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Geomorphology of the Courel Mountains Unesco Global Geopark (Galicia, NW Iberian Peninsula)

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ABSTRACT

The Courel Mountains Geopark is in Galicia, Northwest Spain. Its total area is 578.29 km^2. Parallel valleys and ridges characterize its relief from North to South. Their maximum altitude reaches 1,641 m. Their lithology is dominated by slates, quartzites, and limestones, together with small diabase outcrops. Materials are intensely fractured due to the tectonic dynamics that started during the Cenozoic, and sedimentary formations accumulated in response to environmental changes during the Pleistocene are abundant. As a result, a wide variety of structural landforms are present, along with a wide range of landforms and deposits of alluvial, fluvial, glacial, and periglacial origin. All of them have been mapped to enable sustainable use and management aimed at improving the livelihood of the inhabitants of the geopark area, which has suffered depopulation in recent decades.

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Geopark; Courel Mountains; Galicia; Iberian Peninsula; geomorphology; rural development

KEY POLICY HIGHLIGHTS

- Courel Mountains Unesco Global Geopark stands out for its geological and geomorphological diversity.
- This sector shows evidence of different structural geoforms (alluvial, fluvial, glacier, and periglacial origin).
- Geomorphological cartography graphically draws the most outstanding deposits and geoforms.

1. Introduction

The Courel Mountains UNESCO Global Geopark is in Galicia, northwest of the Iberian Peninsula, and is delimited by coordinates 42.715°N-42.32°N and 7.023°W-7.42°W (Figure 1). Its total area is 578.29 km^2, and, as of 2019, 5178 people inhabited its territory. Topographically, it is characterized by valleys and ridges running from North to South. Their maximum altitude reaches 1,641 m. The mean annual precipitation is 1,277 mm, and the mean annual temperature is 8.1°C. The marked contrasts observed between valleys and ridges cannot be quantified due to the small number of meteorological stations in the area. Biogeographically, it is a zone of transition between the Atlantic and Mediterranean regions.

Despite its small size, the geopark has unique features. These include Variscan folds such as those of Campodola or Castrodares, the excellent visibility of glacial deposits that indicate the importance of ice at elevations below 1600 m, or the presence of periglacial macroclast deposits indicating phases with permafrost.

In addition to the elements associated with the cold periods, there are forms and deposits of fluvial origin. There are stepped terraces that can be differentiated and alluvial deposits that contribute significantly to the analysis of paleoenvironmental evolution. It is necessary to add the presence of karstic forms, exclusive in the northwest of the Iberian Peninsula. In O Courel, exokarstic forms are abundant, such as dolines and also the endokarstic geoforms, with more than 40 caves located.

The main objective of this research was to map the outstanding features present in the geopark by combining points, lines, and polygons in a GIS.

This aims to help the sustainable planning and management of resources to promote sustainable

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Supplemental map for this article can be accessed at https://doi.org/10.1080/17445647.2023.2257714.

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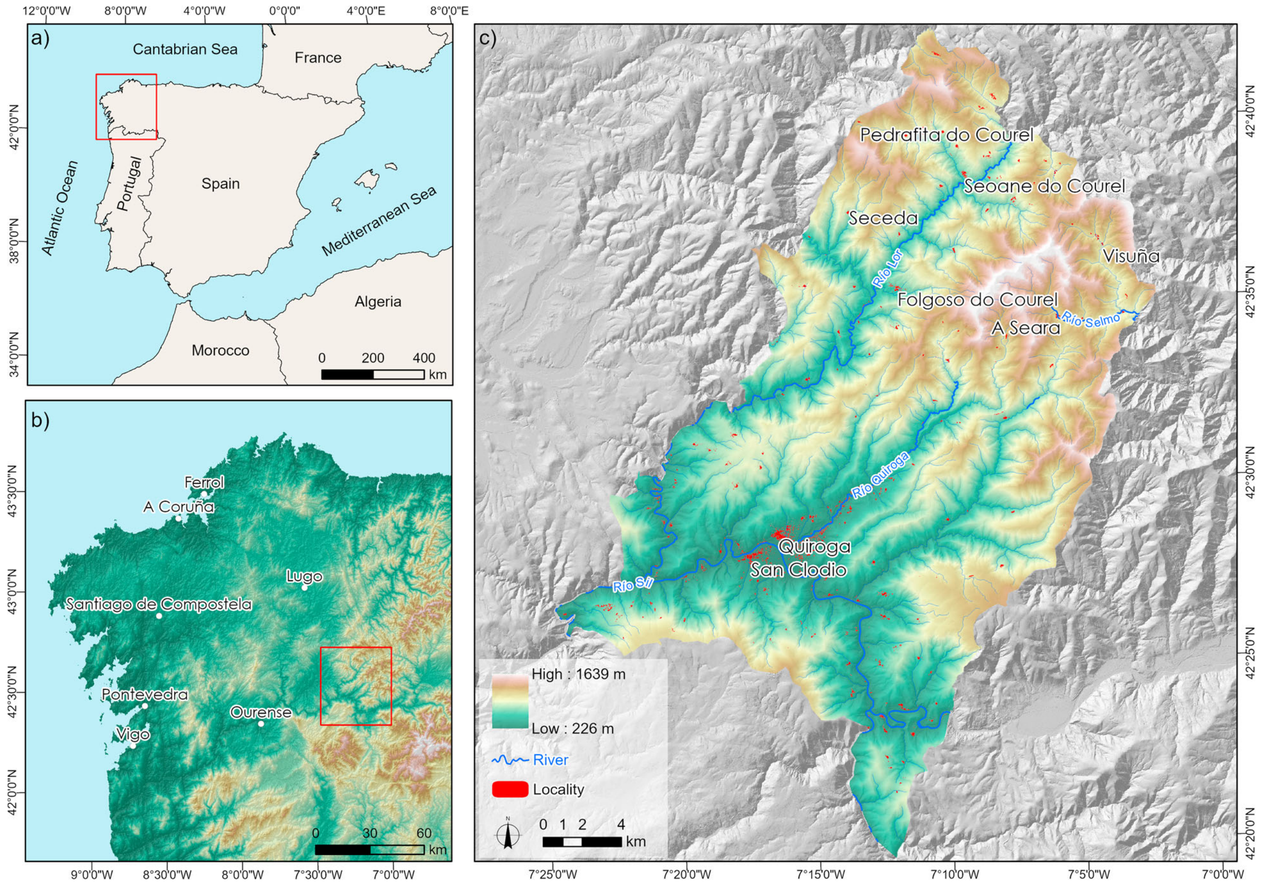

Figure 1. Location of the Courel Mountains Unesco Global Geopark at a) continental scale, b) regional level, and c) detail area. Red polygons indicate the map extension of b) and c) in a) and c), respectively.

rural development of the area based on creating dissemination resources and helps to promote the main landforms of this site, which has suffered a demographic decline in recent decades.

2. Geological settings

The structural forms, which generate the main relief patterns, result from millennia of geological evolution. Over the last 40 years, numerous studies have analyzed the lithological composition and geotectonic features of this sector, some of which are mentioned below: Matte (1968), Parga (1969), Dozy (1983), Martínez-Catalán et al. (1992), Fernández et al. (2007), Martín-González et al. (2014), or Villar Alonso et al. (2018).

Currently, in the lithological context, slates, quartzites, and limestones dominate the area, along with small diabase outcrops (Figure 2). Slates are the primary lithology in the geopark's territory, either uniformly or associated with other rock types such as sandstones, limestones, and dolomites. They determine the steep profile of many slopes. Quartzites dominate the whole area, forming parallel stripes of varying widths running from West to East. Rocky scarps evidence their importance in the terrain, such as those associated with the great recumbent fold of Campodola-Leixazós (Figure 3-a) or those appearing on the beds of many water courses and leading to the existence of many rapids and waterfalls (Figure 3-c). Limestones, in turn, are present mainly in the northern section of the Geopark. They are associated with endokarst landforms, such as caves, and exokarst ones, such as limestone pavements, dolines (Figure 3-b), or even long depressions marked by intense dissolution processes.

The intense deformation of the materials must be related to the Variscan orogeny (Matte, 1968; Martínez-Catalán et al., 2016) and especially to the development during the Cenozoic period (Martín-González et al., 2014). It is particularly worth noting the strike-slip faults that moved the terrain along a general NNE-SSW direction. On the other hand, other fracture systems with NW-SE or W-E orientations can be observed; these systems fragmented the terrain and delimited a large set of elliptic (sigmoid) boulders, which determine the general appearance of many sections of the territory. The river network is highly conditioned by this system of discontinuities that define the master lines of valleys, but it is also uniquely determined by lithology. In this case, limestones introduce an essential aspect, promoting, on the one hand, the generation of sinkholes and, on the other, the presence of outcrops. To summarize, it could be said that

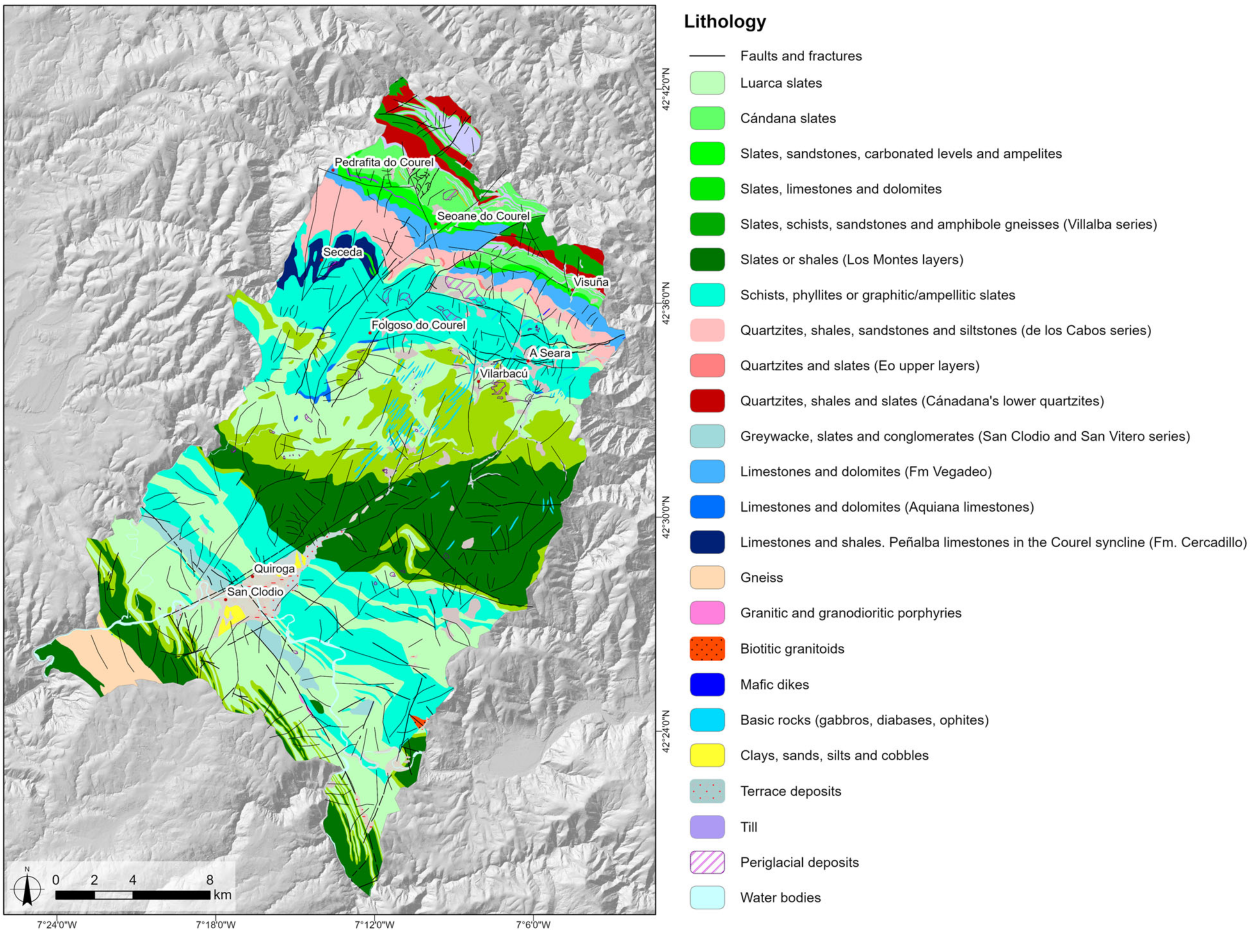

Figure 2. Lithological map of the Courel Mountains Unesco Global Geopark. It was modified from the IGME geological map, adapting the legend to identify each categorie. Source: Xunta de Galicia – IGME.

Figure 3. a) Rocky scarps developed over quartzite in Campodola-Leixazós; b) Doline in Seixo; c) Rocky riverbed on quartzite in the Selmo River (photography ceded by Ramón Vila).

tectonics has determined the main relief lines, while the different types of rock have defined the small-scale design of the slopes.

3. Data and methodology

Different data sources were used to build geomorphological maps, as summarized in Table 1. ArcGIS Pro 3.1.0 (licensed to the USC) was used to manage these data, extract layers of information, and generate new ones. Due to the importance of landforms and deposits of alluvial, fluvial, glacial, and periglacial origin within the geopark, 2-m resolution digital terrain models and digital surface models were generated, on which orthophotographs were overlaid to design the different layers (Figure 4). Fieldwork was essential to analyze and describe the different outcrops, as well as to accurately locate cave entrances, small sectors with limestone pavements (Karren), and waterfalls. For this purpose, an S7-Stonex GPS with sub-meter resolution was used.

Polygons or lines were used whenever landforms and deposits were observable and could be mapped at the map scale 1:100. These features include slopes, alluvial, fluvial, or periglacial deposits, rocky scarps, glacier heads and cirques, and moraine crests. Conversely, points were used for those occupying smaller areas, e.g. dolines, cave entrances, waterfalls, or springs. This was done to ensure that the map was as legible and understandable as possible. In almost all cases, the geomorphological mapping legend of the University of Lausanne was used for the main map and the following figures (Lambiel et al., 2013). In the case of the base map, this is a slope-shaded DEM that helps the reader to understand the valleys distribution and the internal variations in the geopark area (Köse et al., 2022). The slope categories' definition is marked by the experience in the Galician territory and the recommendations of different institutions as FAO, about the soil description and to create a small number of levels for a better map interpretation.

The main map of this project was created to print in A0 size to visualize the landforms better and avoid problems related to the excess of information. Using the A0 format, the map scale is 1:42,000.

4. Results

The map of the singularity geomorphological features of the Courel Mountains Geopark at scale 1:42,000 includes 25 different features (between landforms and deposits). These features were divided into four morphogenetic systems: glacial landforms, periglacial landforms, karst landforms, alluvial and fluvial landforms, and anthropogenic elements. This work allows identifying the distribution of the main landforms and helps to increase the dissemination possibilities of the geopark outstanding features for tourists and Scientifics.

4.1. Alluvial and fluvial landforms

The result of interactions among water, climate, and tectonic dynamics is reflected in three aspects: the genesis of alluvial fans, associated with dry climatic conditions and with episodic, torrential water courses; the formation of different terraced levels in the Sil, Quiroga, and Lor river valleys; and, finally, the existence of a wide abandoned meander loop above the current course of the Lor River.

Both the terraces and the abandoned meander support the existence of recent neotectonics, active from the Cenozoic and persisting-albeit mitigated- in the present day, having been described in the southeast of Galicia by Pérez-Alberti (1993) and later confirmed by the research performed by (De Vicente & Vegas, 2009; De Vicente et al., 2011) at a wider scale in the

Table 1. Datasets and their main characteristics: a) Instituto Geográfico Nacional; b) Instituto do Territorio, Xunta de Galicia; c) Ministerio de Transición Ecológica; d) Instituto Geológico y Minero de España. Goal codes: 1) Mapping dolines, springs, waterfalls, and rock scarps; 2) Toponomy and reservoirs; 3) Generation of DSMs (Digital Surface Models) and DTM (Digital Terrain Model); 4) Locality names; 5) Mapping River courses; 6) Mapping the main summits; 7) Creation of lithological maps; 8) New information generated from field surveys with georeferencing work and remote sensing analysis.

Information	Source	Date	Resolution/Scale	Format	Goal
Orthophotograph	IGN_a	2011 and 2017	0.25 m	Raster	1
National Topographic Map	IGN_a	2017	25K	Vectorial	2
LiDAR data	IGN_a	2010	2 × 2 km	LAS	3
Localities	IET_b	2014	25 K	Vectorial	4
Rivers and springs	MTE_c	2018	25 K	Vectorial	5
Summits	IET_b	2014	25 K	Vectorial	6
Geological Map	$IGME_d$	2009	50 K	Vectorial	7
Rock scarps	This study	2019–2022	0.5 K	Vectorial	8
Fluvial landforms and deposits	This study	2019–2022	0.5 K	Vectorial	8
Alluvial landforms and deposits	This study	2019–2022	0.5 K	Vectorial	8
Glacial landforms and deposits	This study	2019–2022	0.5 K	Vectorial	8
Periglacial deposits	This study	2019–2022	0.5 K	Vectorial	8
Karst landforms	This study	2019–2022	0.5 K	Vectorial	8
Current and ancient mines	This study	2019–2022	0.5 K	Vectorial	8

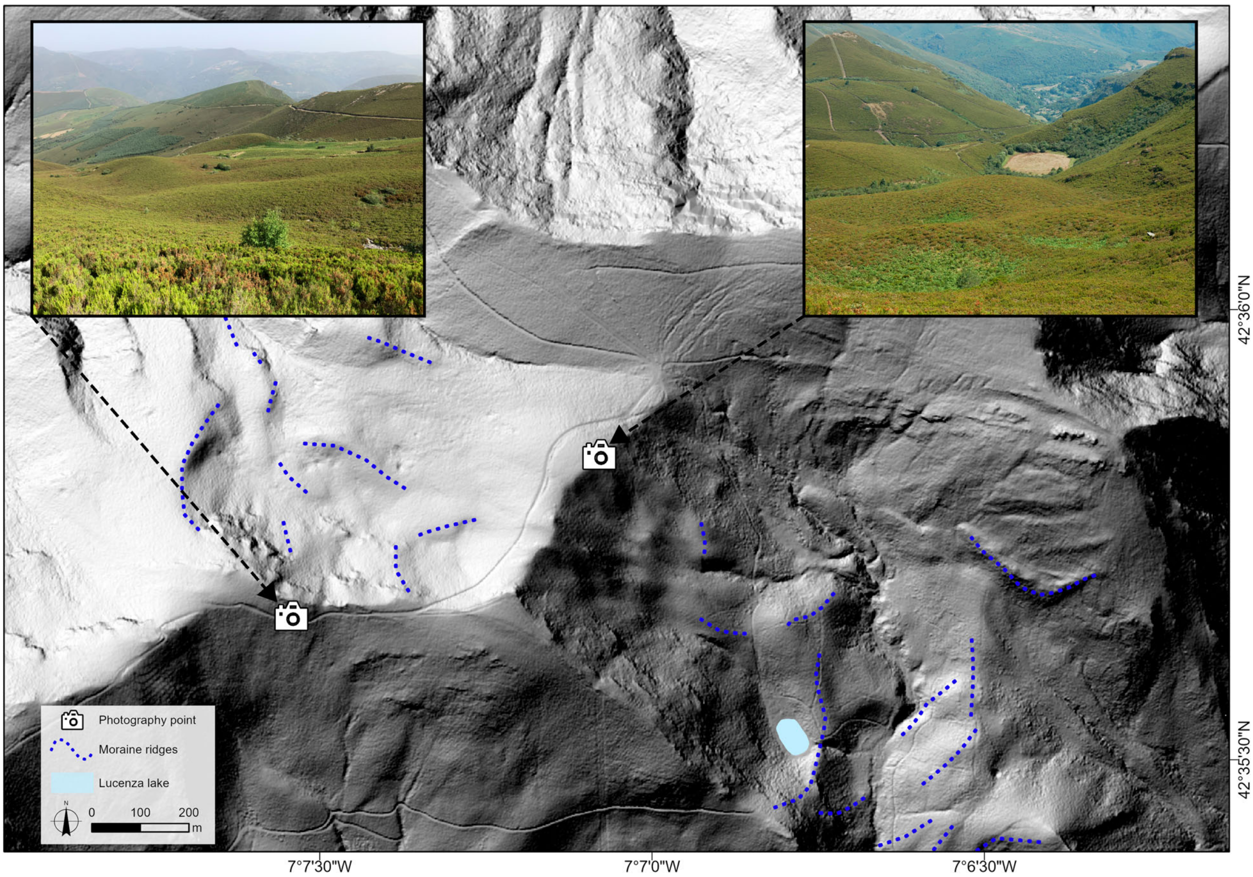

Figure 4. Example of mapped moraine ridges at the Lucenza lake sector.

northwest of the Iberian Peninsula and by Pérez-Alberti et al. (2013) in the Miño River, located west of the geopark. In turn, a series of climatic changes in the late Plio-Quaternary, characterized by the predominance of a drier climate with episodic precipitation (Pérez-Alberti, 1993), promoted the formation of alluvial fans that fossilized the lower river terraces in different sectors. Outcrops are best observed in the vicinity of Quiroga and San Clodio. Recent studies show several sedimentary units preserved in the tectonic depressions of Quiroga-San Clodio: two successive all stratigraphic units of arkoses; two successive units of alluvial fan deposits (AF1-2); an uppermost unit of core heterometric alluvial fan deposits; and a staircase of fluvial terraces (four identified levels: T1-T4) produced during the later stage of fluvial incision (Cunha & Pérez-Alberti, 2022).

Terraces are composed of rounded pebbles, mainly quartzite, clean, clast-supported, and without a fine matrix, suggesting their transport by a permanent water course (Figure 5-a). Vertical changes in pebble size indicate modifications in river transport energy. Over them, silt–clay sediments can occasionally be found; these are likely to be deposited in marginal areas sporadically reached by flood water. Alluvial fans (Figure 5-b) are dominated by fine, silt–clay materials, among which angular and sub-angular clasts appear, mainly composed of slate and transported by episodic, torrential water courses that are intermittently active. Both deposits show reddish

Figure 5. a) Terrace deposits in Quiroga; and b) alluvial deposits close to San Clodio.

colors, suggestive of iron oxidation/reduction processes.

4.2. Glacial landforms and deposits

The first observations of the existence of glacial phenomena in the Courel mountain range date back to Stickel (1928). Their presence has later been mentioned by Aira-Rodríguez (1986); Aira-Rodriguez and Guitián Ojea (1986); Guitían Ojea et al. (1985); Guitián Rivera et al. (1985); Hérail (1984); Lautensach (1964); Nussbaum and Gygax (1953); Vidal-Romaní (1989); Vidal-Romaní et al. (1991); Rodriguez Guitiàn et al. (1995); Pérez-Alberti and Valcárcel-Díaz (2006, 2022); and Pérez-Alberti (2018, 2021). Former glacier tongues (Figure 6) covered up to 4,000 ha, and sediments of glacial origin covered at least 1,000 ha. Data from the different glaciers are summarized in Table 2, where appears between other information, the length of these glaciers, their thickness, or the elevation of the Equilibrium-Line Altitude (ELA).

4.2.1. Paderne glacier

The glacier of the Paderne basin starts at an altitude of 1309 m and ends at an altitude of around 900 m. It would have reached 1.5 km in length, and the ice thickness would have been about 60 m. Two northward-facing cirques would have surrounded the head.

4.2.2. A Rogueira glacier

While A Rogueira glacier aspect is clearly suggestive of a glacial origin, sedimentologic evidence is scarce. Its head is shaped like a wide amphitheater at an altitude of 1639 m. Adjacent to it is a small northward-facing cirque. Landforms of glacial origin can be best observed, and deposits are most abundant in the western sector of the valley. The glacier would have reached 2.6 km in length and would have stretched down to an altitude of around 850 m. Ice thickness could not be determined due to the lack of informative moraine crests.

4.2.3. Ferreirós glacier

The altitude of Ferreirós glacier would have been 1589 m at its head and around 760 m at its toe, and at least two well-defined moraine arcs are found at 1500 and 1400 m. Below them, three more are located between 945 and 970 m. The glacier would have reached 2.5 km in length and 60–65 m in thickness.

4.2.4. Folgoso glacier

The glacier of Folgoso started to form at 1617 m and descended northward to an altitude of around 1000 m. Its length would have reached 1.7 km. Five visible moraine arcs have been distinguished in the western and eastern sectors, between 1300 and 1100 m. Ice depth would have been between 50 and 80 m.

The best visible till outcrop shows a level composed of slate, quartz, and diabase pebbles embedded in a silt/clay matrix. These are massive matrix-supported or clast-supported materials. Rounded or sub-rounded diabase pebbles are relatively frequent.

4.2.5. Visuña glacier

Visuña sector is a complex glacier with small deposits. In its head, located at 1639 m, the valley shows a characteristic glacial shape. Conversely, no moraine systems are found, while its middle and low elevation sections maintain the glacial shape. Although with caution, it could be said that the glacier could have been 4.3 km long, while its toe would have been at an altitude of around 1000 meters and include the higher ELA value, around 1056 m, like the Folgoso glacier, with 1046 m.

4.2.6. A Seara glacier

A Seara is the most particular glacier in the Courel mountains. It would have started at 1641 m and composed, in their head, three glaciers, converging downstream at 950 m. Its length would have been 4.8 km, and the maximum ice thickness would have been 130 m.

Two moraine complexes can be distinguished. The first one, located in the lower section and above the village of A Seara, is composed of two parallel arcs between 1013 and 1065 m of altitude, while the second one is located at the head of the valley. Eight arcs progressively ascending towards the summits have been mapped in the latter. The lower arcs enclose the valley and help to the formation of the Lucenza lake.

The outcrops in the lower complex show matrix- or clast-supported sediments composed of a mix of slate, quartz, and diabase clasts (Figure 7). They are sub-rounded to rounded clasts locally embedded in a silt/clay matrix. The head lacks any outcrops that allow observing its sedimentological features. However, visible clasts are either angular or slightly rounded.

4.2.7. Palleiros glacier

Palleiros glacier is one of the smallest glaciers in the Courel mountain range. Its head would have been located at an altitude of 1485 m and its toe at 1080 m. It would have been 1.2 km long, and the estimated thickness would have reached 65 m.

4.2.8. Vilarbacú glacier

The glacier of Vilarbacú would have started at 1610 m and was composed of three tongues. Jointly, they would have reached an altitude of 966 m. At its maximum advance, it could have reached a length of 2.5 km and a thickness of 130 m. Along its course, it deposited

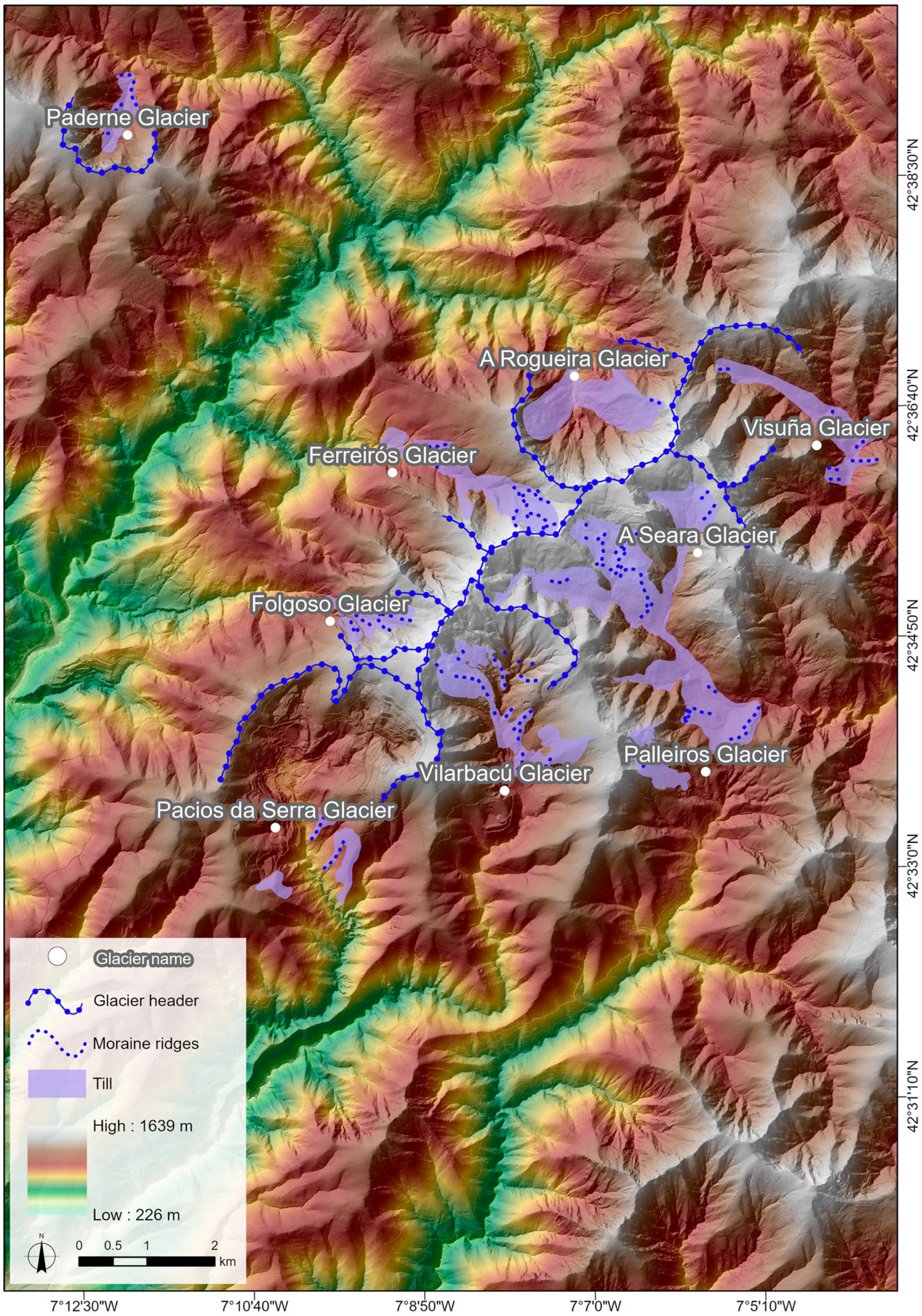

Figure 6. Location of the identified glaciers on the Courel Mountains Unesco Global Geopark and the prominent glacial landforms.

three-tiered moraine systems. The first one, visible near the village of Vilarbacú, is between 1070 and 1100 m. The second one is found between 1100 and 1200 m. A third one can be found at higher altitudes, composed of three moraines located at 1120, 1225, and 1280 m.

Table 2. Summary of main characteristics of the Courel glaciers.

Glacier	Maximum altitude of glacier head (m)	Length (km)	The thickness of the ice sheet (m)	The altitude of the ablation zone (m)	Significant landforms	Deposits	ELA
Paderne	1455	1.5	60	900	Crests	Till	942
A Rogueira	1639	2.6	?	850		Till	995
Ferreirós	1589	2.5	65	760	Crests	Till	939
Folgoso	1617	1.7	50	1000?	Crests	Till	1046
Visuña	1641	4.3	60	1000?		Till	1056?
A Seara	1641	4.8	130	950	Crests	Till	1035
Palleiros	1469	1.2	65	1080	Crests	Till	1019
Vilarbacú	1617	2.5	130	966	Crests	Till	1033
Pacios da Serra	1511	?	60?	800?			924?

4.2.9. Pacios da Serra glacier

The existing mine complicates the reconstruction of the development of glaciers in this area. The analysis of an aerial photograph taken before its establishment allowed for generating an approximate map, although with certain reservations. The glacier head would have been at an altitude of 1511 m and the toe at 800 m. Ice thickness would have reached approximately 60 m, and the analysis defined the ELA as around 924 m.

4.3. Periglacial landforms and deposits

The main landforms of periglacial origin present in the Courel Mountains are stratified slope deposits and block fields and slopes, which, where channeled, led to the formation of boulder streams (Pérez-Alberti & Cunha, 2016; Pérez-Alberti et al., 2013, 2021).

4.3.1. Stratified slope deposits

In sedimentary terms, they are characteristically composed of angular fragments mixed with fine elements (Figure 8-a, b). They show marked stratification, with alternating layers of different thicknesses. They are present in sectors dominated by intensely fractured slates, promoting their fragmentation by freeze/thaw cycles and their mobilization due to other processes (Pérez-Alberti, 2012).

4.3.2. Block fields and slopes

Block fields and slopes occupy the highest sections of the geopark and are associated with quartzites. In some places, clasts show signs of imbrication among boulders, suggesting a downhill motion promoted by the existence of interstitial ice. Boulder streams over 400 m long and over 100 m wide have formed in some troughs, such as the one located over the village of Vilarbacú (Figure 8-c, d). In this case, the outcrop comprises large boulders reaching heights over 2 m along their central axis.

Figure 7. a) subglacial till in A Seara; and b) glacial striations on a boulder in A Seara moraine.

4.3.3. Timeframe of glacial processes

The oldest dating record of glacial deposits was obtained from a coal sample collected at the foot of a stratified slope deposit near the A Toca Roman mine. Its estimate dates it at over 44,000 years BP (Pérez-Alberti et al., 2009). Other dating records from lake sediments collected in the Lucenza lagoon yielded ages between 20,000 and 15,000 BP (Muñoz Sobrino et al., 2001).

The information mentioned above suggests (Oliva et al., 2019) that a cold climate started to predominate in the Courel Mountains over 44,000 years ago. About the geoforms, this could explain the presence of glaciers and stratified slope deposits in this sector, and different analyses identified the start of deglaciation around 20,000 years ago, when glaciers occupied the heads of the valleys. At that moment, the conditions would have been colder than in the previous phase, thus leading to the formation of block fields (Viana-Soto & Pérez-Alberti, 2019).

4.4. Anthropogenic impacts

Human activity in the Courel mountain range dates back to ancient times, mainly since the arrival of the

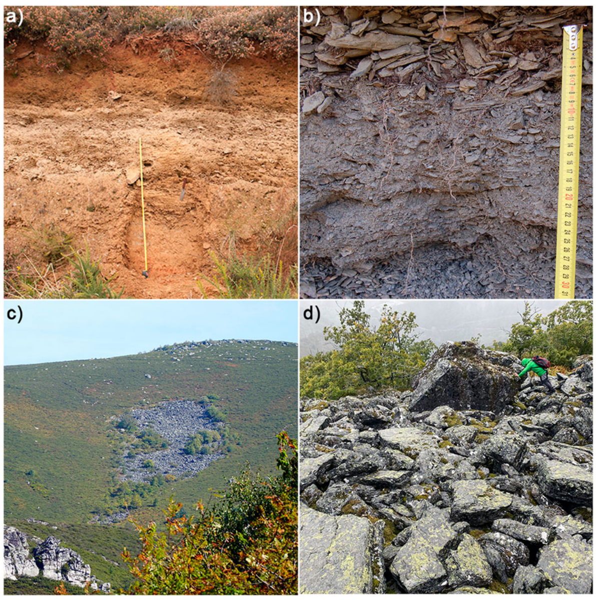

Figure 8. Periglacial deposits: stratified slope deposits a) in Rio Pequeno valley and b) in Soldon valley; c) block stream in Os Pedregoes, Vilarbacú valley; and d) block stream detail in Os Pedregoes.

Romans in the 1st century B.C. Mining activity developed to a great degree (Sánchez-Palencia Ramos & Fernández-Posse, 1998), and its impact is visible in different locations, especially in the A Toca site, Montefurado, and Margaride. This activity led to the construction of settlements and hillforts (Luzón Nogué et al., 1980). In later years, iron ore mining constituted an important activity up until the late nineteenth century (Balboa de Paz, 2014). More recently, slate quarries have been established.

5. Conclusions

(a) Lithological diversity within the Courel Mountains Geopark led to a wide range of landforms. Some of these landforms are excellent examples for teaching geomorphology and attracting tourists.
(b) The main map of this research would be a useful tool to design geomorphological routes and improve the promotion of the geopark.
(c) Cartography has allowed us to identify nine glacial cirques and other glacial landforms that indicate the evolution of Courel Mountains.
(d) Past and present river dynamics generated various landforms and deposits.
(e) The former presence of glaciers at low altitudes makes the Courel Mountains a site of great interest in paleoenvironmental terms. The same is applicable in the case of periglacial deposits and karstic landforms, which are very scarce in the northwest Iberian Peninsula.
(f) The presence of karstic forms in this sector is a great attraction for visitors for their singularity in a context dominated primarily by granites and metamorphic rocks.

Software

The map and figures cartography were produced on Esri ArcGIS Pro 3.1.0. In the figures, the final editing was carried out using Inkscape 1.2. An A0 size is recommended for map printing.

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Disclosure statement

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Data availability statement

The data that support the findings of this study are available from the corresponding author, A.G-P, upon reasonable request.

References

Aira-Rodríguez, M. J. (1986). Contribución al estudio de los suelos fósiles de montaña y antropógenos de Galicia por análisis polínico. Universidade de Santiago de Compostela.
Aira-Rodríguez, M. J., & Guitian Ojea, F. (1986). Contribución al estudio de los suelos y sedimentos de montaña de Galicia y su cronología por análisis polínico. I. Sierra del Caurel (Lugo), *45*(9–10), 1189–1202.
Balboa de Paz, J. A. (2014). La siderurgia tradicional en el noroeste de España (siglos XVI-XIX) [Universidad de León]. https://buleria.unileon.es/handle/10612/3603
Cunha, P. P., & Pérez-Alberti, A. (2022). Discussion of the transition of endorheic to exoreic drainage of Cenozoic Basins in Galicia (NW of Iberia), the development of the ancestral transverse drainage to the Atlantic, and the later stage of fluvial incision. 10th International Conference on Geomorphology, Coimbra. https://doi.org/10.5194/icg2022-322
De Vicente, G., Cloetingh, S., Van Wees, J. D., & Cunha, P. P. (2011). Tectonic classification of Cenozoic Iberian foreland basins. *Tectonophysics*, *502*(1–2), 38–61. https://doi.org/10.1016/j.tecto.2011.02.007
De Vicente, G., & Vegas, R. (2009). Large-scale distributed deformation-controlled topography along the western Africa–Eurasia limit: Tectonic constraints. *Tectonophysics*, *474*(1–2), 124–143. https://doi.org/10.1016/j.tecto.2008.11.026
Dozy, J. J. (1983). The geology of the region to the Southeast of Lugo (NW Spain). *Leidse Geologische Mededelingen*, *52*(3), 513–524.
Fernández, F. J., Aller, J., & Bastida, F. (2007). Kinematics of a kilometric recumbent fold: The Courel syncline (Iberian massif, NW Spain). *Journal of Structural Geology*, *29*(10), 1650–1664. https://doi.org/10.1016/j.jsg.2007.05.009
Guitían Ojea, F., Barral Silva, M. T., Cabaneiro Albadalejo, A. M., Calvo de Anta, R. M., Carballas Fernández, M. T., Díaz-Fierros Viqueira, F., Rodeja Gayoso, J. G., Gil Sotres, F., Giménez de Azcárate Cornide, M., & Guitián Rivera, F. (1985). Geología, geomorfología, hidrología, climatología, suelos. Estudio do medio natural de las montañas gallegas. I: O Caurel, *103*, 13–71.

Guitián Rivera, F., Barral Silva, M., & Guitián Ojea, F. (1985). Aplicación de la exoscopia del cuarzo a la caracterización de diversos ambientes en Galicia. *Cuadernos do Laboratorio Xeolóxico de Laxe*, *9*, 399–419.

Hérail, G. (1984). *Géomorphologie et gîtologie de l'or détritique: piémonts et bassins intramontagneux du nord-ouest de l'Espagne*. Editions du CNRS.

Köse, O., Sarıkaya, M. A., Çiner, A., Candaş, A., Yıldırım, C., & Wilcken, K. M. (2022). Reconstruction of last glacial maximum glaciers and palaeoclimate in the central taurus range, Mt. Karanfil, of the eastern mediterranean. *Quaternary Science Reviews*, *291*, 107656. https://doi.org/10.1016/j.quascirev.2022.107656

Lambiel, C., Maillard, B., Regamei, B., Martin, S., Kummert, M., Schoeneich, P., Pellitero Ondicol, R., & Reynard, E. (2013). Adaptation of the geomorphological mapping system of the University of Lausanne for ArcGIS. In 8th International Conference on Geomorphology (IAG), Paris, pp. 27–31.

Lautensach, H. (1964). Iberische Halbinsel. Geographische Handbücher Volume 3. Keysersche Verlagbuchhandlung, München. 700 p.

Luzón Nogué, J. M., Sánchez-Palencia Ramos, F. J., Acuña Castroviejo, F., Alonso del Real, C., Arias Vilas, F., Caamaño Gesto, J. M., Rodríguez Casal, A., Sierra Rodríguez, J. C., & Vázquez Varela, J. M. (1980). El Caurel. Excavaciones Arqueológicas en España. Ministerio de Cultura, Madrid, 110.

Martínez-Catalán, J., González Clavijo, E., Meireles, C., Díez Fernández, R., & Bevis, J. (2016). Relationships between syn-orogenic sedimentation and nappe emplacement in the hinterland of the Variscan belt in NW Iberia deduced from detrital zircons. *Geological Magazine*, *153*(1), 38–60. https://doi.org/10.1017/S001675681500028X

Martínez-Catalán, J., Hacar Rodríguez, M., Villar Alonso, P., Pérez-Estaún, A., & González Lodeiro, F. (1992). Lower Paleozoic extensional tectonics in the limit between the West Asturian-Leonese and Central Iberian Zones of the Variscan fold-belt in NW Spain. *Geologische Rundschau*, *81*(2), 545–560. https://doi.org/10.1007/BF01828614

Martín-González, F., Freudenthal, M., Heredia, N., Martín-Suárez, E., & Rodríguez-Fernández, R. (2014). Palaeontological age and correlations of the Tertiary deposits of the NW Iberian Peninsula: The tectonic evolution of a broken foreland basin. *Geological Journal*, *49*(1), 15–27. https://doi.org/10.1002/gj.2484

Matte, P. (1968). La structure de la virgation hercynienne de Galice (Espagne). Allier.

Muñoz Sobrino, C., Ramil-Rego, P., & Rodríguez Guitián, M. A. (2001). Vegetation in the mountains of northwest Iberia during the last glacial-interglacial transition. *Vegetation History and Archaeobotany*, 7–21. https://doi.org/10.1007/PL00013366

Nussbaum, F., & Gygax, F. (1953). La glaciación cuaternaria en la Cordillera Cantábrica. *Estudios Geograficos*, *51*(14), 261–270.

Oliva, M., Palacios, D., Fernández-Fernández, J., Rodríguez-Rodríguez, L., García-Ruiz, J., Andrés, N., Carrasco, R. M., Pedraza, J., Pérez-Alberti, A., & Valcárcel, M. (2019). Late quaternary glacial phases in the Iberian Peninsula. *Earth-science Reviews*, *192*, 564–600. https://doi.org/10.1016/j.earscirev.2019.03.015

Parga, J. R. (1969). Sistemas de fracturas tardihercínicas del Macizo Hespérico.

Pérez-Alberti, A. (1993). La interacción entre procesos geomorfológicos en la génesis del relieve del sudeste de Galicia: El ejemplo del Macizo de Manzaneda y de la Depresión de Maceda. 1–24.

Pérez-Alberti, A. (2012). La formación de depósitos estratificados de ladera en un clima frío marítimo (Andes de Tierra del Fuego, Argentina). *Nimbus: Revista de climatología, meteorología y paisaje*, *29-30*, 491–509.

Pérez-Alberti, A. (2018). Xeomorfoloxía das Montañas do Courel. Grupo de Desenvolvemento Rural Ribeira Sacra-O Courel.

Pérez-Alberti, A. (2021). El patrimonio glaciar y periglaciar del Geoparque Mundial UNESCO Montañas do Courel (Galicia). *Cuaternario y Geomorfología*, *35*(1–2), 79–98. https://doi.org/10.17735/cyg.v35i1-2.89295

Pérez-Alberti, A., Bedoya, J., & Cunha, P. P. (2009). Sedimentological analysis of cold-climate stratified slope deposits of Galicia, NW Iberia. IAS 2009 Meeting, Alghero (Italy).

Pérez-Alberti, A., & Cunha, P. P. (2016). The stratified slope deposits of Tierra del Fogo (Argentina) as an annalogue for similar pleistocene deposits in Galicia (NW Spain). *Polígonos. Revista de Geografía*, *28*(28), 183–209. https://doi.org/10.18002/pol.v0i28.4293

Pérez-Alberti, A., Gomes, A., Trenhaile, A., Oliveira, M., & Horacio, J. (2013). Correlating river terrace remnants using an Equotip hardness tester: An example from the Miño River, northwestern Iberian Peninsula. *Geomorphology*, *192*, 59–70. https://doi.org/10.1016/j.geomorph.2013.03.017

Pérez-Alberti, A., & Valcárcel-Díaz, M. (2006). As pegadas glaciares dos vales de Seara e Vieiros. Asociación Río Lor.

Pérez-Alberti, A., & Valcárcel-Díaz, M. (2022). Chapter 4.14—The glaciers in Eastern Galicia (M. Oliva, D. Palacios, & J.M. Fernández-Fernández. Land of Glaciers, Eds.; pp. 375–395). Elsevier. https://doi.org/10.1016/B978-0-12-821941-6.00018-9

Rodriguez Guitiàn, M. A., Valcárcel-Díaz, M., & Pérez-Alberti, A. (1995). Morfogénesis glaciar en la vertiente meridional de la Serra do Courel (NW Ibérico): El valle de A Seara. En Avances en la reconstrucción paleoambiental de las áreas de montaña lucenses (pp. 77–88). Diputación Provincial de Lugo Lugo.

Sánchez-Palencia Ramos, F., & Fernández-Posse, M. D. (1998). El beneficio del oro por las comunidades prerromanas del Noroeste peninsular. 227–246.

Stickel, R. (1928). Observaciones de morfología glaciar en el NO de España. *Boletín de la Real Sociedad Española de Historia Natural*, *29*, 297–313.

Viana-Soto, A., & Pérez-Alberti, A. (2019). Periglacial deposits as indicators of paleotemperatures. A case study in the Iberian Peninsula: The mountains of Galicia. *Permafrost and Periglacial Processes*, *30*(4), 374–388. https://doi.org/10.1002/ppp.2026

Vidal-Romaní, J., Aira-Rodríguez, M., & Santos Fidalgo, L. (1991). La glaciación finicuaternaria en el NO de la Península Ibérica (Serra do Courel, Lugo): Datos geomorfológicos y paleobotánicos. Libro de Resúmenes. VIII Reunión Nacional sobre el Cuaternario. Universidad de Valencia. Valencia.

Vidal-Romaní, J. R. (1989). Mapa del cuaternario de España [Map]. Instituto Tecnológico GeoMinero de España.

Villar Alonso, P., Portero Urroz, G., & González Cuadra, P. (2018). Mapa Geológico Digital Continuo E. 1:50.000, Zona Centroibérica. Dominio Ollo de Sapo [Map]. Instituto Geológico y Minero de España.