

Mapping Geosites for Geoheritage Management: A Methodological Proposal for the Regional Park of Picos de Europa (León, Spain)

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Abstract Mapping is a basic requirement for land use management, as effective protection of nature requires a clear delimitation of the sites involved. Additionally, mapping has other benefits for the transfer of information, as long as it is a comprehensible way of information exchange. The knowledge of geoheritage (geological heritage) and how it can be incorporated into the management of natural areas is an emerging topic. In this paper, a methodology that can be used to map geoheritage is proposed through the example of the Regional Park of Picos de Europa (Spain). Cartography is designed to be used as a tool for both prescriptive geoheritage management and land use planning processes in the protected area. The current examples of mapping consist of two groups of maps: (1) basic descriptive maps, where geosites are represented and which offer an overview of the geoheritage in the territory and (2) applied derived maps, which use the previous base cartography but also implement specific queries for management. Information codified in the derived maps may be diverse, ranging from the geosite degradation risk to the most adequate geosite use. The designed maps also achieve an important aim: They are easily interpreted and, therefore, might be used by many different professionals involved in environmental management.

Keywords Mapping · Geoheritage · Geosites · Land use management · Protected areas · Picos de Europa · Spain

Introduction

Geoheritage mapping can be incorporated into the management of natural areas. According to Brocx and Semeniuk (2007), geoheritage (geological heritage) is a concept concerned with the preservation of features with importance to Earth science, such as landforms, natural and artificial exposures of rocks, and sites where geological features can be examined. A clear and synthetic definition of geoheritage is the one included in the Spanish National Law on Protection of Natural Areas and Wildlife (2007) (Law 42/2007 *de Patrimonio Natural y Biodiversidad*), which was created by specialists from both the Spanish Geological Survey and the Spanish Geological Society and which states that geoheritage includes the natural geological resources of scientific, cultural and/or didactic value: geological formations and structures, terrain shapes, minerals, rocks, meteorites, fossils, soils and other geological features that permit the knowledge, study and interpretation of (a) the origin and evolution of the Earth, (b) the processes which have sculpted it, (c) the climes and landscapes from the past and present and (d) the origin and evolution of life. Other concepts closely connected to that of geoheritage are geoconservation and geodiversity. Geoconservation describes a series of actions intended to preserve the geoheritage of a certain place (Brocx and Semeniuk 2007). Geological diversity (geodiversity) is defined as the variety of geological features, including rocks, minerals, fossils, soils, geological units and landscapes, which are the result of the Earth evolution and history (Law 42/2007 *de Patrimonio Natural y*

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Biodiversidad). A geosite is a locality that constitutes part of the geoheritage of a territory. Besides that, publications by geomorphologists cited through this paper use the concept of geomorphosite defined by Panizza (2001), as they restrict their scope to those localities constituted by geomorphological landforms that are part of geoheritage¹.

Concern for geoheritage has increased across the world over the last two decades. The increasing interest in geoheritage is supported by the growth in the volume of literature on this topic during this time. Firstly, many authors have discussed and specified the main concepts concerning geoheritage, particularly geodiversity, geoheritage and geosite (Elízaga 1988; Wimbledon 1996a; Sharples 2002; Gray 2004; Kozłowskyi 2004; Brilha 2005; Carcavilla and others 2007; Carcavilla and others 2008, between others). Another important group of works has considered the methodology used to select localities that should be recognized as geosites and protected because of geological interest (for example, Duque and others 1983; Águeda and others 1985; Alexandrowicz 1993; Wimbledon and others 1995; Wimbledon 1996b; Gonggrijp 1997; Sharples 2002; Dingwall and others 2005; Leman and others (eds.) 2008; Vdovets and others 2010; Mansur and de Souza 2011). Many other papers have applied and adapted these principles to a range of situations and scales and have developed inventories of geosites in different countries or regions (for example Alexandrowicz 1998; Joyce 2010; de Lima and others 2010; Fuertes-Gutiérrez and Fernández-Martínez 2010; Mansur and de Souza 2011).

There is still work to do, however, to achieve the integration of geoheritage as a fundamental parameter in environmental conservation and management. From our point of view, one of the general aims is to enforce and standardize the methodological bases for geoconservation.

As has been disclosed, the present contribution considers geoheritage mapping, specifically. A methodology for mapping geoheritage is proposed through the example of a protected area in Spain, the Regional Park of Picos de Europa. The mapping is based on the concept of geosite typology as a parameter, which tries to group types of geosites and thereby to find general and common management principles. Our research aims to produce a cartography that may constitute a summary of the geoheritage in a territory. The resulting maps would have the objective of both representing the boundaries and spatial distribution of geosites in a specific area and of summarizing some relevant characteristics that are required for their management.

Therefore, the mapping is thought to be the basis for creating further maps, which are essential for decision making in environmental management, such as zoning of protected areas, the creation of geotourism plans or the protection of geoheritage. In this paper, two examples of such maps are presented, specifically, the map of geosites' intrinsic value and the geosites' risk of degradation.

Mapping Geoheritage

As Coratza and Regolini-Bissig (2009) point out, mapping may be considered as a powerful means of communication, and it is particularly effective because it uses an international language, which is easily transmittable and cannot be misunderstood. Additionally, mapping is a basic tool for environmental management and land planning (Lüttig, 1979; Cendrero 1980, 1990; Sánchez Díaz and others 1995, between others). As previously mentioned, geoheritage research has, until now, been mainly focused on the definition of the basic concepts, the identification and assessment of geosites and the principles for geoconservation. Only in recent years has mapping gained higher prominence and several studies have been specifically centered on mapping methodology: Carton and others 2005; Bissig 2008; Coratza and Regolini-Bissig 2009; Regolini-Bissig and Reynard 2010(eds.).

As Coratza and Regolini-Bissig (2009) explain, designing maps is not a simple procedure. A map can be considered as a link in an information exchange, which includes a codification phase (implementation of the map) and a decodification phase (interpretation of the map). The complexity of creating maps lies in the fact that the codification or implementation stage implies a series of queries. However, the final user must be able to interpret these queries successfully without any additional help or information. This requires that the codification be as precise and objective as possible and that the expression of the information is clear, synthetic and easily readable.

From our perspective, the first assumption to make when considering geoheritage mapping is that this cartography must be based on geological mapping but must also be different from it. As Coratza and Regolini-Bissig (2009) affirm when referring to geomorphosites, these sites are different from other geological or geomorphological features and require their own specific mapping methods and standards to preserve Earth heritage. Additionally, there are three reasons as to why specific geoheritage maps, different from the geological and geomorphological maps, are needed. Firstly, geosite mapping has different aims from geological and/or geomorphological cartography. The second reason is that this cartography must be interpreted by a wider group of specialists, who will take part in the management. Finally,

¹ It is not the aim of this paper to discuss the terminology; the authors intention is only to clarify that, in the present contribution, when using geosites, geomorphosites are also included. For this reason, many ideas and methodologies developed in the field of geomorphosites are extendable and applicable to geosites.

despite the broad range of sites, which constitute geoheritage (from a thermal spring to a mineralogical outcrop, a stratigraphical section or a large area with tectonic interest), some common management principles can be identified and expressed together in a geosite map.

In this context, a methodology for designing geoheritage maps from geological and geomorphological maps may be developed. Some authors have discussed how to create some specific geoheritage maps. For example, both Regolini-Bissig (2010), for interpretative maps, and Erhartič (2010), for geoconserving maps, have described this process, but both approaches still maintain geomorphological map units. In this paper, we present a different approach from the aforementioned reports, which lies in the creation of geosite-specific mapping designed specifically to be used for geoheritage management. The information included in geological and geomorphological maps is fundamental but is not enough for geoheritage management. A geoheritage map must enclose further information, not just that given by the single units constituting the geosite.

Hence, creating geoheritage maps requires the selection of the information represented in the previous maps that is relevant for management and its grouping and expression in a way that is useful for that task (with the specific concepts and terminology required). For example, a geosite constituted by an area with periglacial processes would be represented as a whole in the geoheritage map. Although this area includes different landforms, it constitutes just one geosite, and these geomorphological units must be considered together for the management and conservation of geoheritage (for example, for preserving this landscape in a territory where periglacial processes are relict).

Picos de Europa Regional Park: A Territorial Description

Picos de Europa Regional Park is a protected area located in the León province, in the Castilla y León Region, Spain (Fig. 1). It covers a territory of 120,000 ha that was

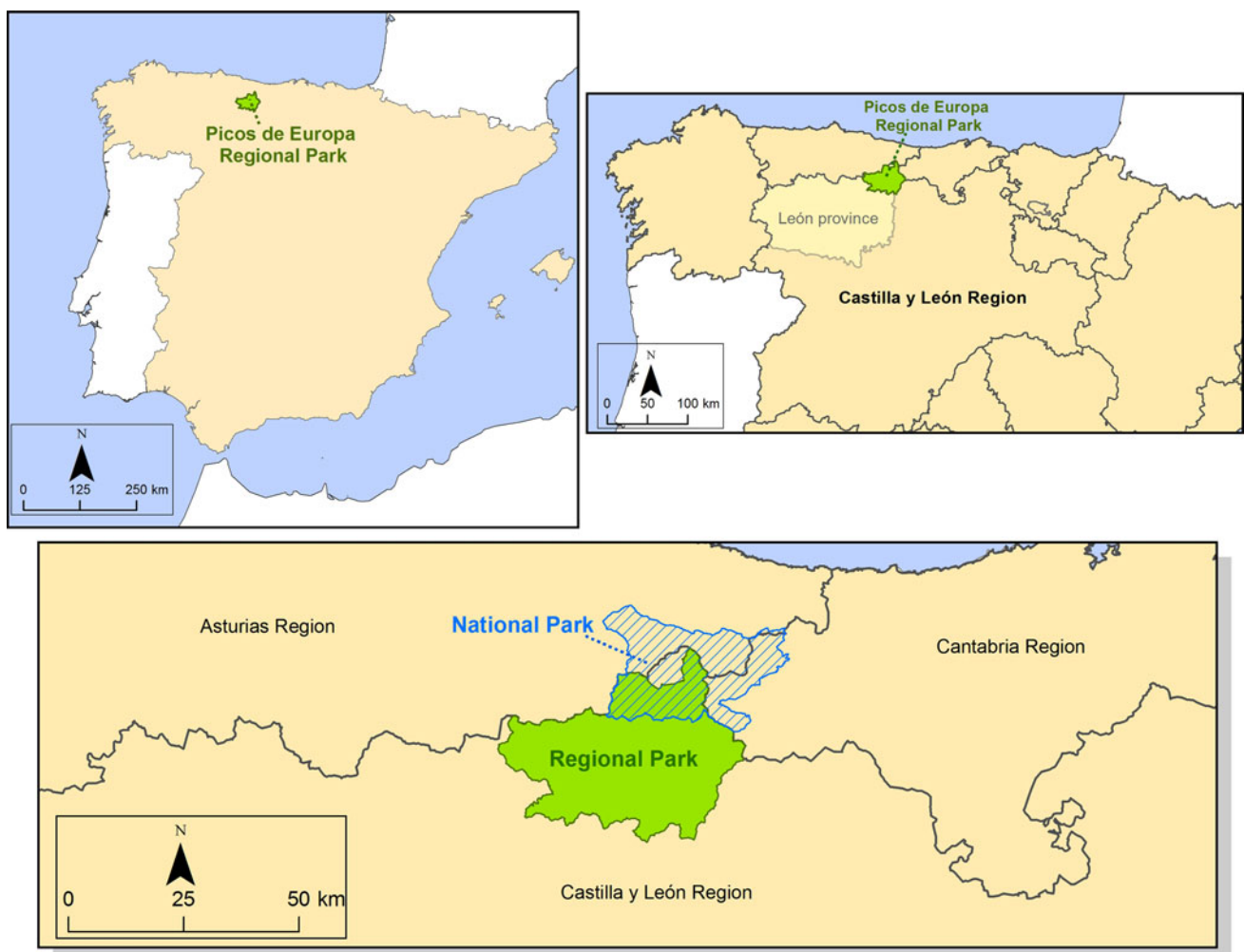


Fig. 1 Location of both Picos de Europa National and Regional Park in Spain

declared under protection in 1994. The name of this Regional Park might cause confusion: the Regional Park is not the same territory as the better known Picos de Europa National Park, but both parks share some common area (Fig. 1). That shared portion comprises a small percentage of the entire Regional Park. The rest of the area is also of great interest, as it is composed of diverse territories from both geological and biological points of view. Therefore, despite its name, the Regional Park is far from simply being a Picos de Europa National Park perimeter protected area.

Presently, inside the territory, there are 58 inhabited villages with a total population of less than 4,500, mainly concentrated in two villages (data from the National Statistics Institute dated January, 2010). In 1987, a reservoir was constructed in the area of Riaño (the main settlement of the territory). Seven villages were flooded, and two more were affected by the building of the dam. Additionally, the widest plains, along with their fine soils and meadows, also disappeared under the water. Consequently, this great transformation strongly accelerated the abandonment of traditional activities (mainly cattle raising and agriculture) in a large part of the area. Despite the declaration of the Regional Park (and the different subsidies received for it), this zone has not recovered its socio-economic dynamism.

From a geological perspective, this territory belongs to the Iberian Massif, a region that covers a large area in the western part of the Iberian Peninsula. The rocks forming this massif are Paleozoic in age (542–251 my) and were emerged and deformed during the Variscan (or Hercynian) Orogeny, a large continental collision that occurred during the upper Paleozoic (360–300 my) and that led to the formation of the supercontinent Pangea.

In this geological context, the Picos de Europa Regional Park is characterized by the occurrence of diverse types of sedimentary rocks, mainly limestone alternating with shale and sandstone. Cambrian to middle Carboniferous rocks were deposited within shallow marine environments and usually they bear fossils of marine invertebrates, such as brachiopods, corals and crinoids. Upper Carboniferous rocks were deposited after the Variscan Orogeny when the old sea became a tropical forest. These rocks are mostly conglomerate, sandstone, shale and coal beds, usually bearing plant fossils.

The Variscan Orogeny affected mainly the first group of rocks (the so-called pre-orogenic sequence) creating a complex structure of folds, faults and nappes, and giving way to the intrusion of some scattered plutonic rocks (Fig. 2a) and hydrothermal mineral deposits.

The Variscan Massif generated during this orogeny became eroded during the Mesozoic, but the region was lifted again during the Alpine Orogeny, which acted in the north of Spain from 50 to 10 my.

Currently, it is a precipitous land with steep slopes that entail very active gravitational processes and river erosion (several mountains more than 2,600 m high and about 25 km far from the coast). The territory is also characterized by vast karstified areas and many examples of Pleistocene glaciation that form wild and impressive landscapes (Fig. 2a, b).

Thus, the relief of this area is the product of a very complex geological history, which is the main cause of the important geodiversity of the Regional Park.

The declaration of the Picos de Europa Regional Park (Law 12/1994 *de 18 de julio de declaración del Parque Regional “Picos de Europa” en Castilla y León*) justifies the park's recognition in the following excerpt: “both climatic conditions and relief in the northwest area of the Leon province, together with its historical evolution have permitted the permanence, in a good conservation status, of Eurosiberian representative ecosystems, whose most significant expressions are the vast extensions of oak and beech Atlantic forests with fauna populations that are, in most cases, the most southern of Europe, emphasizing the brown bear and the capercaillie”. The legal text also mentions that its proximity to the Mediterranean region enriches the biological heritage of the area.

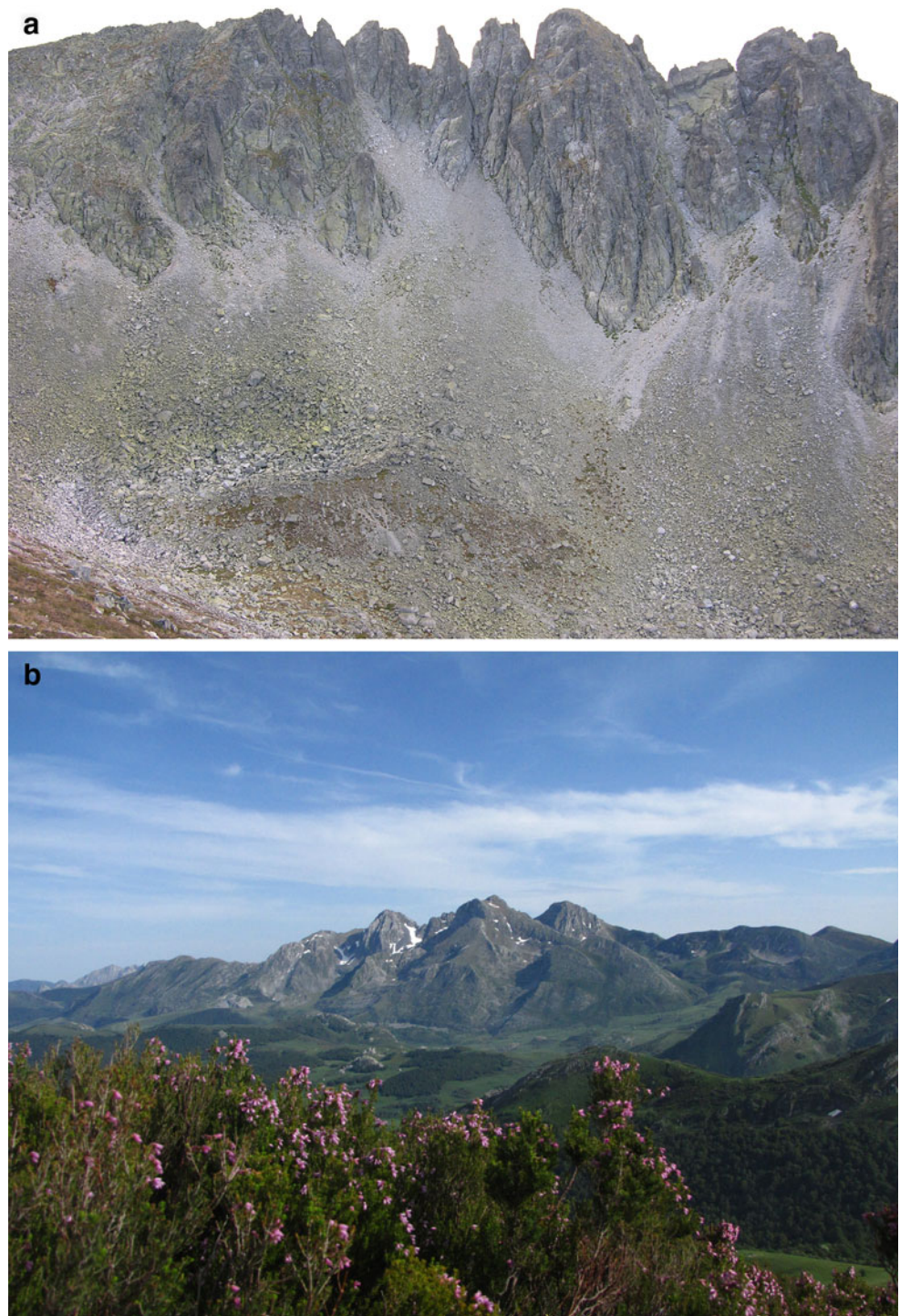
However, as is usual in Spain, the law does not cite the geology of the area as one of the reasons for its protection, and despite the large number of sites of geological interest inside the Regional Park (which will be described in this paper), the only mention of the geology in the entire text is the intention to declare a small calcareous region with some relief peculiarities, the Mampodre Massif, as a geological reserve (Fig. 2b).

In summary, geoheritage is absent from the planning of the protected area, and consequently, some geosites are being irreversibly damaged. For example, some peats with paleontological interest are being used as pasture when other traditional meadows are abandoned. Another example is the planning of a sky station in a unique area of the territory that still maintains some remnants of periglacial processes.

Methodological Principles for the Geoheritage Mapping Proposal

Our approach is inspired by the methodological principles established by Cendrero and Díaz de Terán (1987), Cendrero (1990) and Sánchez Díaz and others (1995) for the elaboration of geoenvironmental cartography aimed at land planning. These authors have suggested the development of at least two types of maps: (1) basic descriptive maps, which include and summarize the main characteristics of

Fig. 2 **a** View of the Aguja de Cardaño Peak, where the largest granodiorite intrusion of this area outcrops. In the left part of the image a small but still active lobulated rock glacier may be distinguished within the vast debris cone. Photograph by Javier Santos González; **b** Panoramic of the Mampodre Massif, one of the emblematic ranges in Picos de Europa Regional Park. This massif was the only locality proposed as a geological reserve in the legal document enclosed for the declaration of the protected area. In that text, it was singled out for its geomorphological peculiarities. In the inventory of geosites used for this paper, Mampodre is one of the largest areas, enhanced by both its geomorphological and tectonic importance; the latter is considered to be the primary interest of the geosite



the territory and (2) interpretative maps, where the units delimited in the basic maps are evaluated with different management perspectives and purposes. In the present paper, these concepts are applied to geoheritage analysis to develop a methodology for mapping geosites and obtaining geosite basic maps and geosite applied maps.

Basic maps may reflect the observable features and main characteristics of the geosites (dimensions, shape, element

disposition, etc.) In our approach, we represent geosites according to three features (which are numbered here and explained later in the section titled “Creating basic descriptive maps”):

- (1) The concept of typology, as a tool that summarizes geosite main characteristics, particularly for management and dissemination.

- (2) The primary interest of every geosite, which is usually connected in some way to its typology.
- (3) Geosite boundaries.

The resulting maps offer a helpful overview of the features composing geoheritage in a territory and their main particularities. They constitute the starting point for the elaboration of applied maps.

Alternatively, in the applied maps, different variables required for management may be represented (for example, degradation risk or potential for use). These maps require interpreted information gathered from the geosite assessment phase, normally developed during the creation of geoheritage inventories. Some examples of the uses of these maps are to express geosite priority for conservation or its most appropriate use.

Considerations for Mapping Scale

Environmental management in general, but particularly that of a protected area, requires very detailed cartography.

Today, present techniques and available data permit precise mapping at a large scale (1:10,000). In this study, information was collected and processed with that degree of detail, and each geosite was mapped at 1:10,000 (Figs. 3, 4, 5, 6). However, this paper attempts to identify general principles and considerations with which to undertake the first steps for geoconservation in a protected area. Thus, it is focused on the geoheritage of the Picos de Europa Regional Park treated as a whole rather than on the specific geosites. To achieve these aims, a complete vision of the geoheritage is needed, and therefore, we present maps of the entire territory with a scale of 1:200,000 (Figs. 7, 8, 9, 10).

Both the methodology and the scale utilized in this paper were designed for this specific aim (geoheritage management in protected areas). The methodology's application to different situations of geoheritage mapping (for example, mapping geological frameworks for inventoring global geosites in a country) might require adaptation to the particularities of the specific project.

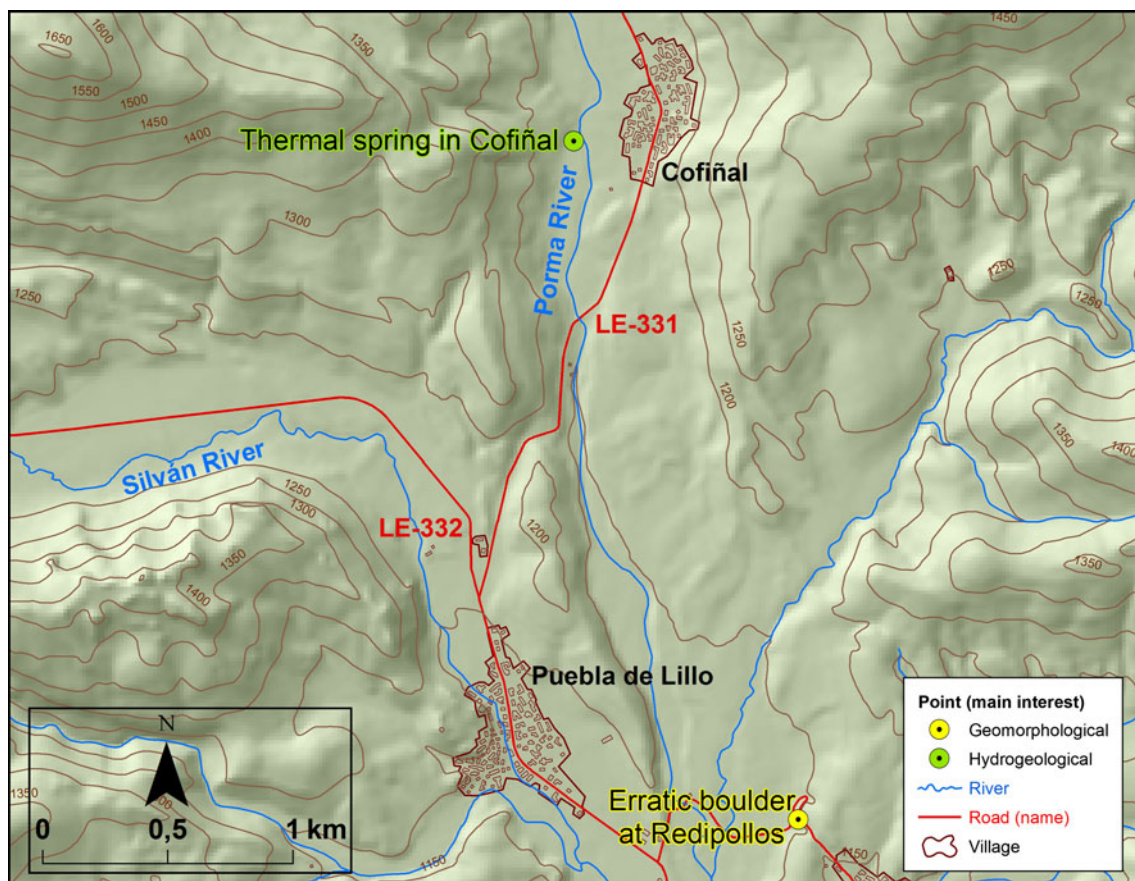


Fig. 3 Map showing point geosites. Typological representation also corresponds to the boundaries of the geosite, but point typology entails that these geosites are isolated features and have very small

dimensions. Thus, even in detailed maps, it is not possible to draw them as polygons. This also informs us that these geosites might be vulnerable because of their small dimensions

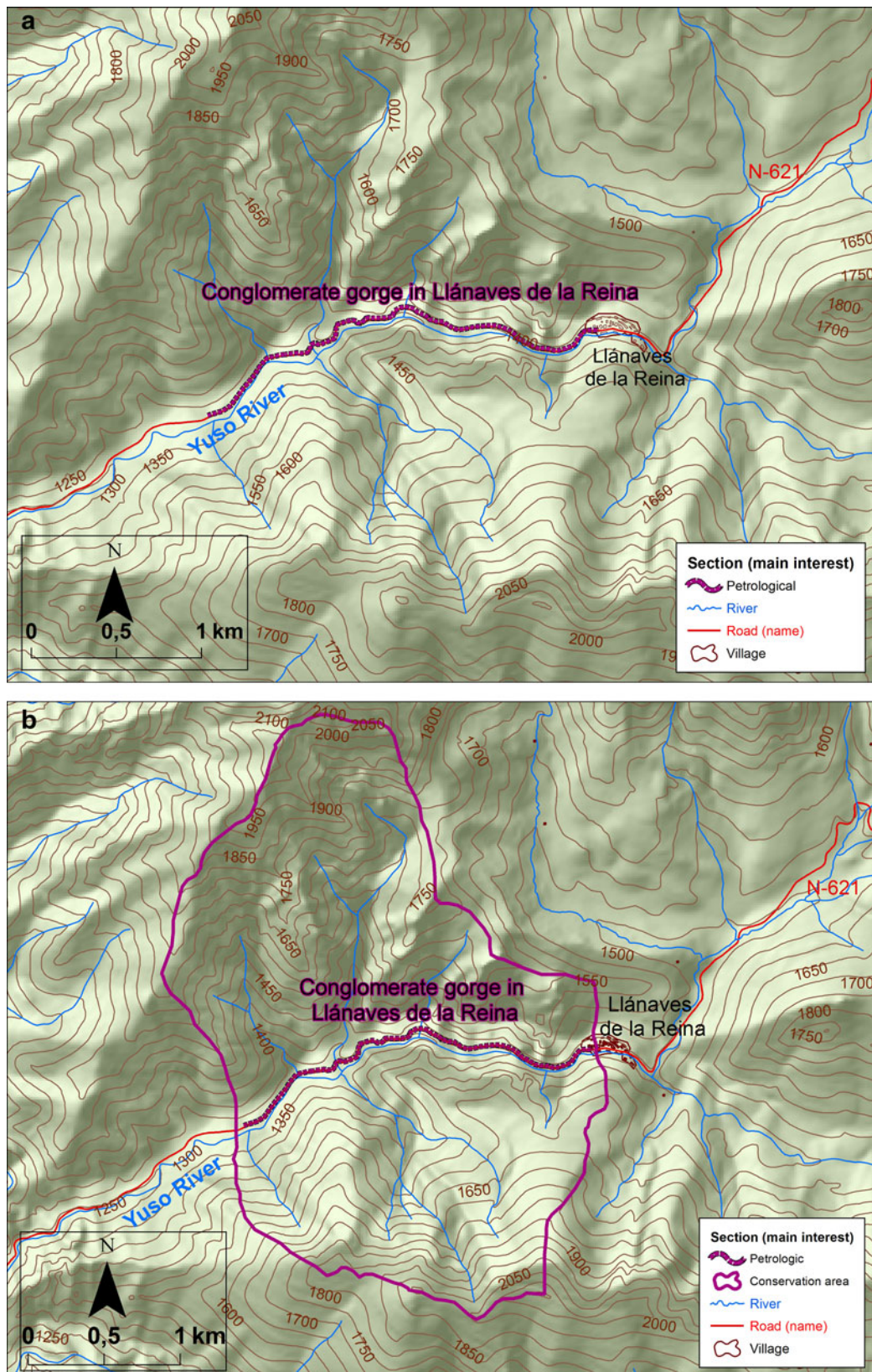


Fig. 4 **a** Map of a section in which the spatial expression of this typological class can be observed. Additionally, and from the point of view of management, this map may also inform that an appropriate

way of disseminating information on this geosite would be on a route along the section; **b** Delimitation of the area, which constitutes the section geosite

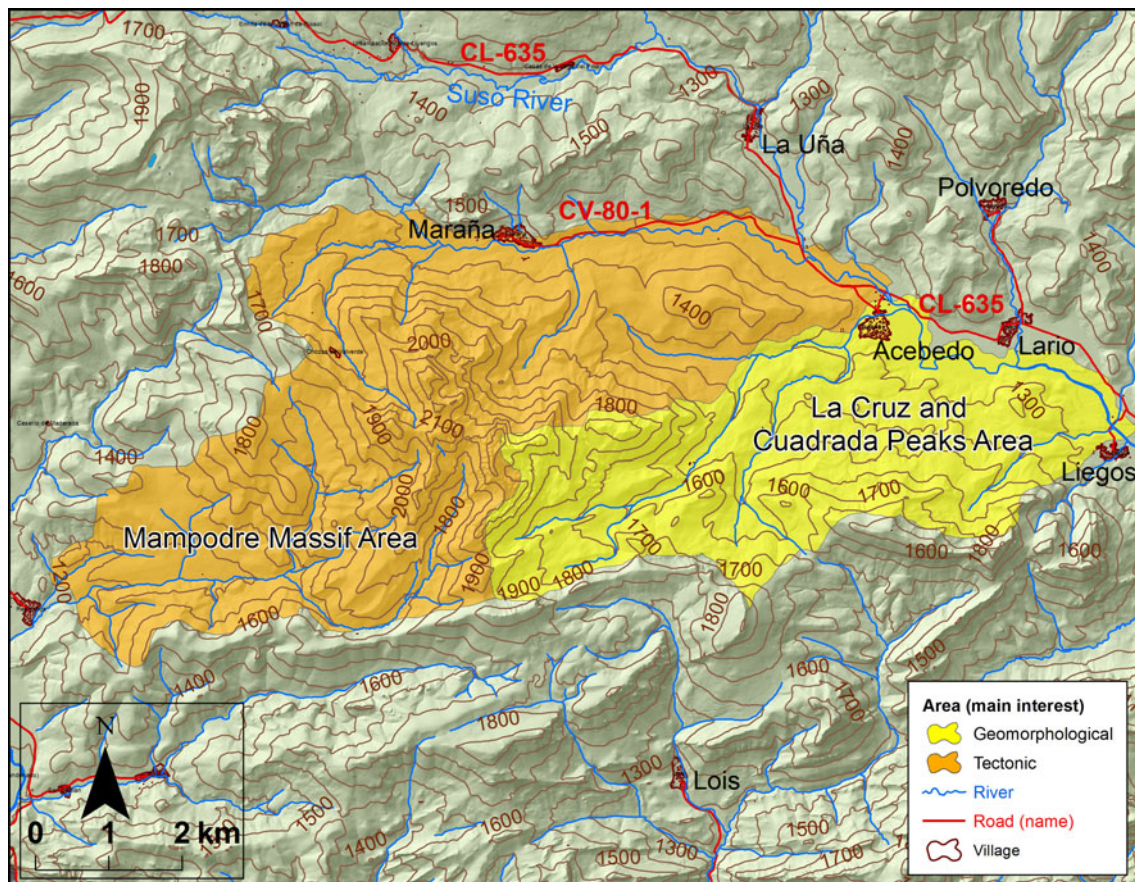


Fig. 5 Example of two areas in which typological representation coincides with the spatial delimitation of the geosite. Their large dimensions suggest that these geosites might be compatible with other land uses apart from conservation

The Starting Point for Mapping

Before the map can be completed, two procedures must be followed, as the information obtained from them is essential to creating the map: (1) identification of geosites and (2) analysis and description of every geosite.

Identification of Geosites

Geosite inventory has been made through the review of previous literature, both that describing the geology of the area and that describing geoheritage. The criteria for geosite cataloguing are taken from the definitions of Carcavilla and others (2007). In this context, geosites are localities that have the following characteristics:

- Contain registered peculiar geological processes,
- Are located where a geological process or feature is represented in a model way,
- Are located where outcrops have been selected as stratigraphical or chronological standard sections and

- Whose landscape is singular or represents the geology of the area.

Apart from listing the features that achieve those characteristics, geosite identification also attempts to determine the features relevant to the reconstruction of the geological history of the territory and/or the geological Zone/Region/Unit in which it is included. Many of the geosites identified (41 from 51) were mentioned in previous reports of the area, including those by Elízaga and others (1983), Alonso Herrero (1987), Alonso Herrero and Gallego Valcarce (1995), Fernández-Martínez and others (Fernández-Martínez and others 1998), González Trueba (2006), Fernández-Martínez and others (Fernández-Martínez and others 2009a).

In this study, no selection of geosites has been made for the definitive list. That is, the final compilation of sites is the result of all inventoried geosites because the inventory's aim is to provide a basis for decision making in geoheritage management and land planning in the protected area. Any process related to geoheritage (for

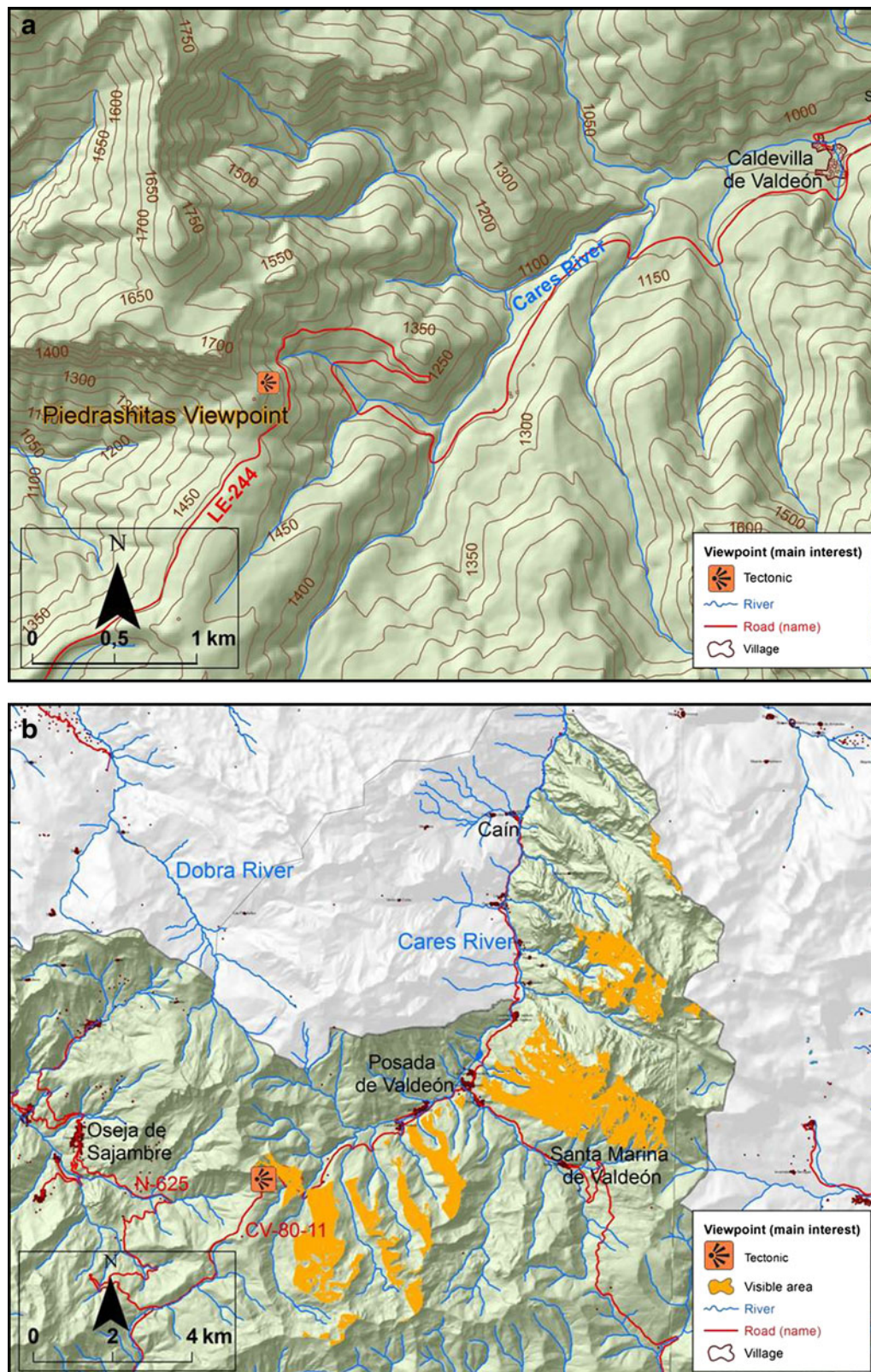


Fig. 6 **a** Typology of a viewpoint; **b, c** Viewpoint and the area observed from it (**b**). For calculating this area, the Digital Elevation Model of the territory and the tool Viewshed from the software ArcGis 9.2. by ESRI have been used. This area is chaotic and useless

for management. Thus, it is transformed into a regular area (**c**). The criterion used for it is the delimitation of the complete hydrographic basins of the areas, which should be protected

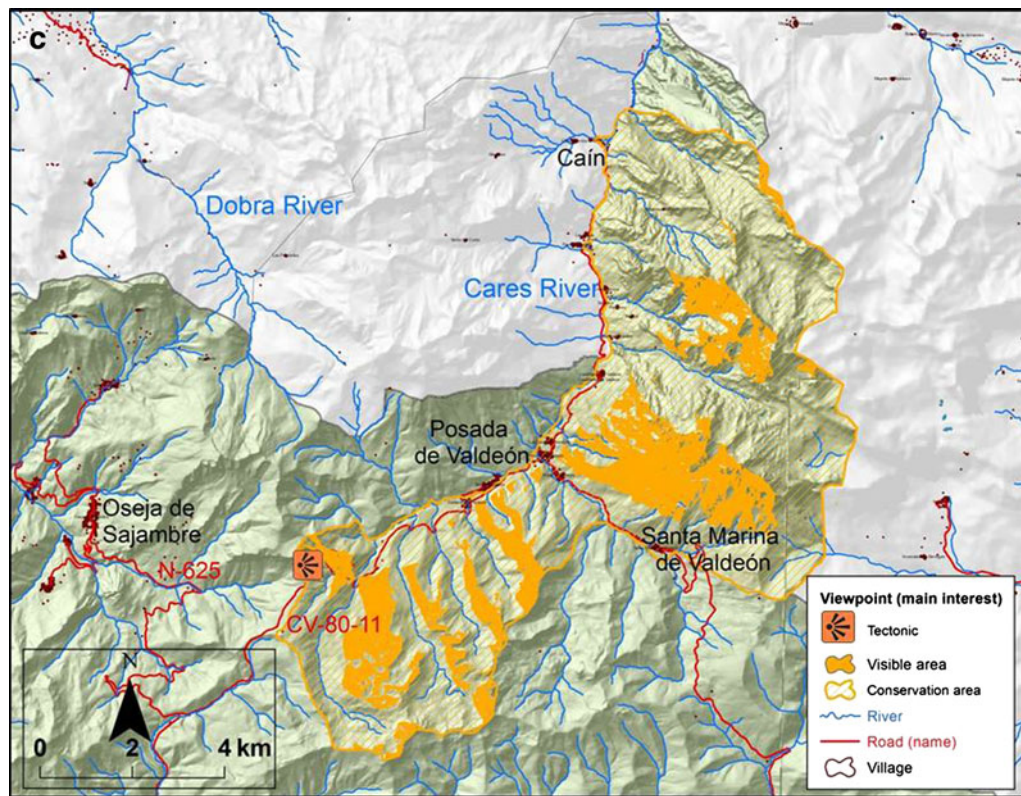


Fig. 6 continued

example, the development of a geotouristic plan or the establishment of reserve zones) must consider every geoheritage feature that is present in the territory.

Description and Analysis of Every Geosite

The analysis of sites comprises the review of the bibliography for each, and the study of the geosites in the field. This work must be performed from the perspective of a heritage feature, i.e., from its potential as scientific, educational and/or a touristic element. With all the information collected, a broad description of every geosite is made. The entire definition of the geosite is gathered in a descriptive survey.

An important task during the analysis and description of the geosites is the study of the spatial distribution and dimensions of the different geological and/or geomorphological features of which they are composed. This study is necessary to assign a typological class to every locality. The concept adopted for typology is the one defined by Fuertes-Gutiérrez and Fernández-Martínez (2010), who conceive typology as a synthetic parameter useful for summarizing the main characteristics of a geosite. Typology gives information on the dimensions of the geosite, the shape and disposition of its features, and its fragility and vulnerability (in this case, fragility is defined as the risk of degradation of a site from natural processes, while

vulnerability is the measure of the degradation risk due to human activities). Thus, these authors link each typological category to general principles for geosite conservation and the potential for use.

Creating Basic Descriptive Maps

As stated above, a geosite basic map is composed of three elements: typology, the point of primary interest and geosite boundaries. These three features will be overlaid over a topographic map.

Related to typology, Fuertes-Gutiérrez and Fernández-Martínez (2010) establish five typological categories: points, sections, areas, viewpoints and complex areas. In this contribution, only the first four of them are used. Complex areas are not taken into account, as they are large zones with a high geodiversity and a type of geosite that results from the grouping of several geosites from different categories. Therefore, we suggest that complex areas should be considered at a higher level and, hence, analyzed in a later stage. The map of the complex areas of a territory may be created when the map of the other categories is finished and when geodiversity spatial distribution may be analyzed.

Typological categories and their associated repercussions for management are fully detailed by Fuertes-

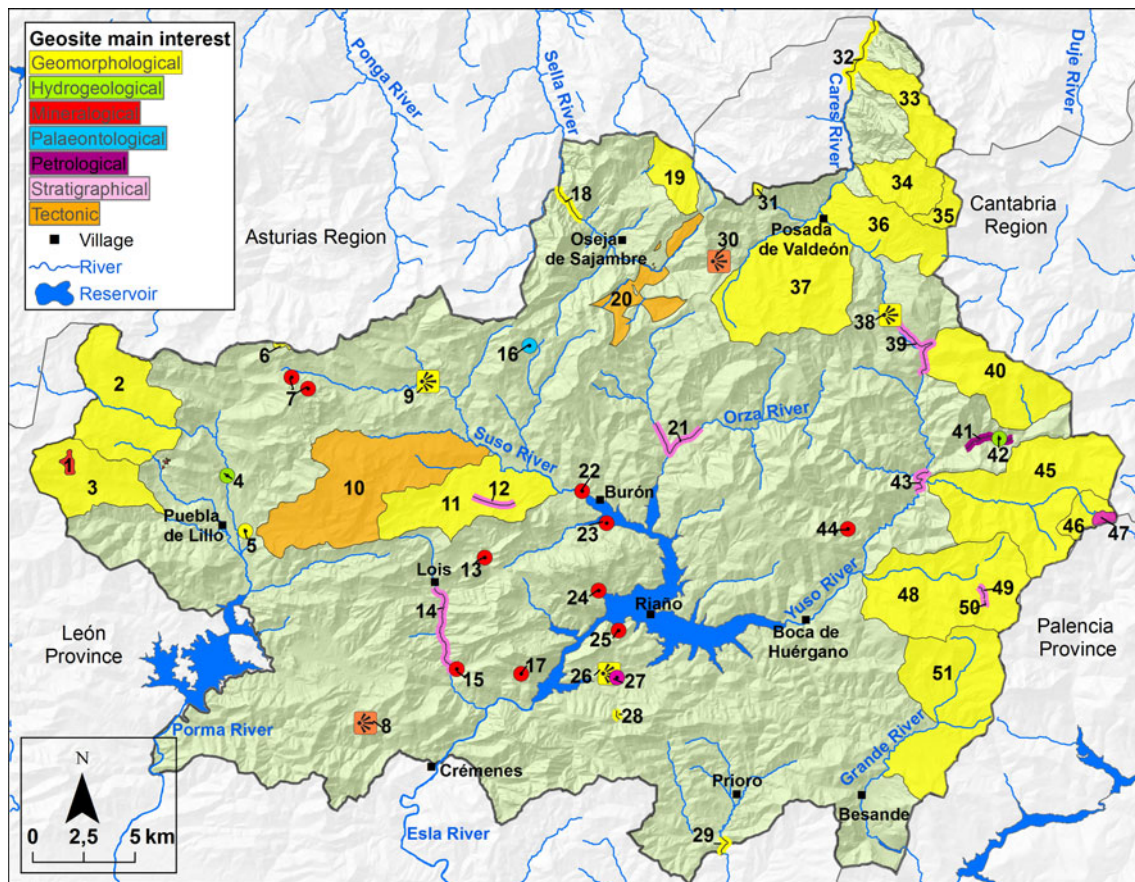


Fig. 7 Map of geosites in Picos de Europa Regional Park. Typological classes are easily discernible within it. Apart from typology, the primary interest of geosites is shown by different colors: mineralogical

(red), petrological (purple), stratigraphical (pink), paleontological (blue), hydrogeological (green) and geomorphological (yellow). The legend of this map is detailed in Table 1 (Color figure online)

Gutiérrez and Fernández-Martínez (2010). Here, we include a short description of every typology, and we analyze its spatial expression.

- Points: Small-sized (in our territory and with the scale used, under 1 ha) isolated features (for example, a thermal spring, an erratic boulder or some mineralogical outcrops). Whether fragile or not, they are always vulnerable because of their dimensions.

Most points cannot be drawn on the map as their own areas because of their small dimensions. Although the limit for separating punctual features from the other typologies is marked in 1 ha, it is worth mentioning that almost every point has metrical or decametrical dimensions (Fig. 3).

- Sections: Chronological (stratigraphical) sequences and/or features having linear spatial development (for example, a stratotype defined along a road, a gorge or some braided channels along a river). At this scale, sections are represented by lines on the map (Fig. 4a).
- Areas: Larger-sized sites including just one type of interest (for example, a glacier valley or a massif with

tectonic interest). Their fragility and vulnerability is low because of their dimensions. Areas are drawn as polygons on the map (Fig. 5).

- Viewpoints: A viewpoint includes two different elements, a large area of geological interest and an observatory from where this area may be viewed. However, typological representations of viewpoints consist of a point but are different from the point geosites, as they are observer points (Fig. 6a).

When representing the point of primary interest, we use different colors on the map. The classification by means of primary interest used is the one proposed by authors who have previously worked in the region (Fernández-Martínez and others 2009a, b and Fuertes-Gutiérrez and Fernández-Martínez 2010) and has seven different categories: mineralogical, petrological, stratigraphical (which includes sedimentological), paleontological, tectonic, geomorphological and hydrogeological.

Concerning the geosite boundaries, charting is based on both the geological and the geomorphological maps. The information taken from these documents is different

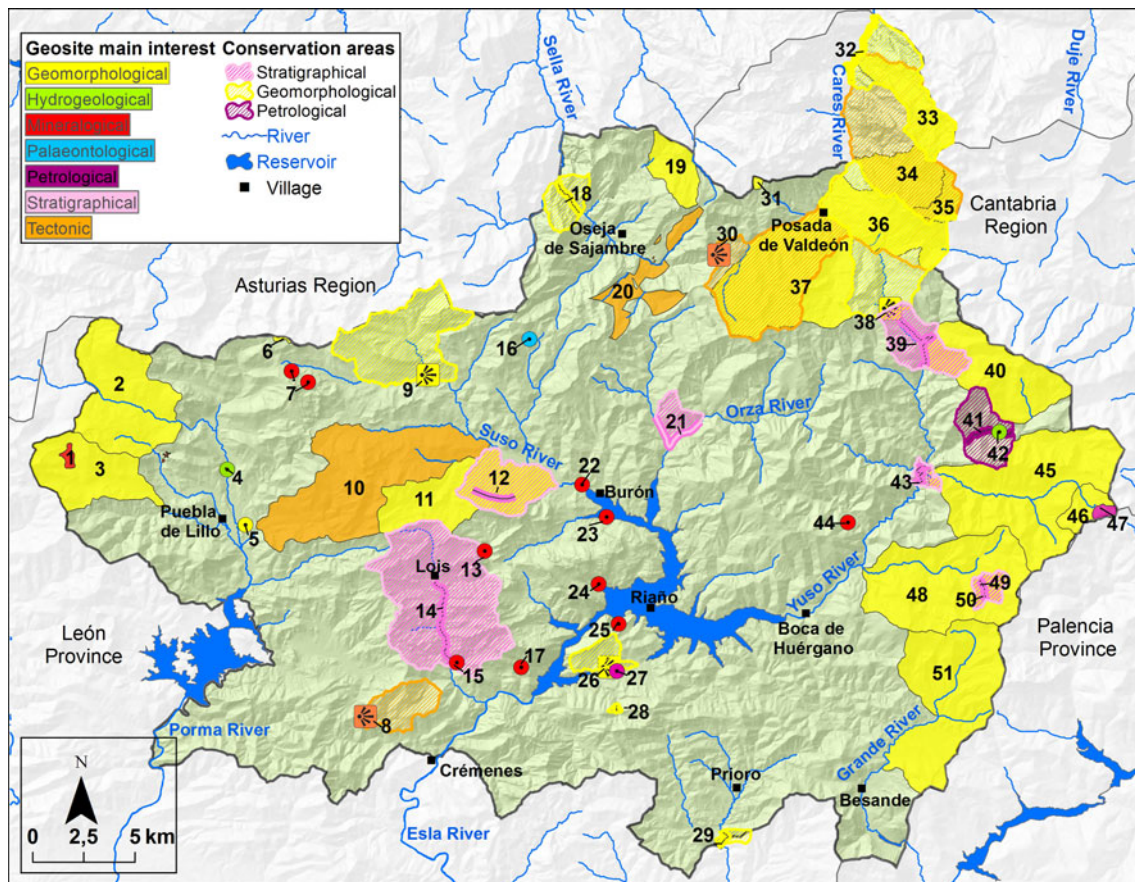


Fig. 8 Map of geosites showing their typology, primary interest and actual limits (Color figure online)

for every type of geosite. Some examples are detailed as follows:

- Some area geosites will be directly transferred from the geological or geomorphological maps to the geosite map. For example, in the petrological area Granodiorite at Peña Prieta (Fig. 7, number 47), the batholith mapped in the geological map constitutes the geosite. The geosite Olistoliths in Sajambre valley is also taken from the geological map (both the olistoliths and the detrital rocks outcrops in which they are included, Fig. 7 number 20).
- The geomorphological areas are delimited after the analysis of the distribution of the different elements inside them (represented in the geomorphological map). For example, in an area of interest due to its glacial morphology (for example, Isoba valley glacial morphology, Fig. 7, number 2), limits are marked taking into account the geomorphological landforms (moraines, terraces, lakes, etc.) but also the studies and publications, which establish the relationships between the glacial elements and determine the limits of the area affected by the same glacier or group of glaciers. This mapping methodology permits the separation of

- different geomorphosites in an area with much glacial evidence. In the case of geosites number 2 and 3, neighboring areas exhibit interesting glacial morphology and deposits but are different from one another. The two valleys have contrasted lithologies, and they were affected by different groups of glaciers with diverse characteristics (aspect, length, thickness, etc.)
- The stratigraphical sections are drawn along the outcrops, which constitute the locality (for example, the petrological section “Conglomerate gorge” in Llánaves de la Reina, Figs. 4a, b and 7, number 41) One criterion that was used in our mountain territory is the delimitation of such outcrops up to the summit line, which implies the change of aspect. In stratigraphical sequences with high scientific value, another criterion might be the additional protection of every outcrop in a perimeter around the section.
- Viewpoints: as previously stated, viewpoints are sites composed of two features: a point (the observatory) and an area (the one viewed from the observatory). The observatory should be processed as a point, and the area should be delimited as the view from the observatory (Fig. 6b, c).

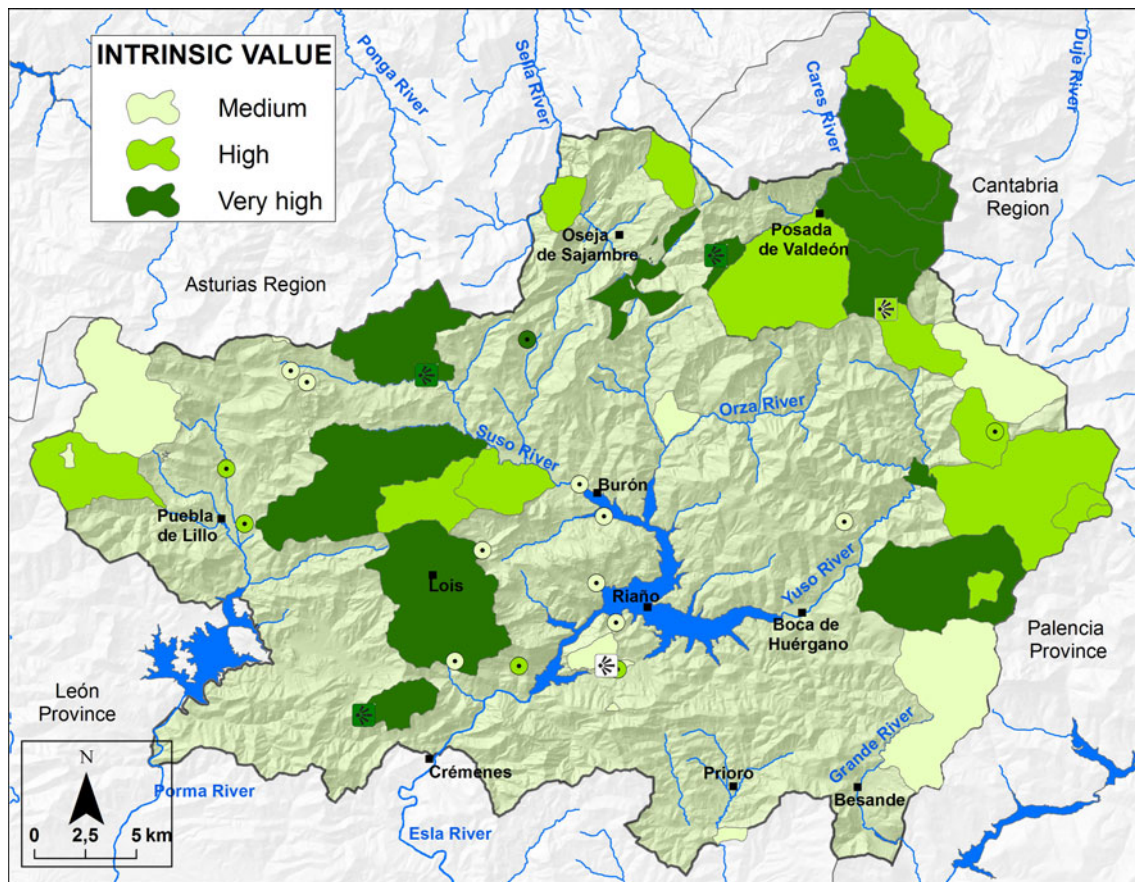


Fig. 9 Map of classes of intrinsic value. Sites are colored by means of their geological importance (Color figure online)

Combining the three different criteria explained above, (typology, primary interest and geosite boundaries), two different descriptive maps were created. As can be seen in Figs. 7 and 8, the first basic map (which includes typology and primary interest) is simpler and much clearer than the second (which also includes geosite limits). The difference between both maps lies in the existence of two typological classes (specifically, sections and viewpoints), which do not have a polygonal representation, i.e., whose spatial expression does not show the exact surface that constitutes the geosite. This information is obviously essential for precise geosite management. Therefore, boundaries of each geosite are defined and implemented in a new, second map that shows the actual dimensions and boundaries of all the localities.

The value of maintaining the first map when the second is more complete may be questioned. In that respect, we would like to argue that, as shown, information in the second map (Fig. 8) is not as easily legible as in the first one (Fig. 7). Moreover, we consider both maps interesting and worthy of development because they have different uses and fulfill different needs. The first map offers an overview of the geoheritage in the territory, showing the types of elements of which it is composed. Each typological class has a characteristic and distinguishable appearance. This

renders the map more easily interpretable and is very useful in a first approach to the geoheritage of a territory². The second map is more complex and not so easily readable but contains the basic information needed for proper geoheritage management and for the derivation of interpretative maps directly related to it.

Deriving Applied Maps

As mentioned above, these maps are interpretative and reflect different parameters with a direct application in management processes. They are developed using the second descriptive map (Fig. 8) as a base cartography and introducing over it some assessment parameters identified during the corresponding inventory stage.

According to Cendrero (1996a, b) and Carcavilla and others (2007), assessment parameters may be grouped into three different categories: intrinsic value, potential for use and degradation risk.

² It is important to remember that typology is a synthetic and integrated parameter; expressing its content in a graphic manner entails the inclusion of much information in a single map.

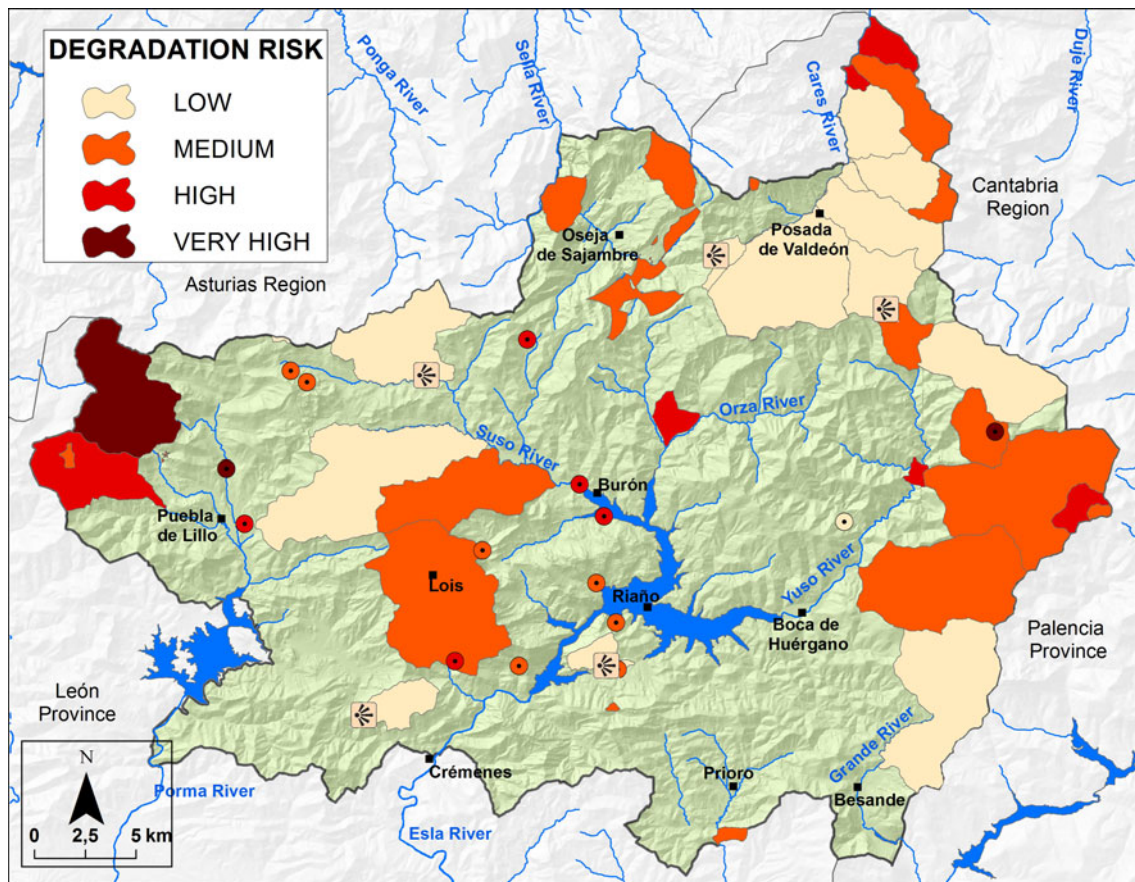


Fig. 10 In this map, sites are scored in four ranking classes on the basis of their risk of degradation (Color figure online)

- Intrinsic value is what we could call geological importance. The variables measured in this section are representativeness, rarity, grade of relevance (from local to international), validity as model of the geological process/feature, diversity of geological processes and elements, conservation status, scientific value and aesthetic value.
- Potential for use refers to the relevance of the geosite for the different activities that could be developed around it as a heritage feature. Activities are restricted to three types, which are scientific, educational or tourist. The most appropriated use, observation conditions, accessibility, comprehension ease, dimensions, conservation status and potential for handicapped people are parameters considered at this stage.
- Degradation risk considers both external threats (vulnerability) and internal threats (fragility) and is complemented by the assessment of accessibility, dimensions, proximity to human settlements, public influx and present or potential threats.

Methodological principles for assessment follow the above mentioned works and also consider both the purpose described by García-Cortés and Carcavilla (2009) and the

reflections of Mansur and de Souza (2011). However, they are not detailed here, as they are far from the aim of this paper. The purpose of this section is to show how basic maps can be implemented to elaborate applied cartography through the consideration of the results obtained during the evaluation phase. Quantifying assessment confers a numerical label for different site parameters and permits the establishment of a hierarchical rank with the sites according to those parameters. Transferring this information permits the elaboration of several maps with diverse aims that are essential for obtaining the cartography needed for geoheritage management, in particular, and land planning, in general, for example, a map showing either most adequate uses for geoheritage, geotourist potential of the area, geosite priority for geoconservation or georeserves. Additionally, the main advantage of these maps is that they are easily interpreted by different staff members with various types of training (and usually with non-specific knowledge of geology) who take part in environmental management.

In this contribution, two examples of derived maps are presented: a map of geosite intrinsic value and a map of geosite degradation risk.

Table 1 Legend of the maps in Figs. 7 and 8

	Geosite name	Typology	Main interest
1	Talc and pyrite at Puebla de Lillo	Area	Mineralogical
2	Isoba valley glacial morphology	Area	Geomorphological
3	Respina valley glacial morphology	Area	Geomorphological
4	Cofiñal thermal spring	Point	Hydrogeological
5	Erratic boulder at Redipollos	Point	Geomorphological
6	Remelende high plateau	Area	Geomorphological
7	Riosol and Las Señales Pass cinnabar deposits	Point	Mineralogical
8	Primajas and Pardaminos duplex viewpoint	Viewpoint	Tectonic
9	Ten peak glacial cirque viewpoint	Viewpoint	Geomorphological
10	Mampodre Massif	Area	Geomorphological
11	Cuadrada and La Cruz Peaks Massif	Area	Geomorphological
12	Ricacabiello formation stratotype	Section	Stratigraphical
13	Mercury at Lois	Point	Mineralogical
14	Salamón-Lois Carboniferous section	Section	Stratigraphical
15	Gold-uranium mineralizations at Salamón	Point	Mineralogical
16	Sinkhole at Polvoredó	Point	Palaeontological
17	Calcopyrite at Las Salas	Point	Mineralogical
18	El Beyo gorge	Section	Geomorphological
19	Glacial forms in Vegabaño	Area	Geomorphological
20	Calcareous olistoliths in Sajambre	Area	Tectonic
21	Vegacarneja formation stratotype	Section	Geomorphological
22	Fluorite at Burón	Point	Mineralogical
23	Antimonite at Burón	Point	Mineralogical
24	Antimonite at Riaño	Point	Mineralogical
25	Arsenopyrite at Puente Bachende	Point	Mineralogical
26	River capture at Cantoro Peak viewpoint	Viewpoint	Geomorphological
27	Igneous rocks at Horcadas	Point	Petrological
28	Dark gorge at Horcadas	Section	Geomorphological
29	Desfiladero de Las Conjas	Section	Geomorphological
30	Piedrashitas viewpoint	Viewpoint	Tectonic
31	Llos valley glaciokarst	Area	Geomorphological
32	Cares gorge	Section	Geomorphological
33	Dobresengos valley	Area	Geomorphological
34	La Sotín valley	Area	Geomorphological
35	Liordes depression	Area	Geomorphological
36	Cifuentes Peaks Massif (Friero-Pedavejo Peaks)	Area	Geomorphological
37	Glacial morphology in Cares river headwaters	Area	Geomorphological
38	Pandetrave viewpoint	Viewpoint	Geomorphological
39	Panda and Pandetrave formations stratotype	Section	Stratigraphical
40	Coriscao Massif	Area	Geomorphologic
41	Conglomerate gorge in Llánaves de la Reina	Section	Petrol. and Geom.
42	Sulphide spring at Llánaves de la Reina	Point	Hydrogeological
43	Lechada syncline and Lechada formation stratotype	Section	Tect. y Stratigraph.
44	Gold deposit at Guspiada valley	Point	Mineralogical
45	Boquerón de Bobias and Lechada and Naranco valleys	Area	Geomorphological
46	Glacial and periglacial morphology in Tres Provincias and Agujas de Cardaño area	Area	Geomorphological
47	Granodiorite at Peña Prieta	Area	Petrological
48	Periglacial morphology at La Rasa Peak	Area	Geomorphological

Table 1 continued

	Geosite name	Typology	Main interest
49	Gustalapedra formation stratotype	Section	Stratigraphical
50	Murcia formation stratotype	Section	Stratigraphical
51	Grande river valley glacial morphology	Area	Geomorphological

List of geosites in Picos de Europa Regional Park and shown in the map of Figs. 7 and 8. Typology and primary interest are also indicated

- (1) Map of geosite intrinsic value (Fig. 9). In this map, geosites are arranged according to the value obtained when assessing the first group of variables. Sites are classified into three different groups: very high intrinsic value, high intrinsic value and medium intrinsic value (Table 2). Low intrinsic value is not used in this case because if a locality is included in the inventory, it is because it has some geological significance. In fact, from a possible maximum of 28 points in this section, there was no geosite with fewer than 16 points.

The map obtained establishes a hierarchy between the sites, separating those whose relevance is outstanding (very high intrinsic value) from the rest of geosites, which are also classified into two groups. Thus, this map is useful for establishing the priority for conservation, for the creation of georeserves and for the zoning of the protected area.

- (2) Map of geosite degradation risk (Fig. 10). In this map, geosites are organized into four classes using the notation obtained when evaluating the third collection of parameters: low degradation risk, medium degradation risk, high degradation risk and very high degradation risk (Table 3).

The map obtained shows which sites should be urgently protected (very high risk of degradation), which others are seriously threatened (high risk of degradation), which ones should be monitored and may require some correction or protection measures (medium risk of degradation) and those which are not gravely endangered (low risk of degradation).

Discussion and Conclusions

The need for detailed cartography focused on supporting an efficient geoheritage control and land planning is well known and unanimously accepted, as many reports stress this fact, for example, those by Gallego and Baretino (1997); Carton and others (2005); Reynard and Panizza (2005); Coratza and Regolini-Bissig (2009) and Erhartič (2010). Although recently, mapping is capturing a higher level of attention in geoheritage research (see, for example, the compilation of papers edited by Regolini-Bissig and Reynard 2010), a specific methodology for geosite mapping is still lacking.

Table 2 Categories of intrinsic value expressed in the map and the number of geosites included in each

Classes	Notation	Number of geosites
Medium	<20 points	17
High	21–24 points	20
Very high	25–28 points	14

Table 3 Categories of degradation risk expressed in the map and the number of geosites included in each

Classes	Notation	Number of geosites
Low	8–11	13
Medium	12–15	26
High	16–19	9
Very high	20–24	3

In this paper, a methodological proposal for geoheritage cartography is presented. Our mapping was specifically planned and designed to provide a useful tool for geoheritage management. The main difference between the present proposal and some recent studies of geoheritage mapping, i.e., those by Erhartič (2010) and Regolini-Bissig (2010), is that we do not maintain the same units of geological or geomorphological maps. We develop specific geoheritage units based mainly on the concept of geosite typology (Fuentes-Gutiérrez and Fernández-Martínez 2010). These units are drawn from the basis of the geological and geomorphological maps, but they contain additional information concerning geoconservation and environmental management.

Maps representing typology units show several advantages:

- (1) Basic maps constitute a visual and useful tool, which offers integrated synthetic information. In addition, they provide an overview of the principal peculiarities of geoheritage in an area.
- (2) Derived maps are a good way to summarize the ranking obtained during the assessment stage as they show geosites classified according to diagnostic parameters for decision making in management.

- (3) Both types of maps are synthetic and clear. Hence, they are easily interpretable by the different specialists that take part in geoheritage management. This point is very important, as many protected areas do not have geoscientists in their staff.

The integration of geoheritage in processes of land planning and environmental management has yet to be accomplished. The proposed maps allow the inclusion of geoheritage in these processes. Mapping geoheritage is especially important in protected areas, as it is essential for the prescriptive zoning of the territory and for the processes of impact assessment. On the other hand, any specific measure directed to geoheritage, such as geoconservation or geotourism, would entail the review of the thematic (geological and geomorphological) maps.

Lastly, the final utilization of the maps presented here would depend on the principles established by the geoheritage conservation law. Unfortunately, neither the region of Castilla y León nor Picos de Europa Regional Park have yet developed specific regulations in this field. We can only hope that, in the near future, lawmakers will lend further support to the proposals and results obtained in the myriad of papers about geoconservation that exist today.

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