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High-resolution morphometric analysis of the rocky coast of the Prebetic System (western Mediterranean)

Análisis morfométrico de alta resolución de la costa rocosa del Sistema Prebético (Mediterráneo occidental)

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Abstract

The rocky coast of the Prebetic System (southeast Iberian Peninsula) presents a marked tecto-structural control and by subaerial processes. The objective of this study is the morphometric characterization of this rocky coast. The analysis of the digital elevation model (2x2 m grid resolution) obtained from LIDAR, combined with the geological map, field work and review of previous studies, allows the identification and morphometric characterization of 271 geomorphological units, which mainly include stretches of high or medium cliffs, intercepted by numerous gullies (some of them hanging), stretches of low rocky coastline associated in many cases with Upper Pleistocene (5e) coastal deposits, and coastal plains of fluvial valleys, as well as some coastal lagoon, tombolo, islands, alluvial fan and a arheic basin. The high and medium cliffs show a smoothed profile in their upper section, evidencing the action of fluvial runoff and karstic erosion. The erosive action of waves is evidenced mainly in the formation of shore platforms, mapped and their minimum area determined from satellite images.

Keywords: *Geomorphology, cliff, shore platform, gully, island, LIDAR.*

Resumen

La costa rocosa del sistema prebético (sureste de la Península Ibérica) presenta un marcado control tecto-estructural y por los procesos subaéros. El objetivo de este estudio es la caracterizacíon morfométrica de esta costa rocosa. El análisis del modelo digital de elevaciones (resolución de malla 2x2 m) obtenido a partir de datos LIDAR, combinado con el mapa geológico, trabajo de campo y revisión de estudios previos, ha permitido identificar y caracterizar morfométricamente 271 unidades geomorfológicas, que incluyen principalmente tramos de acantilados altos o medios, interceptados por numerosos barrancos (algunos de ellos colgados), tramos de costa rocosa baja asociada en muchos casos a depósitos costeros del Pleistoceno Superior (5e) y planicies costeras de valles fluviales, así como también alguna laguna costera, tómbolo, islas, abanico aluvial y una cuenca arreica. Los acantilados altos y medios muestran un perfil suavizado en su tramo superior, evidenciando la acción de la escorrentía fluvial y erosión kárstica. La acción erosiva del oleaje se evidencia principalmente en la formación de plataformas de abrasión, cartografiadas y determinada su área mínima a partir de imágenes de satélite.

Palabras clave: *Geomorfología, acantilado, plataforma de abrasión, barranco, isla, LIDAR.*

1. Introduction

The geomorphology of rocky shores is controlled by their lithology, structure and the gravitational, fluvial, karstic and marine processes. New remote sensing techniques make it possible to obtain high-resolution mapping. In particular, LIDAR makes it possible to cover large areas of the territory. The aim of this study is the morphometric characterization of the rocky coast of the Prebetic System in the southeast of the Iberian Peninsula, based on high-resolution topography obtained with LIDAR.

2. Study area

The study area covers the coastal outcrops of the Prebetic System in the southeastern Iberian Peninsula (Fig. 1). The Alpine orogeny that affected shallow platform environments determines the predominant presence of limestone and marl rocks. This orogeny explains the presence of its mountain ranges and coastline, as well as the main folds and faults, some with neotectonic activity (Rey and Fumanal, 1996; Estévez et al., 2004). Precipitation is more intense in the northern zone. The coast shows a microtidal regime, with bidirectional waves of moderate energy.

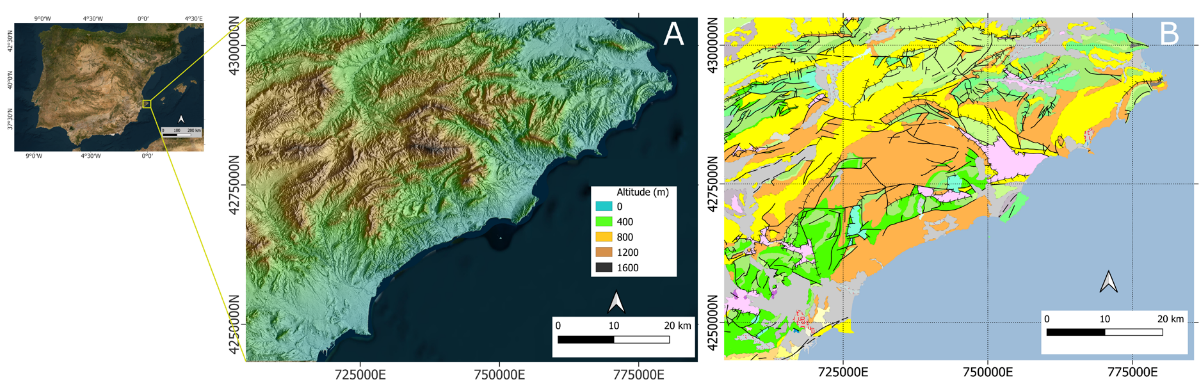

Fig. 1 *Study area. Digital elevation model and geologic map (ETRS89 UTM 30S; Source: Inst. Cartográfico de Valencia)*

3. Material and methods

The characterization of the relief has been obtained from the high-resolution topography of the emerged zone provided by the ICV, measured with LIDAR (2009) by the PNOA and with a grid size resolution of 2x2 m (Fig. 1A). The topographic curve of 0.25 m above mean sea level (a.m.s.l.) has been defined as the shoreline, as it was not possible to identify the curve of 0 m a.m.s.l. Other analyzed shorelines were discarded as they showed inconsistencies. Lithology and geological structures (faults, folds) have been obtained from geological cartography (1:350,000 and 1:25,000) elaborated between the Instituto Geológico Minero of Spain and the Instituto Cartográfico of Valencia (ICV) (Fig. 1B), field work, and review of previous studies (among others, Sanjaume, 1985; Blázquez Morilla, 1998; Blázquez Morilla et al., 1996, Rey et al., 1999, Tent et al., 2024). The geomorphological units have been obtained considering the division of the fluvial basins (rivers and gullies) and cliffs, as well as the different lithologies and geological structures. After delimiting the geomorphological units, their slope map has been obtained. The current marine abrasion platforms have been identified and delimited from the most recent satellite images available in Google Earth, as they have better resolution than the orthophotos of the IGN, ICV and other data sources analyzed. All the cartography has been generated in the ERTS89 UTM zone 30, projecting the easternmost part of the area to this system.

4. Results and discussion

The littoral is articulated with an alternation of wide rocky headlands and bays, in which some rocky sections also outcrop. The fragmentation of the cliffs in numerous sections due to the intersection of the gullies stands out. A total of 271 geomorphological units have been identified and delimited, grouped into 18 sectors, most of which correspond to stretches of cliffs and gullies; stretches of low rocky coast, alluvial plains, coastal lagoons, tombolos, islands and an arheic basin have also been identified (Fig. 2). Abrasion platforms are not included in this calculation.

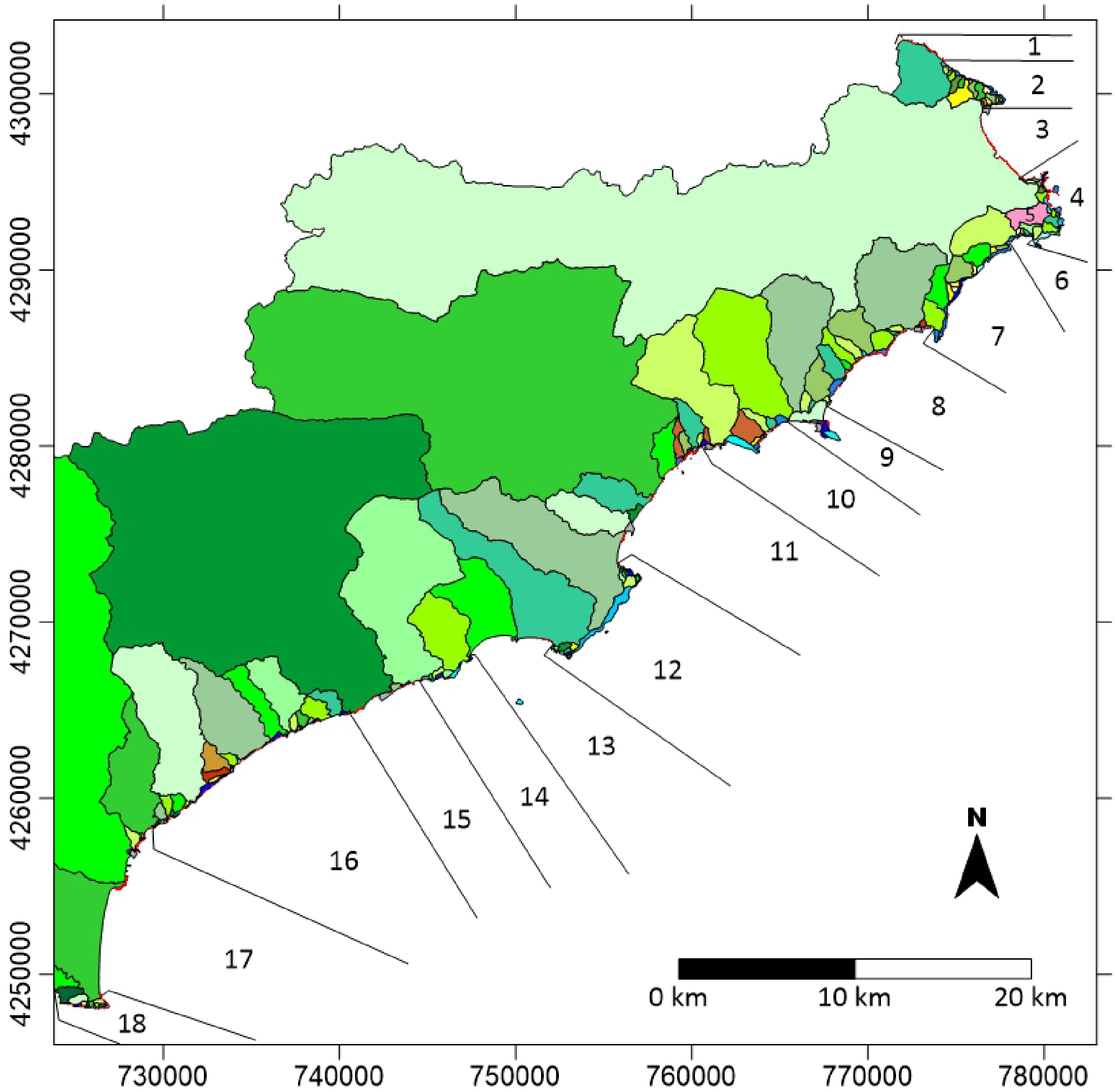

Fig. 2 *Sectors and geomorphological units. The units include cliffs and low rocky coast (blue colors, or purple if inactive due to harbor construction), shore platforms (red), river basins (green colors, yellow if their mouth is overhanging, or brown if they flow into a harbor). The location of the arheic basin (sector 5, pink color) and harbors (gray color) are also indicated.*

The highest cliffs are located in Gelada Range, Toix Promontory and Ifach Rock. Some sectors have stretches with vertical cliffs associated with faults (Gelada Range, Toix Promontory), olistoliths (Ifach Rock) or dolines (San Antonio Cape), with no wave action determining their formation. Most of the cliffs, high or low, show a lower slope in their upper zone, as a result of the action of subaerial agents; therefore, the average slope of no sector exceeds 50º (Fig. 3, Table 1).

The seaward-dipping cliffs show profiles with gentle slopes, but those with the opposite dip show stepped rather than vertical profiles, evidence of the importance of subaerial processes and the existence of strata of different hardness (e.g. at Moraira Point). Structural control is also evident in that the straightest rocky coastal section is associated with folding axes parallel to the coast, south of Villajoyosa City.

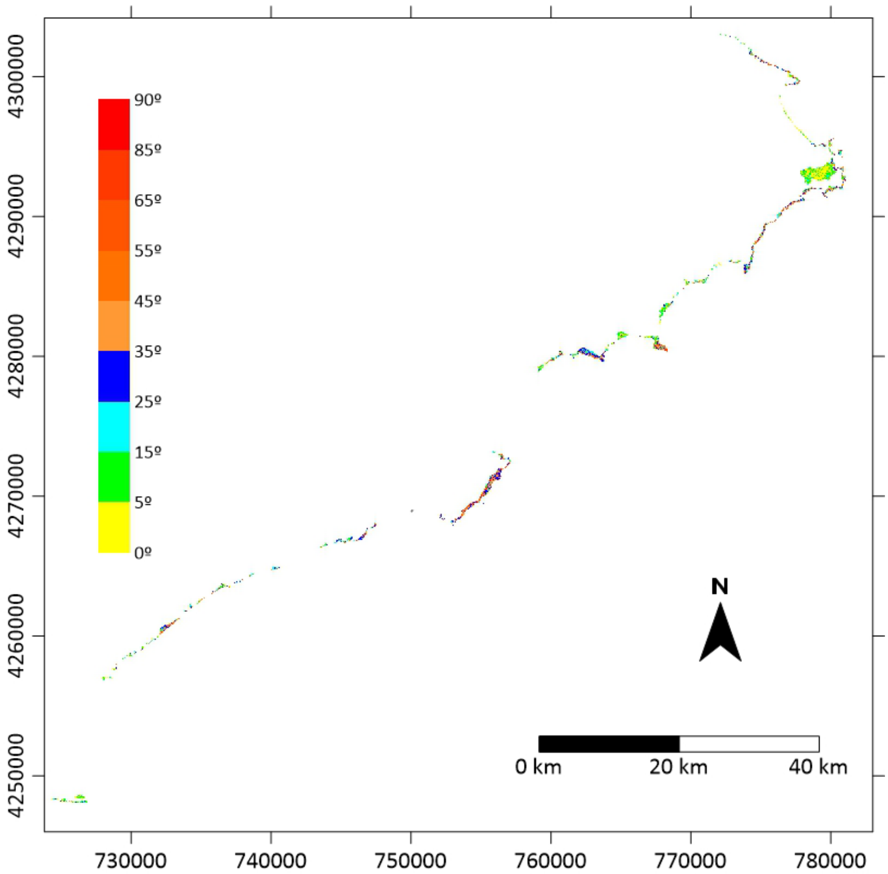

Fig. 3 *Slope map of the rocky coast and the arheic basin (sector 5) units.*

Tabla 1. *Morphometric characterization of the rocky coast sectors. Due to its complexity, sector 9 has been divided among units 9A Ifach Rock, 9B hillside deposits, and 9C Upper Pleistocene eolianites. The area of lagoons and coastal plains is included in that of the river basins that drain into each coastal sector.*

Sector	No. of rocky coast stretches	No. of islands	Total area (km^2)	Area of shore platforms (km^2)	Max. Altitude (m)	Average slope (º)	Max. slope (º)	Area of fluvial basins (km^2)	No. of hanging wallies
1	1		0.05	0.17	12.24	12.10	70.60	8.43	
2	11		0.57	0.02	168.47	35.59	88.61	3.49	6
3	2		0.12	0.33	5.24	5.01	48.14	440.01	
4	13	3	1.10	0.34	150.84	33.37	88.29	1.77	
6	3		0.19	0	155.32	37.24	85.94	6.20	2
7	7		1.10	0	196.85	38.57	87.99	5.92	5
8	12		0.89	0.39	67.73	15.69	84.97	30.46	
9A	1		0.27	0	326.26	49.24	89.17		
9B	3		0.40	0.05	148.77	20.95	75.40	48.80	
9C	4		0.04	0.01	13.91	9.36	62.43		
10	7		1.30	0.13	340.71	27.42	86.92	23.83	2
11	7	2	0.23	0.37	80.90	18.27	82.93	255.47	
12	10	1	1.73	0.03	432.82	41.51	88.23	1.35	2
13	2	1	0.07	0.07	71.68	21.39	76.97	39.86	
14	4		0.42	0.03	146.77	29.49	86.14	10.03	
15	1		0.06	0.14	48.13	19.07	76.17	268.50	
16	26		1.04	0.31	198.96	27.30	83.08	76.84	5
17	3		0.13	0.30	25.92	12.91	69.10	526.32	
18	9		0.38	0.17	57.79	11.72	69.06	1.67	

There are also several sectors with low rocky coast (maximum altitude < 15 m), which mainly correspond to Upper Pleistocene cemented coastal deposits located in the coastal plains (Sectors 1, 3, 9C, 11 and 13). The erosive action of waves is manifested in the formation of shore platforms, mainly located in these Pleistocene deposits, as well as at the base of the marl cliffs. There are also numerous stretches of medium cliffs with marl lithology at the base of which small beach deposits are formed, mainly on the coast of Villajoyosa, which gives these cliffs an inactive character for most of the year. Finally, the waves also form notches in the vertical cliffs of more competent rocks, as is the case of the Ifach Rock and Toix Promontory.

Several studies have questioned whether the plains west of San Antonio Cape and between San Martí Cape and La Nao Cape are marine terraces or continental formations (Dumas, 1977, López-Gómez and Roselló, 1978). Coinciding with the opinion of Cavanilles (1797) and Sanjaume (1985), the present morphometric analysis, based on high-resolution topography, shows that they are not marine terraces. Thus, in the plain at the base of the Montgó Mountain there is a doline in the central area and a hanging valley on the nearby coastline, also due to karstic subsidence processes. There are also two coves just west of Cape San Antonio associated with the collapse of dolines, with small hanging valleys at the top. To the west of Cape San Martín, the area of gentle slopes (mean slope 5.87º) corresponds to a 2.2 km^2 arheic basin where a doline has formed, with a minimum altitude of 88 m a.m.s.l. in the interior and a peripheral altitude ranging between 99 and 166 m a.m.s.l., surrounded by mountainous elevations (Fig. 4a). Also associated with karst processes, there are numerous caves on the shore of different sectors of resistant lithology (limestone) in the northern half of the study area, but it is not possible to identify them in the topography obtained by LIDAR.

The river courses intercepting the cliff sections show drainage networks ranging from linear to bifurcate and dendritic. The headwaters of the gullies are located in the vast majority of cases further inland than the headwaters of the cliffs. The mouths of most of the gullies reach the current coastline, but some of them appear as hanging gullies. The upward erosion at the head of some gullies with parallel drainage networks to the coastline or dendritic drainage networks also generates erosion of the upper part of the cliffs from the landward side (Fig. 4b). Gullies are therefore a very important erosional agent in the evolution of this rocky coast.

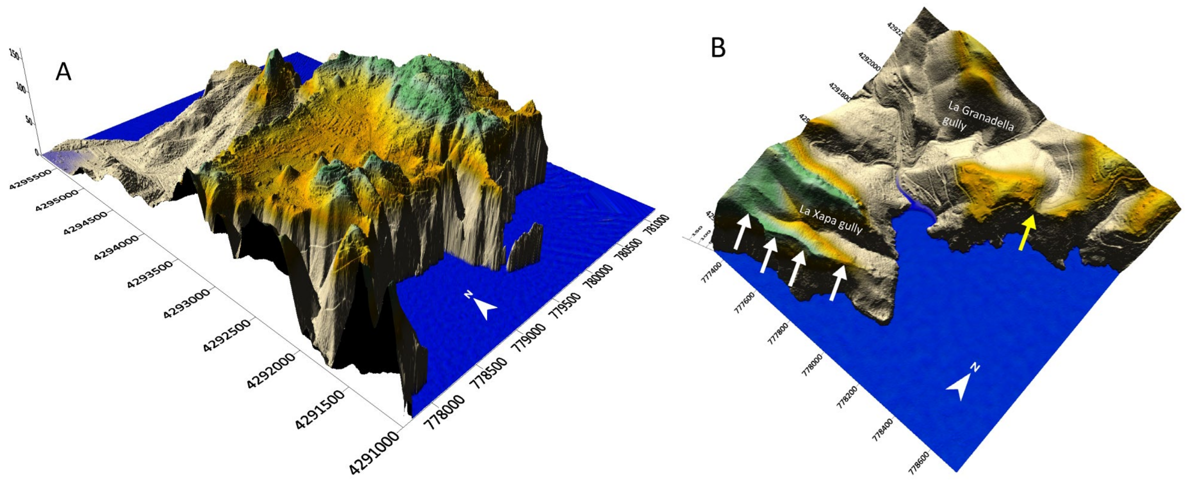

Fig. 4 *Karstic and fluvial runoff processes. A) arheic basin surrounded by mountains, excluding the possibility of a marine terrace, B) valley parallel to cliff top in La Xapa gully (white arrows) and head of La Granadella gully (yellow arrow).*

The formation processes of the islands are generally clear. For example, the Portixoll and Berganti islands are the result of differential erosion, while Peñas de Arabi and Benidorm islands are associated with blocks sinking by faults. The Benidorm and La Olla islands are also located at the top of the dividing line between two river courses, currently submerged due to the high sea level in the current Holocene interglacial. On the other hand, the origin of El Descubridor Island is more uncertain. This island has an elongated shape (maximum length 333 m, area 2.25 ha, maximum height 58.44 m). The present small strait (minimum width 21 m) that separates it from the continental promontory is probably the result of subaerial erosion during periods of lower sea level (Sanjaume, 1985). However, the orientation of the island (N110ºE) is different from the nearby coast, with very vertical slopes up to 30 m deep and then a large area (minimum length 1.5 km) of very low slope up to 35 m deep. Therefore, its formation may also be related to the fall of a block or an unidentified fault.

Urban occupation is high in many areas, reaching in many cases to the very top of the cliff. Some marinas are located at the mouth of gullies and others have caused some sections of cliffs to become inactive. In addition, the construction of numerous roads modifies the drainage network of the basins, with possible repercussions during floods.

5. Conclusions

The cliffs show in their topographic profile the action of both subaerial and marine agents, as well as lithological and structural control. Tectonics marks the general alignment of the coast. The straight stretches are controlled by folds (Villajoyosa) or faults (Toix Promontory, Gelada Range). The highest heights are located in sections with high tectonic control (Gelada Range, Toix Promontory, and Ifach Rock). The entire rocky coast shows a great deal of erosion by subaerial processes (surface runoff and karstic processes), with numerous gullies and smoothed profiles in the upper part of the medium or high cliffs, while in the bays (e.g. Javea, Altea) there remain small stretches of low rocky coast, in many cases associated with cemented deposits from the Upper Pleistocene. The gullies produce an intense fragmentation of the cliffs and in some valleys parallel to the cliff or with dendritic networks there is even cliff top back erosion. At San Antonio Cape and west of San Martin Cape there are no marine terraces, but their morphology is associated with the predominance of karstic processes. The formation of the caves is mainly associated with endokarst processes, rather than wave action. Shore platforms are mainly located in areas with Pleistocene biocalcarenite or marl deposits. The origin of some islands is associated with the block sinking by fault planes (Benidorm and Peñas de Arabi islands), they are vestiges of the dividing line between contiguous riverbeds now flooded by the high interglacial sea level (Benidorm and La Olla islands), or the result of differential erosion (Portixoll and Bergantí islands).

6. Acknowledgements

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