Journal of Maps

ISSN: (Print) 1744-5647 (Online) Journal homepage: https://www.tandfonline.com/loi/tjom20

Geomorphology of the Sierra del Aramo (Asturian Central Massif, Cantabrian Mountains, NW Spain)

Salvador Beato Bergua, Miguel Ángel Poblete Piedrabuena, Carmen Rodríguez Pérez & José Luis Marino Alfonso

To cite this article: Salvador Beato Bergua, Miguel Ángel Poblete Piedrabuena, Carmen Rodríguez Pérez & José Luis Marino Alfonso (2019) Geomorphology of the Sierra del Aramo (Asturian Central Massif, Cantabrian Mountains, NW Spain), Journal of Maps, 15:2, 590-600, DOI: 10.1080/17445647.2019.1646675

To link to this article: https://doi.org/10.1080/17445647.2019.1646675

JOURNAL OF MAPS
2019, VOL. 15, NO. 2, 590–600
https://doi.org/10.1080/17445647.2019.1646675

Science

OPEN ACCESS Check for updates

Geomorphology of the Sierra del Aramo (Asturian Central Massif, Cantabrian Mountains, NW Spain)

Salvador Beato Bergua, Miguel Ángel Poblete Piedrabuena, Carmen Rodríguez Pérez and José Luis Marino Alfonso

Department of Geography, University of Oviedo, Oviedo, Spain

ABSTRACT
A detailed geomorphological map of the Sierra del Aramo (Asturian Central Massif) is presented at a scale of 1:25,000. The Sierra del Aramo is one of the major middle-altitude mountains of the Asturian Central Massif (maximum altitude 1,791 m a.s.l.). Specifically, the lithology and the structural landforms, as well as karst, fluvial, periglacial and other landforms and deposits, have been mapped based on meticulous fieldwork, photointerpretation and a geographic information system. The final printing has been drawn carefully following the RCP 77 geomorphological mapping system of the French CNRS to achieve a graphic design that adequately expresses the true nature of the landforms. Thus, the geomorphological map is a precise scientific tool that serves as a basis for geoheritage studies, and the analysis of natural hazards; in short, for territorial planning.

ARTICLE HISTORY
Received 15 March 2019
Revised 15 July 2019
Accepted 18 July 2019

KEYWORDS
Geomorphological mapping; karst; periglacial forms; slope dynamics; mid-mountain; Asturian Central Massif

1. Introduction

The geomorphology of the Cantabrian Mountains (northern Spain) is being scientifically analyzed in recent decades from the coast to the high mountain (Ballesteros, Jiménez-Sánchez, García-Sansegundo, & Giralt, 2010; Castañón & Frochoso, 1994; Domínguez-Cuesta et al., 2019; Domínguez-Cuesta, Jiménez-Sánchez, & Berrezueta, 2007; Flor & Flor-Blanco, 2014; Flor, Flor-Blanco, Cedrún, Flores-Soriano, & Borghero, 2019; Jiménez, 1999; Jiménez-Sánchez et al., 2013; Menéndez-Duarte, Marquínez, Fernández-Menéndez, & Santos, 2007; Rodríguez-Rodríguez, Jiménez-Sánchez, Domínguez-Cuesta, & Aranburu, 2015; Ruiz Fernández & Poblete Piedrabuena, 2011; Serrano, González-Trueba, Pellitero, & Gómez-Lende, 2016; Serrano, González-Trueba, Pellitero, González-García, & Gómez-Lende, 2013) to reach an accurate understanding of the geomorphological dynamics (fluvial, coastal, periglacial, glacial) in relation to past and current global changes (Beato Bergua, Poblete Piedrabuena, & Marino Alfonso, 2019a; Slaymaker, Spencer, & Embleton-Hamann, 2009). The development of geomorphological mapping has contributed to show the relevance and richness of their landforms and processes (Alonso, 2014; García de Celis, 1997; González-Gutiérrez, 2002; González-Gutiérrez et al., 2010; González-Gutiérrez, Santos-González, Gómez-Villar, Redondo-Vega, & Prieto-Sarro, 2017; Pellitero, 2009, 2014; Santos-González, 2011), especially in the Asturian sector affected by the Würm glaciation (Alonso, 2019; González-Trueba, 2007; González-Trueba, Serrano, & González, 2011; Rodríguez, 2009; Rodríguez-Rodríguez et al., 2018; Serrano & González-Trueba, 2005). Nevertheless, it should be noted that this richness is not limited to the highest elevations, as is revealed by the geomorphological maps of the mid-altitude mountains (Rodríguez, 2011, 2012, 2015; Ruiz-Fernández, 2011), which have shown their usefulness in territorial management, despite the fact that these areas are not well studied and have not received the same degree of interest (Beato Bergua, Poblete Piedrabuena, & Marino Alfonso, 2018). Indeed, the Sierra del Aramo, a middle mountain range and the object of study of this paper, presents a great variety of landforms and geomorphological processes that constitute both an important natural heritage, and one of the foundations of its rich landscape, all of which, until now, has been undervalued (Beato Bergua, 2018).

Geomorphological mapping is invaluable for understanding the spatial distribution of landforms, their origin and their morphological processes (Alcalá-Reygosa, Palacios, & Zamorano Orozco, 2016; Campos, Tanarro, & Palacios, 2018; Sánchez-Fabre, Peña-Monné, & Sampietro-Vattuone, 2018; Theler, Reynard, Lambiel, & Bardou, 2010). Such mapping provides essential information for territorial planning and risk assessment (Poblete Piedrabuena, Beato Bergua, & Marino Alfonso, 2016) and is fundamental in any

CONTACT Salvador Beato Bergua uo187213@uniovi.es Department of Geography, University of Oviedo, Campus de El Milán. C/ Amparo Pedregal, s/n, Oviedo, Asturias 33011, Spain

landscape analysis (Rodríguez & Castañón, 2016). Without a doubt, geomorphological maps have an analytical character that is critical at local scale, and which should be based on fieldwork and geomorphological photointerpretation to avoid underestimating both the natural heritage and the threats to low and mid-altitude mountains (Beato Bergua, 2018). On the other hand, Geographic Information System (GIS) technology has improved the storage and indexing of data, and facilitated georeferencing and dynamic cartographic representation (Bocco, Mendoza, & Velázquez, 2001; Krygier & Wood, 2011; Maksud Kamal, 2004), especially for geomorphological mapping (Gustavsson, 2006; Kertesz & Markus, 1992; Minár, Mentlík, Jedlička, & Barka, 2005; Pavlopoulos, Evelpidou, & Vassilopoulos, 2009). As a result, it is necessary to employ what is already a classic combination of field work, GIS and design tools in order to understand and represent complex areas such as these mountains (González-Gutiérrez et al., 2017; Gustavsson, Kolstrup, & Seijmonsbergen, 2006; Otto & Smith, 2013; Verstappen, 2011).

In addition, geomorphological maps present a depth of data and are also complex in themselves (Rodríguez & Castañón, 2016). In fact, they must reach four fundamental questions in cartographic representation: morphography, morphometry, morphogenesis and morphochronology (Klimaszewsky, 1988). To this we must add the lithological characteristics in the context of the structural reliefs to fully achieve the great interpretative power of geomorphological maps, and thus grant them scientific character (Rodríguez & Castañón, 2016).

The main purpose of this paper is to present the geomorphological mapping of the Sierra del Aramo from a precise and thorough study of the terrain with the use of the French CNRS mapping system at a scale of 1:25,000 and GIS. In addition, landforms and morphogenetic processes are described and explained in order to improve our awareness of the relationship between karst, periglacial processes and slope dynamics in mid-altitude mountain ranges at temperate latitudes.

2. Study area

The Sierra del Aramo is part of the Cantabrian Mountains in the NW Spain. More specifically, it is a mid-altitude mountain range situated at the intersection of the 43°16′N parallel and the 5°53′W meridian, in the Asturian Central Massif, just 20 km southwest of Oviedo, the Asturian capital (Figure 1). It constitutes a limestone ridge that extends for about 12 km with a north–south orientation. It rises above the Trubia and Caudal river basins carved out of weaker siliceous materials. Stratigraphically, almost all of the rocks are from the Carboniferous, with Namurian limestones, and pre-Stephanian shales, sandstones, limestones and coal strata. The verticalized sheets of Namurian limestones are folded and fractured, and as a group are being thrust over the Asturian Central Coal Basin by the Aramo Overthrust (Figure 2).

Thus, the Sierra del Aramo is a mountain of medium altitude but hugely elevated over the surrounding valleys, which explains the topographical and ecological differences, as well as the assorted geomorphological processes. The Gamoniterio is the highest peak which at 1,791 m a.s.l. crowns the Aramo summit platform, a karst area (dry valleys, dolines, pipes or chimneys, caves, sinks) over 1,300 m a.s.l. dominated by grasslands with the occasional shrubs (Beato Bergua, Marino Alfonso, & Poblete Piedrabuena, 2017). On the slopes of the Aramo, the karst processes are heightened significantly by the morphogenetic action of the snow (nivo-karst dolines and niches). In fact, the Aramo hillsides are steep and present rectilinear slopes between rocky escarpments, debris deposits, mass movements, and paths eroded by snow avalanches.

Climatically, the Sierra del Aramo experiences Atlantic conditions. Rainfall oscillates between 1,100 and 1,500 mm (around 2,000 mm on the summits) and is well-distributed throughout the year. On the other hand, temperatures are mild (between 6 and 13°C) with minimums at higher altitudes. Thus, we can expect four types of climate according to the Köppen classification (Beato Bergua, 2018): the first type, at lower elevations, is properly temperate and rainy all year round ($Cfsb_2$); a climate of transition to fresh ($Cfsb_3$) is found between 700 and 1,000 m a.s.l.; there is a properly fresh climate (Cfsc) between 1,000 and 1,500 m a.s.l.; finally, above 1,500 m a.s.l. the climatic rigours create a typical cold mountain climate (Dfsc). Indeed, at these altitudes there are sub-zero temperatures 3–6 months a year, and half the precipitation falls as snow (Muñoz Jiménez, 1982); in winter the range is affected by very intense snowstorms (3 or 4 annually), which produce snow cover in the order of 1 m at altitudes from 980 m a.s.l. upwards (Beato Bergua et al., 2018).

The relief of the analyzed area is defined by the existence of Namurian limestones standing out over the Devonian and Carboniferous valleys carved in weaker materials (shales, sandstones, marls, coal layers). The lithology is folded directed by the Hercynian axes that formed the *Rodilla Asturiana* or Asturian Arc (Aramburu & Bastida, 1995). The structures generated by the Hercynian orogeny and transformed over 250 Ma by different erosive agents were reactivated during the Alpine orogeny (Marquínez, 1992).

During the cold Quaternary phases in the NW of the Iberian Peninsula, the Sierra del Aramo was not affected by glaciation but did suffer intense periglacial processes (Beato Bergua, Poblete Piedrabuena, & Marino Alfonso, 2019b). Thus, the Sierra del Aramo is characterized by a markedly morphostructural relief. In the first place, the stacking of thrust sheets explains the overlapping of the limestones on the shales and sandstones, which are

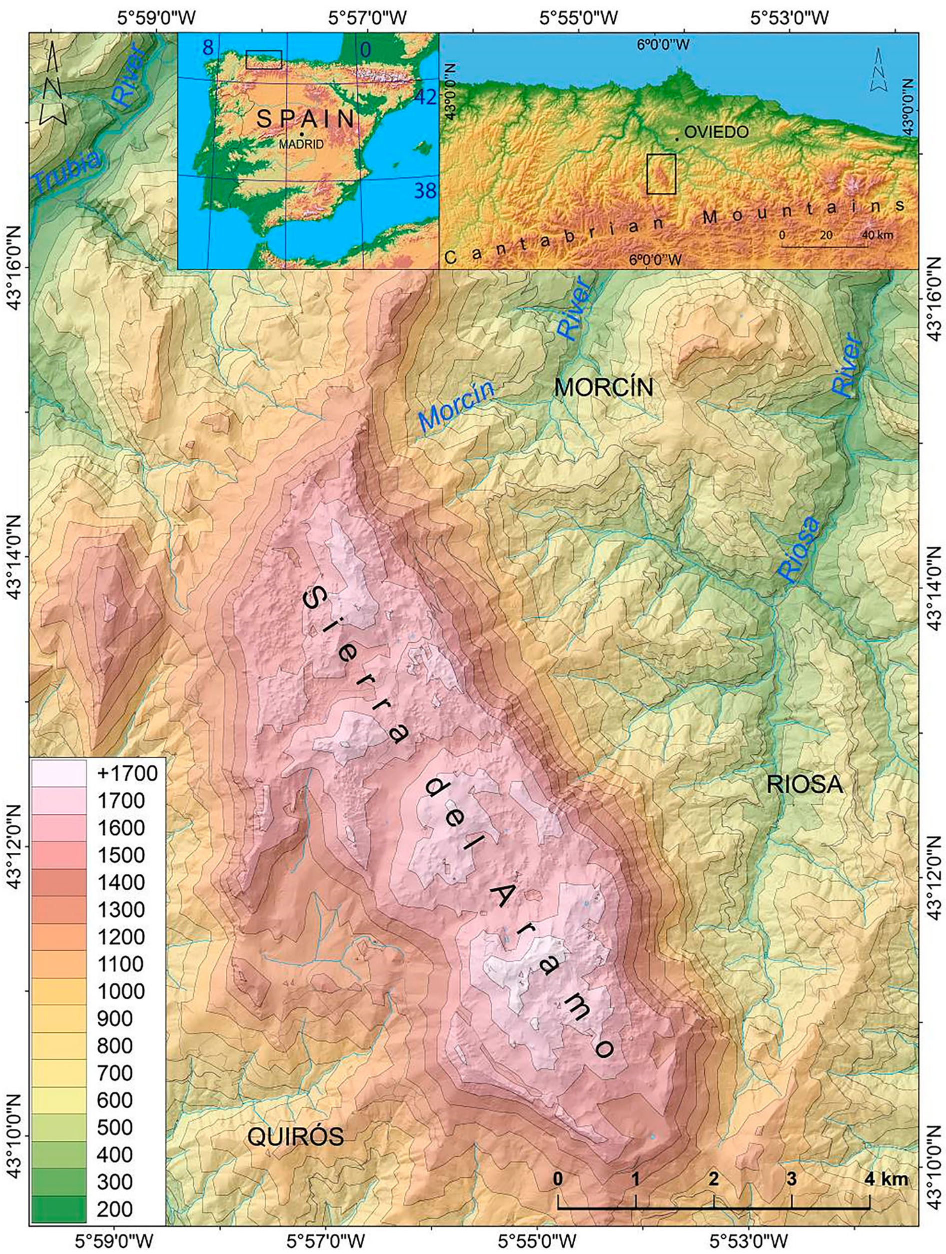

Figure 1. Location of the study area.

more fragile and are cut through by the fluvial network. Second, the massiveness of the limestone and the dense network of fractures has allowed extensive karst formation, both exogenous and endogenous. Thirdly, the lithological contrasts, the altimetric differences, and the steep slopes explain the great size of the slope movements. Finally, nivo-periglacial processes take place in the higher areas and contribute both to the increased effectiveness of the erosive agents on the lines of weakness, and to the dissolution of the limestones and the development of accumulation deposits on the Aramo slopes (Beato Bergua, 2018).

3. Materials and methods

The geomorphological map of the Sierra del Aramo has been made thanks to the digital data of the Spanish National Geographic Institute (IGN). The National Topographic Base at 1:25,000, vector format SHAPEFILE (.shp), has been used in the construction of the map. The Digital Terrain Model with 5-meter grid spacing, raster format ASCII (.asc) ESRI array, has served for the development of the hillshade and relief models that are so useful in the delineation of geomorphological units. The 0.5 m pixel, colour digital orthophotography from the Aerial Orthophoto National Program (PNOA) taken from 2015 have been used (ECW format) for the photointerpretation through stereoscope or digital screen, as well as the black and white aerial photographs at a 1:30.000 scale processed in 1980–1986, also from the IGN (http://www.ign.es/). Geologic information was provided by the Geological and Mining Institute of Spain, IGME (http://www.igme.es/). Specifically, the geological base has been drawn through from Merino-Tomé, Suárez, and Alonso (2014), and Aller (1993).

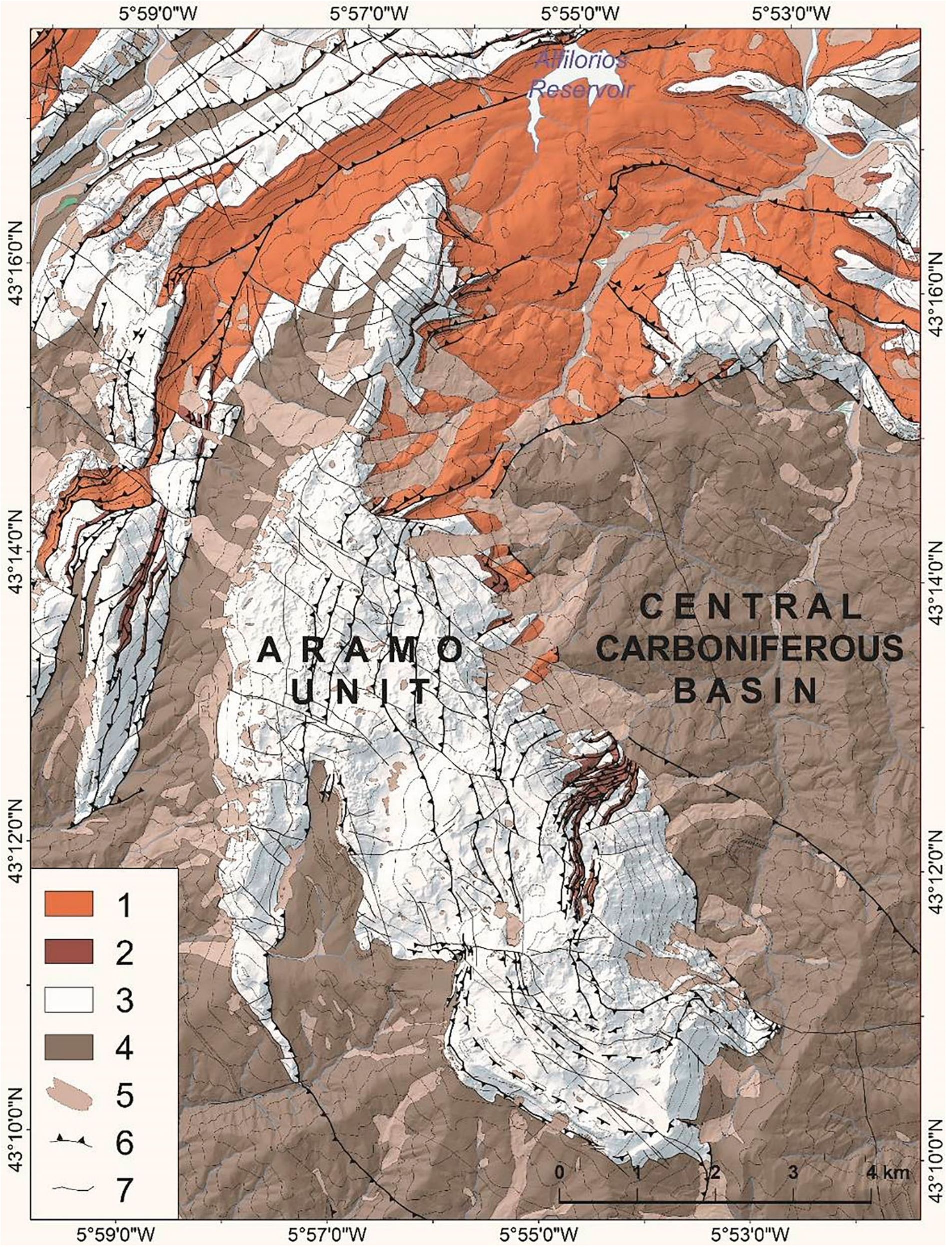

Figure 2. Geological scheme of the Sierra del Aramo. 1. Dolomites, limestones, sandstones, shales, marlstones, microconglomerates and siltstones (Devonian). 2. Quartzite sandstones, marlstones and limestones (Upper Devonian – Carboniferous). 3. Massive limestones (Namurian Carboniferous). 4. Shales, sandstones, limestones, quartzite conglomerates and coal (Moscovian Carboniferous). 5. Mass movement deposits, debris deposits and alluvial deposits (Quaternary). 6. Overthrusts. 7. Faults.

Thus, the method employed involved field observations together with the interpretation of the Digital Terrain Model, the remote sensing of aerial photos and digital orthophotographs, and the consultation of both bibliographic and cartographic sources, especially geological ones (Alonso, 2019; Beato Bergua et al., 2018; Poblete Piedrabuena et al., 2016). The fieldwork was based on the use of GPS to locate and delineate the landforms and deposits that had been identified, described and included in geomorphological sketches. The digital base and the indexing of georeferenced data were carried out by means of ESRI ArcMap10.1 with a Universal Transverse Mercator (UTM) projection (Zone 30) and the European Terrestrial Reference System 1989 Datum (ETRS89). The use of high spatial resolution materials has allowed us to work at scales higher than 1:5,000. ArcMap allows the georeferencing of the items and organizes each landform and deposit in a database for future analysis and processing.

Finally, the graphic project was performed exporting the layers of each element from ArcMap to ADOBE Illustrator CS6. Adobe Illustrator has allowed the careful delineation and representation of each element (lithology, structural and morphodynamic landforms), leading to an aesthetically pleasing and accurate image. The final printing at a scale of 1:25,000 has been designed following the RCP 77 (Recherche Coopérative sur Programme) geomorphological mapping system of the French CNRS (Centre National de la Recherche Scientifique) (CNRS, 1972; Joly, 1997), combined with adaptations of our own, and taking into account the graphical criteria of Krygier and Wood (2011) and Otto, Gustavsson, and Geilhaussen (2011) to create order, harmony and readability. In fact, the French method is the one that best reflects the extent to which systematic organization and cartographic representation can be achieved in different levels of interpretation of all the information related to the geomorphology of a certain study area (Rodríguez & Castañón, 2016).

The colour of the lithological base is light purple (P680 corresponding to Paleozoic sedimentary rocks), softened so as not to obstruct the interpretation of the geomorphological symbols. The overprints (in white or negative) serve to identify the type of rocks according to the classic criteria. The Namurian limestones are in a darker shade to enhance the relief. The tectonic lines are represented in grey (Pantone 409 of tectonics). In contrast, crests and scarps (sharp crest, rounded crest, rock wall, structural scarp) are represented in brown, to emphasize the physiographic character of these forms. Karstic landforms are represented in bluish green with the P569 colour of the karst morphodynamic system. The fluvial landforms are represented in olive green, that is, P583 corresponding to the morphodynamic system of the water's diffuse action. This colour is used for the linear symbols, outlines, and overprints, while the background has the same colour but with less intensity. The hydrographic network is in light blue (P306). For periglacial morphodynamic system a purple colour has been used, specifically colour P252, save for the colour of the background of the polygons, which is degraded. For the symbols in the Other landforms and deposits section, a brownish green has been used, as this is very common in the cartographic representation of slope landforms and temperate latitude processes. Anthropogenic landforms are indicated by light grey polygons.

4. Representation of landforms and deposits

Following the French cartographic method, the final design using ADOBE Illustrator has tried to provide the map with adequate morphographic and morphometric expressive power (using differentiated line thicknesses and different overprints). The idea is that the symbolic elements used should be reflective of the true aspect of the relief forms (Rodríguez & Castañón, 2016). Similarly, the corresponding graphic representation of both the morphogenesis and the chronology of the landforms has been made using different colours, and different shades of the same colour.

The symbols in the legend were classified into seven groups: lithology, structural landforms, karst landforms and deposits, fluvial landforms and deposits, periglacial landforms and deposits, other landforms and deposits (mass movements, interfluves, etc.), and anthropogenic landforms.

4.1. Lithology

In the foothills of the Sierra del Aramo there are some strips of the shales and sandstones of the Middle Cambrian (Oville Formation), the quartzites of the Ordovician (Barrios Formation), and the Silurian slates and sandstones (Formigoso Formation). Although there are small Devonian outcrops in the SW sector (ferruginous sandstones of the Furada Formation), the Devonian materials are predominant in the NE quadrant, where the limestones, dolomites, sandstones and marls of the Rañeces Group are found, together with the limestones of the Moniello Formation, the sandstones and shales of the Naranco Formation, and the quartzites of the Ermita Formation. Finally, in the transition to the Carboniferous, the thin layer of nodular limestones of the Alba Formation was deposited.

However, the structural shell of the Sierra del Aramo is made up of Namurian limestones, specifically the Valdeteja and Barcaliente Formations, regionally known as *Caliza de Montaña*. They rise above the pre-Stefanian materials that surround the entire Sierra del Aramo. These are the Westfalian slate and sandstones that together with limestone strata and coal layers assemble the Asturian Central Carboniferous Basin.

4.2. Structural landforms

The thrusted limestone sheets that make up the structural skeleton of the Aramo are arranged according to the N-S synorogenic axis. However, as a solution to the Variscan orogeny of the Asturian Arc, the stratigraphic inversion changes to W-E both in the North of the study area and in the South. These arched tectonic lines are largely preserved reactivated by the Alpine orogeny. Both orogenic stages produced fractures and reverse faults with the rising of some lithological units with respect to others.

In summary, fault and thrust scarps are still clearly visible in the modern-day landscape.

The most prominent thrust scarp is on the eastern slope where the Aramo Unit thrusts on the Central Carboniferous Basin, generating vertical scarps of about 100 m. Other thrusting units in which scarps have been produced are the Alba Formation and the Namurian limestones. On the one hand, we are talking about small metric differences (5–20 metres) due to thrust and the differential erosion of the materials corresponding to the transition between the Devonian and the Carboniferous; on the other, we are looking at small escarpments (20–100 metres), created both by thrust and by fracture, in the Namurian limestones that are conserved in the high karstic platform (Figure 3).

Figure 3. Area between Gamoniteiro and Barriscal peaks. Fractures, thrusts and lithological contacts between Barcaliente and Valdeteja limestone formations.

4.3. Karst landforms and deposits

Although karstic forms are a subset of the structural relief forms, they are dealt with separately due to their importance. Specifically, the Sierra del Aramo has four main dry valleys, hundreds of dolines (grouped in fields), and several uvalas formed by the coalescence of other karst depressions. They are arranged according to the lines of stratification, thrusting and fracture, in the same way as bogaz (wide and deep clefts) and fluvial-karst gorges. Ponor (shallow holes that capture surface drainage) are also abundant in the karstic platform (there is no exogenous fluvial network, and all the water circulates underground), as are karst springs on the slopes in contact with the impermeable siliciclastic materials, which contain clay.

The limestone reliefs are full of residual hills, depressions with clay-ferruginous filling and allochthonous materials, and extensive surfaces with lapies or *karren* (small forms a few centimetres to a metre in size, caused by solution on the surface of the rock) (Figure 4). Among the latter, it is worth mentioning the smaller structural forms called *splitkarren* (fine etching of craks), and also the metric-size forms known as grykes or *kluftkarren* that individualize blocks (clints or *flachkarren*). Among the linear forms outside the structures, the most common are the *rillenkarren*, *rinnekarren* and *wandkarren* types (rill lapies). As for the covered lapies, the variety of forms is smaller and limited to *rundkarren*.

4.4. Fluvial landforms and deposits

Forms of fluvial origin surround the limestone reliefs, effectively eroding the slates and sandstones (more detachable materials) of the Caudal (Morcín, Grandiella, Llamo, Riosa) and Trubia (Quirós, Lindes) river basins. Through the underground galleries these rivers

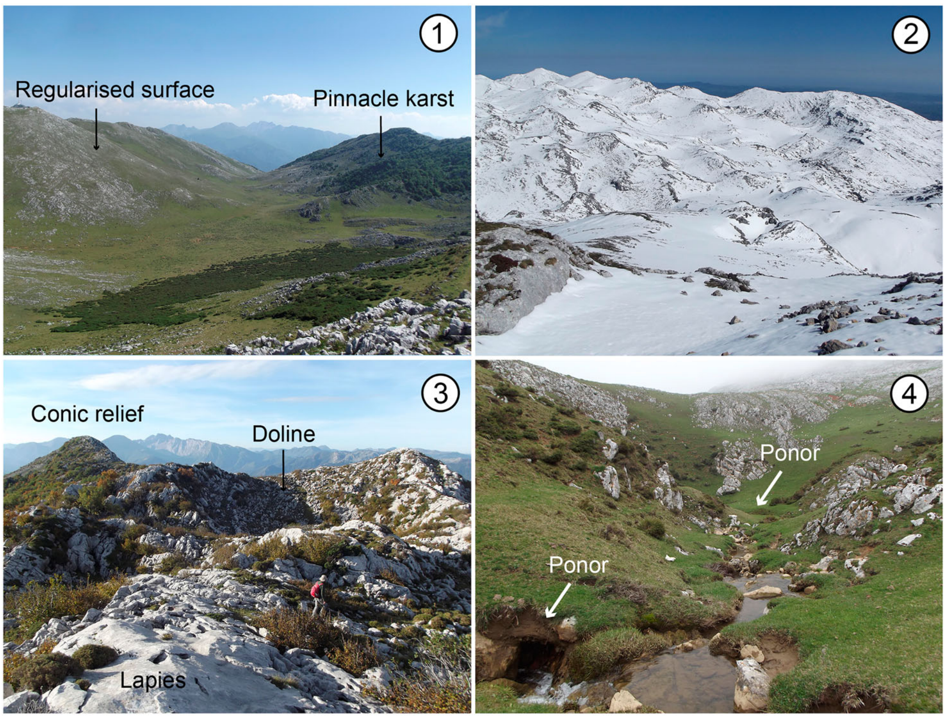

Figure 4. 1) Vallongo dry valley. 2) Landscape of residual hills, dolines and uvalas in the central sector of the Aramo karstic platform. 3) Lapies, dolines and conic reliefs in Braña de Vallongo. 4) Ponors and blind valley of Agüeras.

feed on the abundant waters coming from the Atlantic precipitations and the limestone summits like that of the Sierra del Aramo.

Basically, we find two types of fluvial forms: those derived from erosion and those produced by accumulation processes. As for the first, these are linear incisions that give rise to small gullies on the removable materials, or valleys with a V-shaped profile, of medium dimensions. With regard to the accumulation forms, it is worth highlighting the narrow floodplains of the Quirós, Trubia and Morcín rivers, as well as various alluvial fans and small-scale alluvial terraces along the same rivers. In fact, the reduced length and the great unevenness of the Cantabrian fluvial courses impose very efficient erosive dynamics.

4.5. Periglacial landforms and deposits

The Sierra del Aramo presents a large sample of geomorphological items of periglacial and cryonival origin (such as nivation hollows and snow avalanche paths). These landforms and deposits are for the most part inherited from colder past climatic conditions. Indeed, the cold Pleistocene periods have left multiple traces of the action of the ice in the Asturian Central Massif (Castañón, 1986, 1989; Castañón & Frochoso, 1994; Rodríguez, 2009, 2012), as is the case of the screes and the stratified deposits in our study area. On the other hand, there are some landforms and deposits in which the periglacial denudation processes were combined to slope processes. Thus, regularized surfaces by erosion, mixed channels, and colluvium (also regularizing the slopes) on the hillsides were favoured by a intense crioclastic activity during the cold phases of the Quaternary.

However, a lot of other landforms are due to current mixed processes involving snow, karst dissolution, and slope dynamics. An example of this are the snow avalanche paths and deposits, especially in the eastern hillside (see Beato Bergua et al., 2018), or the niches and dolines of nivo-karstic origin in the highest platform, above 1.500 m. a.s.l. In addition, it is worth highlighting the existence of active solifluction lobes in the dry valley at the foot of the Gamoniteiro and Xistras peaks (Figure 5).

4.6. Other landforms and deposits

This section includes non-channellised snow avalanches, physiographic aspects such as interfluves, and also deposits originating from mass movements. The latter are generally characterized by angular and heterometric debris (dominated by blocks) of limestone arranged in chaotic structures. Many of these blocks are large, tens or even hundreds of m^3 in size. The surface of mass movements deposits has convex sides and bulges as hummocks. On the contrary, there are lobated shapes in the front that indicate a certain flow. In the upper part of the slumped mass there are scars with wide escarpments (Figure 6).

4.7. Anthropogenic landforms

The Westfalian coal seams and the copper and fluorite deposits have been exploited since ancient times,

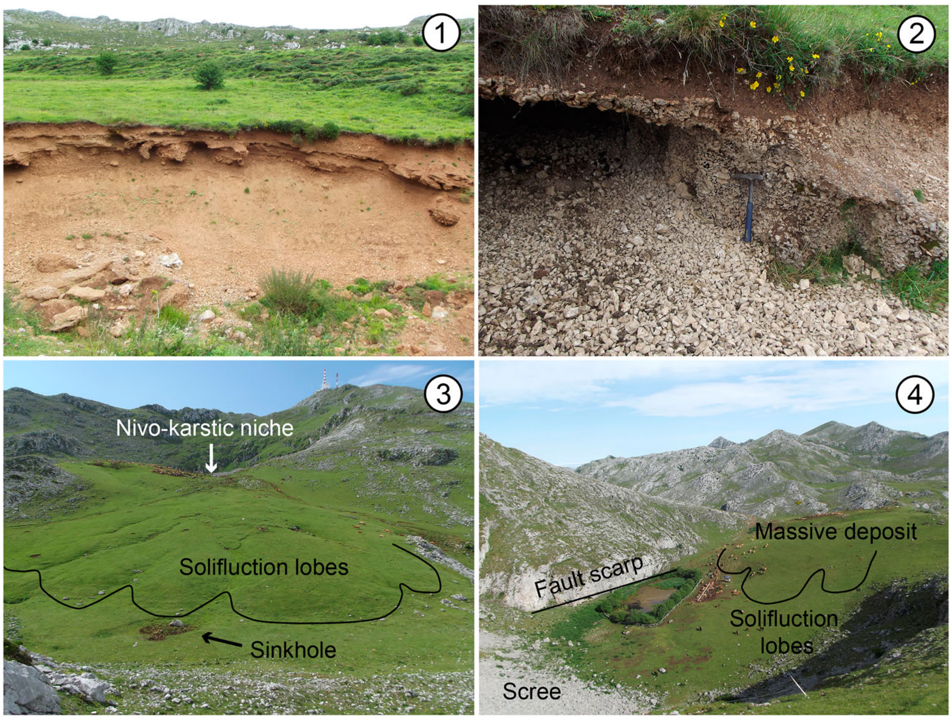

Figure 5. 1) Stratified scree in Braña de Linares. 2) Non-cemented gelifracts deposit above the previous. 3) Solifluction lobes in the dry valley under the nivo-karstic niche near Gamoniteiro Peak. 4) Periglacial scree, nivo-karstic niche and massive deposit with solifluction lobes under Gamoniteiro Peak.

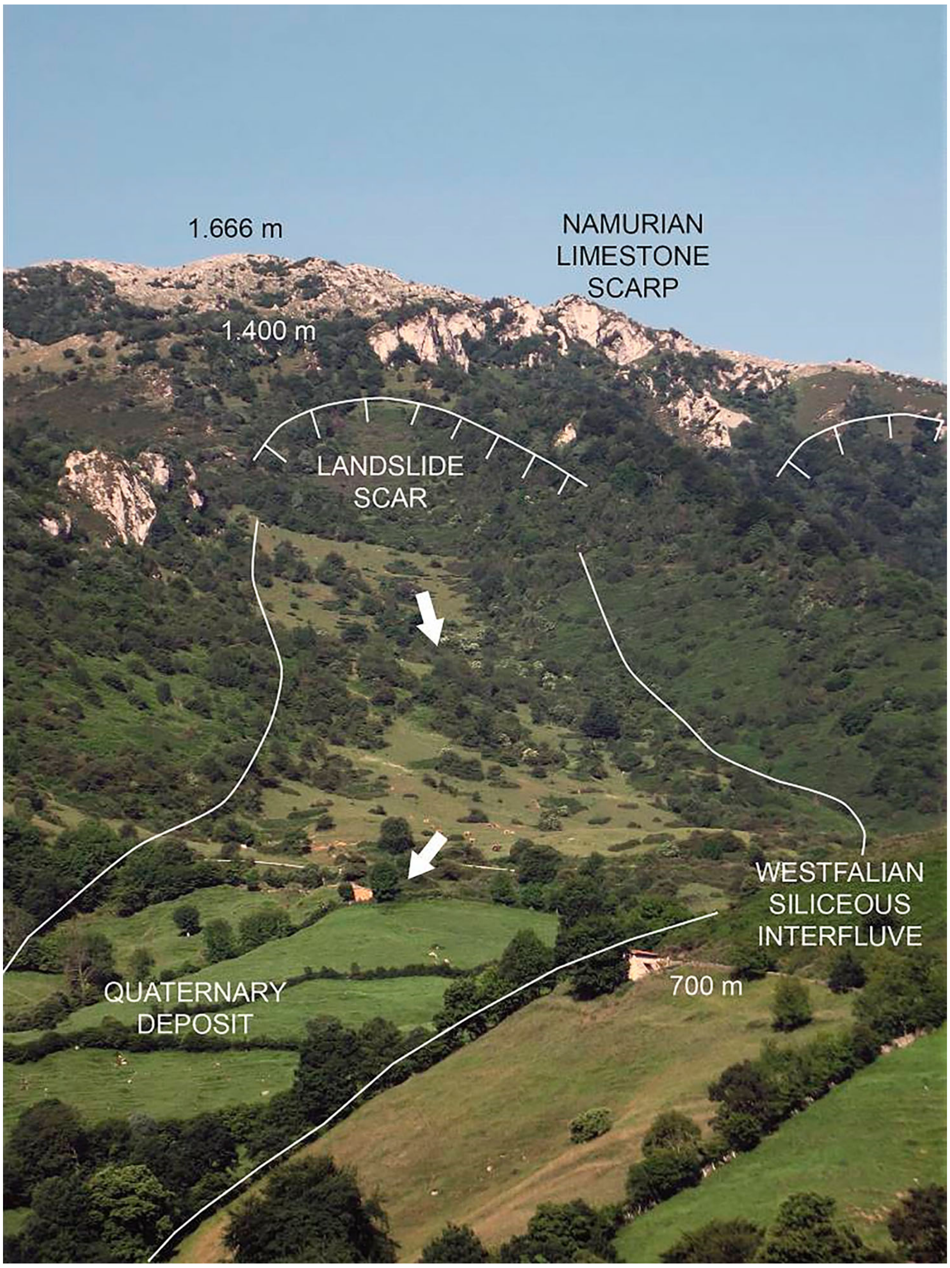

Figure 6. Mass movement in the eastern hillside.

leaving a trail of mining operations from different eras throughout the study area. Geomorphologically the most notable are the numerous mining waste dumps, small terraces and entrances to underground galleries. Likewise, there are dozens of villages and cottages dotted around the territory. The exploitation of water resources has also been very important, and this is outlined by the existence of two reservoirs (Valdemurio and Los Alfilorios) and several ponds, represented in blue.

5. Conclusions

This article describes the geomorphological mapping for the Sierra del Aramo, whose wealth of landforms and deposits had not been mapped until now. In fact, with few exceptions, the mid-altitude mountains of the Asturian Massif have hardly been analysed from a geomorphological perspective, eclipsed as they are by the greater mountains of the region. This paper demonstrates the geomorphological diversity of these lesser-investigated mountainous environments and the need for their mapping, which can become a fundamental tool in the assessment of geoheritage and geomorphic hazards. In particular, the dominant landforms on the Sierra del Aramo map are those due to karstification (hundreds of sinkholes and nivo-karstic dolines have been mapped) or produced by mass movements, together with those due to current and past cryonival phenomena. The most important active geomorphological processes in this area are the fluvial erosion of the slates and sandstones, the karstic dissolution in the limestones, and the slope processes of landslides and snow avalanches, the latter constituting a natural risk that must be analysed correctly.

Software

The digital cartographic base, the lithological base, and the digitalization of landforms and deposits used in the preparation of this map were performed with ESRI ArcMap10.1. The final design was carried out with the graphic program ADOBE Illustrator CS6.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Salvador Beato Bergua http://orcid.org/0000-0001-5538-7685
Miguel Ángel Poblete Piedrabuena http://orcid.org/0000-0003-1030-5310
Carmen Rodríguez Pérez http://orcid.org/0000-0002-2065-7515
José Luis Marino Alfonso http://orcid.org/0000-0001-6213-407X

References

Alcalá-Reygosa, J., Palacios, D., & Zamorano Orozco, J. J. (2016). Geomorphology of the Ampato volcanic complex (Southern Peru). *Journal of Maps*, *22*, 1–10. doi:10.1080/17445647.2016.1142479

Aller, J. (1993). La estructura geológica de la Sierra del Aramo (Zona Cantábrica, NO de España). *Trabajos de Geología*, *19*, 3–15.

Alonso, V. (2014). Mapa geomorfológico del sector sur del Macizo de las Ubiñas (Cordillera Cantábrica, NO de España). *Trabajos de Geología*, *34*, 125–132.

Alonso, V. (2019). Geomorphology of the Ubiñas Massif, Cantabrian Mountains, NW Spain (1:22,000). *Journal of Maps*. doi:10.1080/17445647.2019.1579763

Aramburu, C., & Bastida, F. (Eds.). (1995). *Geología de Asturias*. Gijón: Editorial Trea.

Ballesteros, D., Jiménez-Sánchez, M., García-Sansegundo, J., & Giralt, S. (2010). Geomorphology and structural control in caves: A research in Torca Teyera (Picos de Europa, NW Spain). In B. Andreo, F. Carrasco, J. Durán, & J. LaMoreaux (Eds.), *Advances in research in Karst Media. Environmental earth sciences* (pp. 337–342). Berlin, Heidelberg: Springer. doi:10.1007/978-3-642-12486-0_52

Beato Bergua, S. (2018). *El patrimonio natural de la Sierra del Aramo (Montaña Central Asturiana) y la evolución de su paisaje*. (Unpublished PhD Thesis). University of Oviedo, 596 pp.

Beato Bergua, S., Marino Alfonso, J. L., & Poblete Piedrabuena, MÁ. (2017). El paisaje vegetal y los hábitats forestales de interés comunitario en la Montaña Central Asturiana. *Cuadernos Geográficos*, *56*(1), 26–52.

Beato Bergua, S., Poblete Piedrabuena, MÁ, & Marino Alfonso, J. L. (2018). Snow avalanche susceptibility in the eastern hillside of the Aramo range (Asturian Central Massif, Cantabrian Mountains, NW Spain). *Journal of Maps*, *14*(2), 373–381. doi:10.1080/17445647.2018.1480974

Beato Bergua, S., Poblete Piedrabuena, MÁ, & Marino Alfonso, J. L. (2019a). Snow avalanches, land use changes, and atmospheric warming in landscape dynamics of the Atlantic mid-mountains (Cantabrian range, NW Spain). *Applied Geography*, *107*, 38–50. doi:10.1016/j.apgeog.2019.04.007

Beato Bergua, S., Poblete Piedrabuena, MÁ, & Marino Alfonso, J. L. (2019b). Formas periglaciares y nivoperiglaciares en la Sierra del Aramo (Macizo Central Asturiano). *Eria*, Volumen 2019-1. Año XXXIX, 1, 5–23. doi:10.17811/er.1.2019.5-23

Bocco, G., Mendoza, M., & Velázquez, A. (2001). Remote sensing and GIS-based regional geomorphological mapping—a tool for land use planning in developing countries. *Geomorphology*, *39*(3–4), 211–219. doi:10.1016/S0169-555X(01)00027-7

Campos, N., Tanarro, L. M., & Palacios, D. (2018). Geomorphology of glaciated gorges in a granitic massif (Gredos range, central Spain). *Journal of Maps*, *14*(2), 321–329. doi:10.1080/17445647.2018.1468829

Castañón, J. C. (1986). Formas de relieve de origen glaciar y periglaciar en el borde noroccidental de la sierra del Aramo. *Eria*, *10*, 127–130.

Castañón, J. C. (1989). *Las formas de relieve de origen glaciar en los sectores central y oriental del Macizo Asturiano*. (Unpublished PhD Thesis). University of Oviedo, 697 pp.

Castañón, J. C., Frochoso, M. (1994). El periglaciarismo de la Cordillera Cantábrica. In A. Gómez Ortiz, et al. (Ed.), *Periglaciarismo en la Península Ibérica, Canarias y Baleares. Monografías de la Sociedad española de Geomorfología, n° 7* (pp. 75–91). Granada: Universidad de Granada.

CNRS. (1972). *Cartographie géomorphologique. Travaux de la RCP77. Mémoires et Documents, vol. 12*. París: Éditions du Centre National de la Recherche Scientifique.

Domínguez-Cuesta, M. J., Jiménez-Sánchez, M., & Berrezueta, E. (2007). Landslides in the Central Coalfield (Cantabrian Mountains, NW Spain): Geomorphological features, conditioning factors and methodological implications in susceptibility assessment. *Geomorphology*, *89*(3–4), 358–369. doi:10.1016/j.geomorph.2007.01.004

Domínguez-Cuesta, M. J., Valenzuela, P., Rodríguez-Rodríguez, L., Ballesteros, D., Jiménez-Sánchez, M., Piñuela, L., & García-Ramos, J. C. (2019). Cliff coast of Asturias. In J. Morales (Ed.), *The Spanish coastal systems* (pp. 49–77). Cham: Springer. doi:10.1007/978-3-319-93169-2_3

Flor, G., & Flor-Blanco, G. (2014). Raised Beaches in the Cantabrian coast. In F. Gutiérrez, & M. Gutiérrez (Eds.), *Landscapes and landforms of Spain. World geomorphological landscapes* (pp. 239–248). Dordrecht: Springer. doi:10.1007/978-94-017-8628-7_20

Flor, G., Flor-Blanco, G., Cedrún, P. M., Flores-Soriano, C., & Borghero, C. (2019). Aeolian Dune fields in the coasts of Asturias and Cantabria (Spain, Nw Iberian Peninsula). In J. Morales (Ed.), *The Spanish coastal Systems* (pp. 585–609). Cham: Springer. doi:10.1007/978-3-319-93169-2_25

García de Celis, A. (1997). *El relieve de la Montaña Occidental de León*. Valladolid: Secretariado de Publicaciones de la Universidad de Valladolid. 290 pp.

González-Gutiérrez, R. B. (2002). *El relieve de los valles del Torío y Curueño (Montaña Cantábrica Leonesa)*. León: Secretariado de Publicaciones y Medios Audiovisuales de la Universidad de León.

González-Gutiérrez, R. B., Redondo-Vega, J. M., Gómez-Villar, A., Santos-González, J., Prieto-Sarro, I., Fernández-Prieto, R., & Luna-Rabanal, C. (2010). *Mapa geomorfológico de Boñar. León (M.T.N. 104), Escala 1/50.000*. Unpublished manuscript.

González-Gutiérrez, R. B., Santos-González, J., Gómez-Villar, A., Redondo-Vega, J. M., & Prieto-Sarro, I. (2017). Geomorphology of the Curueño river headwaters, Cantabrian mountains (NW Spain). *Journal of Maps*, *13*(2), 382–394. doi:10.1080/17445647.2017.1316217

González-Trueba, J. J. (2007). *Mapa geomorfológico del Macizo Central del Parque Nacional Picos de Europa. E. 1:25.000*. Madrid: OAPN, Ministerio de Medio Ambiente.

González-Trueba, J. J., Serrano, E., & González, M. (2011). *Mapa geomorfológico del Macizo Occidental (Cornión) del Parque Nacional Picos de Europa. E. 1:25.000*. Madrid: OAPN, Ministerio de Medio Ambiente.

Gustavsson, M. (2006). *Development of a detailed geomorphological mapping system and GIS geodatabase in Sweden*. Acta Universitatis Upsaliensis. Digital Comprehensive Summaries of Uppsala Dissertations from the Faculty of Science and Technology 236. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-7222

Gustavsson, M., Kolstrup, E., & Seijmonsbergen, A. C. (2006). A new symbol-and-GIS based detailed geomorphological mapping system: Renewal of a scientific discipline for understanding landscape development. *Geomorphology*, *77*(12), 90–111. doi:10.1016/j.geomorph.2006.01.026

Jiménez, M. (1999). Geomorfología fluvial en la cabecera del río Nalón (Cordillera Cantábrica, Noroeste de España). *Trabajos de Geología*, *21*, 189–200.

Jiménez-Sánchez, M., Rodríguez-Rodríguez, L., García-Ruiz, J. M., Domínguez-Cuesta, M. J., Farias, P., Valero-Garcés, B., … Valcárcel, M. (2013). A review of glacial geomorphology and chronology in northern Spain: Timing and regional variability during the last glacial cycle. *Geomorphology*, *196*, 50–64. doi:10.1016/j.geomorph.2012.06.009

Joly, F. (1997). *Glossaire de géomorphologie. Base de données sémiologiques pour la cartographie*. Paris: Armand Colin. 325 pp.

Kertesz, A., & Markus, B. (1992). GIS applications in geomorphology and in geomorphology mapping. *Geologishe Jahrbuch*, *A 122*, 381–387.

Klimaszewsky, M. (1988). On constructing detailed geomorphological maps. *Zeitschrift für Geomorphologie*, *32*(4), 457–470.

Krygier, J., & Wood, D. (2011). *Making maps: A visual guide to map design for GIS*. New York, NY: The Guilford Press. 256 pp.

Maksud Kamal, A. S. M. & Saburoh Midorikawa. (2004). GIS-based geomorphological mapping using remote sensing data and supplementary geoinformation: A case study of the Dhaka city area, Bangladesh. *International Journal of Applied Earth Observation and Geoinformation*, *6*(2), 111–125. doi:10.1016/j.jag.2004.08.003

Marquínez, J. (1992). Tectónica y relieve en la Cornisa Cantábrica. In A. Cearreta y F.M. Ugarte (Eds.), *The late quaternary in the western Pyrenean region* (pp. 141–157). Leioa, Bizkaia: Servicio Editorial de la Universidad del País Vasco.

Menéndez-Duarte, R., Marquínez, J., Fernández-Menéndez, S., & Santos, R. (2007). Incised channels and gully erosion in Northern Iberian Peninsula: Controls and geomorphic setting. *CATENA*, *71*(2), 267–278. doi:10.1016/j.catena.2007.01.002

Merino-Tomé, O., Suárez, A., & Alonso, J. L. (2014). Mapa Geológico Digital Continuo 1: 50.000, Zona Cantábrica (Zona-1000). In *GEODE. Mapa Geológico Digital Continuo de España*. http//info.igme.es/cartografiadigital/geologica/geodezona.aspx?Id=Z1000

Minár, J., Mentlík, P., Jedlička, K., & Barka, I. (2005). Geomorphological information system: Idea and option for practical implementation. *Geografický Časopis*, *57*(3), 247–266. Retrieved from https://www.sav.sk/journals/uploads/03121121GC-05-3_Minar_et_al.pdf

Muñoz Jiménez, J. (1982). Geografía Física. El relieve, el clima y las aguas. In F. Quirós (Ed.), *Geografía de Asturias* (pp. 1–271). Oviedo: Ayalga.

Otto, J.-C., Gustavsson, M., & Geilhaussen, M. (2011). Cartography: Design, symbolisation and visualisation of geomorphological maps. In M. J. Smith, P. Paron, & J. S. Griffiths (Eds.), *Geomorphological mapping: Methods and Applications* (pp. 253–295). London: Elsevier. doi:10.1016/B978-0-444-53446-0.00009-4

Otto, J.-C., & Smith, M. J. (2013). Geomorphological mapping. *British Society for Geomorphology Geomorphological Techniques*, *6*, Chap. (2), Sec. (6), 1–10.

Pavlopoulos, K., Evelpidou, N., & Vassilopoulos, A. (2009). *Mapping geomorphological environments*. Berlin: Springer. doi:10.1007/978-3-642-01950-0_1

Pellitero, R. (2009). Application of an alpine geomorphological mapping system to an Atlantic mountain environment: The Curavacas Massif (Cantabrian range, Northwest Spain). *Journal of Maps*, *5*(1), 194–205. doi:10.4113/jom.2009.1065

Pellitero, R. (2014). Geomorphology and geomorphological landscapes of Fuentes Carrionas. *Journal of Maps*, *10*(2), 313–323. doi:10.1080/17445647.2013.867822

Poblete Piedrabuena, MÁ, Beato Bergua, S., & Marino Alfonso, J. L. (2016). Landforms in the Campo de Calatrava Volcanic field (Ciudad Real, Central Spain). *Journal of Maps*, *12*(S1), 271–279. doi:10.1080/17445647.2016.1195302

Rodríguez, C. (2009). *Geomorfología de la Montaña Astur-Leonesa entre los puertos de Ventana y Somiedo*. (Unpublished PhD Thesis). University of Oviedo, 365 pp.

Rodríguez, C. (2011). La evolución geomorfológica de la media montaña cantábrica: las sierras cuarcíticas de Porcabezas y de Santa Cristina (área central de Asturias). *Ería*, *84–85*, 47–75.

Rodríguez, C. (2012). La evolución antigua del relieve en el área central de la Cordillera Cantábrica. *Ería*, *89*, 203–230.

Rodríguez, C. (2015). *El relieve de la montaña central asturiana: la sierra de Sobia y el macizo de Somiedo*. RIDEA, Oviedo, 180 pp.

Rodríguez, C., y Castañón, J. C. (2016). Modos de representación cartográfica de las unidades de paisaje: revisión y propuestas. *Ería*, *99-100-100 bis*, 15–40.

Rodríguez-Rodríguez, L., Jiménez-Sánchez, M., Domínguez-Cuesta, M. J., & Aranburu, A. (2015). Research history on glacial geomorphology and geochronology of the Cantabrian Mountains, north Iberia (43–42°N/7–2°W). *Quaternary International*, *364*, 6–21. doi:10.1016/j.quaint.2014.06.007

Rodríguez-Rodríguez, L., González-Lemos, S., Ballesteros, D., Valenzuela, P., Domínguez-Cuesta, M. J., Llana-Fúnez, S., & Jiménez-Sánchez, M. (2018). Timing of paraglacial rock-slope failures and denudation signatures in the Cantabrian Mountains (North Iberian Peninsula). *Land Degradation & Development*, *29*, 3159–3173. doi:10.1002/ldr.3012

Ruiz-Fernández, J. (2011). Geomorphological map of an Atlantic mid-height mountain area: The Juan Robre and Jana ridge (Cantabrian range, Northwest Spain). *Journal of Maps*, *7*(1), 260–272. doi:10.4113/jom.2011.1173

Ruiz Fernández, J., & Poblete Piedrabuena, MÁ. (2011). Las terrazas fluviales del río Cares: aportaciones sedimentológicas y cronológicas (Picos de Europa, Asturias). *Estudios Geográficos*, *LXXII*(270), 173–202. doi:10.3989/estgeogr.201108

Sánchez-Fabre, M., Peña-Monné, J. L., & Sampietro-Vattuone, M. M. (2018). Geomorphology of the northern sector of the Alfambra-Teruel depression (Iberian ranges, NE Spain). *Journal of Maps*. doi:10.1080/17445647.2018.1551157

Santos-González, J. (2011). *Glaciarismo y periglaciarismo en el Alto Sil, provincia de León (Cordillera Cantábrica)*. (Unpublished PhD Thesis). University of León.

Serrano, E., & González-Trueba, J. J. (2005). Assessment of geomorphosites in natural protected areas: The Picos de Europa National Park (Spain). *Géomorphologie Relief. Processus. Environment*, *11*(3), 197–208. doi:10.4000/geomorphologie.364

Serrano, E., González-Trueba, J. J., Pellitero, R., González-García, M., & Gómez-Lende, M. (2013). Quaternary glacial evolution in the Central Cantabrian Mountains (Northern Spain). *Geomorphology*, *196*, 65–82. doi:10.1016/j.geomorph.2012.05.001

Serrano, E., González-Trueba, J. J., Pellitero, R., & Gómez-Lende, M. (2016). Quaternary glacial history of the Cantabrian Mountains of northern Spain: A new synthesis. *Geological Society (London, Special Publications)*, *433*, 55–85. doi:10.1144/SP433.8

Slaymaker, O., Spencer, T., & Embleton-Hamann, C. (Eds.). (2009). *Geomorphology and global environmental change*. Cambridge: Cambridge University Press.

Theler, D., Reynard, E., Lambiel, C., & Bardou, E. (2010). The contribution of geomorphological mapping to sediment transfer evaluation in small alpine catchments. *Geomorphology*, *124*(3–4), 113–123. doi:10.1016/j.geomorph.2010.03.006

Verstappen, H. (2011). Chapter Two – Old and New trends in geomorphological and landform mapping. *Developments in Earth Surface Processes*, *15*, 13–38. doi:10.1016/B978-0-444-53446-0.00002-1