.R. (1970) - *Sui rapporti fra fenomeni carsici e tettonica nella Liguria Orientale*. Memorie dell'Accademia Lunigianese di Scienze, 40, 7-18.

FEDERICI P.R. (1987) - *Uno sguardo alla struttura e alla morfologia del Golfo della Spezia*. Quaderni dell'Istituto di Geologia dell'Università di Genova, 5, 293-306.

FEDERICI P.R. & PAPPALARDO M. (2006) - *Evidence of Marine Isotope Stage 5.5 highstand in Liguria (Italy) and its tectonic significance.* Quaternary International, 145-146, 68-77.

FEDERICI P.R. & RAGGI G. (1975) - *Una nuova interpretazione della tettonica dei monti della Spezia*. Bollettino della Società Geologica Italiana, 94, 945-960.

FERRANTI L., ANTONIOLI F., MAUZ B., AMOROSI A., DAI PRA G., MASTRONUZZI G., MONACO C., ORRÙ P., PAPPALARDO M., RADTKE U., RENDA P., ROMANO P., SANSÒ P. & VERRUBBI V. (2006)- *Markers of the last interglacial sea-level high stand along the coast of Italy: Tectonic implications.* Quaternary International, 145-146, 30-54.

HAWLEY D.L. (1965) - *Rock platforms, their formation, modification, and destruction.* University of Sydney, BA Thesis.

HILLS E.S. (1949) - *Shore platforms*. Geological Magazine, 86, 137-152.

HILLS E.S. (1972) - *Shore platforms and wave ramps.* Geological Magazine, 86, 137-152.

ISSEL A. (1883) - *Antiche linee litorali della Liguria*. Bollettino della Società Geologica Italiana, 1, 222-232.

ISETTI G., DE LUMLEY M. & MISKOVSKY J.C. (1962) - *Il giacimento musteriano della grotta della Madonna dell'Arma presso Bussano.* Rivista di Studi Liguri, 14, 1-142.

ISTITUTO IDROGRAFICO DELLA MARINA DI GENOVA. (1978) - *Il vento e lo stato del mare lungo le coste italiane e dell'Adriatico. Vol. 1: Coste del Mar Ligure e coste orientali dell'Alto e Medio Tirreno.* Istituto Idrografico della Marina, Genova, 1978.

JOHNSON D.W. (1919) - *Shore Processes and shoreline development*. Hafner, New York, 608 pp.

JUTSON J.T. (1939) - *Shore platforms near Sydney, New South Wales.* Journal of Geomorphology, 61, 43-59.

KIRK R.M. (1977) - *Rates and forms of erosion on intertidal platforms at Kaikoura Peninsula, South Island, New Zealand*. New Zealand Journal of Geology and Geophysics, 20, 571-613.

LEE K.L. & FOCHT J.A. (1976) - *Strength of clay subjected to cyclic loading.* Marine Geotechnology, 1, 165-185.

LONGWELL C.R., FLINT R.F. & SANDERS J.E. (1969) - *Physical Geology*. Wiley, New York, 685 pp.

MII H. (1962) - *Coastal geology of Tanabe bay*. Scientific Report, Tohoku University, 2nd Ser. (Geology), 34, 1-93.

MOTTERSHEAD D.N. (1993) - *Tafoni on coastal slopes, South Devon, U.K.* Earth Surface Processes and Landforms, 19, 543-563.

PIRAZZOLI P.A., MASTRONUZZI G., SALIÈGE J.F. & SANSÒ P. (1997) - *Late Holocene emergence in Calabria, Italy*. Marine Geology, 141, 61-70.

ROVERETO G. (1939) - *Liguria Geologica*. Memorie della Società Geologica Italiana, 2, 742 pp.

STEPHENSON W.J. & KIRK R.M. (1996) - *Measuring rates using the micro-erosion meter: 20 years of data from shore platforms, Kaikoura peninsula, South Island, New Zealand*, Marine Geology, 131, 209-218.

STEPHENSON W.J. & KIRK R.M. (1998) - *Rates and patterns of erosion on intertidal shore platforms, Kaikoura Peninsula, South Island, New Zealand*, Earth Surface Processes and Landforms, 23, 1071-1085.

STEPHENSON W.J. & KIRK R.M. (2000 a) - *Development of shore platforms on Kaikoura Peninsula, Sputh Island, New Zealand. Part One: the role of waves*. Geomorphology, 32, 21-41.

STEPHENSON W.J. & KIRK R.M. (2000 b) - *Development of shore platforms on Kaikoura Peninsula, South Island, New Zealand. II: The role of subaerial weathering*, Geomorphology 32, 43-56.

STORTI F. (1995) - *Tectonics of the Punta Bianca Promontory: Insights for the evolution of the Nothern Appennines-Northern Tyrrenian Sea basin*. Tectonics, 14, 832-847.

SUNAMURA T. (1977 a) - *A relationship between wave-induced cliff erosion and erosive force of waves.* Journal of Geology, 85, 613-618.

SUNAMURA T. (1977 b) - *Mechanisms of shore platform formation on the southeastern coast of the Izu Peninsula, Japan.* Journal of Geology, 86, 211-222.

SUNAMURA T. (1982) - *A predictive model for wave induced cliff erosion, with application to pacific coasts of Japan*. Journal of Geology, 90, 167-178.

SUNAMURA T. (1991) - *The elevation of shore platforms: a laboratory approach to the unsolved problem*. Journal of Geology, 99, 761-766.

TRENHAILE A.S. (1971) - *Lithological control on high-water rock ledges in the Vale of Glamoran, Wales.* Geographisca Annaler, 53A, 59-69.

TRENHAILE A.S. (1972) - The *shore platforms of the Vale of Glamoran, Wales*. Transactions of the Institut of British Geographers, 68, 95-114.

THENHAILE A.S. (1974) - *The morphology and classification of shore platforms in England and Wales.* Geographisca Annaler, 56A, 103-110.

TRENHAILE A.S. (1978) - *The shore platforms of Gaspè, Québec*. Annales of Association of American Geographers, 68, 95-114.

TRENHAILE A.S. (1987) - *The Geomorphology of Rocky Coasts*. Clarendon Press, Oxford.

TRENHAILE A.S, COSTA CASAIS M, MARTÍNEZ CORTIZAS M, PÉREZ ALBERTI A. & BLANCO CHAO R. (2003) - *Evolution and Inheritance of a rock coast: Western Galicia, Northwestern Spain.* Earth Surface Processes and Landforms, 28, 757-775.

WAELBROECK C., LABEYRIE L., MICHEL E., DUPLESSY J.C., LAMBECK K., MCMANUS J.F., BALBON E. & LABRACHERIE M. (2002) - *Sea-level and deep water temperature changes derived from benthic foraminifera isotopic records*. Quaternary Scientific, 21, 295-305.

WENTWORTH C.K. (1938) - *Marine bench forming processes-water layer weathering.* Zeitschrift für Geomorphologie, 1, 5-32.

WENTWORTH C.K. (1939) - *Marine bench forming processes: Solution benching.* Journal of Geomorphology, 2, 3-25.

(Ms. received 15 February 2005; accepted 30 September 2005)