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ORIGINAL ARTICLE

Linking Geoheritage and Traditional Architecture for Mitigating Depopulation in Rural Areas: the Palaeozoic Villages Route (Courel Mountains UNESCO Global Geopark, Spain)

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Abstract
The use of stone in traditional architecture represents one of the most relevant links between geological and cultural heritage. As a topic of general interest and easily understandable to all public, this link is a guiding thread for touristic routes mitigating the depopulation trend that affects large inland rural areas, including many areas in UNESCO Global Geoparks (UGGp). In the northwest of Spain, the Courel Mountains UGGp created the Palaeozoic Villages Route for touristic purposes in 2018, highlighting the relevance of local stones in traditional architecture as a key feature for sustainable development. For the design and creation of this route, seven villages were selected along six criteria: (1) the representativeness of the building stone with the bedrock of the UGGp, (2) the preserved traditional architecture, (3) their link with geoheritage, (4) the scenic beauty of their surroundings, (5) the potential combination with other touristic activities, and (6) the presence of local services. The Palaeozoic Villages Route exhibits four rock types/sections/structures spanning four Palaeozoic periods, as well as different uses for walling and roofing depending on the rock feature. Since 2018, the route experienced an increased revenue of 19% in the touristic sector to the traditional villages, while visitors used up to 61% of the local services of the UGGp for one or more days. In addition, the route reinforces the awareness of depopulation and abandonment of rural villages, fostering the purchase and/or restoration of dwellings as second regular residences in tranquil and scenic environments. In the short to medium term, these actions are expected to reverse or, at least, minimise the loss of population in the UGGp.

Keywords Depopulation · Geotourism · Courel Mountains UGGp · Rural areas · Traditional architecture

Introduction

In the twenty-first century, depopulation continues to strongly affect large rural areas, being one of the main socioeconomic issues of many UNESCO Global Geoparks (UGGp), due to the lack of industry and service sectors (Takenouchi et al. 2018; Van Geert 2019; Telbisz et al. 2020). At the same time, these deficits favoured the preservation of villages with a traditional architecture, laying the bases for sustainable rural tourism (Lane and Kastenholz 2015; Gao and Wu 2017). As traditional architecture is frequently preserved in stone, it provides a great opportunity to link cultural and geological heritages as a touristic resource for all public (Gordon 2018; La Felice et al. 2019). To this

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end, many remarkable historical monuments preserved in stone were declared UNESCO World Heritage sites (Larsen and Wijesuriya 2015). The Art of Dry-Stone Walling (load-bearing walls of interlocking stones, without mortar) of Croatia, Cyprus, France, Greece, Italy, Slovenia, Spain, and Switzerland (2018) is an example of the harmonious relationship between traditional architecture and geology, with a particular touristic appeal in rural areas (Mallafrè Balsells et al. 2019). Other examples linking cultural heritage and rock geology are Global Heritage Stone Resource (GHSR) and Global Heritage Stone Province (GHSP), designations related to stone largely used for historical buildings at regional or international scale for a significant historical period (Pereira and Marker 2016).

The economic sustained development of UGGp's is based on the integration of its geoheritage and local relations with cultural heritage and biodiversity (e.g. Brilha 2018; Sá and Rocha 2020). The depopulation trend has been one of the larger challenges for geoparks since their beginnings (Nowlan et al. 2004), centring activities and efforts to avoid the negative socioeconomic impacts of local population declines (Ramsay 2017; Alcalá 2018; Álvarez 2020), often by linking geological and cultural heritages (Scarlett and Riede 2019; Carvalho et al. 2020). In Spain, territorial policies against the depopulation of rural areas are mainly based on cultural tourism (Sánchez-Mesa 2019). The growing Spanish Geoparks Forum is currently implementing geoheritage in fifteen areas for reversing the demographical situation (Hilario and Carcavilla, 2020), including the Palaeozoic Villages Route (PVR) in the Courel Mountains UGGp created in 2018. This route highlights the role played by representative local stones on the traditional architecture of rural villages as a key point for sustainable development. The relationship between geoheritage and the local town communities constitutes the cornerstone of the UGGp as the main differentiating thematic feature. Here, we discuss the design of the PVR combining cultural, geological, and other criteria, as well as the analyses of its benefits and potential disadvantages for the area and its local populations.

Setting

The Courel Mountains UGGp (42.48° N, 7.28° W) is located in Galicia, the most northwest Spanish region of the Iberian Peninsula (Fig. 1A). The UGGp covers an area of 578 km^2, comprising three municipalities (Folgoso do Courel, Quiroga, and Ribas de Sil) and 190 villages (Fig. 1B), most of them with less than ten residents. The municipalities manage the UGGp under the direction of the Ribeira Sacra-Courel Local Action Group. The UGGp contains tourism offices, museums, viewpoints, and other tourism sites, as well as over 60 geosites (Fig. 1C). According to the National Statistics Institute (INE) of Spain, the population has declined by 30% in the UGGp since 2000, reporting 5178 inhabitants in 2019 (9.0 inhabitants per km^2), urging the development of new adaptive strategies for inland touristic destinations based on cultural and natural aspects (De Uña-Álvarez and Villarino-Pérez 2017).

As a mountainous territory, the weather during the touristic period is constrained by the Atlantic climate (3–29 °C) with temperate summers and an annual precipitation of 1100 mm. Peak precipitation falls in winter during which a snow cover appears (Csb climatic type according to Cunha et al. 2011). Tens of thousands of tourists visit the UGGp annually for cultural and outdoor activities, especially in summer, but also in autumn for watching the intense colours of the preserved native deciduous woodlands (Fig. 1B). These forests, formed by oaks, birchs, hazels, and beeches, and their associated fauna motivated the declaration of a Community Site of Interest (European Nature 2000 Network) in the northern mountains, where traditional woodlots produce chestnuts as a local product (Guitián et al. 2012). In the south of the UGGp, an orographic rain shadow favours the development of Mediterranean conditions allowing the elaboration of local wine and olive oil, both with an indication of the official Designation of Origin (Fig. 1C).

The geoheritage of the Courel Mountains UGGp is highlighted by its tectonic, stratigraphic, geomorphological, and mineral resources and claims attention at national or international scales. The UGGp lies in the metamorphic areas of the Variscan Domain and its bedrock, Neoproterozoic to Carboniferous in age (Fig. 2), is mainly constituted of slate and quartzite, although gneiss and marbled limestone are also present (Martínez Catalán et al. 1992, 2004). Palaeozoic fossils are poorly preserved due to the Variscan Orogeny (Gutiérrez-Marco et al. 2001), which formed 11 km long recumbent folds and other structures, mainly during lower Carboniferous (Martínez Catalán et al. 1992, 2004). One of these folds is the Courel recumbent fold (see Gutiérrez-Marco 2005; Fernández et al. 2007), which was declared Global Geosite (2011) and Natural Monument by the Regional Government of Galicia (2012). After the Permian-Mesozoic extension with associated diabase intrusions, some previous faults were reactivated, causing the Alpine uplifting from the Palaeocene to the Miocene (Martín-González 2009; Martín-González et al. 2012). The uplifting triggered fluvial incisions, which formed the current narrow and deep gorges and valleys in northwest Spain, as well as the development of fluvial terraces and alluvial fans from the Miocene to the Pleistocene (Heredia et al. 2015). Karst caves were developed since at least the Pleistocene (Railsback et al. 2011, 2017) and glaciers occupied the higher areas (see Pérez Alberti 2018) prior to 21 cal ka BP, where a lake recorded later the growth of Holocene forests (Santos et al. 2000; Muñoz Sobrino et al. 2001; Leira and

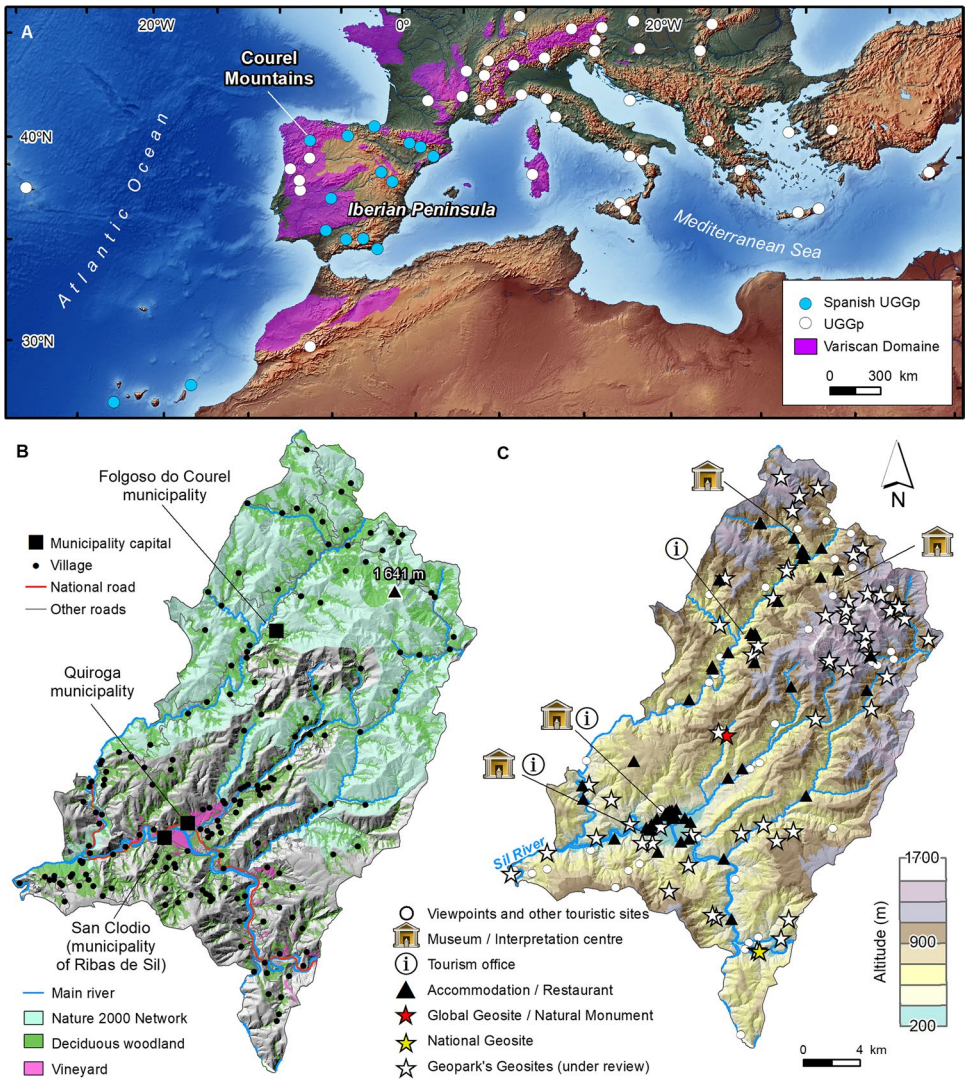

Fig. 1 **A** Location of the Courel Mountains UGGp in the northwest of the Iberian Peninsula. **B** Localities, infrastructures, deciduous forest, mixed woodlands, and vineyards. **C** Touristic sites, local services, and geosites

Santos 2002). Finally, periglacial and slope processes locally modelled the mountains up to the present day (Pérez Alberti 2018; Viana-Soto and Pérez-Alberti 2019). Archaeological studies largely evidenced the historical use of geological resources, including settlement areas, building stones, lime kilns, iron workshops, and Au, Fe, Sb, and Pb mining. Palaeolithic tools and Neolithic tombs built in local stone (Lombera and Fábregas Valcarce 2011) were followed by Iron Age and Roman hillforts. The latter were fortified combining stonewalls and natural scarps to protect dwellings, also constructed in Palaeozoic rocks, using slate for roofing (Luzón Nogué and Sánchez-Palencia 1980; Álvarez Núñez 1996). The Romans mined gold deposits up to the fall of the empire (e.g. Pérez-García et al. 2000; Sánchez-Palencia et al. 2006) but hillforts continued being used after the Fall of the Roman Empire (Tejerizo-García and Canosa-Betés 2018). New villages were established on flatter areas, such as alluvial fans, large old landslides, glacial valleys, and ancient Roman open cast works. The villages have been walled and roofed using local Palaeozoic stones until this day, resulting in the current traditional villages whose noticeable architecture motivated the creation of the PVR. Castles and churches were also built with local rock material, expect for medieval abbeys, which were made of granitoids imported from nearby areas. Slate quarrying continues at present, being part of an Iberian Roofing Slate Global Heritage Stone Province (GHSP) (Cárdenes et al. 2015). These quarries constitute one of the main economic activities of the Courel Mountains UGGp, supplying roofing slate to Spain and North-Central Europe.

Methodology

The touristic route was designed in three steps: (1) definition of the route name, (2) definition of criteria for evaluating villages, and (3) selection of the villages which would constitute the PVR.

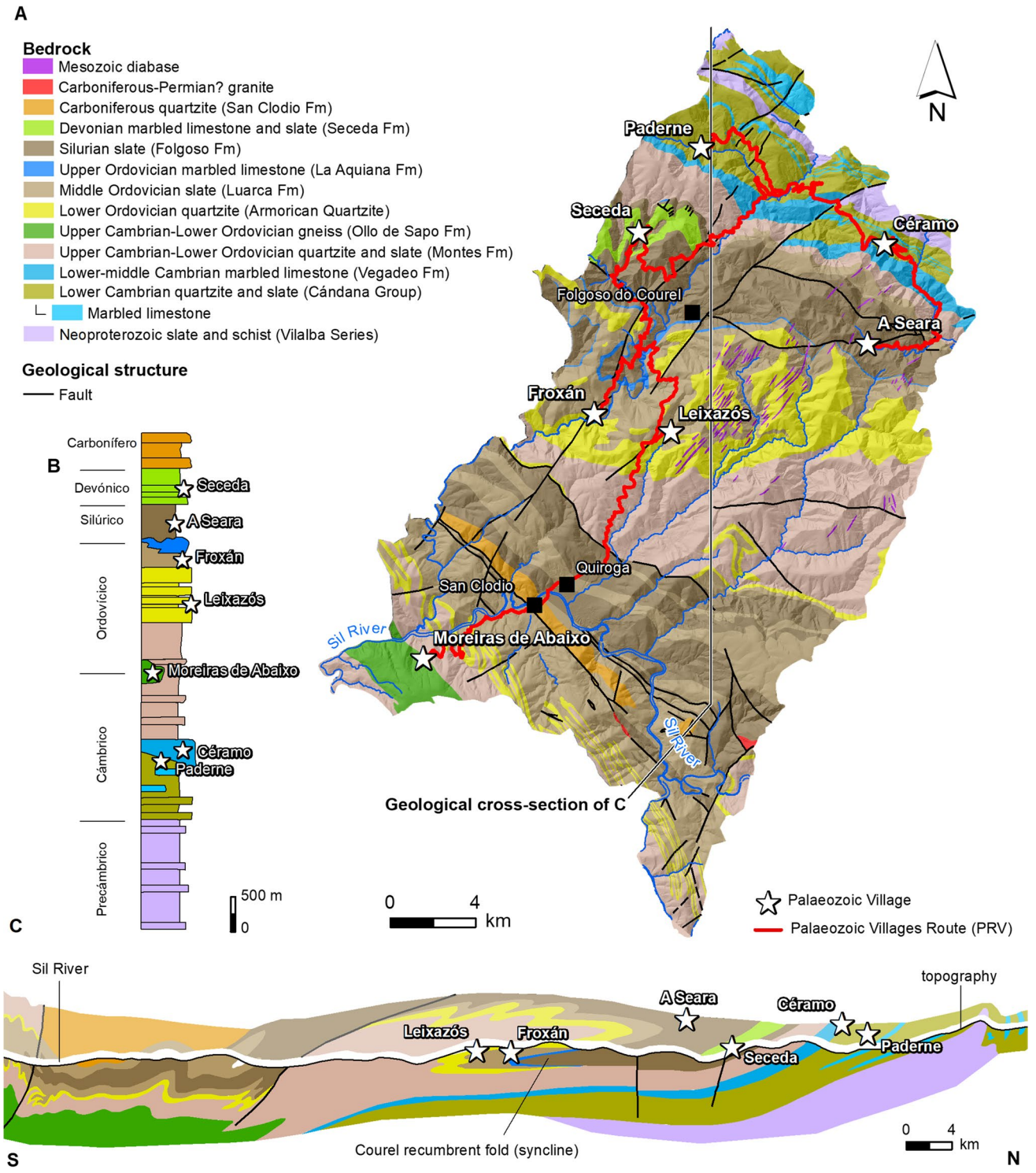

Fig. 2 **A** The Palaeozoic Village Route (PVR) plotted on the geological map of the Courel Mountains UGGp after Villar-Alonso et al. (2018). **B** Simplified stratigraphical section of the territory after Dozy (1983) and Martínez Catalán et al. (1992, 2004). **C** Palaeozoic Villages projected on the geological cross-section after Martínez Catalán et al. (2004). Moreiras de Abaixo is not represented, as its projection falls outside of the cross-section

Route Name

The name of the route was chosen for concisely covering the subject matter and having an attractive touristic appeal. It comes from the main Era (Palaeozoic) of the representative bedrock of the UGGp. At the same time, the System/Period (Cambrian to Devonian) of the rock used in each village is added to the village name (e.g. the Cambrian Village). This lenience of scientific rigour allowed us to break the barrier between geology and society with a name that approximately describes the geology and is also easily understandable for the larger public.

Criteria for Selection of Villages

The suitability of a village to be included in the PVR was determined by scoring five objective criteria from 0 to 3 for each of the 190 villages in the UGGp (Table 1). We based the criteria on previous works regarding tourism in rural villages (e.g. Ruhimat et al. 2018; Fang 2020). These criteria were evaluated using the geographical information system of the UGGp, which include amongst others digital elevation models, villages and infrastructures (road, railway), vegetation cover, geological and geomorphological maps, geosites, ore deposits, karst caves, cultural/archaeological sites, interesting points, viewpoints, information panels, museums and interpretation centres, and local amenities (hotels, hostels, campings, bars, restaurants) (Fig. 1B and C). The average value of these criteria constituted the score of each village.

– Representativeness of building stones with respect to the bedrock. The main lithologies of the UGGp (slate, quartzite, gneiss, and marbled limestone) and geological ages (Cambrian to Carboniferous) should be involved in the set of selected villages. Ideally, each village is associated with a specific lithology and age. In the

Table 1 Criteria used for selection of villages

Score	
1. Representativeness of the Geopark's bedrock	
0	Village not mainly built in Palaeozoic stone quarried locally
1	Village involves mainly Palaeozoic rocks of the Geopark coming from alluvial deposits
2	Village built using only the most common rocks (slate and quartzite) of the Geopark
3	Village involving the scarce rocks (gneiss and marbled limestone) of the Geopark
2. Traditional architecture	
0	Village without traditional architecture
1	Village with poorly preserved traditional constructions
2	Village with well-preserved singular constructions walled using the dry stone technique and roofed using local slate
3	Village declared Site of Cultural Interest by the Regional Government
3. Geoheritage	
0	Village not related to any singular geological feature
1	Village emplaced on ancient large landslides or alluvial fans or terraces, but this is not clearly observed at the village
2	Village emplaced on ancient large landslides or alluvial fans or terraces, being this clearly observed at the village
3	Village is located in a Geosite or constitutes a viewpoint of a Geosite
	4. Scenic beauty
0	Village is anthrophically degraded, showing industrial and urban area, national roads, or railways
1	Village located in a natural area without singular natural elements
2	Village with views to watercourses, native forests or remarkable mountain landscapes
3	Village located within a remarkable natural area with watercourses and native forests
	5. Complementary activities
0	Suitable sites for outdoor activities or touristic sites are not present within an area of 1 km radius
1	Suitable sites for outdoor activities or tourism are present within an area of 1 km radius
2	Suitable sites for outdoor activities and tourism are present within an area of 1 km radius
3	Exhibitions are regularly organised in the village
	6. Local services
0	Nearest accommodation and restaurants located at a distance > 10 km
1	Nearest accommodation and restaurants located at a distance of 5–10 km
2	Nearest accommodation and restaurants located at a distance < 5 km
3	Village with accommodation and restaurants

Courel Mountains UGGp, Carboniferous rocks were not employed for settlement building; therefore, only Cambrian to Devonian rocks were considered.

- Traditional architecture. The traditional architecture of villages includes well-preserved singular buildings walled with the dry-stone walling technique and roofed using local slate from the UGGp quarries. As far as possible, modern materials as concrete, metal, or plastic should not be present or, at least, not be visible. Singular buildings include dwellings (frequently with remarkable balconies), stables, water mills, and other constructions such as structures used for the traditional curing of chestnuts. In addition, official recognitions like the declaration of "Sites of Cultural Interest by the Regional Government" increase the cultural value of a village.
- Scenic beauty. The surroundings of a village should be aesthetic and attractive, determined by the presence of natural areas including native forests, watercourses, and panoramic viewpoints (see Brilha 2016).
- Complementary activities. Complementary activities reinforce the touristic value of a village. These activities include the following: (1) exhibitions related to traditional activities or local products, (2) cultural activities, some of them related to museums and interpretation centres of the UGGp (Fig. 1C), and (3) outdoor sports (e.g. hiking, trekking, speleology, or canyoning) that would finish with a visit to a Palaeozoic Village. Only hiking routes approved by the regional federation of hiking have been considered. All these activities provide additional resources to active tourism companies, especially with unpredictable weather in the mountains.
- Local services. The presence of restaurants and accommodation in the village or nearby villages was accounted for to promote the local economy. The services of the UGGp include 38 bars and restaurants, 13 hotels, two hostels, 10 apartments in traditional houses, and one camping, accounting for approximately 700 beds (Fig. 1C).

Selection of the Villages

The number of selected villages was aimed to represent the characteristic lithologies and ages of the bedrock. In the Courel Mountains UGGp, the bedrock is mainly represented by four lithologies (slate, quartzite, gneiss, and marbled limestone) associated with four geological periods (Cambrian, Ordovician, Silurian, and Devonian) (Dozy 1983; Martínez Catalán et al. 1992, 2004; Villar Alonso et al. 2018). This representativeness was achieved by selecting the seven villages whose ratings are equal or greater than 2.00 (Fig. 3). The selected villages are Froxán (2.83 points), Seceda (2.50 points), A Seara (2.50 points), Moreiras de Abaixo (2.17 points), Leixazós (2.17 points), Céramo (2.17 points), and Paderne (2.00 points), representing 4% of all the villages within the UGGp, and drawing the PVR running from the south to the north of the Courel Mountains UGGp.

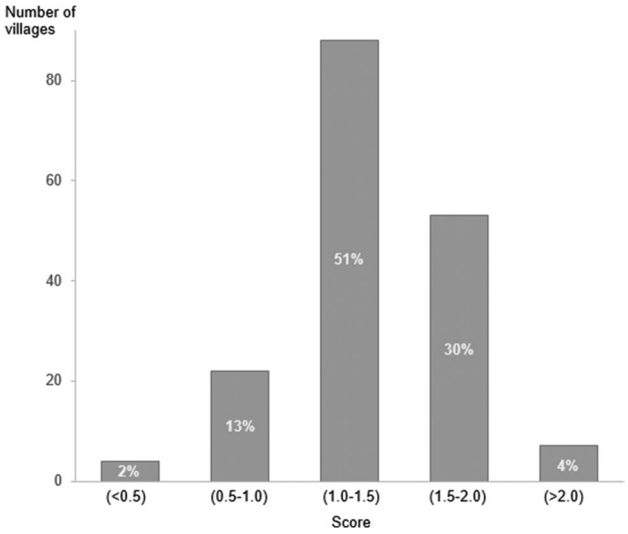

Fig. 3 Number of villages and percentage with respect to the total (190) resulted from the evaluation (scoring from 0 to 3) defined in the "Criteria for Selection of Villages" section and Table 1

Results

The PVR comprises walks to the seven selected traditional stone villages, which can be visited following a 113 km long route (Fig. 2). The entire route requires 2 days to complete, promoting that the visitor spends at least one night in the Courel Mountains UGGp. However, each Palaeozoic Village could be individually visited as a one-journey activity, which could be complemented with other cultural, geotouristic, and/or outdoor activities.

Moreiras de Abaixo Cambrian-Ordovician Village

Moreiras de Abaixo was constructed on the slopes of the Sil River Valley in the southwest of the Courel Mountains UGGp at 550 m altitude, supporting agricultural and pastoral activities and situated close to forest resources (Fig. 4A). The 400 m deep valley was formed by a fluvial incision coevally with the uplifting of the mountain (Martín-González 2009). In the village, around 15 traditional dwellings, barns and stables are made of angular boulders of gneiss (Fig. 4B), as well as ashlars in openings (doors, windows) and corners (Fig. 4C). Of all the Palaeozoic bedrock in the area, only gneiss rock was widely transformed into cuboid-shaped

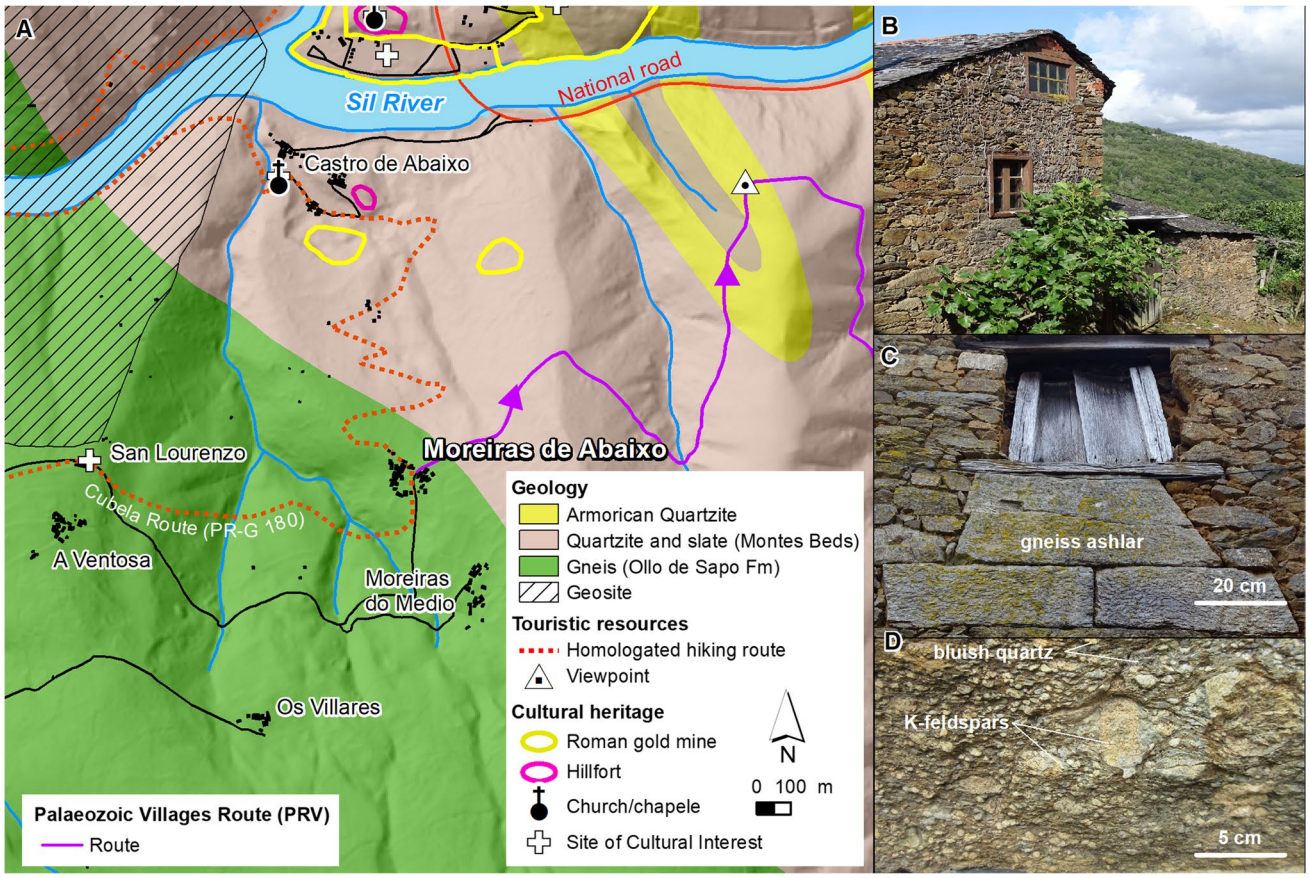

Fig. 4 Moreiras de Abaixo Cambrian-Ordovician Village. **A** Geological map of the surroundings after Villar-Alonso et al. (2018), and showing tourism resources and cultural heritage. **B** Traditional architecture in gneiss. **C** Ashlars below a traditional window in wood. **D** Gneiss from Ollo de Sapo Fm. made of K-feldspar, quartz, and muscovite

ashlars due to its coarse-grained foliation and the cohesiveness between minerals.

Moreiras de Abaixo was exclusively constructed using the gneiss of the Ollo de Sapo Formation that crops out inside the village. The gneiss corresponds to one of the most singular rocks of the northwest Iberian Peninsula. The rock is traditionally named with the Galician term *Ollo de Sapo* ("toad's eye"; Hernández Sampelayo 1922) and their outcrops extend from the Atlantic coast to inland, being also present at the northeast of Madrid. The gneiss exhibits a foliated structure formed by white K-feldspars, bluish quartz, and bright muscovite, visible to the naked eye (Fig. 4C). The bluish colour is due to the presence of titanium in the quartz crystalline structure. The bluish quartz is linked to the eye colour of toads' eyes to increase the attractiveness and singularity of the rock. The origin and age of the gneiss have been broadly discussed since 1922. Recent interpretations pointed out that the gneiss resulted from the metamorphism of igneous rocks during the Variscan orogeny (see Montero et al. 2017). In turn, the igneous rocks were formed by the crystallisation of magmas derived from the partial melting of previous quartzite and schist 477–488 million years ago, making the Ollo de Sapo gneiss upper Cambrian-Lower Ordovician in age (see Fernández-Suárez et al. 2000). A visit to Moreiras de Abaixo would be complemented with a visit to the panoramic viewpoint of the River Sil Valley and nearby Roman mines. In addition, the village may also be visited within the Cubela Route (PR-G 181).

Leixazós Ordovician Village

In the geographic centre of the Courel Mountains UGGp, the village of Leixazós (707 m altitude) was built on the bottom of an incised fluvial valley (Fig. 5A–B). The village contains around 25 dwellings, stables, a watermill (Fig. 5C), and other constructions, mostly abandoned. The main building stone is Armorican Quartzite, which crops out locally and represents a singular geological in the Iberian Peninsula, Brittany, and Normandy (France) since the XIX century (e.g. Martínez Catalán et al. 1992). In the UGGp, this unit comprises 150–200 m of white quartzite with more than 95% of quartz content, and usually constitutes the positive reliefs

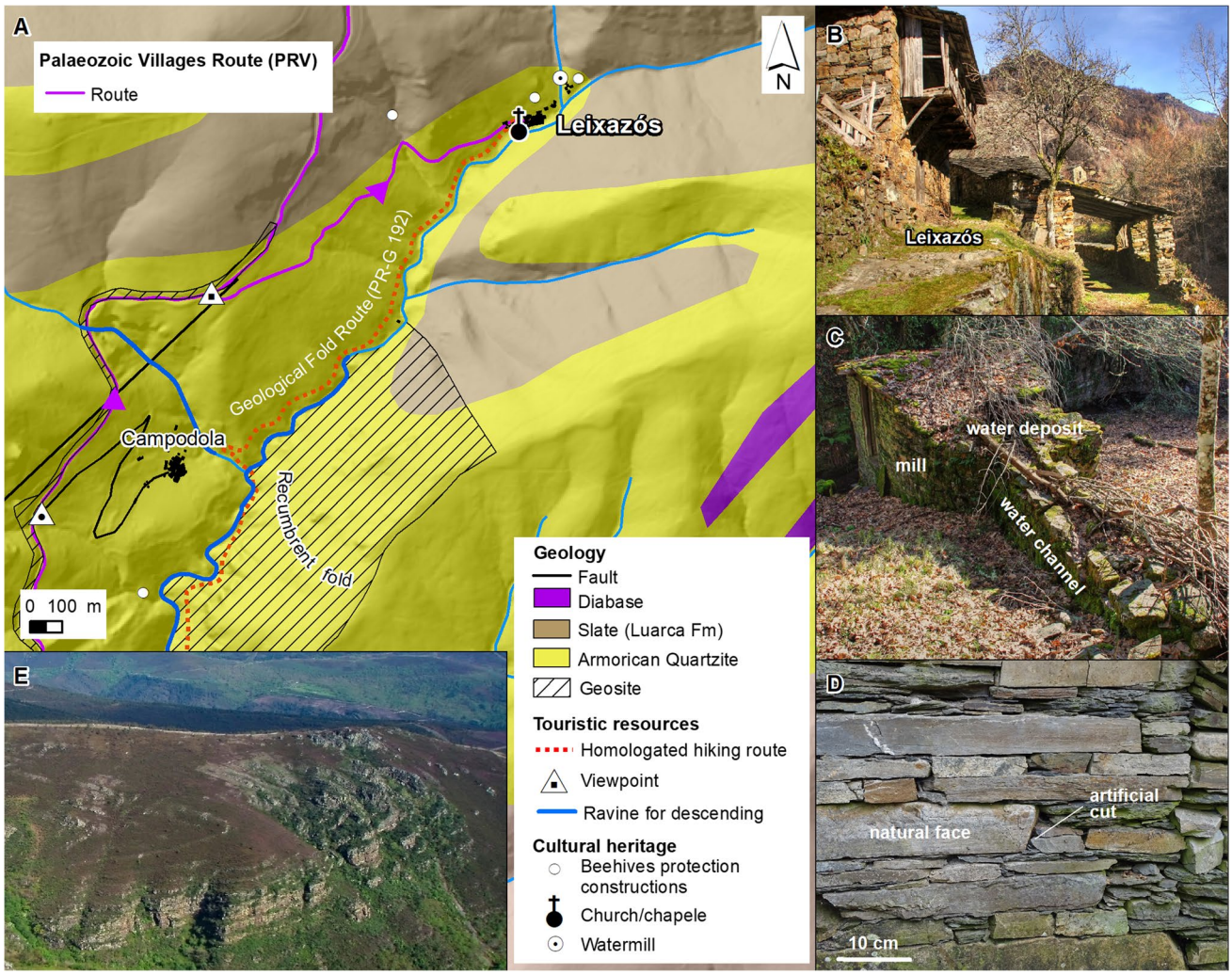

Fig. 5 Leixazós Ordovician Village. **A** Geological map of the area, after Villar-Alonso et al. (2018), showing the nearby tourism resources, cultural heritage, and geosites. **B** Traditional architecture in quartzite and wood. **C** Watermill built in Armorican Quartzite. **D** Dry-stone in Armorican Quartzite with natural faces orientated outwards and artificial cuts hidden inside the wall. **E** Courel recumbent fold Natural Monument and Global Geosite seen from the viewpoints which location is shown in **A**

of the Courel Mountains. The natural bedding, foliation, and fissures of the quartzite favour that the rock breaks forming sub-rectangular blocks, thereby making them adequate for dry-stone walling (Fig. 5D). In building constructions, the natural faces of quartzite blocks are usually orientated outwards, while artificial faces are hidden within the walls. This configuration reduces rock weathering by rain, freezing, and other processes.

Armorican Quartzite defines also the abundant Variscan folds, such as the Global Geosite and Natural monument of Courel recumbent syncline (Fig. 5E), observed in the surroundings of Leixazós (Martínez Catalán et al. 1992; Fernández et al. 2007). Therefore, a visit to the village allows enjoying the main geosite of the UGGp, as well as another geosite related to the Ordovician stratigraphy (Fig. 5A). In addition, a visit to the village is easily combined with outdoor activities, such as canyoning within the Armorican Quartzite, or the Campodola Geological Fold Route (PR-G 192), where *Cruziana* and other ichnofossils can be found within the Ordovician rocks (Fig. 5A).

Froxán Ordovician Village

Froxán is located at 450 m altitude on an ancient alluvial fan surrounded by native forests and woodlots, in the western-central part of the Courel Mountains UGGp (Fig. 6A). This village was declared a Site of Cultural Interest by the Regional Government in 2006 for its traditional architecture, and several stone houses have been restored recently. Froxán includes over 40 dwellings, stables, fountains, and constructions for chestnut curation, all of them walled and roofed in Ordovician slate (Fig. 6B). The penetrative foliation of the

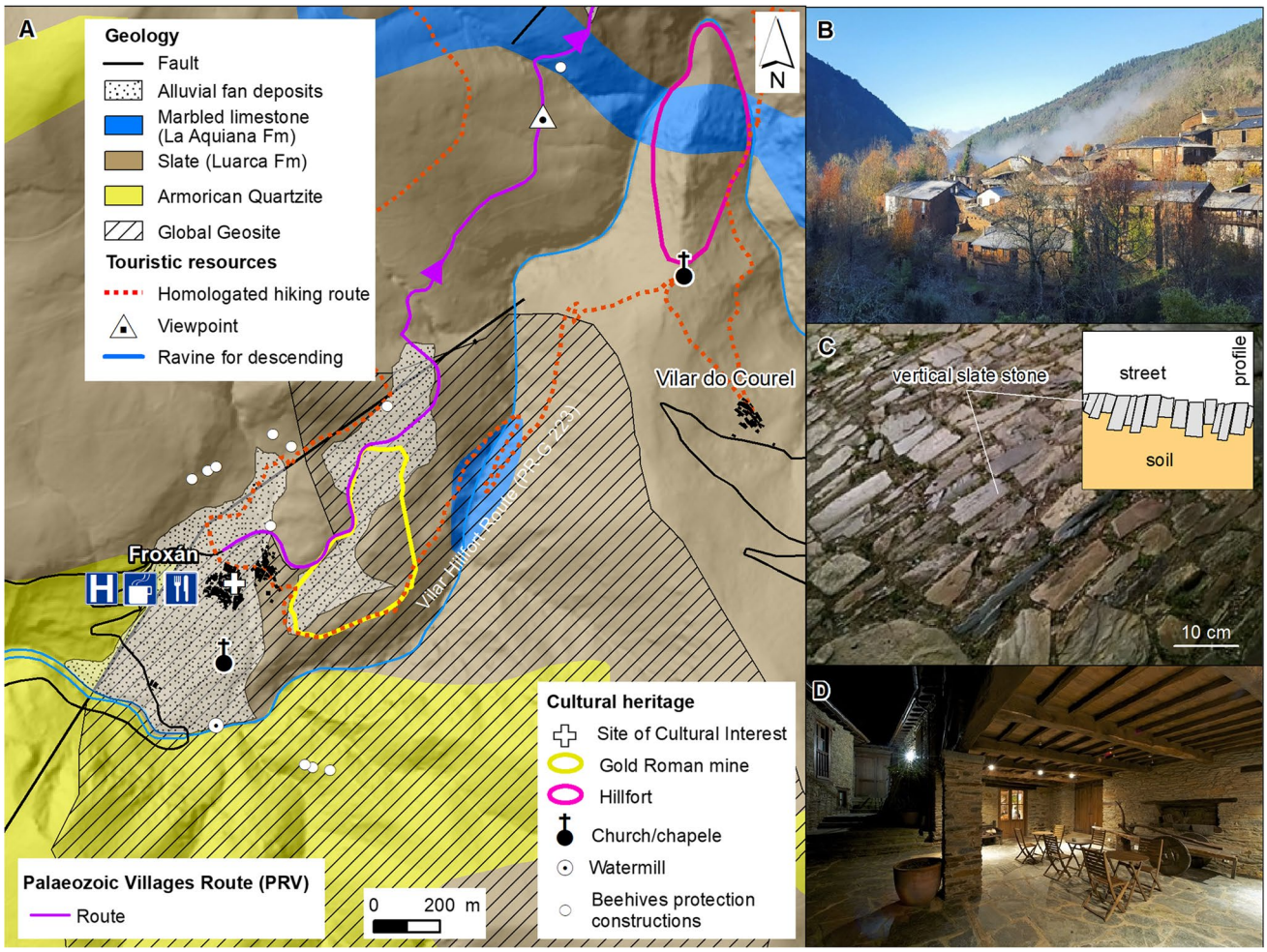

Fig. 6 Froxán Ordovician Village. **A** Geological map of the surroundings after Villar-Alonso et al. (2018), showing the nearby tourism resources and cultural heritage. **B** Overview of the village walled and roofed with Middle Ordovician slate. **C** Traditional technique for paving streets with vertical slate stones. **D** Bar-restaurant exhibiting local slate in walls, columns and floors

slate facilitates its cutting in rectangular blocks for walling, or sheets for roofing. The stone streets are paved using a local technique with rectangular stones placed perpendicular to the ground for increased stability (Fig. 6C). The Ordovician slate, essentially composed of chlorite, muscovite, and quartz, was locally quarried within the Luarca Formation (Fm) (e.g. Villar Alonso et al. 2018). At present, this geological unit is extensively quarried in the UGGp forming part of the Iberian Roofing Slate GHSP (Cardenes et al. 2015).

Froxán has a restaurant-hotel walled using Middle Ordovician slate, allowing the visitor to experience dinner and accommodation within a "rocky environment" (Fig. 6D). A visit to Froxán can be combined with the Vilar Hillfort Route (PR-G 223), visits to nearby viewpoints and the ancient Roman mines that exploited gold related to alluvial fan deposits, and to ancient beehives protection constructions (Fig. 6A). These constructions are circular walls around the beehives to protect them from the brown bear (*Ursus arctos*), a keystone species of the Courel Mountains. Additionally, the local cultural association of the village organises exhibitions related to the curation of chestnuts and wood charcoal elaboration practices since 1999. In 2019, the chestnut exhibition received over 2000 people attendees.

Seceda Devonian Village

Seceda is situated at 760 m of altitude in the western-central part of the Courel Mountains UGGp, surrounded by woodlots, farmlands, and incised streams (Fig. 7A and B). The village was also declared a Site of Cultural Interest for its traditional architecture (Fig. 7B, C, and D), which include similar constructions to those in the village of Froxán (the "Froxán Ordovician Village" section). However, the streets of Seceda are narrower and partially covered by the edges of the roofs for protection against severe weather. This village also shows remarkable wood constructions which connect

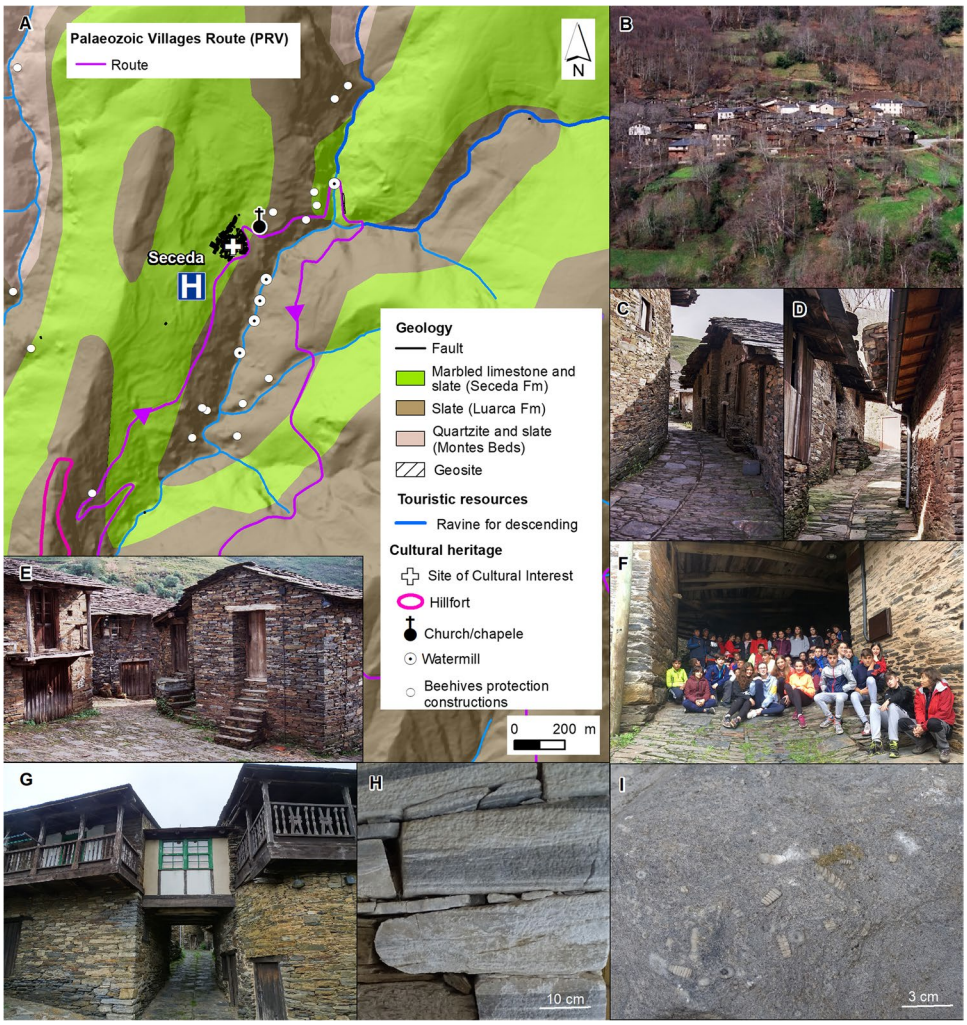

Fig. 7 Seceda Devonian Village. **A** Geological map of the surroundings after Villar-Alonso et al. (2018), showing the nearby tourism resources, cultural heritage, and geosites. **B** Overview of the village walled using Devonian marbled limestone and shale. **C–G** Traditional buildings and pavements. **H** Marbled limestone from a traditional dwelling. **I** Crinoids

houses through bridges running over the streets (Fig. 7F). The singular stone of Seceda is Devonian marbled limestone (Fig. 7G) that crops out in the village surroundings. which are mainly populated by beech forests (*Fagus sylvatica*). The limestone is made of calcite with some quartz, chlorite, and muscovite and, sometimes, exhibits crinoids (Fig. 7I), as can be seen by specimen rocks displayed at the municipality tourist office. Devonian limestone is very scarce in the northwest of the Iberian Peninsula, but here constitutes the core of the Courel recumbent fold (Martínez Catalán et al. 1992). Secada is reached by a descent through ravines of partially Devonian limestone. Local accommodation is provided by two hotels located in traditional buildings. A visit could be complemented by a tour along the abundant ancient beehive constructions and the abandoned stone watermills (Fig. 7A).

Paderne Cambrian Village

Paderne is located in a valley at 873 m altitude surrounded by native forests and traditional chestnut woodlots (Fig. 8A and B). The village includes around 30 traditional dwellings with balconies in wood or slate with smaller constructions, and conventional bread ovens preserved in stone (Fig. 8C, D). The characteristic building stone of Paderne is Cambrian laminated grey quartzite (Fig. 8E), although the roofs are made of slate as is normally the case in traditional villages. Cambrian quartzite crops out in the surroundings of the village dipping around 30–45° to the SW (Fig. 8A). This rock belongs to the Candana Group, a geological unit with a large extension in the NW of the Iberian Peninsula (e.g. Martinez Catalán et al. 1992).

The village of Paderne offers six rural apartments for tourism (Fig. 8F) summing a total of 60 beds and providing the necessary accommodation for the 2 days travelling along the PVR. Traditional locally managed chestnut forests (*Castanea sativa*) are a village highlight. Viewpoints around the village also allow the visitor to watch native forests and woodlands dominated by birches (*Betula alba*) and white oaks (*Quercus pyrenaica*). These forests and woodlands are connected for hikers by the Río Pequeno Route (Fig. 8A).

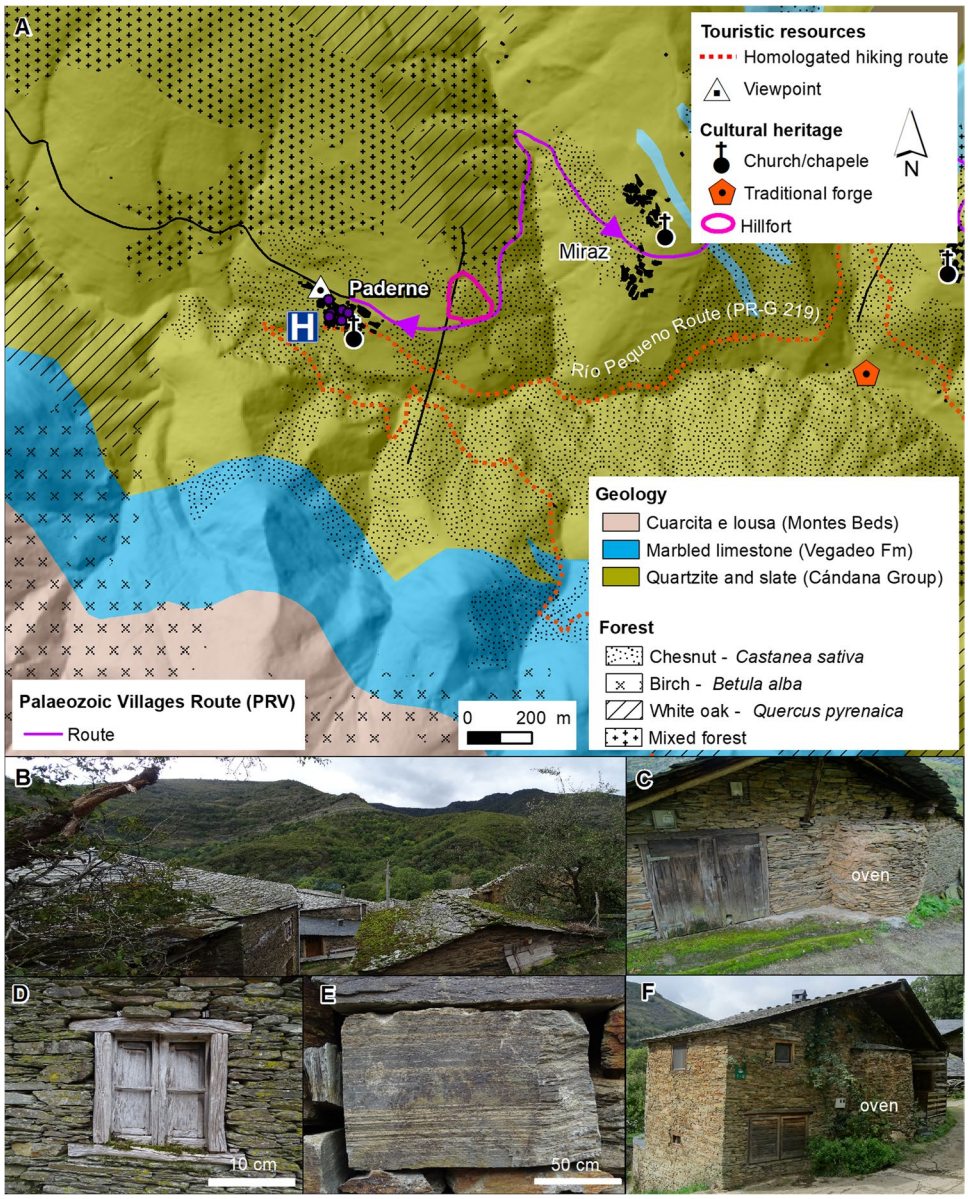

Fig. 8 Paderne Cambrian Village. **A** Geological map of the surroundings after Villar-Alonso et al. (2018), showing native forest and traditional chestnut woodlots. **B** Overview of Paderne and the nearby native forests. **C** Traditional construction. **D** Traditional quartzite wall with a window in wood. **E** Cambrian laminated grey quartzite. **F** Rural apartment for tourism

Céramo Cambrian Village

Céramo (1110 m altitude) was constructed to support iron mining activities in the northeast of the Courel Mountains UGGp (Fig. 9A), provisioning ore for the 15 documented pre-industrial workshops in the area that ran from the sixteenth to nineteenth centuries. At present day, only one resident inhabits one of the 10 dwellings in the village. The local stone used here is Cambrian marbled limestone, essentially formed by calcite and some dolomite, muscovite, chlorite, and quartz. The stratification of the calcareous rocks favours the production of cuboid blocks used for traditional walling (Fig. 9B).

Limestone was obtained from nearby calcareous areas, which can be observed from the villages and from a panoramic viewpoint (Fig. 9A and C). From this viewpoint, two glacial cirques are visible. The limestone areas host five karst caves with a total length of 5 km. The caves are used for speleology and speleotourism conducted by local companies (Fig. 9C). Studies on stalagmites from the Arcoia cave, declared geosite, recorded climatic changes occurred in Courel Mountains during the last 550,000 years (Railsback et al. 2011, 2017). Furthermore, remains of cave and brown bears recovered from these caves and other cavities in the UGGp enabled the study of their genetics and hibernation habits during the Upper Pleistocene (see García-Vázquez et al. 2011; Grandal-d'Anglade et al. 2019). A visit to the Cambrian Village is complemented with visiting the microreserves (Fig. 9A) hosting endemic orchids and other native flora managed by the regional environmental group

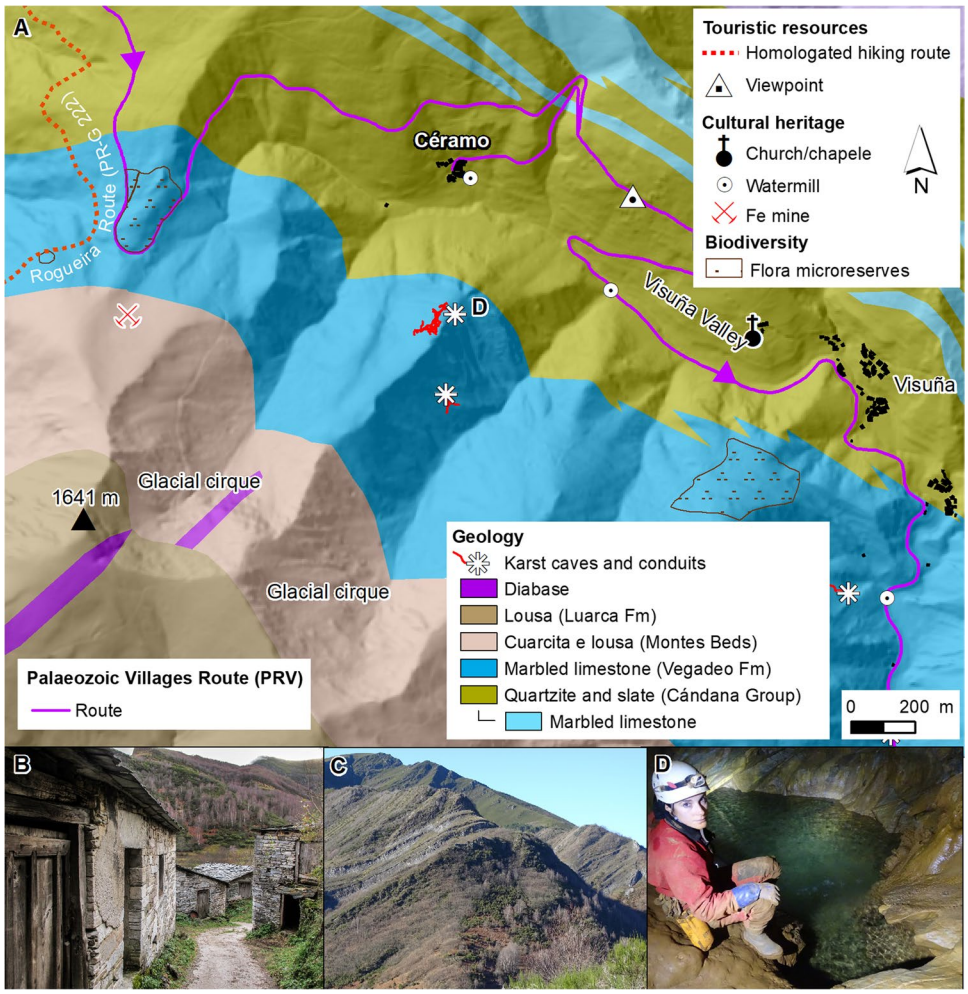

Fig. 9 Céramo Cambrian Village. **A** Geological map of the surroundings after Villar-Alonso et al. (2018), showing the nearby tourism resources, cultural heritage, and geosites. **B** Traditional buildings walled using Cambrian marbled limestone. **C** Calcareous areas seen from the viewpoint, whose location is shown in **A**. **D** Speleologist enjoying a nearby cave positioned also in **A**

"Asociación Galega de Custodia do Territorio" and the Biodiversity Foundation of Spain.

A Seara Silurian Village

The Palaeozoic Village A Seara is situated in an ancient U-shaped glacial valley (declared geosite) at 1000 m altitude for pastoral and agricultural practices, and mining activities (Fig. 10A). A Seara contains over 40 dwellings, stables, and barns, as well as a bridge (Fig. 10B) and three watermills, one of them used for electricity production in the past. Traditional constructions, sometimes restored, predominantly have slate walls and roofs similar as in Froxán (the "Froxán Ordovician Village" section). In addition, slate slabs were used to close singular balconies of the houses (Fig. 10C) and to create small paved areas for agricultural applications (Fig. 10D). The Silurian slate used here is darker and sometimes silkier than the Ordovician slate of Froxán due to the occurrence of graphite (Dozy 1983). This mineral comes from the preserved organic matter accumulated in poorly oxygenated marine environments during the Silurian (e.g. Martínez Catalán et al. 1992). Mesozoic igneous rocks also occur in constructions of A Seara (Fig. 10E). These rocks mainly correspond to a diabase, identified by their concave fractures and the presence of white plagioclase. Diabase boulders are usually located at the bottom of the corners of the buildings for their protection (Fig. 10E). These boulders either come from nearby igneous dykes or were transported from the headwaters of the valley where magmatic intrusions also occur (Fig. 10A) (Villar Alonso et al. 2018). Furthermore, the diabase has long been used as a sharpening stone for knives and farming tools (Fig. 10F).

The village includes a refuge maintained by the Regional Federation of Hiking. A visit of A Seara is highlighted by a visit to two waterfalls, one traditional lime kiln, a panoramic viewpoint over the glacial valley, and a watermill located in the nearby village of Vieiros (Fig. 10A). This watermill runs for touristic exhibitions after its restoration by local residents. A Seara is connected through the trekking routes PR-G 184 and PR-G 197.

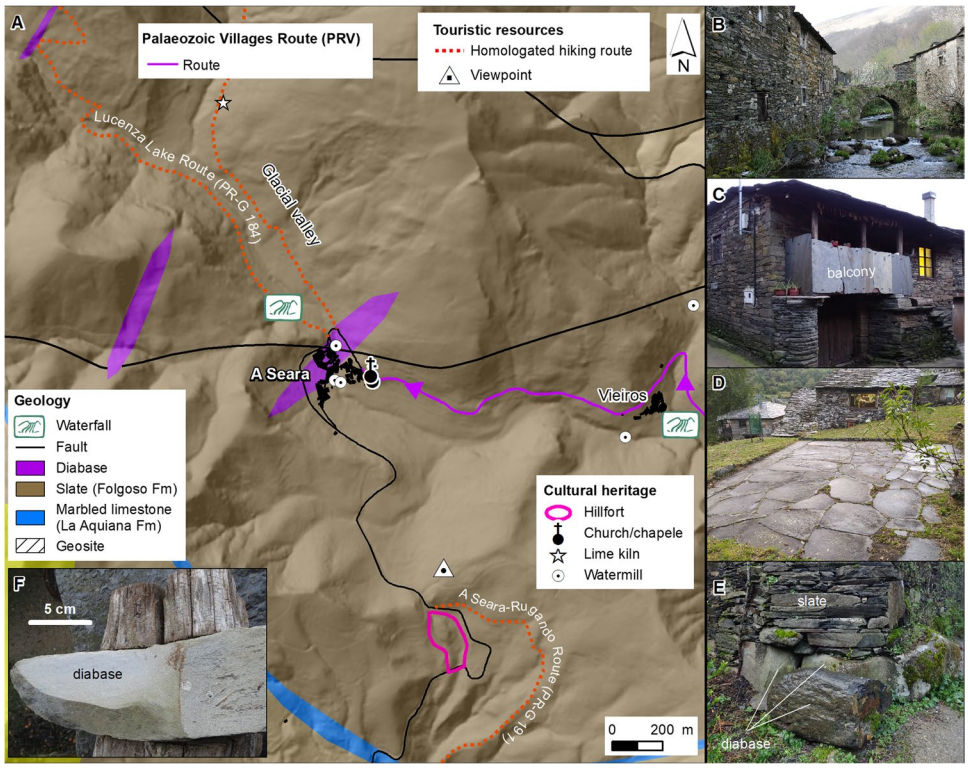

Fig. 10 A Seara Silurian village. **A** Geological map of the surroundings after Villar-Alonso et al. (2018), showing the nearby tourism resources, cultural heritage, and geosites. **B** Overview of the village walled using Devonian marble limestone. **C**–**E** Traditional buildings and pavements

Impact on the UGGp Development

New Educative Resources and Differentiating Features

The PVR integrates the geological and cultural heritage of rural areas for geotourism activities targeted at all audiences. Visitors can familiarise themselves with the main lithologies and geological periods of the Courel Mountains UGGp by observing unweathered rocks, minerals, and fossils. The Palaeozoic Villages encourage the understanding of the role of local stones in traditional architecture, using rocks for specific functions according to its geological characteristics, e.g. quartzite and slate for walling, slate for roofing and closing balconies, quartzite metric-sized blocks for corner protection, or gneiss ashlars for openings (windows and doors). The PVR opens the opportunity to discuss the depopulation of rural areas and abandonment of local villages, raising more awareness of this problem and provide tools to UGGp to mitigate the economic and social impacts. In addition, these actions encourage close cooperation between the UGGp and the local residents. Finally, the route provides a new vision of the traditional architecture, reinforcing the relations between local geology and society as differentiating features of the Courel Mountains UGGp.

Visitor Affluence

The annual number of visitors to all the Palaeozoic Villages is currently estimated to 12,500 visitors, according to surveys carried out by the tourism offices and the Geological Museum of Quiroga. During 2018–2019, the affluence to the Palaeozoic Villages increased around 19% (Fig. 11A). The largest growth (+75%) took place in Leixazós Cambrian Village due to the development of activities organised by the management structure of the Courel Mountains UGGp. The increment of +3 to +11% in Froxán, Seceda, Paderne, A Seara, and Moreiras de Abaixo villages comes from an increase in tourism, sometimes guided by local companies, and their use of local services (restaurants and accommodation). The affluence to the Céramo Cambrian Marbled limestone Village remained constant. Currently, seven local companies organise annually visits to the Palaeozoic Villages, which can also be booked through international agencies. Together, they manage around 10% of the tourist visits to the UGGp. Officials of the Courel Mountains UGGp guided only 5% of the visitors, while 10% were guided by local companies and 85% visited the Palaeozoic Villages on their own account. Indirectly, the characteristics of the PVR encourage that the visitor stays more than 1 day within the UGGp, thereby using some of the 39 restaurants, bars, hotels, hostels, camping, and apartments located in the route

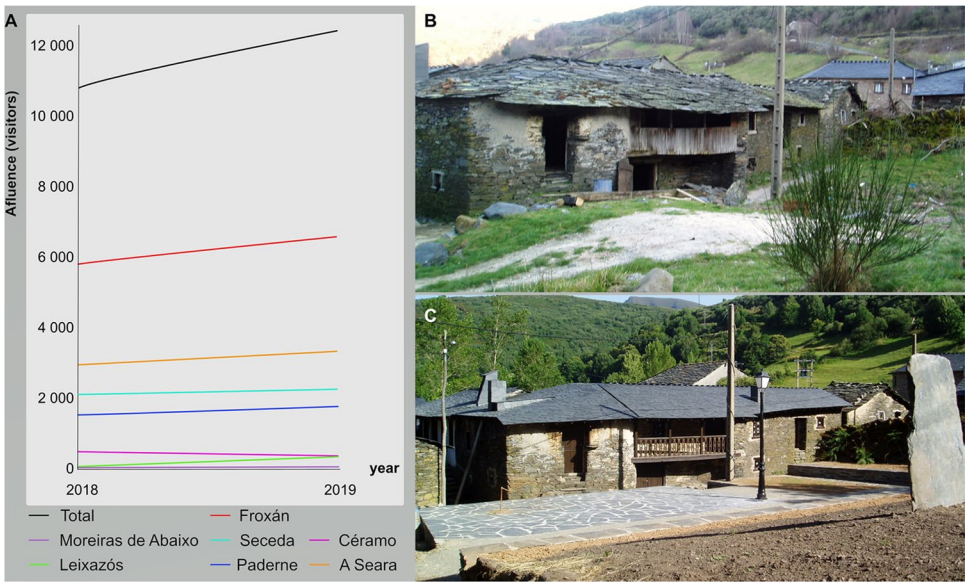

Fig. 11 **A** Visitors of the Palaeozoic Village Route (PVR) during 2018–2019. **B** Ancient traditional building in the A Seara Silurian Village. **C** Same building than **B** after restoration

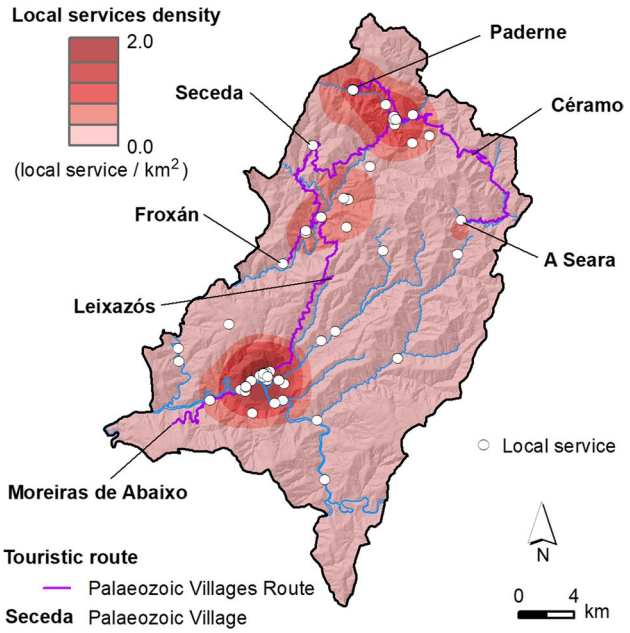

Fig. 12 Projection of the PVR on the local service density map calculated using the Kernel probability estimation in GIS

(Fig. 12). These local services represent 61% of the hospitality industry of the Courel Mountains UGGp.

Preserving Traditional Architecture and Avoiding Depopulation

The PVR favours the arrival of tourists and new habitants to the villages within and nearby the UGGp. Tourists and new residents require food and accommodation services, preventing the abandonment of dwellings and roads, whose conservation is mainly carried out by the municipalities. More than 10 dwellings and other constructions have been restored since 2018 by their owners in three Palaeozoic Villages, following the traditional architecture, which obtained grants from the Regional Government owing to the management of the Ribeira Sacra-Courel Local Action Group (Fig. 11B and C). In addition, ten houses were purchased as second homes for weekends and holidays. Even though these new residents are occasional, their presence decreases the depopulation of rural villages in the UGGp.

Geoconservation and Potential Problems

The PVR does not affect the geoconservation of the Courel Mountains UGGp as the route is developed within the villages, and no additional resources required implementation to establish the route. The main potential problems could be derived from nuisances caused by tourists, such as increased traffic, full parking facilities and local services, and pollution. However, the municipalities and tourist offices have so far not reporting any significant problems related to the PVR and the coexistence of local residents. To avoid road congestions, the management structure of the Courel Mountains UGGp and tourist agents provide instructions for adequate parking and recommend a circular driving route by taking western roads moving up north and returning south following the eastern roads. Tourists usually park their cars at the entrance of the village due to the narrow streets inside. Therefore, new parking facilities are not yet required. Potential environmental impacts are minimised because the villages are located far away from the most sensitive areas of the Natura 2000 Network.

Conclusions

The Courel Mountains UGGp established a new touristic route with educational content for a broad public to highlight the presence of Palaeozoic rock formations in the UGGp and the important role the rocks played in traditional architecture, and to avoid the depopulation of rural areas. The PVR was designed considering seven traditional villages built with local stone, selected according to five criteria: the representativeness with respect to the bedrock of the UGGp, the links to the geoheritage, the preservation of the traditional architecture, the scenic beauty, and the potential combination with other touristic outdoor activities.

The PVR constitutes a new educational resource linking lithologies, geological periods, traditional use of the geological resources, and awareness of current societal problems in rural areas. Since 2018, the route generates an increase in touristic affluence to rural villages with subsequent economic benefits, promoting the purchase and restoration of dwellings and other constructions following the local traditional architecture. These actions mitigate the degradation and depopulation of rural villages, which largely affect many geoparks and other rural areas in the Iberian Peninsula and other places in the world. The designed PVR is a fundamental example of the relationship between humans and geology, the most distinctive features of the Courel Mountains UGGp.

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Author Contributions RV and MA conceived the original idea and directed the research. DB and PC designed the methdological procedure in cooperation with RV and XCB. In particular, RV reported about the specific uses of building stones and XCB provided the geological knowledge. MA carried out the funding acquisition and project administration. DB and PC wrote the original draft, with contributions by all authors to the final version.

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Data Availability All data and materials are public and free to use.

Declarations

Conflict of Interest The authors declare no competing interests.

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