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GEOMORPHOLOGICAL MAPPING, A BASIC TOOL FOR INTERPRETING ROCK COASTS LANDFORMS: AN EXAMPLE FROM EASTERN LIGURIA (ITALY)

ABSTRACT: CHELLI A. & PAPPALARDO M., *Geomorphological mapping, a basic tool for interpreting rock coasts landforms: an example from EasternLiguria (Italy)*. (IT ISSN 1724-4757, 2008).

This work deals with the geomorphological setting, with particular regard of rock coast morphologies along the coastline, of Palmaria Island, in the easternmost part of the Ligurian coast.

We carried out a detailed geomorphologic survey on the island, focused on coastal landforms. The rock seaward slope of Palmaria Island has two types of long profiles: 1) a slope over wall profile (plunging cliff) and 2) narrow rock surfaces at sea level or a few meters above it backed by steep slopes (palaeocliff).

The first type of slope profile is due to the presence of faults, linked to NW-SE-striking fault system, responsible for the displacement of the eastern Ligurian continental shelf. Our data indicate the up-throw side of the fault, corresponding to the island coast, is stable, so that an incipient notch can evolve along the cliff face in connection with present day sea level.

The second type of slope profile shows at its bottom a narrow, discontinuous rock platform which is currently being demantled, constrained in elevation below 5 m asl. This surface is interpreted as inherited from a past interglacial phase, thanks also to the OSL dating of a scree slope deposits that overlaps it.

KEY WORDS: Rock coast; Geomorphological mapping, Rock platform; Italy.

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Questo lavoro illustra i caratteri morfologici, con particolare riguardo alle forme in roccia lungo costa, dell'Isola Palmaria, all'estremità orientale della Liguria. È stato condotto un rilevamento geomorfologico di dettaglio, ponendo l'accento sulle forme costiere. I profili che caratterizzano i versanti rocciosi dell'Isola Palmaria sono di due tipi: a) con la falesia direttamente immergente in mare, e b) con una modesta piattaforma rocciosa che si interpone fra il mare e la falesia. Il primo tipo di versante è in connessione con sistemi di faglie orientate NO-SE, responsabili del movimento relativo della piattaforma continentale ligure. La presenza di un incipiente solco di battente alla base della falesia testimonia che la porzione emersa del margine continentale è attualmente stabile. Il secondo tipo di profilo presenta una modesta piattaforma in smantellamento, il cui margine interno non supera i 5 m di quota. Questa piattaforma è interpretata, grazie anche ad una datazione OSL del deposito di versante che vi si sovrappone, come ereditata da una precedente fase interglaciale.

TERMINI CHIAVE: Costa rocciosa; Cartografia geomorfologica; Piattaforma in roccia; Italia.

INTRODUCTION

Research on rock coasts is currently experiencing renewed interest from geomorphologists concerned with coastal studies. One of the most investigated topics is the origin and evolution of shore platforms; debate remains about the relative contribution of wave action, weathering and the effect of tides on the formation of shore platforms (Stephenson & Kirk, 2001; Trenhaile, 2002). Studies on shore platforms have traditionally been constrained in areas where such morphologies are widespread and well-developed, such as in Australia, New Zealand and the coastline around the Northern Atlantic Ocean (for references see Trenhaile 2004; Thornton & Stephenson, 2006).

It is also important to determine whether or to what degree rock coasts and related landforms (such as shore platforms or cliffs) are contemporary or a legacy of Quaternary glacial and interglacial stages, when sea level and climate were quite different or similar to today, respectively. As Trenhaile (2002) stated, this is an important and dif-

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ficult challenge, due in part to the difficulty of measuring and observing rock coast evolution, because of very slow rates of change and the common lack of datable sediments in these erosionally dominated features.

Theories and models of shore platform development (Trenhaile, 1980, 1987; Sunamura, 1992) have barely been applied to the Mediterranean rock coast, where plunging cliffs are typical and widespread. Research has been focused instead on marine terraces, considered evolutions of shore platforms in uplifting areas. We believe that it is important to study shore platforms in areas where they are not typical and not the most relevant morphology, and to discuss how inheritance might be the key for interpreting rock coast profiles that are intermediate between shore platforms and plunging cliffs. The concept of inheritance for shore platforms (Trenhaile 2002; Blanco Chao & *alii*, 2003), can be intended in its widest meaning as the result of the erosion of a surface that might have originally developed in an older morphoclimatic phase. In this sense, the topic of inheritance may be relevant in explaining the altitudinal displacement of marine terraces along the coast of Eastern Liguria (NW Italy).

In this paper, we focus on the coastline of Palmaria Island, a small island very close to the western promontory of La Spezia Gulf in the easternmost part of Liguria (fig. 1a). The coast of Liguria is characterized by alternating plunging cliff morphologies, landslide-dominated slopes, brief tracts of minor coastal plains and complex rocky profiles (Arozarena, 2006), of which some platforms are slightly elevated with respect to present day sea level. We provide a detailed mapping of the landforms of Palmaria Island, the most interesting of which are some slightly elevated rock surfaces developed along its coast, about the features and genesis of which some preliminary data are illustrated.

GENERAL SETTING

Palmaria Island, with two minor ones Tino and Tinetto, is the continuation of the western promontory of the La Spezia Gulf (Porto Venere Promontory) (fig. 1b), the easternmost margin of the Liguria rock coast. Palmaria Island has an area of about 1.65 km^2 and reaches its maximum altitude, 185 m a.s.l., on its western side.

The geologic setting of the western promontory of La Spezia Gulf and the three islands (fig. 1a) is the result of the tectonic history of this part of the Northern Apennines, a fold-thrust belt whose western portion formed during the collision of the Sardinia-Corsica microplate with the Italian peninsula in the Oligocene, characterized by compression followed by progressive extension. The Tuscan Nappe sequence outcrops in the Porto Venere promontory and Palmaria Island, with recumbent westward verging fold, dipping weakly towards the NNW (Federici & Raggi, 1975). In detail, the reverse flank of the fold appears in Palmaria Island, with the following rock types outcropping: limestones with dolomitic layers and veins, dolomite, marls and shales. The strikes of the rock strata are almost invariably NW-SE, while, because of the macro-and meso-scale folds, they tend to dip both west and east.

The tectonic framework of the La Spezia Gulf is complex and various fault systems cut the previous folded structure. The promontory of Porto Venere is the southwesternmost portion of the horst limiting the two adjoining NW-SE Vara and Magra Valley grabens, displaying a marked asymmetry with steep SW-dipping faults and low angle NE-dipping faults (Argnani & *alii*, 2003). A secondary system of NE-SW striking faults cuts the structure throughout the promontory.

On its western side, the Porto Venere promontory is cut by NW-SE-striking faults belonging to the fault system responsible for displacing the eastern Ligurian continental shelf. Seismic data indicate that nearshore the fault system cuts Upper Pleistocene deposits (Fanucci, 1978).

NW-SE-striking faults dipping NE, belonging to the principal system of grabens, outcrop along the western side and in the centre of Palmaria Island, while NE-SW striking faults, generally dipping SE, cut the rocks in the northern part. The south-western side of the island coincides with the NW-SE striking fault or fault system dipping towards the SW. This side is an almost continuous steep scarp, reaching an altitude of 100-150 m and plunging into the sea to a depth of 20 m.

Data on Quaternary vertical displacements of the coast of the Ligurian Apennine are scattered and variable. Abbate & *alii* (1994) used apatite fission-tracks in rocks collected in the Tuscan Nappe outcrops in the Porto Venere promontory to determine an exhumation rate for the La Spezia area of 0.7 mm/yr for the last 5 Ma. Federici (1980) used geomorphologic markers to state that the Porto Venere promontory uplifted since the middle Pliocene and has probably been stable at least since MIS 5.5 (Tyrrhenian).

Independent data on geodynamics of the chain derive from studies on marine terraces, which point to moderate uplift affecting the coast of Eastern Liguria (Federici & Pappalardo, 2006) with values decreasing since MIS 9 (Biagioni, 2008) to the Holocene (Chelli & *alii*, 2005).

The study area is affected by SE incoming waves (Libeccio waves). The sector of maximum fetch lies between Cap Corse and the d'Hyeres Islands (France), and has maximum values of 500 nautical miles. Annual percent frequencies of wind velocity and direction at Palmaria Island show that NE and SW winds dominate. Offshore waves with heights between 0.10 and 4 m have an annual frequency of about 70%. The presence of Palmaria Island causes important refraction of SW incoming wave crests, that are displaced in a S-N trend. Along the eastern coast, the sea bottom is shallower (the cliff foot reaches a depth of –10 m) and the transition from the cliff to the sea bottom is gradual.

The tidal range is very low (microtidal), not exceeding 40 cm with a semidiurnal regime.

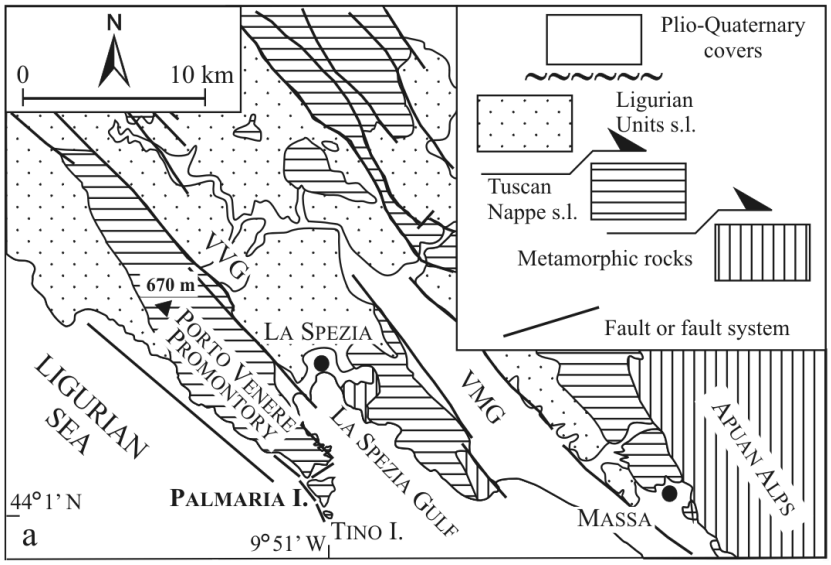

FIG. 1a - Geographical and geological sketch map of the Gulf of La Spezia (modified from Del Tredici and Perilli, 1998): VVG Vara valley graben, VMG Magra valley graben.

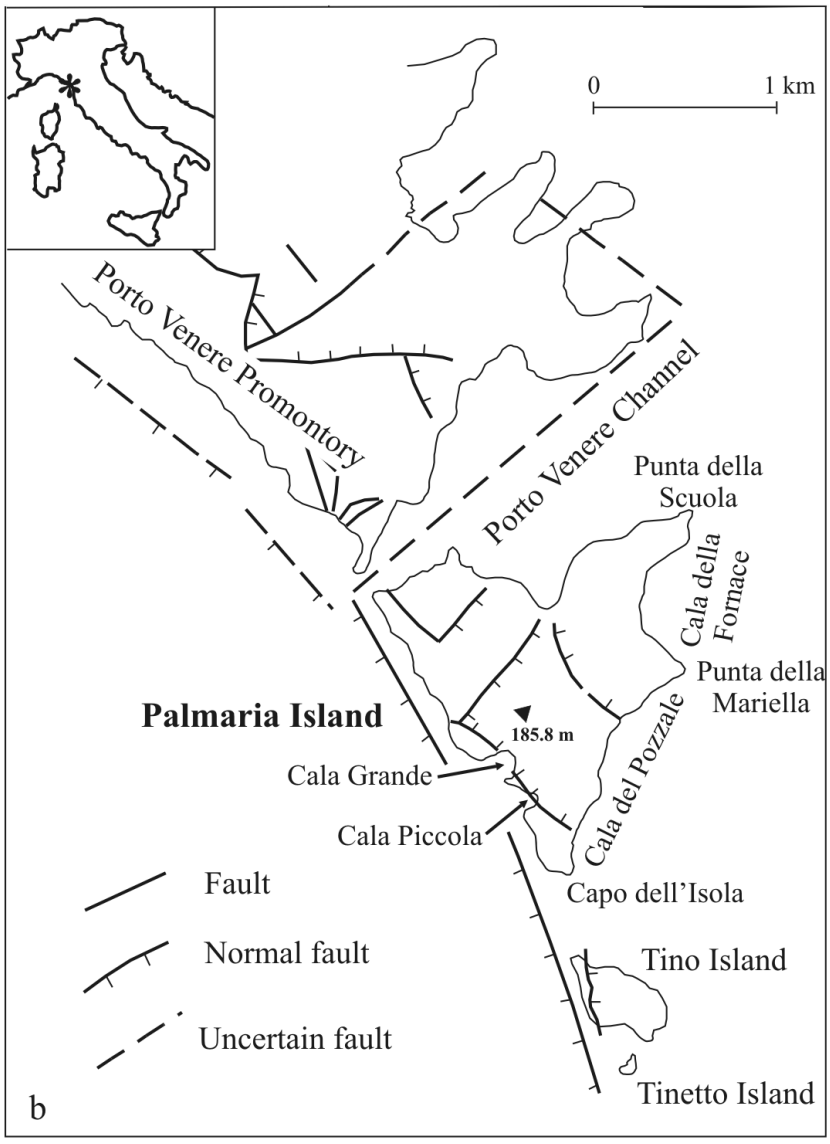

FIG. 1b - Geographical sketch map of the Palmaria, Tino and Tinetto islands showing also the faults of the area.

GEOMORPHOLOGIC FEATURES OF PALMARIA ISLAND

In fig. 2 are shown the main landforms mapped at Palmaria Island. The area is characterized by few presently active processes (i.e. wave and running water action) and by prevailing relict morphologies, typical of very different environments, which highlight a long term evolution of the area, mostly developed in conditions of sea level lowstand, when the island was linked to the Porto Venere Promontory. The Porto Venere Channel is shallow, deepening from east to west from 5 to about 20 m.

The geological structure exerts a tight control on major topographic features (e.g., the Porto Venere Channel is probably related to the NE-SW-striking faults, Carter, 1991) as well as on some elementary but most evident morphologies; the faults and fault systems recognized in the area display the same orientation as the structurally controlled landforms (coastline orientation, embayment axes, crests along the main island divides, stream network, structurally controlled scarps and saddles. More than half of the island coasts are made of active, wave-modelled rocky cliff. At the base of the structural scarps facing the open-sea of Palmaria and Tino Islands, as well as the southern coast of Tino Island itself, the crest of a wave-modelled cliff is evident as an undulating line not exceeding an elevation of 5 m a.s.l. Below the cliff crest, the slope profile is vertical and shows a smoothed concavity between +2 and –2 m in connection with sea level; within the tide range, molluscs, barnacles and algae encrust the rock. Along the south-eastern coast of Palmaria Island, the cliff develops north of Punta della Mariella at the base of a moderately steep slope (slope-over-wall profile), with a crest at 5 m a.s.l. All the cliffs are plunging, and their base is 10-20 m below present-day sea level. This reduces the pressure exerted by waves on the cliff face, as they do not break close to the coast; the water hammer effect is the only wave-induced process responsible for rock modelling. There is no evidence of uplifted cliff crests along the scarp above the level of present-day wave activity.

Slope profiles characterized by cliff-backed flat or gently dipping rock surfaces (rock platforms) or ramps can be found in the sheltered coves of the south-western and

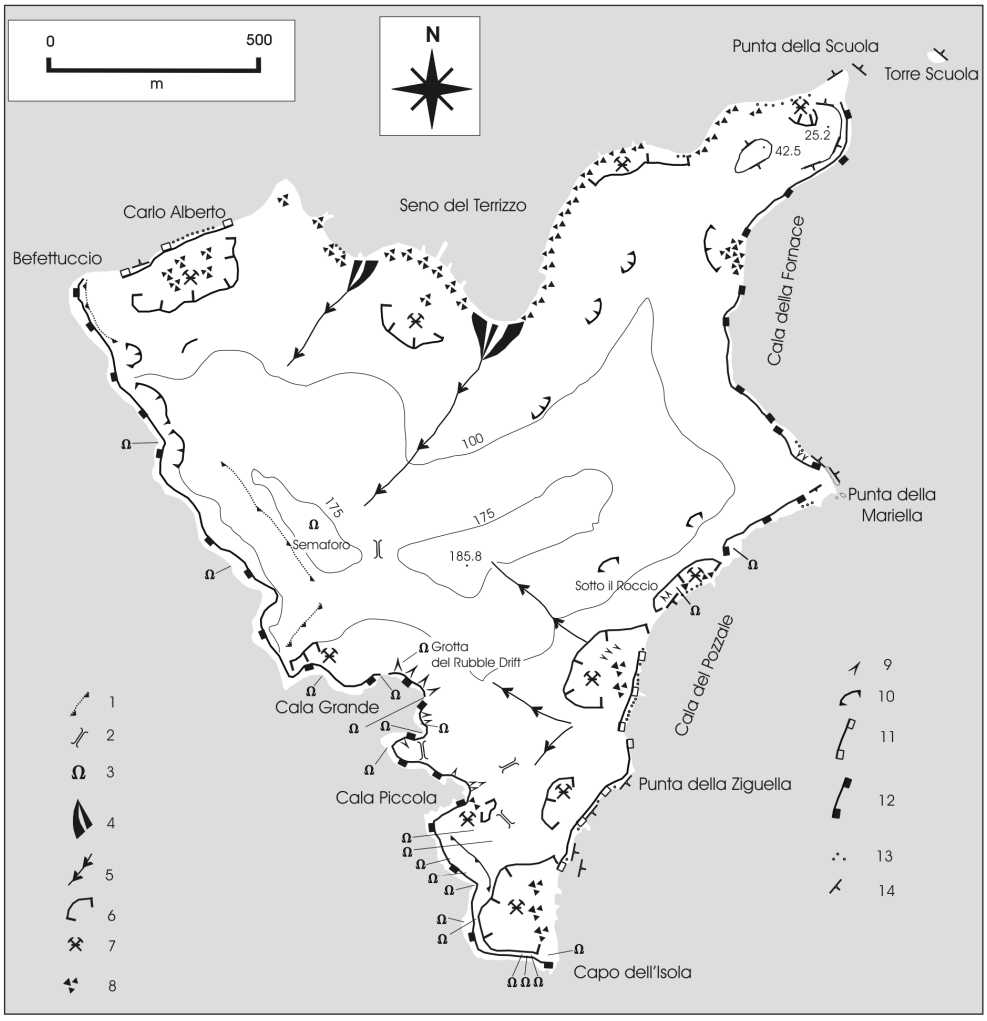

FIG. 2 - Geomorphological map of Palmaria Island: 1) edge of structural scarp; 2) structural saddle; 3) cave; 4) alluvial cone; 5) gully; 6) edge of quarry scarp; 7) quarry; 8) man produced debris; 9) scree slope; 10) edge of landslide scarp; 11) wave-cut cliff in the debris; 12) rocky cliff; 13) gravel beach; 14) rock platform.

eastern sides of the island, with moderate differences in elevation along different stretches of the coast.

In the Cala Grande and Cala Piccola coves rock platforms are raised between 4 and 6 meters above present sea level and are overlapped by stratified scree older than 38.5±1.8 Ka BP (Chelli & Pappalardo, 2006), beneath from which they are being exhumed by present-day wave action. The features of the scree slope are consistent with its formation during a period characterized by climatic conditions wetter and cooler than today's, as reported for the bordering coast of Tuscany around the LGM by Jaurand (1998) and for the period between MIS 4 and MIS 3 by Sarti & *alii* (2005). The rock platforms should therefor be considered not in equilibrium with present-day sea-level.

Along the eastern coast of Palmaria, another relict rock platform that is being demantled in current meteo-marine conditions can be reconstructed connecting sub-horizontal rock outcrops and rock ledges close to present-day sea level (fig. 3). Differences in the altitudes of various patches of the surface may reflect different responses of parts of the rock basement to coastal erosion. The most seaward part of the original platform is reresented by a wide shallow submerged platform along the eastern coast of the island. The continental scree that overlaps the platform at Cala della Fornace belongs to a cold climate phase in the Holocene (Chelli & Pappalardo, 2006). Nearby (Punta della Scuola headland) a staircase of two marine terraces was recognised, displaying their inner margins at 40 and 25 m a.s.l.

Beaches are moderately developed along the coasts of Palmaria. These are pocket beaches, developed in bays thanks to the presence of slope, alluvial or landslide de-

FIG. 3 - Different stretches of the eastern coast of the Palmaria Island. Photograph a) shows the cliff cut in the debris cover (1) overlying the inner part of the rock surface (2). Photograph b) shows the stacks in front of Punta della Ziguella. Photograph c) shows the coast just at north of Punta della Mariella where it is possible to recognize the rock surface (1), its inner margin below sea level (2) and the tracts of it covered by the sea (3) and by the pocket beach (4). Photograph d) shows Punta della Scuola with the pocket beach at the foot of the waste deposit (pale grey portion of the slope) and the cliff; in photograph d_1) the rock platform at the cliff foot and the stacks are shown.

posits at the back. In some cases quarrying activities contributed to beach nourishing (Chelli & *alii*, 2005), locally supplying rounded gravel that is the main component of these beaches.

Landforms due to gravity are common, especially along the steepest slopes facing the coast. These are recognized as presently inactive, apart from some degradation scarps and a few falls along the cliff. No great landslides occur now, testifying to present and past slope stability for mass movement.

A past phase of enhanced talus scree production left important relicts that have been partly dismantled by the sea or rehandled by quarrying. The slope at the back of most of this talus was quarried and deposition was in such cases more or less radically cut off and displaced to build quarry yards (e.g., the quarry of Cala del Pozzale and that between Carlo Alberto and Befettuccio). Their features and original extension are relevant to interpreting those platforms moderately elevated above present-day sea level, because in some cases these clearly overlap the rocky platforms.

A thick and continuous colluvium covers the inner slopes of the island, partly rehandled by agricultural terracing and presently inactive, thanks to vegetation cover. The most typical feature of this colluvium is that the fine material is generally reddish. This fact accounts for a phase in landscape evolution in which karst processes were responsible for chemical weathering and running water displaced weathered material. Colluvium mantle formation should have taken place during one or more interglacial stages during which karst processes were active, whereas talus formation should have occurred in a cold phase.

Past karst activity is testified to by the presence of many caves in connection with minor vertical faults. The presence of thick concretions on the cave walls, even in the smallest caves, and of multiple chambers in the biggest, indicates their karstic origin. Wave modelling is thought to be partly responsible for those at present partly or totally submerged, for the first few meters above the sea level. Their altitudinal distribution indicates a polycyclic activity of karst processes. The caves are located at different altitudes, concentrated within the first 50 m a.s.l. Almost one third of the caves have their floor within the range of –1 m and +1 m of present day sea level. As karst processes are presently inactive, this concentration might be the result of a past base level close to today's.

Two alluvial cones in Terrizzo Bay (northwestern side of Palmaria Island) must have formed in equilibrium with a base level close to present day sea level. These are located at the end of the two main gullies and have very flat surfaces; their extension is constrained to within a few meters below the sea level. The base level to which they are related may have been local, as they may have been flowing into a main river moving E to W in the present day submerged bottom of the Porto Venere Channel, in conditions of sea low-stand.

CONCLUSIONS

In this paper, we present the first modern detailed geomorphologic survey of Palmaria Island, after the general work on La Spezia Gulf by Federici (1987), in which we map and describe the coastline of the island. This work permitted us to interpret some slope long profiles as characterized by inherited marine morphologies. The reasons that led to our interpretation are:

– The presence of strips of a raised shore platform in different contexts along the coastline;
– The presence of scree deposits formed during MIS 3 overlapping shore platforms in the south-western coast.

The strips of shore platforms are at slightly different altitudes along the island coastline and are not in equilibrium with present-day sea level. They could be connected to a unique original shore platform developed along most of the island perimeter that was subsequently destroyed by enhanced backwearing and downcutting that occurred when sea level started falling, causing thousands of years of subaerial weathering. Portions are preserved in sheltered embayments where they were buried beneath periglacial scree along the south-western coast; they were later exhumed from beneath these deposits and gradually demantled.

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