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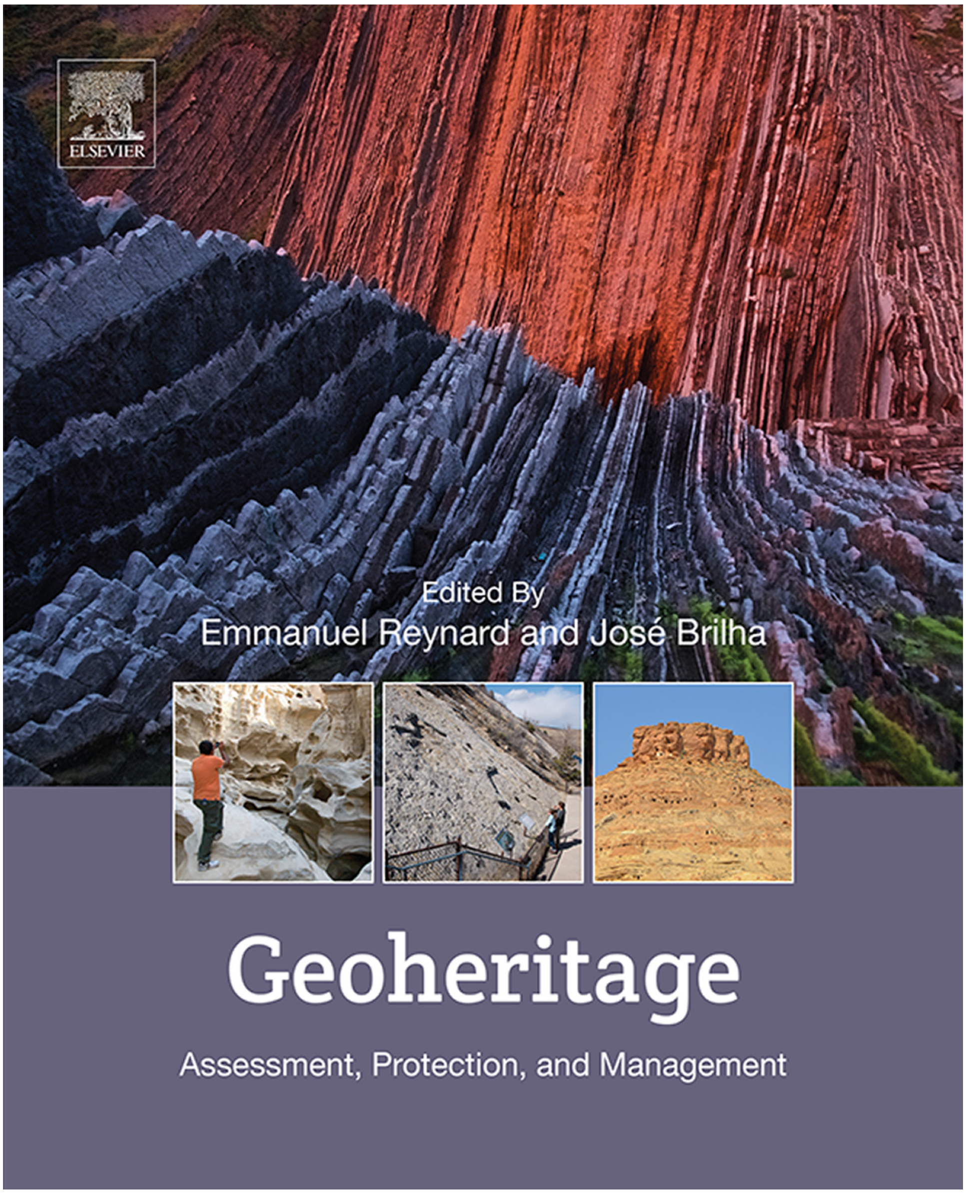

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CHAPTER 4

GEOHERITAGE: INVENTORIES AND EVALUATION

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The conservation of geological sites using a systematic and scientific background seems to have started in the United Kingdom in 1977, after the establishment of the Geological Conservation Review by the Nature Conservancy (Allen et al., 1987; Wimbledon, 1988). However, isolated efforts to protect geological localities were already happening in different countries from the 17th century (for a compilation of examples, see Gray, 2013; Larwood, 2016). A detailed description of more recent protection initiatives in most of the European countries was presented by Wimbledon and Smith-Meyer (2012). A similar analysis for Latin America countries was recently done by Palacio Prieto et al. (2016).

The protection of geological occurrences has always faced a big challenge: with so many rocks occurring all over the Earth's surface, which ones should be managed in order to be conserved for the benefit of present and future generations? How should outcrops be selected? Which criteria should be used in order to ensure that the chosen localities are really the ones that must be protected?

This chapter aims to give clear answers to these questions. It presents a general perspective about geoheritage, mainly focusing on concepts, terminology, and methods for its inventorying and assessment. It should be stated from the beginning that geoheritage, or geological heritage in its extended form, is materialised by exceptional elements of geodiversity, namely minerals, fossils, rocks, landforms and their landscapes, soils, and active geological and geomorphological processes. Thus, in this chapter, the word 'geology' and its derivatives include all Earth sciences domains (mineralogy, petrology, geomorphology, palaeontology, etc.).

This chapter is organised into three sections, each one addressing a particular issue that is especially relevant to an increasing number of newcomers that are becoming interested in geoheritage:

1. What makes an element of geodiversity exceptional?
2. How should the high value of geodiversity elements be identified and characterised?
3. How and why should geoheritage be assessed?

4.1 WHAT MAKES AN ELEMENT OF GEODIVERSITY EXCEPTIONAL?

When something is considered exceptional, typically what is really being appreciated is its high value. Geodiversity elements may have different types of values, starting from those more concrete like the economic, functional, scientific and educational, to the more intangible ones, such as the

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intrinsic or existence, cultural, and the aesthetic values (Gray, 2013). With the exclusion of the intrinsic or existence value, all other types of value are strongly associated with an anthropogenic vision of nature, particularly in what concerns the use we make of nature. This is what Gray (2013) and Gray et al. (2013) refer to as 'geosystem services', i.e., the benefits that society gains from geodiversity elements, including regulating, supporting, provisioning, cultural and knowledge services.

Hence, for a geodiversity element to be considered exceptional, a high value must be assigned to it (Table 4.1). When a geodiversity element is considered important for several types of values, it means that its overall exceptionality is higher. For instance, all types of values can be assigned to the typical landforms of the Uluṟu-Kata Tjuṯa National Park in Central Australia, apart from just the cultural one referred to in Table 4.1.

It is generally assumed by society that the main benefit obtained from geodiversity elements is limited to quarrying and mining of geological resources. This is the traditional understanding of what is the goal of geology, always associated with the exploitation of gold, coal, oil, etc. It is

Table 4.1 Examples of Locations Where Geodiversity Elements Have an Exceptional Value. *Ex Situ* Exemplars of Minerals, Fossils, and Rocks May Also Have All Types of Values, Except the Functional One

Value	Site/Location	Justification
Economic	Escondida Mine (Chile)	Chile is the top copper-producing country in the world. In 2015 this mine alone produced 1148 million metric tons comprising mostly copper concentrate, which generates important revenues for this country
Functional	Göreme National Park (Turkey)	The volcanic rocks of Cappadocia sculpted by erosion were used as dwellings, troglodyte villages and underground towns, which constitute the remains of a traditional human habitat dating back to the 4th century
Scientific	Basque Coast UNESCO Global Geopark (Spain)	The definition of two Global Boundary Stratotype Sections and Points (GSSPs, lower boundaries of the Selandian Stage and of the Thanetian Stage, both belonging to the Paleocene Series) turns the coastal cliffs of Zumaia into a place with global importance for geosciences
Educational	Terras de Cavaleiros UNESCO Global Geopark (Portugal)	The occurrence of a complete ophiolite sequence resulting from the obduction of Palaeothetys oceanic lithosphere over the Allochthonous Basal Complex attracts students from universities of different countries
Intrinsic	Volcanoes of Kamchatka (Russia)	Independently of human appreciation, this is one of the areas of higher density and diversity of active volcanoes on Earth
Cultural	Uluṟu-Kata Tjuṯa National Park (Australia)	The inselbergs of this park form an integral part of the traditional belief system of one of the oldest human societies in the world and it is considered a sacred place for the Anangu Aboriginal people
Aesthetic	Iguaçu National Park (Argentina/Brazil)	One of the world's largest and most impressive waterfalls extending over some 2700 m, attracting about 1.5 million visitors each year to enjoy the natural beauty of the site

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unquestionable that our complete dependence on geological resources to maintain the growing consumption of all sorts of products justifies the economic value of rocks and minerals.

However, many geoscientists around the world are trying to demonstrate that there is another way for geodiversity elements to be exploited by society, without the need to open a quarry, a mine or a borehole. In fact, based on their values, geodiversity elements may be used in a nonextractable sustainable way by different users/beneficiaries (Table 4.2). What kind of activities can be supported?

Firstly, a scientific use carried out by geoscientists to produce meaningful scientific knowledge of how the geosphere works and interacts with other Earth systems (biosphere, hydrosphere and atmosphere). This knowledge ensures the continuous advancement of geosciences with clear benefits for a growing human population that wishes to live safely and healthily. It is considered that a site has scientific value when the research done directly at that location or using samples collected from it has produced significant scientific understanding to allow the advancement of geosciences nationally and internationally (Brilha, 2016). In addition, sites that were relevant for the history of geosciences at the national and international levels may also be considered to have scientific value.

Secondly, an educational use can be applied by geoscience teachers in order to give students a solid knowledge about how planet Earth changes through time. This type of use is also related to the training of new generations of geoscientists.

Finally, certain geodiversity elements may justify a distinct form of economic use based on geotourism and leisure, which is a type of sustainable tourism aimed at the environmental and cultural interpretation of a region, with clear benefits and profits for local communities.

Table 4.2 Examples of Uses of Geodiversity Elements, Besides the Traditional Exploitation of Geological Resources. Each Type of Use Carried Out by Direct Users/Beneficiaries Is Based on Geodiversity Values

Uses of Geodiversity Elements	Users/Beneficiaries	Values
Scientific	• Geoscientists • Social scientists (archaeologists, ethnographers. . .)	Scientific Cultural
Educational (formal and informal)	• Students and teachers of different domains are direct users of formal educational activities. • Informal educational actions are addressed to the general public. In both cases, tourism companies, guides, restaurant and hotel industries, handicraft companies, local cooperatives, rental bus and rent-a-car companies may obtain economic benefits.	Educational (geosciences, social and cultural sciences, etc.) Cultural Economic (indirectly)
Geotourism and recreation	• Nature tourism companies, guides, restaurant and hotel industries, handicraft companies, local cooperatives, rental bus and rent-a-car companies, etc.	Economic Aesthetic Cultural

The scientific and educational use is not restricted to geosciences as it may be also applied to other disciplines.

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The *in situ* occurrence of geodiversity elements with high scientific, educational, aesthetic, and cultural value is usually known as 'geosite' — or 'geomorphosite' if the valued element has a geomorphological nature (Reynard, 2005). Used as a synonym, the term 'geotope' (Grandgirard, 1999a) is more common in German-speaking countries. However, 'geotope' in Nordic countries has a different meaning being applied to sites that have not been designed with a value, parallel to the neutral biological term 'biotope' (Erikstad et al., 2017). In the literature, other terms with similar meanings to geosite can be found, such as geological (or geo) monument, site (or point) of geological interest, or geological site.

Considering that:

1. most of these values are subjective and consequently difficult to evaluate with precision;
2. in most countries, there are very few sites properly protected and managed but instead there are inventories being done with hundreds or thousands of sites with different levels of relevance, making them very difficult to be effectively conserved and managed;
3. National and international scientific sites are crucial for geosciences but still lack international agreements or conventions.

Brilha (2016) has proposed to restrict the use of the term 'geosite' only to the occurrences with scientific value, in order not to trivialize the use of this term (Figs. 4.1 and 4.2). In fact, as there are site inventories being made at different scales — international (between countries), national (inside one country), regional (in particular areas of a country like a state, a county or a

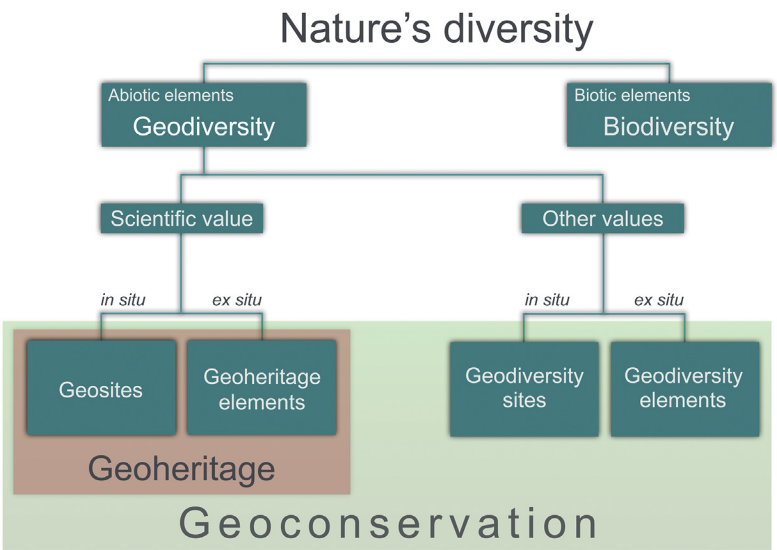

FIGURE 4.1

Conceptual relations between nature's diversity, biodiversity, geodiversity, geoheritage, and geoconservation. Valued geodiversity elements should be managed by the implementation of geoconservation strategies.

Modified from Brilha (2016).

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FIGURE 4.2

Examples of a ‘geosite’, a ‘geodiversity site’ and ‘*ex situ* geodiversity elements’ (see. Fig. 4.1). Photographs by J. Brilha. (A) The Kīlauea’s summit caldera and Halemaʻumaʻu crater (Hawaiʻi island, USA) is a geosite with international scientific value. In addition, it has also high educational, cultural, and aesthetic values, justified by the almost 2 million visitors in 2015. (B) Outcrop of Neoproterozoic stromatolites near the town of Morro do Chapéu (Bahia, Brazil), a geosite with no other relevant value, besides the scientific one. (C) Geodiversity site in Southern Jordan visited by tourists due to the aesthetic value of this landform, just one among hundreds of others not very different, occurring in the same area. (D) *Ex situ* geodiversity elements with cultural and educational values in the Merrion Square gardens (Dublin, Ireland), where a curious selection of rocks was used to erect a sculpture representing Oscar Wilde. The jacket is carved from nephrite jade, the pink collar and cuffs are of thulite, the trousers are of larvikite and the shoes and socks are of Black Indian Granite (Stillman, 1999).

municipality), and local (in a protected area or in a geopark) — the number of sites may easily reach several thousands for just one country. This exaggerated number of sites may give the authorities the impression that a geosite is not rare or special and therefore there is no need to implement special management actions.

However, some geoscientists disagree with this perspective and claim that the use of the term ‘geosite’ even applied to a site of local relevance is the only way to attract people’s attention. Brilha (2016) has also proposed to restrict the term ‘geological heritage’ or ‘geoheritage’ to *in situ* and *ex situ* elements with scientific value (Fig. 4.1). For sites with no scientific value, this author has proposed the term ‘geodiversity site’ (Fig. 4.2). ‘Geodiversity site’ means a location where one or more geodiversity elements have a particular value(s) (except the scientific one) but not

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necessarily a location characterised by a variety of elements, as the term might suggest in the first place. However, it must be underlined that Brilha's proposals for a more restrictive use of terms is under discussion in the geoconservationist community and is not presently widely accepted.

To conclude the discussion related to the first question, independently of the terminology, the main scope of geoconservation is the management of sites and *ex situ* valued geodiversity elements by means of specific inventory, evaluation, conservation, valuing, and monitoring procedures (Brilha, 2015; Henriques et al., 2011). This is what all geoconservationists work for and aspire to have implemented in all nature conservation and land-use planning policies.

4.2 HOW SHOULD THE HIGH VALUE OF GEODIVERSITY ELEMENTS BE IDENTIFIED AND CHARACTERISED?

Now that we have understood that among the whole geodiversity of the Earth's surface, there are a limited number of elements with one or more high value(s), we must define how these special geodiversity elements may be identified and selected for protection, as many of them are rare and at risk of deterioration or destruction.

The key answer to this challenge is to implement a well-structured systematic inventory to cover all the area under study, supported by clear criteria well-adapted to each type of value, in order to allow an unbiased selection of sites with the lowest degree of subjectivity possible. Therefore, we present a kind of 'road map' to help the development of site inventories (Table 4.3).

Table 4.3 Sequential Tasks to Produce a Systematic Site Inventory Taking Into Account the Scientific, Educational, and Geotourism/Recreational Uses

Scientific Use	Educational Use	Geotourism/Recreational Use
Define the topic, the value, the scale, and the aim of the inventory		
Geological literature review Consulting with experts that have worked in the area before		
Eventual definition of geological frameworks	Review of sites used in educational activities	Review of touristic advertisement materials
List of potential sites Fieldwork aiming at the identification of new sites and the qualitative assessment of each site in the list of potential sites, based on the following selection criteria:		
• Representativeness • Integrity • Rarity • Scientific knowledge	• Didactic potential • Variety of geological elements • Accessibility • Safety	• Scenery • Interpretative potential • Accessibility • Safety
Final list of sites with complete characterisation[a]		

[a]*If the inventory of sites for scientific use is made using the geological frameworks method (Wimbledon et al., 1999), these final lists of sites should be prepared for each framework.*
Modified from Brilha (2016).

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There are many published works about inventorying methods (e.g., Alexandrowicz and Kozlowski, 1999; Díaz-Martínez and Díez-Herrero, 2011; Fuertes-Gutiérrez and Fernández-Martínez, 2010; García-Cortés and Carcavilla Urquí, 2009; Grandgirard, 1999b; JNCC, 1977; Lapo et al., 1993; Parkes and Morris, 1999; Pereira and Pereira, 2010; Pereira et al., 2007; Reynard and Coratza, 2013; Reynard et al., 2007, 2016; Sellier, 2016; White and Mitchell, 2006; Wimbledon, 2011; Wimbledon et al., 1995, 1999). In general, all methods are based on a set of criteria that intend to reduce the subjectivity, always associated with the selection procedure of natural objects. For instance, between two outcrops with similar rocks and fossils, which one should be included in the inventory, as it is pointless to add to the inventory multiple sites with repetition of the main geological element?

The method presented here is basically the one published by Brilha (2016), which was produced taking into account the best practices of other methods and the author's experience (Table 4.3). It should be underlined that the procedure exposed here is adapted to identify and characterise the high value of *in situ* geodiversity elements.

There are four main pillars that support a good inventory (Lima et al., 2010): the topic, the value, the scale and the aim. The topic is the subject or theme to be inventoried, for instance the whole geological heritage, just a partial component of it, like the palaeontological or the geomorphological heritage, a specific geological framework, etc. Each inventory should be built taking into consideration which main value must be assigned to the geodiversity elements that are going to be selected. As mentioned above (Table 4.2), the value is closely related to the potential use of sites, essentially the scientific, educational, and/or geotouristic/recreational use. The scale concerns the size of the area where the inventorying will take place (a protected area, a geopark, a municipality, a state, a country, a continent, etc.). Finally, the aim of the inventory is related to its final purpose, which may consist of a national geoconservation strategy, a geotouristic project, an educational programme, etc.

It should be emphasised that while the inventories of sites for scientific use are usually done in large areas (a country or state, in case of federal countries), the inventories regarding sites with other types of uses are typically made in small areas (a protected area, geopark, a municipality, etc.).

The next step of a systematic site inventory is the preparation of a list of potential sites (Table 4.3). This list is based on published data and on the opinion of experts that have worked in the area of the inventory. The review of scientific papers, Master's and PhD theses, and guidebooks of scientific fieldtrips is highly recommended in order to build a list of potential sites. If the aim is to select sites for scientific use, this review should be focused on specific locations that are described in the literature for their geological relevance (particularly good exposures, sites where samples were collected that allowed the numerical dating of rocks, outcrops with remarkable fossil content, etc.). In addition, it might be useful to adopt the method based on the definition of geological frameworks. This method was developed in Europe during the 1980s, mainly through the action of ProGEO – The European Association for the Conservation of the Geological Heritage (Erikstad, 2008; Wimbledon, 2011; Wimbledon et al., 1999, and references therein). Geological frameworks are main themes related to geoscience materials and/or processes that allow a better understanding of the geological history of the area where the site inventory is being performed (e.g., 'Geology and metallogenesis of the Iberian Pyrite Belt' or 'Neogene ultrapotassic volcanism'). Geological frameworks should represent the main chapters of the Earth's history that left evidence in the area under study. These frameworks may not have geographical continuity within the area and they can

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also exist in contiguous territories, i.e., they may not be exclusive to the area under analysis. The larger the area of the inventory, the more appropriate is the use of this method for the inventory of sites with scientific value. Hence, this method has been used for national inventories in many European countries (Wimbledon and Smith-Meyer, 2012) and was applied for the first time in Latin America in the inventory of the São Paulo State in Brazil (Garcia et al., 2017). Representative geosites of each geological framework should be included in the respective list of potential geosites (a list for each framework should be prepared separately).

To produce a list of sites with potential educational use it is recommended to get the opinion of teachers that organise field classes with students in the area of the inventory, together with the reading of literature related to geoscience education with a focus on the same geographical area.

For the list of sites with potential geotourism/recreational use it is advisable to review touristic advertisement materials of the area. Quite often, these touristic leaflets, webpages, brochures, and guides use certain nature landmarks that are in fact geodiversity elements with high aesthetic value, even if tourism managers are not fully aware of this.

When the list of potential sites is concluded, it is necessary to convert it into the definitive list of sites. In order to establish the final list, it is necessary to carry out fieldwork with two main goals: to confirm each potential site of the list and to eventually identify new sites. In order for a site to be listed as definitive, it is necessary that its value is well justified taking into account four qualitative criteria per type of use (Table 4.3).

Hence, for sites with potential scientific use, the following four criteria should be applied:

1. **Representativeness**: concerning the appropriateness of the site to illustrate a geological process or feature that brings a meaningful contribution to the understanding of the geological topic, process, feature or geological framework.
2. **Integrity**: related to the present conservation status of the site, taking into account both natural processes and human actions.
3. **Rarity**: number of sites in the study area presenting similar geological features;
4. **Scientific knowledge**: based on the existence of scientific data already published about the site.

Therefore, sites suitable for scientific use should be the best ones in the area concerning their capacity to illustrate geological processes or features, which are important to allow the advancement of geosciences. They should also be in the best possible conservation status and have some characteristics that differentiate them from other sites with similar geological features. The scientific relevance of a site is also attested if there are national and international publications directly related to its geological value.

The selection of sites suitable for educational use should be supported using the following four criteria:

1. **Didactic potential**: related to the capacity of a geological feature to be easily understood by students of different educational levels (primary and secondary schools, universities).
2. **Variety of geological elements**: number of different types of geodiversity elements present in the same site.
3. **Accessibility**: conditions of access to the site in terms of difficulty and time spent on foot for ordinary students.
4. **Safety**: related to the visiting conditions, taking into consideration minimum risk for students.

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These four criteria contribute to the sound selection of safe sites with good accessibility and with geological features that will be easily understood by students and, in preference, with several types of geodiversity elements occurring together in the same site.

Finally, the selection of sites suitable for geotouristic/recreational use should be based on the next four criteria:

1. **Scenery**: associated with the visual beauty of the geological occurrence (landscape or outcrop).
2. **Interpretative potential**: related to the capacity of a geological feature to be easily understood by lay people.
3. **Accessibility**: conditions of access to the site in terms of difficulty and time of the walk for the general public.
4. **Safety**: related to the visiting conditions, taking into consideration minimum risk for visitors.

These criteria allow the selection of safe sites with good accessibility, high aesthetic value and geological features that can be easily interpreted by lay people with no geological background.

All necessary information in order to have a full characterisation of each site should be collected during the fieldwork stage, including photographic coverage from different perspectives and at different scales, and the geographical delimitation using a high-precision GPS receiver (particularly necessary for sites with metric scale).

4.3 WHY AND HOW SHOULD GEOHERITAGE BE ASSESSED?

For inventories in large areas and with dozens of sites, the numerical assessment of sites is an important step to support subsequent stages of a geoconservation strategy. It should be noted that this assessment is not needed for inventories in small areas with a low number of sites.

The results of the numerical assessment are an important tool to support a proper site management that is a crucial step of any geoconservation action plan (Prosser et al., 2018) or geotourism development (Newsome and Dowling, 2018). The numerical evaluation of the sites' capacity to support scientific, educational, and geotourism/recreational uses, together with the sites' degradation risk, is vital to allow managers to define priorities. Obviously, sites with high potentiality for a certain type of use and with a high degradation risk should have a higher priority in the management planning.

The aim of a quantitative assessment is to decrease the subjectivity associated with any evaluation procedure, particularly when among dozens or hundreds of sites, managers need to decide in which sites their (usually limited) resources should be applied.

In spite of many published methods about the numerical assessment of sites, so far there is no general accepted method. Usually, quantitative methods are based on several criteria and respective indicators to which different scores or parameters may be assigned (e.g., Bollati et al., 2013; Bruschi and Cendrero, 2005, 2009; Bruschi et al., 2011; Cendrero, 1996a,b; Coratza and Giusti, 2005; Erhartic, 2010; Fassoulas et al., 2012; Pereira and Pereira, 2010, 2012; Pereira et al., 2007; Pralong and Reynard, 2005; Reynard, 2009; Reynard et al., 2007; Vujičić et al., 2011; Zouros, 2007). The method presented next is essentially the one proposed by Brilha (2016), which should

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Table 4.4 The Final Lists of Sorted Sites Are Based on Criteria Applied for the Quantitative Assessment of Sites' Capacities to Support Scientific, Educational, and Geotourism/Recreational Uses, as Well as of the Sites' Degradation Risks

<table>
<tr><th>Scientific Use</th><th>Educational Use</th><th>Geotourism/Recreational Use</th></tr>
<tr><td>Quantitative assessment of the sites' capacities to support scientific use based on the following criteria:
• Representativeness
• Key locality
• Scientific knowledge
• Integrity
• Variety of geological elements
• Rarity
• Use limitations</td><td>Quantitative assessment of the sites' capacities to support educational use based on the following criteria:
• Vulnerability
• Accessibility
• Use limitations
• Safety
• Logistics
• Density of population
• Association with other values
• Scenery
• Uniqueness
• Observation conditions
• Didactic potential
• Variety of geological elements</td><td>Quantitative assessment of the sites' capacities to support geotourism/recreational use based on the following criteria:
• Vulnerability
• Accessibility
• Use limitations
• Safety
• Logistics
• Density of population
• Association with other values
• Scenery
• Uniqueness
• Observation conditions
• Outreach potential
• Economic level
• Proximity of recreational areas</td></tr>
<tr><td colspan="3">Quantitative assessment of the sites' degradation risks based on the following criteria:
• Deterioration of geological elements
• Proximity to areas/activities with potential to cause degradation
• Legal protection
• Accessibility
• Density of population</td></tr>
<tr><td>Final list of sites sorted by the capacity to support scientific use and degradation risk[a]</td><td>Final list of sites sorted by the capacity to support educational use and degradation risk</td><td>Final list of sites sorted by the capacity to support geotourism/recreational use and degradation risk</td></tr>
<tr><td colspan="3">[a]If the inventory was made using the geological frameworks method, final lists should be prepared for each framework.
Modified from Brilha (2016).</td></tr>
</table>

be considered as an example that has resulted from a survey and compilation of the best practices and of the author's own experience.

Similar to the sites selection procedure (Table 4.3), the numerical assessment is also based on some criteria (Table 4.4). Each criterion is characterised by several indicators and each indicator is scored with a numerical parameter. The final score of the potential use and degradation risk for each site is a weighted sum of the several criteria. More details about the evaluation process are available in Brilha (2016). It is important to remark that it is mandatory to make a final reflection about the results of the sites' quantitative assessments. As there are no infallible criteria and totally objective indicators, the coordinator of the site inventory must undertake a discussion about the coherence of the final scores. The key question is: knowing all the sites of the inventory, do the final scores make total sense?

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Table 4.5 Criteria Used for the Quantitative Assessment of the Geosites' Capacity to Support Scientific Use and Respective Weight for the Calculation of the Final Score	
Representativeness – capacity of a geosite to illustrate geological elements or processes (related to the geological framework under consideration when applicable)	**30%**
Key locality – importance of a geosite as a reference or model for stratigraphy, palaeontology, mineralogy, etc.	**20%**
Scientific knowledge – the existence of published scientific studies about the geosite (related to the geological framework under consideration when applicable) reflects the scientific value given by the geoscientific community	**5%**
Integrity – related to the conservation status of the main geological elements (related to the geological framework under consideration when applicable); the better the integrity, the higher the scientific value	**15%**
Variety of geological elements – a high number of different geological elements with scientific interest (related to the geological framework under consideration when applicable) in a geosite implies a higher value	**5%**
Rarity – a small number of similar geosites in the study area (representing the geological framework under consideration when applicable) increases the scientific value	**15%**
Use limitations – the existence of obstacles that may be problematic for the regular scientific use of the geosite has impacts on its scientific value	**10%**
See Brilha (2016) for details about indicators and parameters.	

The criteria for the quantitative assessment of the geosites' capacities to support scientific use are presented in Table 4.5. A geosite has a maximum potential to be used for scientific purposes when it is the best representative occurrence of a certain geological feature or geological framework (if applicable), a rare well-known international reference with publications about it, and when it presents several well-conserved geological features with scientific relevance that are easily available for future research.

The assessment of the geosites' capacities to support educational and geotourism/recreational uses (Table 4.6) is based on the same procedure applied to evaluating the scientific use (Table 4.5). Twelve criteria are proposed to assess the sites' potentials to support educational activities and 13 for geotourism/recreational activities (Table 4.6). The first 10 criteria are the same for both types of uses, the only difference being the weight of some of the criteria used to calculate the final score. For instance, the criterion 'scenery' has a weight of 5% in the final score of the educational use and 15% in the score regarding the geotourism/recreational use. This difference is justified by the higher relevance of the aesthetic value for tourism activities than for educational ones.

The calculation of a geosite's degradation risk is of paramount importance for the preparation and implementation of a site management plan. The degradation risk is a combination of two components known as fragility (risk provoked by natural causes) and vulnerability (risk provoked by anthropic causes), according to the definitions of Fuertes-Gutiérrez and Fernández-Martínez (2010, 2012). The procedure for the numerical assessment of the degradation risk (Table 4.7) is similar to the above-mentioned procedure, and was proposed by Brilha (2016), based on the best practices published in recent years, including Carcavilla et al. (2007), Cendrero (1996a,b),

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Table 4.6 Criteria Used for the Quantitative Assessment of Geosites' Capacities to Support Educational and Geotourism/Recreational Uses and Respective Weight for the Determination of the Final Score

	A	B
Vulnerability – existence of geological elements that can be destroyed by students or visitors	10%	10%
Accessibility – the easier and shorter the walk between the means of transportation and the site is, the higher the site's potential use	10%	10%
Use limitations – existence of obstacles that may be problematic for the development of educative or touristic activities	5%	5%
Safety – when the field activity can be carried out under low risk conditions for students and visitors, the site's potential use increases	10%	10%
Logistics – existence of facilities to receive students and visitors, such as accommodation, food and toilets	5%	5%
Density of population – existence of a population near the site potentially provides students and visitors who will use the site	5%	5%
Association with other values – the existence of other natural or cultural elements associated with the site may justify interdisciplinary fieldtrips and attract visitors	5%	5%
Scenery – represents the beauty of the geological elements that could stimulate students' and visitors' interest for the site	5%	15%
Uniqueness – concerns the distinctiveness and the rarity of the geodiversity element that could promote students' interest for the site and attract visitors	5%	10%
Observation conditions – the better the conditions for observation of all the geodiversity elements on the site, the higher its potential use	10%	5%
Didactic potential – the use of the site by students of different education levels increases its potential use	20%	–
Variety of geological elements – a high number of different geological elements with didactic potential increases its potential use	10%	–
Outreach potential – related to the capacity of a geodiversity feature to be easily understood by people with no geological background	–	10%
Economic level – the high level of income of people living near the site suggests a higher probability of it being visited	–	5%
Proximity of recreational areas – a touristic visit to a site may benefit from the existence of well-known tourist attractions in the surrounding area	–	5%

A, *educational use;* B, *geotourism/recreational use. See* Brilha (2016) *for details about indicators and parameters.*

Fassoulas et al. (2012), García-Cortés and Carcavilla Urquí (2009), Lima et al. (2010), Pereira and Pereira (2010) and Reynard et al. (2007).

A site has a maximum degradation risk when its main geological elements have a high probability of being damaged either by natural or anthropic factors, when the site is not under legal

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Table 4.7 Criteria Used for the Quantitative Assessment of Sites' Degradation Risk and Respective Weight for the Calculation of the Final Score	
Deterioration of geological elements – reflects the possibility of loss of geological elements in the site as a consequence of: (1) its fragility, namely its intrinsic characteristics (size of the geological element, ease of obtaining samples, resistance of the rock, etc.) and natural actions (sensitivity to erosion, intensity of erosional agents, etc.) and (2) its vulnerability to anthropic actions (tourism, agriculture, urban development, vandalism, etc.)	**35%**
Proximity to areas/activities with potential to cause degradation – mining, industrial facilities, recreational areas, roads, urban areas, etc.	**20%**
Legal protection – related to the location of the site in an area with any type of legal protection (direct or indirect). Access control refers to the existence of obstacles, such as: restrictions by the owner, fences, need to pay entrance fees, mining activities	**20%**
Accessibility – reflects the conditions of access to the site for the general public (not considering disabled people). A site with easy access is more likely to be damaged by visitors' misuse than one with difficult access	**15%**
Density of population – reveals the number of persons that live near the site and that can cause potential deterioration due to inappropriate use (vandalism, theft, etc.)	**10%**
See Brilha (2016) for details about indicators and parameters.	

protection, and when it is located near a potentially harmful activity or area with a high density of population.

When the inventory and final assessment of all sites is concluded, the scientific team that has coordinated all these tasks can deliver the results to the authorities that have the legal competence to implement geoconservation strategies in the area. With this information and data, managers and administrators can define priorities and take the wisest decisions.

The assessment of *ex situ* geodiversity elements with heritage value is not considered in this chapter. Due to specific characteristics of *ex situ* geoheritage De Wever and Guiraud, 2018, other approaches can be implemented, such as those presented by Henriques and Pena dos Reis (2015).

4.4 FINAL REMARKS

Among the abiotic diversity of the Earth's crust, to choose which rocks should be protected from natural and anthropic threats is always a delicate mission for geoscientists. Associated with this difficult task is another that requires an extra effort from geoscientists: to explain to society why scarce public resources should be invested in the protection of rocks.

This chapter tries to help geoscientists to fulfil the first task. As only the very special geodiversity elements should be protected and managed, particular attention should be paid in order to apply the most objective and accurate methods to select these occurrences. A site inventory should not be the result of an individual choice, very often controlled by personal emotions, but rather the outcome of a systematic method using proper criteria and with the participation of the geoscientific community.

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It is true that site inventories can be made at different scales, from the continental scale to a small protected area of just a few hectares. However, independently of scale, the coordinator of a site inventory should always have in mind the four pillars that sustain a solid inventory: the topic, the value, the scale, and the aim. A preliminary reflection on these four pillars is essential in deciding which are the appropriate criteria that guarantee the correct selection of sites. No inventory should leave behind important sites nor include irrelevant ones.

The quantitative assessment of the sites' capacities to support certain types of use and of the sites' degradation risks, particularly necessary for small-scale inventories (large areas) with dozens or hundreds of sites, is a very good tool to help manage decisions. To have a clear idea, for each site, of what is the most appropriate use for it and what is the risk of degradation, is an excellent contribution geoscientists can deliver to nature conservation managers. When educational and geotouristic/recreational uses are planned, carrying capacity data should also be provided to site managers, which is another type of information not covered in this chapter.

The numerical assessment method presented here is of course a proposal, and some of the criteria/indicators/parameters can be adapted to particular local circumstances. Furthermore, it is always necessary that the inventory coordinator makes a detailed reflection about the results of the quantitative assessment. The method is not fully infallible and for this reason people should not be deceived by a numerical final score, i.e., just apparently, objective and unquestionable.

This chapter covers the first steps of a geoconservation strategy: the inventory and assessment of sites. Considerations about site delimitation and mapping, and the cartographic representation of geoheritage are also relevant and directly associated with these steps, for which the following references are recommended: Carton et al. (2005), Coratza and Regolini-Bissig (2009), Fuertes-Gutiérrez and Fernández-Martínez (2012), Lozano et al. (2011), Martin et al. (2014), Reynard et al. (2016) and Rocha and Brilha (2016). The proper management of geosites and geodiversity sites implies not only a correct characterisation of sites, but also their geographic delimitation because this aspect is fundamental to establishing property regimes and the type of legal setting that may be applicable in each case.

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