Chapter 2
The Rocky Coasts of Northwest Spain

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2.1 Introduction

The coastline of Galicia is more than 2100 km long (POL Galicia 2010) (Fig. 2.1). Two broad types of coast can be differentiated in the region: zones with rías and zones without rías. Marine inlets dominate in the former, whereas rectilinear stretches dominate in the latter and only small coves or estuaries occur. The megaforms of coastal relief in northwest Spain are clearly determined by the tectonic structure, whereas lithological differentiation has played a predominant role in the genesis of meso and microforms (Pérez-Alberti and Blanco-Chao 2005). In general, different factors are involved in shaping the coastline: the overall structure is determined by tectonic processes; the lithology causes differential erosional processes that define the broad features of the coastal front; and, finally, the succession of geomorphological processes that have taken place over time have determined the specific forms and distribution of the different environments. In addition, human activity has affected many areas, particularly the low-lying coastline.

The Galician coast is classified as mesotidal, with a mean tidal range of 2.5 m and a maximal range of around 4 m. According to Davies (1972), the tidal regime occurs in the transition zone between areas mainly affected by swell waves and those affected by storm waves. The swell waves mainly arise from the northwest and less often from the west and southwest. High waves (>3 m) mainly occur in winter and are generated by depressions moving from northwest and western directions. The largest waves have been recorded at Cabo Vilán (13.5 m in 2009), Estaca de Bares (2.9 m in 2008) and Cabo Silleiro (12.01 m in 2014).

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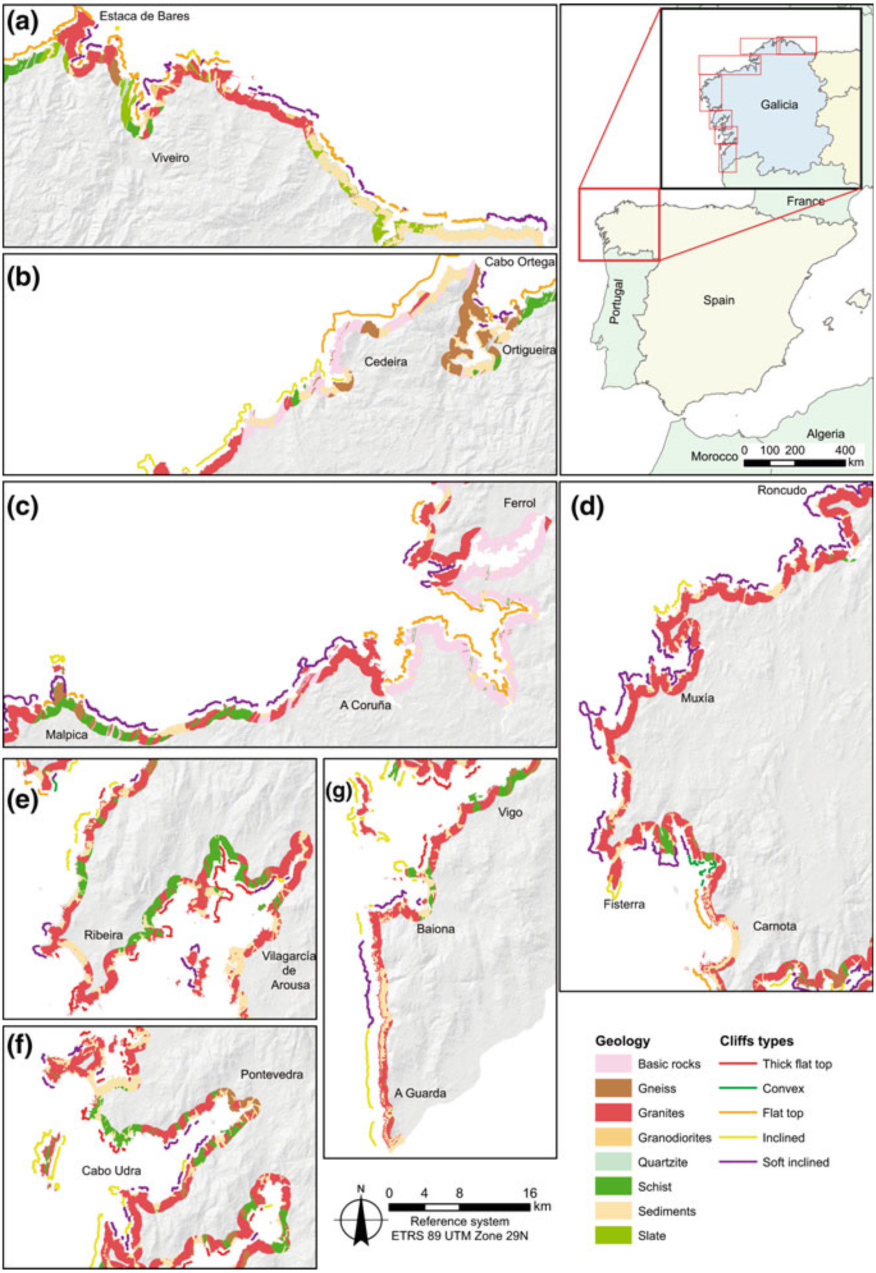

Fig. 2.1 Lithological map and types of cliffs on the Galician coast

2.2 Structural and Lithological Control of the Genesis of Rocky Coasts

The structure of coastal landforms is closely related to the geotectonic evolution of Galicia and can be observed at different scales, ranging from megaforms, which demarcate the overall design of the coast, to microforms, which introduce subtle, small-scale differences. The structural configuration of Galicia in general, and of the coast in particular, is the result of a complex evolutionary process characterized by the overlapping of two orogenic cycles: the Variscan and the Alpine orogenies. The first gave rise to a group of paleozoic rocks originating between the Precambrian and the Upper Carboniferous and whose structure is marked by the effects of the Variscan orogeny, although some structures were altered during the Alpine cycle, giving rise to the Cantabrian Range (Alonso et al. 1996).

Generation of an intense fracture network led to compartmentalization of the coast and the genesis of a sawtooth design with numerous inlets and outlets. Obviously not all of the structures are related to the fracture network as the lithological banding also introduces differentiating elements derived from the presence of different types of rock and as a result of this, differential weathering processes.

A large part of the Galician coastline is formed on granitic rock, although other types of rock appear in some areas (Fig. 2.1). This is the case of the basic and ultrabasic rocks that dominate in the Cabo Ortegal Complex within the Serra da Capelada, and of the slates and schists in the surroundings of the Ría de Ortigueira and the northern part of the Ría de Vigo. Thus, the type of rock, its mineralogical composition and degree of fracturing are, along with the degree of weathering, of vital importance in shaping the coastline. For any scale of analysis, the arrangement of the rocky outcrops establishes many of the lines traced by vegetation on the coast and, similarly, may establish a relationship between the shape of the vertical profile and the structural arrangement of the materials. However, the effectivity and action of the erosive processes not only depend on the type of rock, but also on the geometry and on patterns of discontinuities, which establish lines of weaknesses that favour erosion (Trenhaile 1987; Sunamura 1992).

2.3 The Coastal Cliffs

Sea cliffs are understood to comprise rock faces that occur at the edge of the sea and that are directly or indirectly affected by wave dynamics. However, the multiple factors involved both in the past and at present make it very difficult to generate a clear, unequivocal classification of cliffs. The shape of a cliff is the result of interactions between diverse variables: geological, climate, oceanic and biogeographical, together with the depth of the water and the amount and type of base material, the topography of the cliff surface and changes in height relative to sea level. As a result of the combined actions of these factors, the cliff profile is related to erosion by marine or subaerial agents and the time during which these operate (Emery and Kuhn 1982). Cliff profiles are therefore determined by the interaction between marine and terrestrial processes, the influence of which is more closely related to the relative than to the absolute effectivity, i.e. there is no dominant process but rather a balance between processes, which together determine the dynamics that shape the profile.

Marine erosion includes abrasion processes, weathering, mechanical attack and biological activity. In turn, the effects of marine erosion also initiate other processes, such as mass movements, which may also occur as a direct result of terrestrial factors. Littoral morphogenetic processes are therefore not linear in nature and are not accumulative but vary in accordance with the existing system (Cowell and Thom 1994). Although these processes may act at the same time, overlap or occur in spatial juxtaposition, they may also give rise to temporal succession. Thus, although the profiles of many cliffs are inherited, they are continually being affected by other phenomena. Most cliffs can therefore be characterized as polygenic forms.

Cliffs can therefore be differentiated by their shape, the dominant type of rock, the composition of the cliff base, the height, slope and orientation and the degree of stability. The number of types of cliff will therefore depend on the number of analytical elements considered.

2.4 Classification of Galician Cliffs by Their Shape

Analysis using a Geographic Information System (GIS) tool including a 2 and a 5 m Digital Elevation Model (DEM) and an orthophoto of spatial resolution 0.25 m, together with field validation of the data has enabled differentiation of 3 broad categories of cliffs. These also include numerous slight differences at local levels. The main categories are (a) cliffs with convex or concave slope; (b) flat-topped cliffs with no associated posterior plain; and (c) flat-topped cliffs with associated posterior plain.

The profiles shown in Figs. 2.2 and 2.3 were constructed using a DEM of spatial resolution 5 m, except for those in Figs. 2.2(9) and 2.3(3), which were constructed using a 2 m DEM to enable more detailed analysis of the shapes of these sectors. Different elevational and longitudinal scales were used to improve the accuracy of representation of the morphological characteristics of the cliff profiles.

2.4.1 Cliffs with Convex or Concave Slopes

These cliffs have a profile with two well-differentiated segments: a basal escarpment or sea cliff and an upper slope that tends to be either convex or concave, depending on the form, height and slope of each of the segments. Although all authors

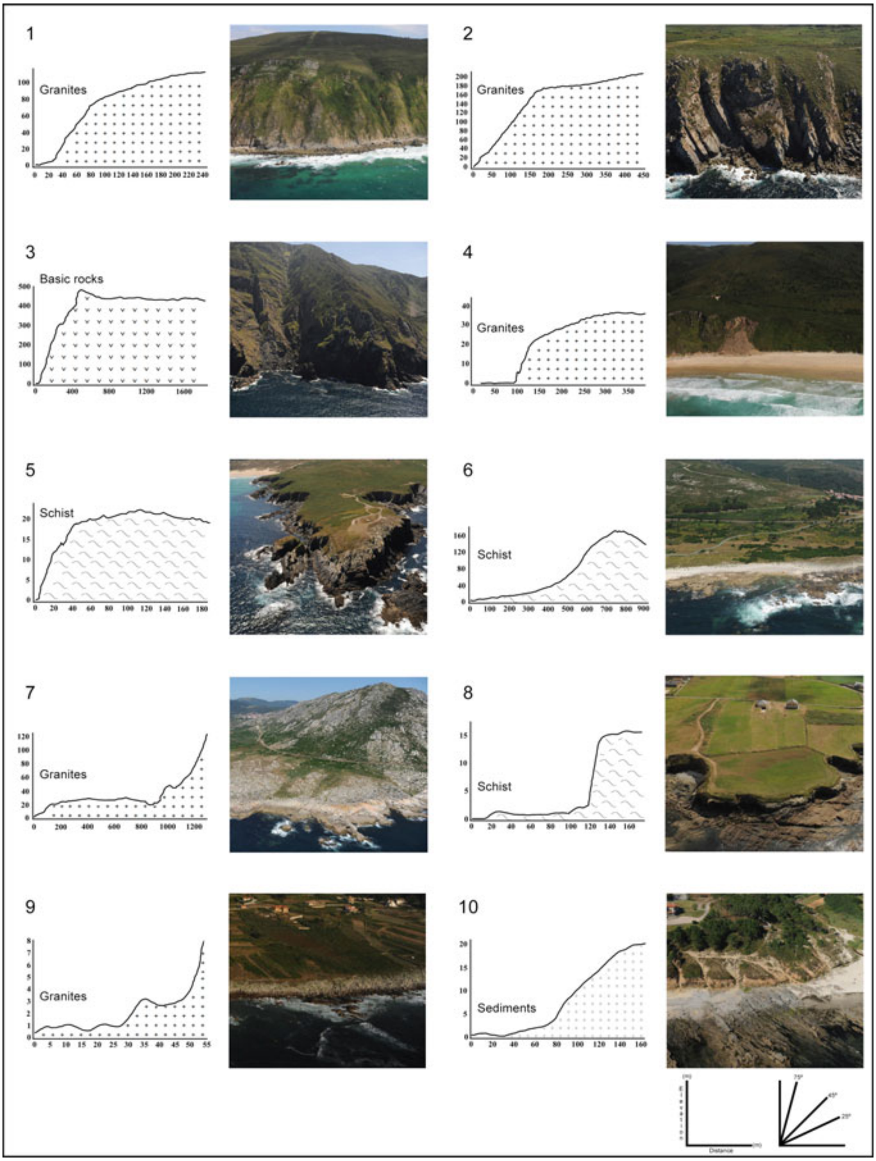

Fig. 2.2 Types of cliffs and associated profiles (I)

generally consider that these cliffs are recent forms, opinions about their origin vary. Cliffs are thus considered to be the result of the synchronous interaction of subaerial and marine processes, but are also viewed as undulating relief with gentle slopes, shaped under continental conditions and later attacked by the sea (Guilcher 1954). Emery and Khun (1982) consider that the compound-type profiles, with

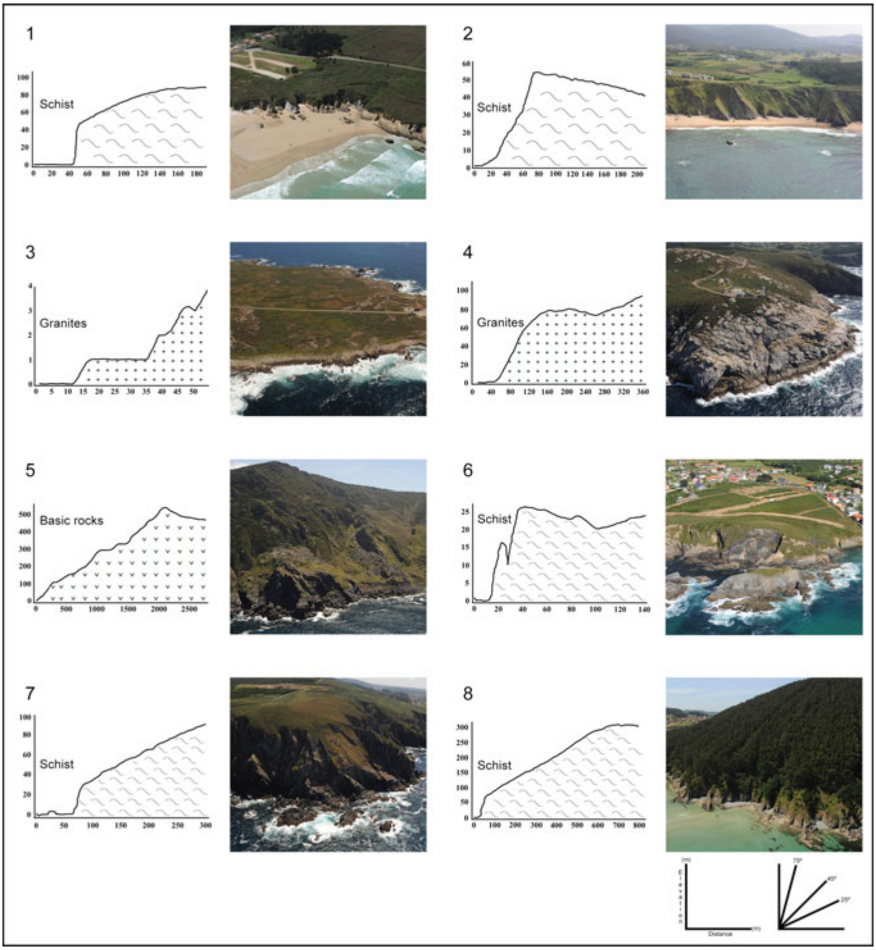

Fig. 2.3 Types of cliffs and associated profiles (II)

convex upper slope, merely reflect a predominance of subaerial processes that are more closely related to the resistance of the rock than to the temporal succession of different types of climate. The scheme proposed by Trenhaile (1987) suggests that the shape of a cliff depends on the balance between subaerial and marine processes, mainly due to the variations in sea level, as a consequence of climate variations during the Quaternary.

It is also possible to differentiate between cliff slopes with steep gradients (Fig. 2.2(2)) and those with gentle gradients (Fig. 2.3(8)). Concave (Fig. 2.2(4)) and convex (Fig. 2.2(6)) slopes can also be distinguished. These types of cliffs and profiles are mainly associated with granitic rock, in the case of the concave profiles, and with schists, as observed in the profile used as an example of a convex form.

These types of cliffs are widely distributed along the Galician coast, between the Rías Baixas in the south and Ferrol in the north (A Coruña).

2.4.2 Flat-Topped Cliffs Without Associated Plain

Sea-facing slopes vary greatly, ranging from almost horizontal flanks to slopes of less than 20°. The profile may also be concave or convex and is therefore somewhat similar to the previous category. The difference lies in the existence of a small plateau in the upper part of slope less than 8°, which does not favour continental dynamics and therefore a marine influence is essential.

This type of cliff is represented in Fig. 2.3(6) and is characteristic of zones where schists dominate, as in northern coastal areas such as Valdoviño (A Coruña).

2.4.3 Flat-Topped Cliffs with Associated Plain

These cliffs are associated with wide inland plateaus. These plateaus have traditionally been considered ancient marine features. The best examples of this is the Rasa Cantábrica. However, apart from the obvious difficulties in explaining the conditions necessary for shaping a coastal platform, of more than 1000 m, there is also no erosive (grottos/caves, paleocliffs, potholes etc.) or sedimentary (beach) evidence. These plateaus may therefore correspond to ancient, flattened continental surfaces that are currently beside the sea.

The profile of these cliffs varies depending on the location, ranging from almost vertical (Fig. 2.2(8)) to gentle slopes (Fig. 2.3(5)). This, along with the lithology or degree of fracture has a greater influence on the dynamics than the existence of large surfaces, as flat surfaces dissipate the energy of the continental waters, favouring the influence of wave action on cliff evolution. The best examples of this type of cliff is found in areas dominated by schists and where the predominant material is classified as basic or ultrabasic rock. The most representative examples of these cliffs appear in eastern Galicia, on the Cantabrian coast.

2.5 Classification of Cliffs by Height and Slope

Guilcher (1954) classified sea cliffs on the basis of height as follows: low cliffs (less than 2 m), medium cliffs (between 2 and 10 m), high cliffs (more than 10 m), and mega-cliffs (higher than 500 m). Bird (2008) used the same terms for cliffs higher than 500 m, but applied the term high cliffs to those of between 100 and 500 m. These classifications are theoretical and do not have a clear empirical basis.

Table 2.1 Relationship between elevation and cliff slope on the Galician coast

Slope \ Elevation	0	< 50	50-100	100-150	150-200	200-250	250-300	> 300
0	5.79	93.88	0.25	0.05	0.01	0.01	0.00	0.00
< 4	0.00	88.39	8.32	2.16	0.69	0.29	0.06	0.10
4 - 8	0.00	70.09	20.16	6.05	2.12	0.66	0.29	0.63
8 - 16	0.00	47.15	31.29	13.24	4.84	1.80	0.76	0.92
16 - 32	0.00	31.25	30.39	20.30	9.86	4.43	2.09	1.69
32 - 64	0.00	43.06	20.22	10.79	7.26	5.56	4.73	8.38
> 64	0.00	18.73	37.48	19.78	9.89	4.24	1.77	8.12
Total	0.87	67.42	18.04	7.78	3.19	1.32	0.62	0.76

The red colors are the highest percentages and the green colors indicate the lowest values

Examination of the Galician coastline, in this case using a DEM of spatial resolution 5 m, indicates a predominance of low-lying cliffs, also with low slopes (Table 2.1). For example, 94% of the cliffs lower than 50 m have a slope of less than 4°. However, 8% of the higher cliffs have slopes higher than 64°. It appears evident that the importance of higher slopes increases with increasing elevation.

2.6 Classification of Cliffs on the Basis on Lithology

2.6.1 Cliffs Formed by Granite Rock

The composition of granite is not uniform and granite rocks do not all respond in the same way to weathering processes. Two mica fine-grained granite may give rise to very different forms than those formed by granodiorites and coarse-grained granite. There is not, therefore a clear relationship between the type of granite and the cliff profile. The degree of fracturing is also important. Rectilinear cliffs tend to be abundant in sites where the granite rocks are associated with intense fracture networks. When flat surfaces occur towards the interior, flat-topped cliffs or with a gently sloping posterior plateau are formed. By contrast, when the relief is more abrupt, with steeper slopes and a higher degree of weathering, the cliffs tend to be sub-vertical, with numerous signs of detachments and landslides. Cliffs formed on granodiorites are usually curved and covered by boulders.

A third element to consider is the height of the profile. The change in height of a cliff and profile may increase the area and slope of the basin that receives water, leading to a higher concentration of moisture in the upper part of the seaward slopes. This explains the presence of detachments associated with hydrostatic overloading and the existence of accumulations of boulders at the cliff base. The change in energy as a consequence of changes in the sea level will influence the importance of marine processes.

Rock weathering should not be overlooked as in intensely weathered zones with abundant detachments, the cliffs are undulating, with circular inlets and significant changes in vegetation cover. The presence of weathered material and numerous fractures enables water to penetrate and saturate the soil, thus increasing the weight and favouring detachments at the cliff face. In cliffs formed on granodiorites, edaphogenic processes have given rise to differential weathering of the rock. The wave action causes gradual washing away of the weathered material, thus favouring the detachment of boulders or the in situ disinterment of forms carved in the rock interior. These weathering and/or disinterment processes cause the appearance of rounded, convex forms and of accumulations of boulders at the base of the cliff. When the erosion causes the disappearance of the weathering layer, the cliff landscape is characterized by large boulders.

Cliffs formed on granite rocks are widely distributed along the Galician coast. Those on the northern coast are particularly noteworthy (Fig. 2.1a, c), in contrast to those in areas of the southern coast between Cabo Silleiro and A Guarda (Pontevedra) (Fig. 2.1g) where the granite forms have less influence and are often found associated with accumulations of heterometric debris at the cliff base (Fig. 2.2(9)).

2.6.2 *Cliffs Formed on Metamorphic Rocks*

The mineralogical composition, the relative amount of quartz, the degree of stratification, schistosity and weathering generate very different types of cliffs, leading to coastline with numerous inlets and outlets marked by fracturing. Cliffs formed on slates and schists are highly conditioned both by the presence of dipping strata and by the orientation relative to wave attack. This explains the presence of vertical, inclined or sheer cliffs.

Intense weathering changes the shape of the coastline. Rotational detachments or landslides usually predominate, depending on the degree of weathering, and rocky platforms usually appear in front of cliffs, as seen in the interior of the Galician rías. In high energy zones, the dynamics of the cliffs formed on metamorphic rocks are marked by detachments, rotational landslides or by sedimentary cover.

Cliffs that form on metamorphic rock are widely distributed along the Cantabrian coast in Galicia. The most notable examples of this flat-topped type of cliff are found on schist material in the zone between Viveiro and Ribadeo (Lugo) (Fig. 2.1a). In other areas such as in northern Galicia, the metamorphic rocks are associated with variable slopes with numerous detachments (Fig. 2.3(1, 2)).

2.6.3 *Cliffs Formed on Recent Sediments*

Numerous ancient deposits formed by variable depositional sequences are found on the coast and give rise to heterogeneous granulometric composition and well-defined morphosedimentary evolution (Pérez-Alberti et al. 2009). These areas reflect the changes that the coast has undergone during at least 40 000 years (Pérez-Alberti et al. 2009), as a result of the interactions of marine regressions and transgressions with variations in climate and local depositional conditions. At an individual level, the characteristics defining these cliffs depend on the location, the source area, the association of sedimentary faces and the cliff shape.

Coastal deposits are currently being subjected to intense erosion, making it difficult to evaluate the area occupied at the moment of maximum accumulation. In general, depositional facies of continental origin are frequent and are acting as active cliffs with a high degree of mobility and which are affected by erosive processes, mainly of marine and to a lesser extent continental origin. The destruction of these deposits uncovers ancient littoral forms, such as platforms and caves.

The appearance of this dynamic cliff type is more localized that that of other cliff types by the more frequent presence of low sedimentary zones relative to well-defined cliffs. The profiles in these areas correspond to forms with gentle slopes and low to intermediate heights (Fig. 2.2(10)).

2.7 Classification of Cliffs According to the Composition of the Base

Information about the composition of the cliff base is fundamental for understanding cliff dynamics and evolutionary behaviour as the presence of material at the cliff base can slow down some erosion processes.

2.7.1 Cliffs with Sandy Areas at the Base

Sandy beaches dominate at the base of cliffs as a result of the action of sedimentary processes, which mobilize the material from nearby areas. The beach is converted into a type of defence at the cliff base so that the cliff is only affected by very high energy wave action. In this context, the coastal front mainly develops as a result of the action of continental run-off as large detachments or landslides, of potential risk to beach users.

Cliffs with beaches at their base are relatively common on the Galician coast. These types of cliffs may have different forms and composition, ranging from areas dominated by schists with vertical slopes and with a beach at the base (Fig. 2.3(1)) to granite cliffs with large accumulations of sediment at the base (Fig. 2.3(4)). Examples of the first type are found in the surroundings of Rinlo (Lugo) (Fig. 2.1a), whereas examples of the second type occur in the area of Ferrol (A Coruña) (Fig. 2.1b, c).

2.7.2 Cliffs with Accumulations of Boulders at the Base

This type of cliff is relatively abundant in Galicia. The boulders are of different sizes, with the longest axis reaching more than 2 m. They usually appear together with small abrasive platforms or stacks, which indicate that the cliff is retreating. The blocks effectively protect the cliff wall from the wave action by dissipating the energy of the waves.

Accumulation of boulders at the cliff base is almost exclusively associated with granitic areas of the Galician coast. The cliffs at Corrubedo (A Coruña) (Fig. 2.1e) and in the area between Cabo Silleiro and A Guarda (Pontevedra) (Fig. 2.1g) are clear examples of this type of cliff. In general, two types of profile are possible: one in which the height increases gradually with the boulders height that are present at the base (Fig. 2.3(3)) and the other in which the boulder-covered base is succeeded by an almost vertical cliff (Fig. 2.2(9)).

2.7.3 Cliffs with Platforms at the Base

These are found in highly localised areas of the coast, e.g. on the Cantabrian coast (Fig. 2.1a). They are formed on metamorphic rocks, in which stratification of the material or the degree of weathering favour retreat of the cliff.

2.8 Cliff Dynamics

Cliff stability depends on (a) the type of rock; (b) the structure; (c) the degree of weathering; (d) location in a high or low energy site; (e) orientation relative to the passage of storms and (f) the gradient, which favours the different types of movement of the existing material. These movements basically comprise detachments, collapses and rotational landslides, in addition to leaching of the weathered layer in granite zones (Pérez-Alberti et al. 2009).

2.8.1 Detachments

Detachments are basically fallen rocks. They can be differentiated into those that affect the cliff face and those produced in specific parts of the cliff. The latter type can be further divided into those produced in the upper part of the cliff and those at the bottom of the cliff. They are generally produced in deeply fractured, weathered rocks and in recent deposits. In the former case, detachments are most abundant in the highest sites. The best examples are found in coastal areas between Estaca de Bares and Ortigueira, although they also occur in other sites such as the sea wall on the coasts of Valdoviño, Narón and Ferrol (A Coruña) (Fig. 2.1b, c).

2.8.2 Collapses

These are produced as a result of a basal sapping. They can be differentiated into those produced in rocks and those affecting only the sedimentary cover. They may give rise to variable forms, the most spectacular of which are the blowholes (called *ollos* in Galicia) located on the coasts of Ribadeo (Lugo), Arteixo, Malpica and Laracha (A Coruña) (Fig. 2.1c).

2.8.3 Rotational Landslides

These are circular, spoon-shaped movements that cause overall retreat of the cliff. They have been observed in highly weathered rock, especially in the basic rocks in the Cabo Ortegal complex in the surroundings of Cariño (A Coruña) (Figs. 2.1a, b and 2.4).

2.9 Coastal Platforms

These are generally narrow platforms located in the intertidal zone. The term most commonly used at present is *shore platform*. However, various synonyms are used in the relevant literature, including *coastal platform, marine bench, high-water rock platform, abrasion platform, storm-wave platform* and *abrasion platform* (Sunamura 1992; Stephenson and Kirk 2005; Feal-Pérez et al. 2009).

Use of the term *shore platform* is generally adopted because it does not indicate the origin, as in the term abrasion, which in the context of littoral geomorphology, describes the erosion of a rocky surface by the movement of particles of sediment by wave action (Sunamura 1992; Trenhaile 1987, 1997). The movements produced by bearing, friction and saltation may potentially be produced from the fracture line to the maximum level reached by the *wave run-up*, whereas some sediment cannot be mobilized. However, although abrasion is not directly related to the tidal range, their efficacy tends to decrease rapidly at depth, outside of the *foreshore* zone (Robinson 1977a, b; Trenhaile 1987, 1997).

Platforms are very abundant in the northwest of the Iberian Peninsula and occur both in the interior of the rías and outside of these, in high and low energy zones,

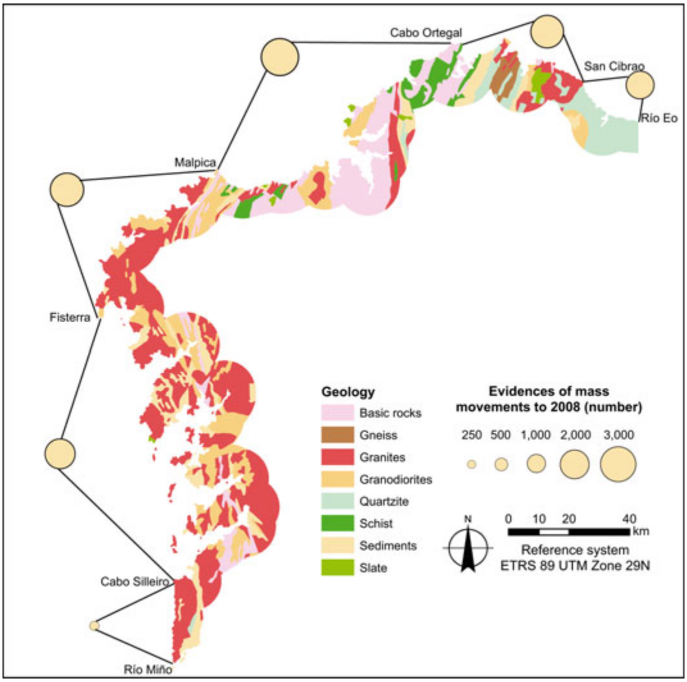

Fig. 2.4 Evidence of mass movements on the Galician coast since 2008 (modified from Pérez-Alberti et al. 2009)

and are formed on either metamorphic rock (Fig. 2.5(1, 2 and 4)) or granitic rock (Fig. 2.5(3)). In some sites, narrow platforms (5 m wide) exist: these are subhorizontal and of low uniformity, sometimes even with ledges of up to 1 m high. In other sites, the platforms are more highly developed, of width up to 50–100 m, notably uniform and with slope of between 0° and 2° covered by drift material that forms deposits of variable size and power, comprising material ranging in size from gravel to metre-wide boulders. Although the platforms are sometimes caused by abrasion, there is some evidence showing that they are formed as a result of weathering processes and therefore differential dissection.

2.9.1 Platform Formation

The question arises as to whether the platforms are formed by the same processes as cliff retreat or by other processes not necessarily consistent with the former (Trenhaile 1982). Various authors have suggested that the platforms are developed close to a level of weathering defined by saturation of the rock, either by leaching of

Fig. 2.5 Coastal platforms: (1) Caamaño (A Coruña); (2) Sanxenxo (Pontevedra); (3) Punta Corrubedo (A Coruña); (4) Ridadeo (Lugo)

weathered material or by concentration of wave energy (Dana 1849; Bartrum 1916; Bell and Clarke 1909 cited by Trenhaile 1987).

Trenhaile (1973, 1974, 1978, 1980, 1982, 1987) attempted to establish a relationship between the diverse parameters of the geometry of the platforms based on mathematical models and statistical techniques, observing a correlation between the tidal range, resistance of the rock and wave energy. According to this author, of all parameters considered, the tidal range is the main factor determining the slope of the platforms and is more important than others such as structure and lithology. The slope of the platform will also decrease with the tidal range, as the wave energy is spatially and temporally concentrated in a narrower area. Thus, almost horizontal platforms may be formed when the tidal range is less than 3 m (Trenhaile 1974). Other aspects, such as the mean elevation of the platform, or its uniformity or width will depend to a greater extent on local conditions, such as the type of rock, height of the cliff or amount and size of the rubble accumulated at the base.

In light of the evidence from the Galician coast, it is considered that, as for cliff retreat, the formation and evolution of coastal platforms is largely determined by the balance between previous weathering of the rock, structural factors and wave energy. The formation of platforms involves a balance between the rock resistance and the wave energy, where the rock resistance is understood to result from the different factors that determine the fragility of a material (mineralogical and petrological characteristics, degree of fracturing, etc.) for example boulder beaches, considered below.

The existence in some sites of ancient deposits on the platforms (Trenhaile et al. 1999) indicate that these are polygenic forms formed during the Eemiense interglacial period (Perez-Alberti et al. 2010) and are currently being reshaped.

2.10 Boulder Beaches (*coídos*)

Areas characterised by large accumulations of boulders are relatively abundant on the Atlantic coast. These areas are called *coidos* in Galician. They can be differentiated into those resulting from (i) weathering of the layer of granite rock, (ii) the dismantling of granite platforms, and (iii) the remobilization of deposits generated by movement of material on the cliff faces or of ancient deposits, mainly of periglacial or snow origin (Blanco-Chao et al. 2002; Pérez-Alberti and Bedoya 2004).

In the first case, an initial phase of subsurface weathering of the rock is followed by leaching by marine or continental waters. Granite weathering has been marked by the existence of an extensive network of fractures generated as the weathering advances and by the genetic predisposition of some types of granite, such as granodiorites, to undergo spheroidal decomposition. Moreover, the presence of nuclei of unaltered granite within the weathered material has favoured the accumulation of boulders of variable size. Good examples of these are found at the mouths of the rías of Ferrol and O Barqueiro (A Coruña) (Fig. 2.1c), at the Punta do Couso, in Corrubedo (A Coruña) and on the coast of O Grove (Pontevedra). The size of the boulders does not favour their movement as the wave energy is generally dissipated by these massive macro-supported accumulations with numerous cavities, leading to differential accumulation. The hollow spaces between the largest blocks act as sediment traps for the smaller blocks. By contrast, accumulations formed by smaller clasts are highly dynamic. Independently of their origin, boulder beaches can be differentiated into 5 main morphological types: longitudinal, double-peaked, bow-shaped, channel-type and simple-peaked (Fig. 2.6).

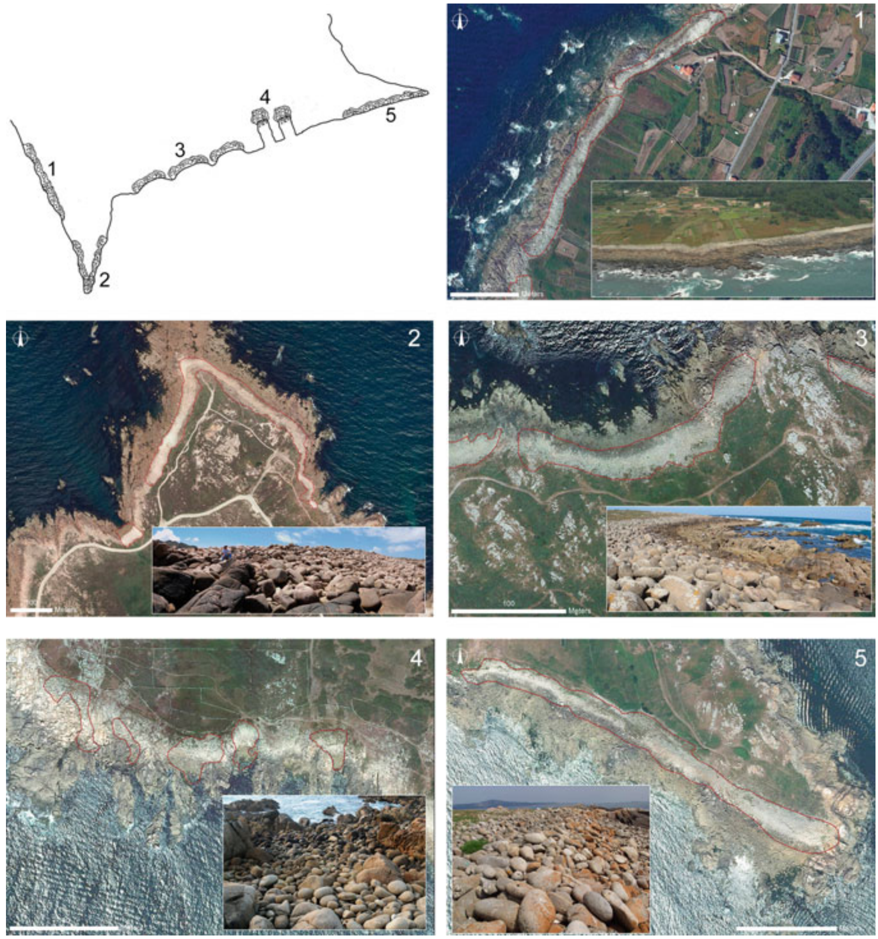

Fig. 2.6 Types of boulder beaches (*coidos*)

2.10.1 Types

2.10.1.1 Longitudinal

Boulder beaches are formed at the upper level of narrow and irregular coastal platforms of width 50–75 m (depending on the area). These beaches become progressively longer between Cabo Silleiro and A Guarda (Fig. 2.1g). They are comprised of heterometric granite boulders of diameter up to 4 m with many specimens larger than 1 m in diameter. The boulders are rounded or angular and form crests of width less than 80 m and height between 5 and 6 m (Pérez-Alberti et al. 2012).

Their origin is related to processes driven by the fracturing of the material on the platforms, favouring weathering at the discontinuities and thus contributing to the fragmentation. Channels or small cavities then gradually open up along lines of weakness in the structure or lithology, gradually forming an extensive network both horizontally and vertically. The high wave energy from NW or SW directions has driven the mobilization and accumulation of material.

2.10.1.2 Double Peaked

Good examples of this type of boulder beach are found in the area of the coast between Cabo Vilán and Camelle (A Coruña) (Fig. 2.1d). The extensive fracture network favours the formation of small boulders, generally of diameter less than 50 cm. The size favours the mobility of the boulders making them rounder than otherwise. On the other hand, the sawtooth arrangement of the coastline gives rise to numerous inlets and outlets. The area is thus affected by a combination of high energy waves of SW, W and NW components that transport the boulders to one face or other from arrowhead-shaped outlets.

Boulder beaches of width 20–40 m and height 4–5 m are located (as in the previously described type) at the upper level of narrow platforms not usually wider than 60–70 m.

2.10.1.3 Bow-Shaped

Shorter than the previous type, bow-shaped boulder beaches can reach lengths of 200–300 m (depending on the area) and are separated by rocky outlets. The accumulations can cover areas of width up to 80 m. Unlike the previously described types, these beaches are not always associated with platforms and usually extend from the lower tidal level to 8 m above the tidal levels in areas such as Laxe Brava (Ribeira, A Coruña) (Fig. 2.6(3)).

The granulometric properties of the material are more variable and the boulders are rounder than on other beaches. The largest diameter of some of the boulders reaches 2 m, although it is not usually greater than 1 m. They overlap towards the land, pushed by waves from a NW or SW direction (Pérez-Alberti et al. 2012; Pérez-Alberti and Trenhaile 2015a, b).

2.10.1.4 Channel-Type

Boulder beaches can also form narrow channels, of width 30–50 m and length 70–80 m, opening up from a wide network of fractures that follow a N-S direction (Fig. 2.6(4)). These beaches are very similar to the bow-type beaches regarding the clast size and distribution from low tide level. However, they are characterized by being mushroom shaped, with a lower level delimited by rocky walls and an upper level on the coastal plateau (Pérez-Alberti et al. 2012).

2.10.1.5 Simple Peaked

This type of beach is formed by accumulations of boulders that have been moved in the direction of the sedimentary materials. To some extent, they comprise the final sectors of long beaches situated at the upper level of the platform (Fig. 2.5(3)). The only example in Galicia is at Punta Corrubedo (Ribeira, A Coruña) (Fig. 2.6(5)). The beach is of maximum width 40 m and maximum height, 5 m. It is formed by rounded boulders usually of diameter less than 1 m.

2.10.2 Dynamics

Boulder beaches are surprisingly dynamic. Their movements have been monitored in two areas of the Galicia coast: Laxe Brava (Barbanza Peninsula) (Fig. 2.1f) and Oia (south of Pontevedra) (Fig. 2.1g). Pérez-Alberti and Trenhaile (2015a, b) have demonstrated movement of 80% of the boulders located at between 0.5 and 6 masl at Oia (Pontevedra) and between 58 and 69% of the boulders at Laxe Brava (Ribeira, A Coruña) located at of between 1 and 4.5 masl.

RFID (Radio-Frequency IDentification) sensors have recently been used to monitor the movements of boulders at Oia. Gómez-Pazo and Pérez-Alberti (2017) have reported that 81% of the boulders moved more than 50 cm in the winter of 2016–2017, with an average displacement of 5.06 m. These changes in position are associated with winter storms and the arrangement of the boulders on the beach.

Although boulder beaches in Galicia are usually associated with granite platforms, in other parts of the world they have been reported to be associated with other types of rock. However, they are always associated with intensely fractured, high energy areas (Blanco-Chao et al. 2007; Knight et al. 2009; Hall 2011; McKenna et al. 2011; Knight and Burningham 2011; Stephenson and Naylor 2011). Interest in their study has, however focused on discussing whether boulder beaches are formed by paleo-tsunami or storm waves (Nott 2004; Paris et al. 2011), and most studies have concentrated on almost bare rock surfaces without much associated sediment (Trenhaile 1987, 2011). Scarce interest has been shown in rocky coasts as sedimentary environments (Felton 2002; Noormets et al. 2004). Thus, despite the evident dynamic relationship between terrestrial and depositional forms and processes, boulder beaches are generally considered to be different entities.

As already mentioned, the boulders present on boulder beaches have either arisen as a result of platform or cliff erosion, or by washing of deposits of glacial, periglacial or nival origin or of other Quaternary deposits (Oak 1984; McKenna 2005; Chen et al. 2011; Blanco-Chao et al. 2007; Pérez-Alberti et al. 2009). However, independently of their origin, it has been shown that the boulder beaches in Galicia (Pérez-Alberti and Trenhaile 2015a, b) are moving on coastal platforms pushed by large storm waves, to sites located well above the high tide level. This gives rise to intense erosion in some areas and has a protective role in the evolution of the platform edges, especially in sites where the beaches are adjusting to the current sea level.

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