Geomorphology of the Curueño River headwaters, Cantabrian mountains (NW Spain)

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ABSTRACT

The article presents the 1:25,000-scale geomorphological map of the upper reaches of the Curueño River, on the southern slope of the Central Cantabrian Mountains, NW Spain. The study area spans approximately 125 km² and corresponds to the 1:25,000-scale Spanish National Topographical Map Sheet 104-I of Lugueros. The area is moderately mountainous with elevation ranging from 1100 to 2100 m.a.s.l. The main landforms are river gorges, karst, and glacial landforms. The map legend contains 78 elements divided into 9 groups: lithostructural, polygenic, karst, fluvial, glacial, periglacial, nival, gravitational, weathering, and anthropic forms. The map was prepared using Esri ArcGIS with the Universal Transverse Mercator (UTM, Zone 30) projection. In addition, a database and style set were created for each landform with the goal of using this set of symbols in other areas and performing complementary mapping of geologic and geomorphologic risk, protection of natural geoheritage, land-use classification, and applied geomorphology.

1. Introduction

Geomorphological mapping has been a basic component of geomorphological work since the first geomorphological maps were prepared in the early twentieth century (Beckinsale & Chorley, 1991). Its importance is that with a map, any landform can be located and recorded spatially. Such a map also creates possibilities for performing other geomorphological tasks such as measurement of landforms, quantification, and statistical analysis, studies on evolution of and interrelations between landforms, and development of secondary thematic maps. The value of a geomorphological map, as expressed by Jean Tricart (1979), is that it is like a ‘population census that does not allow any object to escape’ and from which one can extract abundant information needed in the Earth sciences and other fields of knowledge.

However, the systematic development of geomorphological maps and legends in a standard way did not begin until the 1960s (Verstappen, 2011). Since then, countries such as Poland, France, the Netherlands, Germany, the United Kingdom, Romania, Hungary, the USA, and Italy have constructed geomorphological maps at various scales, often by using a grid designed for topographical maps of those countries. Conferences and congresses held (Demek & Embleton, 1978) consolidated the development of geomorphological cartography as a discipline during the 1970s and 1980s. Research groups, commissions, and national and international institutions expended tremendous effort to develop standardized maps and legends (Paron & Claessens, 2011; Pavlopoulos, Evelydou, & Vassilopoulos, 2009). In recent years, the use of Geographic Information Systems (GIS) has improved the development of geomorphological maps (Gustavsson, 2006; Kertesz & Markus, 1992; Minár, Mentlik, Jedlička, & Barka, 2005; Pavlopoulos et al., 2009).

In Spain, geomorphological maps have been carried out at various scales, being most notable in the Pyrenees (García-Ruiz et al., 2011) and the Iberian Range (Arnáez-Vadillo & García-Ruiz, 1990; García-Ruiz, Gómez-Villar, Arnáez-Vadillo, & Ortigosa-Izquierdo, 2007). In contrast, geomorphological maps in the Cantabrian Mountains are less common, although some regional maps have been developed since the 1990s (e.g. Alonso, 2014; García de Celis, 1997; González-Gutiérrez, 2002; González-Trueba, 2007; Pellitero, 2014; Pellitero, Manosso, & Serrano, 2014; Rodríguez-Pérez, 2009; Ruiz-Fernández, 2011; Santos-González, 2011; Serrano & González-Trueba, 2005). Most of these maps address only selected geomorphological features such as fluvial, glacial, periglacial, slope, structural, or karst landforms, although they show careful attention to cartographic detail (Ballesteros, Jiménez-Sánchez, Giralt, García-Sansegundo, & Meléndez-Asensio, 2015a; Domínguez-Cuesta, Jiménez-Sánchez, & Berrezuela, 2007; Frochoso-Sánchez & Castañón-Álvarez, 1998; Redondo-Vega, Gómez-Villar, González-Gutiérrez, & Carrera-Gómez, 2014; García de Celis, 1997; González-Gutiérrez, 2002; González-Trueba, 2007; Pellitero, 2014; Pellitero, Manosso, & Serrano, 2014; Rodríguez-Pérez, 2009; Ruiz-Fernández, 2011; Santos-González, 2011; Serrano & González-Trueba, 2005).
Topographic Sheet number 104-I of Lugueros spans the South middle part of the Central Cantabrian Mountains, in the north-western Iberian Peninsula. The design of this map follows the grid created by the Spanish National Geographic Institute (IGN) for the presentation of topographic maps at scales of 1:50,000 and 1:25,000 (Figure 1(A)). The objective of this work is to produce a 1:25,000 scale map to improve the geomorphological knowledge of the area and to create a suitable symbology for the geomorphological representation with Esri ArcGIS at this scale. This map is also the basis for future thematic and applied maps in this study area.

2. Study area

The study area spans nearly 125 km² and is located on the southern side of the Cantabrian Mountains,

![Map of study area](image)

Figure 1. Location of the study area in NW Iberian Peninsula (A) and Cantabrian Mountains (B) and its location in relation to the Spanish topographic map at scales of 1:50,000 and 1:25,000. (C) Physiographic features of Lugueros Sheet 104-I.
Province of León, NW Spain (Figure 1(A)). The main watercourse is the Curueño River, which flows to the south into the Porma River. The western portion belongs to the Torío River, a tributary of the Bernesga River, and the lower right part spans part of the Porma basin, which empties into the Esla River (Figure 1(B)). All these rivers are part of the Duero drainage. The relief is abrupt, with altitudes between 1100 and 2100 m.a.s.l. The climate is oceanic (Cfb according to the Köppen classification, with variations due to altitude and exposure), with 1200–1700 mm of mean annual precipitation. Mean annual temperature (based on data or nearby meteorological stations) is around 9°C in the lowest areas and 2°C at the summits (AEMET-IM, 2011).

The geology of the study area is dominated by a Palaeozoic sedimentary series ranging from Cambrian to Carboniferous age. Limestone, quartzite, sandstone, shale, lutite, and dolomite are the predominant rocks (Truyols et al., 1984). These rocks were deformed during the Variscan Orogeny, when the main tectonic structures were formed (Figure 2). This area is part of the Fold and Thrust Region and the Central Coal Basin (Alonso, Marcos, & Suárez, 2009; Pérez-Estaún 2014).

Figure 2. Geology of Lugueros sheet 104-I: rock types: (A) regional geological framerock; (B) age, palaeozoic structures and geologic units of study area; and (C) main lithologies.

Source: Julivert, Fontboté, Ribeiro, & Nabais-Conde, 1972. Geological data: http://www.igme.es; Merino-Tome, Suárez Rodríguez, & Alonso Alonso, 2014.
et al., 1988), which includes many thrusts, folds, and faults. Both tectonostratigraphic provinces belong to the Cantabrian Zone, which makes up a major portion of the Iberian Massif (Lotze, 1945).

The present morphostructural landforms of the area are related to the Alpine Orogeny, which uplifted the Cantabrian Mountains in relation to the Cenozoic Duero basin generating an alpine structure formed by a south-direct thrust system (Alonso et al., 2009; Alonso, Pulgar, García-Ramos, & Barba, 1996). Morphologically, these processes generated uplifted and sunken blocks (García-Fernández, 2006; González-Gutiérrez, 2002). The fluvial system was also modified by this new morphostructural arrangement. Throughout the Neogene and Quaternary the rivers organized hierarchically to accommodate the reactivated blocks of the Variscan massif. The main river valleys follow the line of maximum slope between the Cantabrian divide and the Duero basin, cutting the geological structures perpendicularly. Where the rivers cross cohesive rocks, they follow lines of tectonic weakness and carve deep epigenetic gorges in a process that is still ongoing (Frochoso Sánchez, 2016).

The present relief of the Cantabrian Mountains comprises glacial (e.g. Frochoso, González-Pellejero, & Allende, 2013; Gómez-Villar, Santos-González, González-Gutiérrez, & Redondo-Vega, 2015; Jiménez-Sánchez et al., 2013; Rodríguez-Rodríguez et al., 2016; Rodríguez-Rodríguez, Jiménez-Sánchez, Domínguez-Cuesta, & Aranburu, 2015; Ruiz-Fernández, Poblete-Piedrabuena, Serrano-Muela, Martí-Bono, & García-Ruiz, 2009; Santos-González, Redondo-Vega, González-Gutiérrez, & Gómez-Villar, 2013; Santos-González, Santos, González-Gutiérrez, Redondo-Vega, & Gómez-Villar, 2013; Serrano, González-trueba, Pellitero, González-García, & Gómez-Lende, 2013), periglacial (e.g. Gómez-Villar, González-Gutiérrez, Redondo-Vega, & Santos-González, 2011; Nieuwendam et al., 2016; Pizarro, Pellitero, Serrano, Gómez-Lende, & González-Trueba, 2017), fluvial (e.g. Gómez-Villar, Redondo-Vega, González-Gutiérrez, & Carrera-Gómez, 2002), karst (e.g. Aranburu et al., 2015; Ballesteros et al., 2015), gravitational (e.g. Domínguez-Cuesta et al., 2007; Menéndez Duarte & Marquín, 2002), and anthropic (e.g. Redondo-Vega, Gómez-Villar, Santos-González, González-Gutiérrez, & Álvarez Martínez, 2017) landforms.

3. Materials and methods

The following cartographic sources were used to prepare the geomorphological map: a vector map provided by the Spanish Geographic National Institute (IGN) (http://www.ign.es/), geologic information available from the Geological and Mining Institute of Spain (IGME, http://www.igme.es/), aerial photographs from the National Plan of Aerial Orthophotography (PNOA), performed by the Spanish Geographic National Institute and Agrarian Technological Institute of the Castilla and León Region (ITACYL, http://www.itacyl.es/).

Following Knight, Mitchell, and Rose (2011), the following steps were performed for the preparation of the map (Main Map):

- A preliminary geomorphological map was prepared at a scale of 1:10,000 based on the existing literature and the interpretation of aerial photographs.
- Fieldwork was performed to identify landforms and deposits not recognized in the aerial photography or digital orthomagery.
- A georeferenced database of all landforms was created, and symbols for representing each landform at a scale of 1:25,000 were designed.
- Graphic design was performed for the final printing at a scale of 1:25,000.

The geomorphologic map was produced in Esri ArcGIS 10.3 at a scale of 1:25,000 with a Universal Transverse Mercator (UTM) projection (Zone 30) and the European Terrestrial Reference System 1989 Datum (ETRS89). The mapped landforms were classified in to nine groups: litho-structural and karst landforms, weathering and gravitational landforms, polygenetic erosion surfaces, and glacial, periglacial, and fluvial forms. In some areas, there is an overlap between landforms (e.g. karst and glacial landforms in the Sancenas massif), hindering the decision about symbol representation. In these cases, the main landform has been chosen.

Three considerations were taken into account when creating the geomorphological map, such as the choice of symbols as a function of the map scale, graphic design, and, in particular, the inclusion of each landform in the georeferenced database. The symbols were driven by a vector model: the landforms were represented by points, lines, or polygons, and care was taken to select their size to accommodate the map scale. Because the map scale is 1:25,000, features smaller than 50–75 m (2–3 mm on the map) were represented by points, and line or polygon formats were reserved for features larger than this threshold. Because certain landforms range greatly in size, they are represented by different symbols consisting of points, lines, or polygons, for example, are sinkholes. Certain point features are shown larger than their true size due to their geomorphologic value. These features include glacial erratic boulder, kettle, ponor, surgence, and terracette, which are the results of important dynamics or processes that must be mapped, however, small the feature might be.

The second aspect of the preparation was designing the symbols. Several systems that have been used to represent landforms since the mid-twentieth century were taken into account: the French system of the Centre National de la Recherche Scientifique (CNRS, 1976; Joly, 1997), the Dutch system proposed by the
International Institute for Geo-Information Science and Earth Observation (Verstappen & Van Zuidam, 1991), and numerous adaptations used in various locations in Spain (Chueca-Cía & Julián-Andrés, 2008; Gómez-Ortiz, 2002; Peña-Monné, 1997; Ruiz-Fernández, 2011). The symbols were grouped by colour based on their geomorphic dynamics and processes and, where possible, by distinguishing between erosional and sedimentary landforms (Figure 3(B)).

Other systems were also reviewed when matching certain landforms or creating new symbols adapted to the study area. These systems include those of IGME and the geomorphological maps accompanying the latest geological maps of the MAGNA series (Martín-Serrano, Salazar, Nozal, & Suárez, 2004); the system of the IGN presented by Herrero-Matías (1988); the legend developed by the Geographic Institute of Lausanne University (IGUL), which is devised for mountainous environments (Pellitero, 2014; Reynard, Holzmann, Lambiel, & Phillips, 2005); and the nearly 400 symbols in the Italian system, which are vector and separated into erosional and depositional landforms (Dramis & Bisci, 1998; Panizza, 2005; Servizio Geologico Nazionale, 1994).

A third important aspect of the preparation was the adaptation of the geomorphological symbols to the georeferenced database of the GIS. This step entailed the construction of a geomorphological information

**Table 3.** (A) Symbols used in the geomorphological representation and (B) the colour scheme in decimal codes colour of the RBG (red, blue, green) model.
The preparation of the geomorphological map involved traditional geomorphological design via the creation of a carefully designed geomorphological style set combined with the versatility of a GIS for georeferencing and the spatial analysis of landforms. The administrator of the program styles permits the combination of three basic vector elements in a single symbol (Figure 3(A)) and drawing it at one time when referencing and the spatial analysis of landforms. The style set combined with the versatility of a GIS for georeferencing and the spatial analysis of landforms. The map is a basic geomorphological map with large-scale details (Dramis et al., 2011) focusing on morphodynamic and morphogenetic features of the terrain. The main structural landforms related to tectonic features (faults and thrusts) were not mapped, given that they only allow the production of a geomorphological map of morphostructures (González-Gutiérrez, 2002). However, landforms controlled by lithology, either because of differential resistance to external processes (litho-structural control) or because their mineralogic composition generates its own morphologies (karst relief), were mapped.

An outline of the used symbols and colours employed are shown in Figure 3. The carbonate materials are represented with red lines and hatching (RGB: 229, 94, 46), and the siliceous rocks are shown as light blue (RGB: 102, 119, 205). The erosion surfaces are represented by diagonal and horizontal hatching in grey tones (RBG: 226, 26, 26; 104, 104, 104; and 156, 156, 156). The karst landforms are drawn in red tones (RBG: 255, 190, 232 and/or 255, 199, 191) and by blue tones (0, 92, 230) where water is present (springs, underground flow).

Fourteen symbols are used to draw fluvial and torrential landforms. Blue and green tones (RGB: 0, 92, 230 and 56, 168, 0) are used to highlight erosional landforms and the presence of water, and green and yellowish/earth tones are used to denote depositional landforms (RGB: 38, 115, 0 and 255, 255, 1). There are 10 symbols associated with glacial dynamics which are shown in purple tones (RGB: 158, 187, 215 and 255, 190, 232). The glaciokarst landforms are in reddish tones, periglacial and nival landforms are shown in dark blue (RGB: 59, 0, 99 and 158, 187, 215). Gravitational landforms are shown in green and black tones (RGB: 156, 168, 77 and 196, 204, 161), the weathering forms in black, and the anthropic landforms in brown (RGB: 168, 112, 0) and gray tones.

The geomorphological map includes 78 symbols divided into 9 groups: litho-structural landforms, polygenic erosional surfaces, karst landforms, torrential and fluvial landforms, glacial landforms, periglacial and nival landforms, gravitational, weathering landforms, and, finally, landforms of anthropic origin. The most relevant and characteristic features in this area of the Cantabrian Mountains are those associated with fluvial dynamics, particularly the progressive incision of valleys, the dissolution of carbonate rocks, and the Quaternary glaciations (Main Map).

### 4.1. Litho-structural landforms

The sharp contrast between carbonate and siliceous rocks of moderate bed thicknesses, except for in certain cases (rocks of the Lena Group), favoured the formation of resistant rock outcrops alternating with valleys incised into softer rocks. Therefore, on the geomorphological map, ridges, escarpments, and rocky outcrops and ledges that reflect the stratigraphy have been represented. Due to their influence on geomorphological processes (e.g. karstic landforms), the nature of the rocks (carbonate or siliceous rocks) has been taken into account everywhere, given their differential behaviour in response to external processes.

### 4.2. Polygenic landforms: the erosion surfaces

Three levels of surfaces were identified, related with their degree of connection with the present-day river network. High plateaus and hills lacking connections with present-day rivers lie at elevations above 1600–1700 m. Surfaces sited between 1300 and 1600 m lie near the headwaters of numerous rivers and form the hills between streams, although a few of these surfaces are not connected with the present-day stream network. Lastly, the erosional surfaces in low-lying areas (below
1,300 m) are connected to the present-day stream network and yield evidence of recent fluvial incision.

Key elements of the terrain are the erosional surfaces in the highest elevations and along certain slope flanks. These surfaces are indicative of the morphogenetic evolution of the terrain and are residual evidence of ancient terrains (Mínguez-Menéndez, 2015). They reflect the progressive coupling of the river network and mountains originating from the Alpine tectonics and the erosion of the massif as it formed (González-Gutiérrez, 2002; González-Gutiérrez et al., 2010).

4.3. Karst landforms

Karst topography is significant in the region due to the abundance and thickness of the limestones, particularly those of Carboniferous (Barcaliente and Valdeteja formations) and Devonian age, and is associated with thrusts and faults. The most karstified limestones with the best-developed karst landforms (e.g. four of the main five cavities in the study area) are those of the Barcaliente Formation possibly due to intense jointing and the decimetre capacity of the strata. The Valdeteja Formation and the Devonian limestones display karst topography, but to a lesser extent. The best examples are located in the upper elevations of the Sancenas massif (Figure 4), where there are numerous dolines, solution channels, ouvalas, ponor, shafts, karst grooves, hums, poljes, surgences, and dry valleys (Annys et al., 2014). An interesting overlap between karst and glacial landforms exists in this area.

4.4. Fluvial and torrential landforms

Progressive incision by rivers created gorges in the most cohesive rocks (quartzites and limestones). This incision appears to follow the bedding locally or highly fractured zones perpendicular to the direction of runoff. Examples include the Valdeteja Gorge (Figure 5), which has been carved by the Curueño River and Valdeteja Brook south of Tolibia de Abajo.

Torrential and fluvial sediments are not abundant and are concentrated where valleys widen, thereby allowing for the deposition of alluvium along the banks of the rivers. Examples include the Lugueros Plain and the by slate valley of Valverde–Valdeteja. The locations of alluvial
cones (Gómez-Villar et al., 2002) are similarly distributed and are located where the valleys broaden, particularly where the Carboniferous shales crop out. Their locations are all near rivers, on the floodplain itself or slightly above the bases of the slopes (Figure 6(A)).

4.5. Glacial landforms

Pleistocene cold phases left their mark on this part of the Cantabrian Mountains in the form of abundant glacial features. The most distinctive landforms are a set of cirques, moraines, and erratic boulders of the Sancenas massif (Figure 7(A)), the moraine complex of the Lugueros basin, till in the Yargas Valley, and the cirques of the Morala massif (Gómez-Villar et al., 2015). Without a doubt, in Lugueros (Figure 7(B)) there is one of the best-preserved moraine systems in the Cantabrian Mountains. The deposits and forms left by the Curueño glacier, whose length exceeded 17 km from the port of Vegarada to Valdeteja Gorge (centre of the map), are presented on the geomorphological map (González-Gutiérrez, 2002; Redondo-Vega et al., 2014; Santos-González, Redondo-Vega, et al., 2013). Together with the moraines, erratics, glaciolacustrine deposits (Redondo-Vega, González-Gutiérrez, Santos-González, & Gómez-Villar, 2006), glacial thresholds, and juxtaplacial palaeochannels and shoulders have been mapped.

4.6. Periglacial and nival landforms

The most-distinct periglacial landforms are located in glaciated areas and where nival dynamics are currently present. Compared to other areas of the Cantabrian Mountains, rock glaciers are rare here due to the lesser exposure of quartzitic rocks (Gómez-Villar et al., 2011; Redondo-Vega et al., 2010). Steep slopes and abundant rocky outcrops have produced scree, debris cones, cemented talus slope, and avalanche tracks. In areas of bulging siliceous uplift, such as in the surroundings of the peaks Morala or Cudero, there are small terracettes.

4.7. Gravitational landforms

The presence of gravitational geomorphic processes supported by surface run-off and occasional nival processes depends on many variables such as the gradients and orientations of the slopes, the litho-structural character of the materials, climatic conditions, and the age-old pressure of human activity.

Creeping soil mantles and areas with solifluction lobes have been mapped on slaty bedrock where cultivation has been abandoned (the Valverdín, Valdeteja, Villarías, and Rodillazo valleys). Debris flow deposits such as those of El Fontanal, west of the village of Lugueros, and those deposited by streams descending from Morala Peak are also present. In the northern part of the map, the massifs of Morala and Mullerinas are dominated by different lithologies with interbedded shale. This bedrock, the higher elevations (>1500 m.a.s.l.), and slope gradients above 20° are favourable to the development of torrential headwaters with badlands, rills, and gullies. In contrast, the southern part of the map is characterized by relative stability, especially where siliceous rocks appear (Fito and Tejedo valleys).

4.8. Weathering landforms

At the Sancenas massif, the Ordovician quartzites (Barrío Formation) attain a substantial thickness and are extensively mantled by sandy soil, interpreted as an
alterite. This soil is less extensive than other parts of the Cantabrian Mountains (Rodríguez-Pérez, 1995), but it confers a certain singularity to the massif because in this sector small brooks can be found that transport these alterites to the karst landforms located to the north. (González-Gutiérrez, 2002)

Figure 6. (A) Northern side of Bodón Massif next to Lugueros village with numerous scree and avalanche deposits and snow corridors. (B) Stratified debris flow deposits in the Valdeteja Gorge, east to Valdeteja village (bar length: 2 m).

Figure 7. Glacial landforms: (A) cirques and moraines on the Sancenas massif and (B) a system of terminal and lateral moraines near the villages of Lugueros and Tolibia de Abajo.
4.9. Anthropic landforms

These landforms are related to quarries, waste dumps, villages, and roads. Two quarries for silica extraction have been drawn in the SE of the map, in a small stream that drains to the Porma basin. The map shows 13 villages connected by local roads. They are entities with very few inhabitants located near the bottoms of the valleys and in the best sunny areas during the winter months.

5. Conclusions

The geomorphological map of the Lugueros shows a variety of landforms, demonstrating the high geomorphologic diversity of the region. The map legend contains 78 symbols grouped into 8 categories: lithostructural, polygenetic, karst, fluvial and torrential, glacial, periglacial and nival, gravitational and weathering, and anthropic landforms.

Three landforms give this part of the Cantabrian Mountains their special character: the Valdeteja and many other small gorges created by river incision, exokarst related to the significant calcareous rocks in the region, and the glacial deposits identified in Lugueros, the Yargas valley (North of the map), and the Sancenas and Morala massifs (West and South of study area). The mapped landforms reflect the overlapping of many processes that have shaped the upper reaches of the Curueño River during, at least, the Quaternary. Some landforms are characteristic of this area either because of its tectonic evolution (structural landforms), either by the nature of the materials (karst forms) or even by the influence of the climatic conditions (glacial and periglacial landforms). Other landforms are related to processes triggered far from here, but their consequences have reached this area and left a geomorphological imprint. Such is the case of the fluvial fitting during Cenozoic and the gorges associated, with the evolution of the Duero River.

Overlapping processes have also led to overlapping landforms such that it was difficult to decide which landform to map in places, thus making it difficult to design and prepare the geomorphological map. This situation was applied to the Sancenas massif, where karst landforms overlap with glacial forms providing glaciokarst forms. These forms are also combined with sandy residual soils on the peaks of the massif.

Finally, in designing the map, an attempt was made to combine traditional geomorphological map design with the functionality provided by a GIS. Geomorphological maps drawn by hand or with graphic software were characterized by the careful delineation of forms using intuitive and simple symbols for cartographic representation. The style manager of ArcMap allows the design of a variety of symbols and to create geometric shapes that combine points, lines, and polygons on a single drawing. In addition, each landform, depending on its size and the scale of representation, is part of a database that characterizes the form for future analysis and processing.

Software

The geomorphological map was prepared using Esri ArcGIS 10.3.

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