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ORIGINAL ARTICLE

Integrated Approach for the Inventory and Management of Geomorphological Heritage at the Regional Scale

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Abstract Due to the renewed interest for sites of geological interest, both in nature conservation and tourist sectors, numerous regional and national geosite inventories have been carried out in several countries during the last two decades. Several research groups discussed methodological issues, in particular concerning the assessment, and proposed various assessment methods. The University of Lausanne developed a method for assessing the scientific and additional values of geomorphosites in 2007. The method was widely used in regional inventories in Switzerland and abroad. This paper presents a new version of the method and discusses four main issues: (1) the assessment methodology is included in a larger process, from the selection of potential geomorphosites to their use and evaluation by stakeholders; (2) a particular attention is put on the selection of potential geomorphosites that will then be assessed and a simple approach crossing a spatial selection (the selected geomorphosites should be representative of the regional geomorphological processes) and a temporal one (the selected geomorphosites should cover the whole temporal stages of the regional morphogenesis, with both relict and active landforms) is proposed; (3) a new part is added in the assessment method; it concerns the use characteristics and fills a gap in the existing method; (4) finally, the paper discusses mapping and representation issues: specific maps are produced at two levels: simple geomorphological maps accompany the assessment of each geomorphosite and synthetic maps, covering the whole study area, are produced for the communication of results to stakeholders. For this, four types of representation (qualitative, univariate, bivariate, multivariate) are proposed. The method is illustrated by three examples of inventories carried out in Western Switzerland and Haute-Savoie (France).

Keywords Geoheritage · Geomorphosites · Inventories

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Introduction

For the last 30 years, there has been a renewed interest for geological heritage, its assessment, protection and promotion, in various parts of the world (Collectif 1994; O'Halloran et al. 1994, Sharples 2002; Gray 2004; Brilha 2005; Reynard et al. 2009; 2011). Several countries have carried out national geosite inventories as a basis for their geoconservation policy. The UK has had a geosite inventory since the 1950s and more than 3000 sites are now protected as Sites of Special Scientific Interest (Wimbledon et al. 1995). Spain also carried out a national inventory at the end of the 1970s, which allowed the selection of 144 geosites of national and international interest (Durán Valsero et al. 2005; Carcavilla Urquí et al. 2007). Switzerland inventoried its geoheritage in the 1990s (SAS 1999) and revised this inventory recently, recognising 322 geosites of national importance (Reynard 2012). Several other countries, especially in Europe, realised geoheritage inventories at a national level. Nevertheless, at the World scale, very few countries have completed a national inventory to date (see http://geoheritage-iugs.mnhn.fr/, accessed 16/12/2014).

Various international associations also developed guidelines for inventorying and managing geoheritage. This is the case of ProGeo—The European Association for the Conservation of the Geological Heritage (ProGeo 2011) or the Global geosites inventory (Wimbledon 1996; Wimbledon et al.

1999), launched by the International Union of Geological Sciences (IUGS), but unfortunately interrupted in 2003. IUGS also formed a Geoheritage Task Group (GTG) in 2010, whose aim is to assist IUGS with geoheritage and geoconservation issues. Also the International Association of Geomorphologists (IAG) formed a specific working group on Geomorphosites in 2001 (Reynard and Coratza 2013), which deals with geomorphological heritage issues, in particular methodological ones. More in general, the World Heritage Convention, signed in 1972, allowed the classification of more than 180 geological sites (Migon 2009), and the Geoparks initiative (Zouros 2004; McKeever and Zouros 2005), which started in 2000, allowed a better knowledge and evaluation of geoheritage at the regional scale.

All these initiatives have led to a reflection on methodological issues (e.g. Grandgirard 1999; Bruschi and Cendrero 2005; 2009; Pena dos Reis and Henriques 2009; Reynard 2009; Giusti and Calvet 2010; Pereira and Pereira 2010; de Lima et al. 2010; Kubalíková 2013; Reynard and Coratza 2013; Brilha 2015) and to the development of numerous methods for the selection and the evaluation of geosites or geomorphosites (Rivas et al. 1997; Grandgirard 1999; Bonachea et al. 2005; Coratza and Giusti 2005; Pralong 2005; Serrano and González Trueba 2005; Reynard et al. 2007; Pereira et al. 2007; Zouros 2007; Feuillet and Sourp 2010; Comănescu et al. 2012; Brilha 2015). Grandgirard (1999) stressed the importance of clearly defining the objective of an inventory. The assessment methodology and criteria highly depend on the aim of the evaluation that can be a regional or large-scale inventory of natural assets, an environmental impact assessment (EIA) procedure or an inventory aimed at the (geo)tourism development (Reynard 2008).

De Lima et al. (2010) proposed to take into account four issues when carrying out an inventory: the topic (which kind of heritage is assessed), the value (related to the potential uses of the sites), the scale, and the use (=the aim). Bruschi and Cendrero (2005; 2009) insisted on the subjectivity issue. To avoid an overly subjective selection of geosites, they propose identifying particular characteristics of geosites that can be described and measured with sufficient objectivity and then assessed using transparent criteria. Based on the comparison of five assessment methods, Reynard (2009) proposed some guidelines for geomorphosite inventories: (1) the choice between an evaluation by experts and a numerical assessment should be guided by the aim of the inventory and external factors such as time, finances or available scientific competences; (2) except for EIA procedures, where only the scientific characteristics are evaluated, in other contexts (regional or national natural asset inventories, inventories carried out as a basis for geoheritage popularisation), not only the scientific value of geosites should be assessed but also the so-called additional values (Reynard 2005a); (3) the numerical assessment is only a part of a larger process including the study of the geology and geomorphology of the area considered for the inventory, the selection of potential geomorphosites, the numerical assessment, as well as proposals for management (promotion, protection); (4) the assessment should include indications concerning the potential for use as well as the threats and needs for protection; (5) a specific attention should be dedicated to the representations of the results.

Brilha et al. (2005), Pereira et al. (2007) and de Lima et al. (2010) stressed the need to determine the principal geological frameworks prior to the evaluation process, especially for procedures concerning large areas such as national inventories. These geological frameworks can easily organise the collection of geological data necessary for the inventory. They can be determined based on Earth sciences domains (palaeontology, mineralogy, geomorphology, etc.), time (geological periods) or the main regional geological subdivisions of a country (de Lima et al. 2010). Finally, Brilha (2015) proposed distinguishing geosites (for which only the scientific value is assessed) and geodiversity sites (for which other values can be assessed, depending on the potential use of the sites).

One of the numerous assessment methods was developed at the University of Lausanne (UNIL) (Reynard et al. 2007). Reynard (2009), Erhartič (2010), Comănescu et al. (2012) and Kubalíková (2013) compared this method with others. The method, which was targeted at students working on geomorphological heritage inventories at a regional scale, was developed with the aim of being easy to apply. It makes use of a card divided into six parts: general data (code, location, type, property), descriptive data (description of the forms and analysis of the morphogenesis), assessment of the scientific value (with four criteria: integrity, rarity, representativeness, palaeogeographic value), assessment of four additional values (ecological, aesthetic, cultural and economic value), synthesis (global value, educational interest, threats and management measures) and references. Each value is assessed both in a qualitative and a numerical way. The method was specifically developed for the evaluation of the geomorphological heritage (geomorphosites, in the sense of Panizza (2001) and Reynard et al. (2009)), but it can also be applied to the assessment of other types of geosites with some adaptations.

The method was used in several regional studies in Switzerland, mostly carried out within Master's theses at the University of Lausanne (Kozlik 2006; Duhem 2008; Genoud 2008; Pagano 2008; Perret 2008; Maillard 2009; Maillard and Reynard 2011; Perret and Reynard 2011; Kozlik and Reynard 2013) and was also applied, with some adaptations, in regional studies in Québec (Massé et al. 2011; Vigneault et al. 2011), Romania, Malta (Coratza et al. 2012) and Morocco (Boukhallad and El Khalki 2014). These studies demonstrated some of the strengths of the method such as its ease of use, the transparency of the criteria used, the importance of the cards filled for each site and that represent a wealth of information about the evaluated geosites, the possibility of assessing both in a qualitative and a numerical mode and the possibility of adapting the method to the regional context (Massé et al. 2011; Vigneault et al. 2011). They also stressed some weaknesses:

- a lack of transparency in the pre-selection of sites that will be evaluated;
- a lack of scale or precise indicators (e.g. in classes like in the methods proposed by Pralong (2005) or Pereira et al. (2007)) for the evaluation according to the various criteria;
- the fact that the palaeogeographic value discriminates sites developed recently and that, therefore, have a low value in terms of possibilities for reconstructing the palaeogeography of the studied area;
- the difficulty to assess the additional values (cultural and ecological value) without the help of specialists of other disciplines than geosciences;
- the difficulty to assess the aesthetic value (subjectivity);
- the impossibility of assessing the aesthetic value of endokarstic geosites (criteria such as viewpoints are not adapted in this case) (Perret, 2008);
- the ambivalence of the criteria “protected site” for the evaluation of the ecological value (in large protected areas, such as national parks or regional nature parks, each site obtains the maximal value on this criterion);
- the fact that, in poorly urbanised areas, the economic value is generally low because very few sites are exploited by Man;
- the absence of numerical evaluation of the educational value (not considered as an additional value);

Several authors put out the lack of information regarding the use of the site, in particular

- the lack of any indication concerning the access to the sites (Pagano 2008; Massé et al. 2011; Vigneault et al. 2011; Kubalíková 2013);
- the lack of information concerning the density of sites (which can be considered as a positive aspect when considering the tourist promotion of geosites) (Massé et al. 2011; Vigneault et al. 2011);
- the lack of information concerning the degree of risk when visiting the sites, which can be, on the contrary, a weakness for the tourist use of sites (Massé et al. 2011; Vigneault et al. 2011).

It was, therefore, decided to develop a second version of the method, adding a large part concerning the use and management of the assessed geomorphosites, which was tested in two Master’s theses (Grangier 2013; Bussard 2014). The assessment methodology was also included in a larger reflection, where the assessment procedure was integrated in a broader process, from the selection of potential geomorphosites to their management strategy (Reynard 2011; Perret 2014), and preliminary results were presented in international conferences (Reynard et al. 2012, 2014). This article first presents the whole process, then describes the different steps of the assessment methodology and discusses the choices made for this method in comparison with other proposals, before discussing mapping issues and presenting results from three case studies carried out in the Swiss and French Alps (Grangier 2013; Bussard 2014; Perret 2014).

An Integrative Perspective: the Inventory

The procedure described in this paper concerns the inventory and the management of the geomorphological heritage at the regional scale (e.g. in a province or a region, in natural parks, etc.). The approach is divided in two main stages (Fig. 1)—the inventory and the management—each one being again divided in two steps (selection and assessment of geomorphosites; management/use of geomorphosites and evaluation by the users, respectively).

The Selection

Geoheritage is only a part of the geology (or the geodiversity) of an area. It means that a certain number of sites are selected,

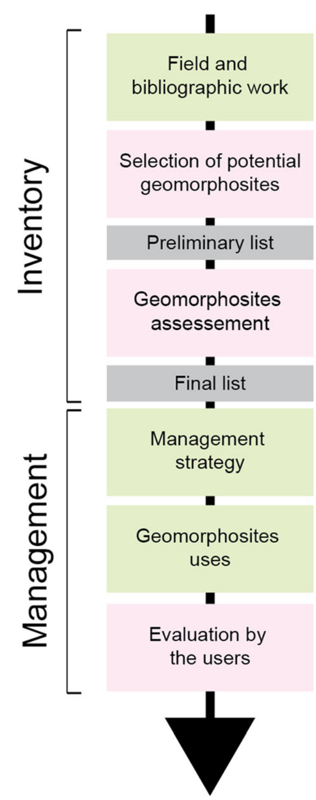

Fig. 1 Two stages of the integrative approach (according to Reynard 2011, modified)

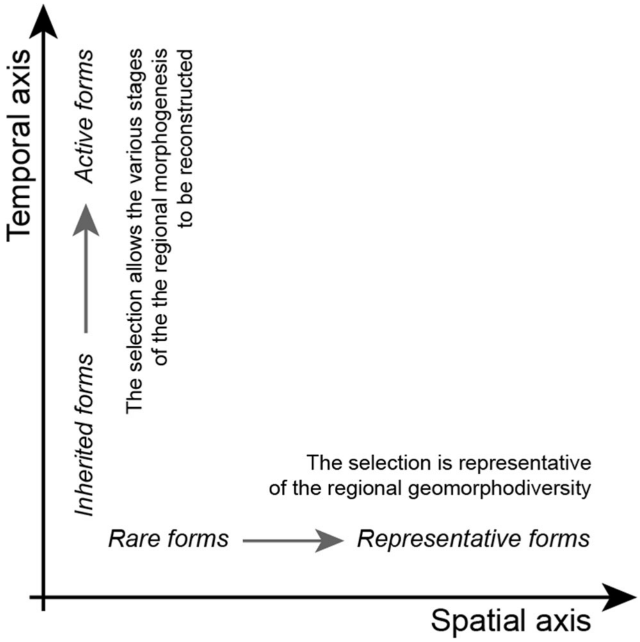

Fig. 2 Selection process based on two criteria (according to Perret 2014, modified)

and then evaluated, and considered as important sites worth being protected or classified by the authorities or developed within tourism or education programmes. The assessment of geosites is a long (and therefore expensive) process. Grandgirard (1999) and Reynard (2008) have evidenced three main contexts where assessment procedures are applied: the environmental impact assessment (EIA), the inventories of geological assets and the assessment of sites in terms of potential for geotourism. In EIA contexts, there is no selection of sites to be assessed. The assessment methodology is applied to the area threatened by a human project, and the aim is to evaluate whether the impacts of the project can be supported or not by the geological features. In the two other contexts, it is necessary to operate a preliminary selection of potential geosites that will then be assessed or characterised.

The majority of the assessment methods proposed until now are not very clear about this preliminary selection (Pereira and Pereira 2010; Sellier 2010), and it seems that in most cases, it is a kind of expert's knowledge based selection, sometimes guided by the limit of the number of sites that will then be assessed in detail. However, several authors proposed methodologies to pre-select potential geosites.

Serrano and González Trueba (2005) based the selection on a complete geomorphological mapping of the studied area, saying that "the map allows the identification of individual or representative sites earmarked for assessment" (Serrano and González Trueba 2005, p. 204), but they did not explain how they selected these sites. Fuertes-Gutiérrez and Fernández-Martínez (2010) selected sites in two steps: firstly, they listed a large set of potential geosites (285 geosites for the entire Leon Province in Spain) based on literature review and taking care to represent the geodiversity of the studied area; secondly, they applied a Delphi methodology: nine experts were consulted and finally 125 geosites were selected.

Pereira et al. (2007) and Pereira and Pereira (2010) proposed a quite complex procedure divided in four sub-stages: the identification of potential geomorphosites, the qualitative assessment of potential geomorphosites, the selection of geomorphosites and finally their characterisation. The identification is based on a pre-defined range of criteria (the scientific value, the value of landform aesthetics and characteristics, the links of landforms with cultural elements and the links between landforms and ecological issues). The collected data for the identification of potential geomorphosites is stored in a database and then assessed qualitatively according to three sets of criteria: (1) the intrinsic value based on their scientific, ecological, cultural and aesthetic performance; (2) the potential use on the basis of three criteria: accessibility, visibility and evidence of importance in other fields (e.g. archaeology, biology); (3) the required protection, which assesses both the site integrity and threats. The selection of geomorphosites is then performed "on their rank performance during the qualitative assessment, with those sites that scored overall highest being selected for further characterisation" (Pereira et al. 2007, p. 160). As noted by the authors, the first step remains very subjective and based on the assessor's knowledge.

In a context of education to geomorphology, Sellier (2010) developed a deductive integrated approach for the selection of

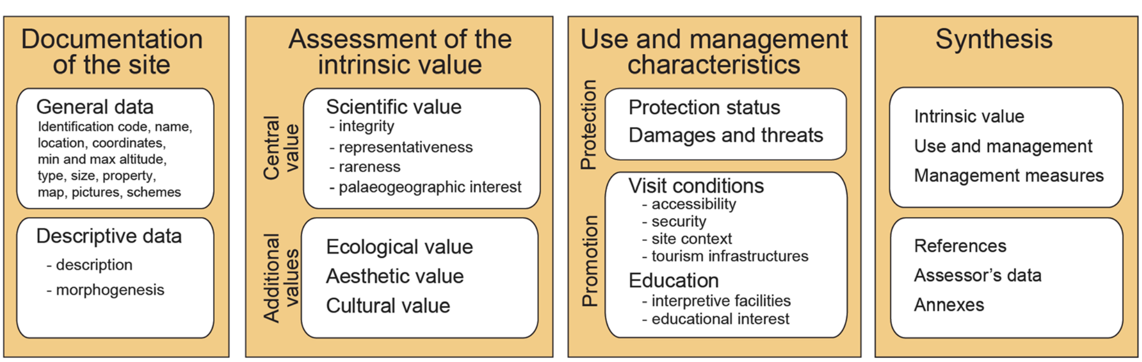

Fig. 3 The four steps of the assessment method

Table 1 General data (from Reynard et al. 2007, modified)

Identification code	
	CAPITAL LETTERS FOR THE REGION; small letters for the process or geomorphological context[a], numerical code for the site. Each code has three characters (e.g. DERgra001 means Project Derborence, gravity form, geosite n°1).
Name	
	Name of the landform or very simplified description of the geomorphosite (e.g. moraine, group of sinkholes, glacier forefield, meander, etc.)
Place	
	As precise as possible (e.g. Mont d'Or N, Le They, Finhaut, Switzerland)
Coordinates	
	National system or international system
Minimum altitude	
Maximum altitude	
Type	
	PNT: point (e.g. sinkhole)
	LIN: line (e.g. river)
	POL: polygon (e.g. glacier forefield)
Size	
	Point: no indication or width [m] (e.g. sinkhole) or volume [m^3] (e.g. erratic boulder)
	Linear: length [m]
	Areal: surface [m^2]
Property	
	Property of the terrain or the site:
	PRI: private
	ASS: association
	PUB: public
	COM: common
Map	
	Scale >1:25,000, with precise location or perimeter and useful geomorphological information
Photographs	
	Good quality, 300 dpi
Schemes	
	e.g. diagram, statistics, palaeogeographic sketch, etc.

[a] Codes used for the processes and geomorphological contexts are the following: *STR*=structural landforms, *FLU*=fluvial, *KAR*=karstic, *GLA*=glacial, *PER*=periglacial, *GRA*=gravity, *ORG*=organic, *EOL*=aeolian, *LIT*=coastal, *ANT*=anthropic, etc.

geomorphosites based on a multilevel analysis of the relief. The process implies the use of a geomorphological map and is divided in four stages: (1) the definition of the main characteristics of the considered area; (2) the identification of key geomorphological components having similar large dimensions but different characteristics based on topographical, structural, hydrological and palaeogeographic features; (3) the subdivision of these main geomorphological components into elementary geomorphological units of analogous dimensions and equivalent geomorphological significance; (4) and, finally, the selection for each geomorphological unit of one or more representative geomorphosites. The interest of this approach is that the selected geomorphosites give an overview of the geomorphology of the studied area.

Based on the idea that the geomorphosites included in a regional inventory should be representative of the regional

Table 2 Criteria used for the assessment of the scientific value (Reynard et al. 2007)

Criterion	Evaluation
Integrity	State of conservation of the site. Bad conservation may be due to natural factors (e.g. erosion) or human factors
Representativeness	Concerns the site's exemplarity
	Used with respect to a reference space (e.g. region, county, country). The selected sites should cover the main processes, active or relict, in the study area
Rareness	Concerns the rarity of the site with respect to a reference space (e.g. region, commune, country)
	The criterion serves to illustrate the exceptional landforms in the area
Palaeogeographical value	Importance of the site for the Earth or climate history (e.g. reference site for a glacial stage)

Table 3 Criteria used for the assessment of the additional values (modified according to Reynard et al. 2007)

Value	Criteria
Ecological value (ECOL)	a. Ecological impact
	b. Protected site
Aesthetic value (AEST)	a. View points
	b. Contrasts, vertical development and space structuration
Cultural value (CULT)	a. Religious importance
	b. Historical importance
	c. Artistic and literary importance
	d. Geohistorical importance
	e. Economic importance

geomorphological characteristics, our approach partly follows Sellier's proposal. It is divided in four stages:

1. The definition of the main geomorphological contexts: the principal active and fossil geomorphological processes present in the area are listed. In our work (see the examples below), we apply a morphogenetic division related to groups of processes (glacial, periglacial, fluvial, karstic, etc.). Other subdivisions (e.g. related to morphostructural contexts) are also possible.
2. Based on a literature survey, consultation of cartographic and photogrammetric material (topographic maps, geologic maps, digital terrain models, aerial photographs), field survey, other existing inventories (e.g. natural assets inventories) and the assessor's knowledge, a first list of landforms is established. The data (location, short description, references) is stored in a database (e.g. Excel file or GIS database) and is classified following the geomorphological contexts.
3. The classification of landforms: for each context, the listed landforms are classified following two sets of criteria: a spatial criterion (representative versus rare landforms), and a temporal criterion (active versus inherited landforms) (Fig. 2).
4. The selection of potential geomorphosites, which leads to the establishment of a final list: the list is representative of the principal geomorphological contexts (more landforms related to very broadly represented processes will be selected) and of the various stages of the regional morphogenesis (inherited and active landforms). It also contains specific and rare landforms. For each site, a brief comment explains the reasons for the selection, and the sites that are not selected are conserved in a list published in the appendix of the inventory. With this, it is possible to better retrace the process that has led to the selection of the potential geomorphosites.

The Assessment

The assessment follows the method published in 2007 (Reynard et al. 2007) with several changes, inspired in particular by the methods proposed by Serrano and González Trueba (2005), Bruschi and Cendrero (2005), Pereira et al. (2007) and Pereira and Pereira (2010) and tested in two master's theses (Grangier

Table 4 Elements documented concerning the promotion of geomorphosites

Visit conditions	Indicators
Accessibility	Three characteristics are documented:
	a. Location of the closest public transportation stop (railway station, bus stop) or the closest parking area
	b. Walking time from the closest public transport stop or car park
	c. Walking difficulty (steep slopes, slippery trail, no tracks, trail accessibility in winter time or on rainy days, etc. (see Piccazzo et al. 2007; Brandolini and Pelfini 2010) or special infrastructure for disabled visitors
Security	The risk of accidents is documented here. Only the natural hazards, related to the trail conditions (see Piccazzo et al. 2007; Brandolini and Pelfini 2010) or the geosite context (e.g. potential rockfalls, high cliffs, holes difficult to access, etc.) are documented. The risks related to inappropriate behaviour are not documented
Site context	Positive (e.g. great landscape, calm environment) and negative aspects (noise, presence of vegetation or buildings hiding the site) of the geomorphosite environment are documented here
Tourism infrastructures	All tourism infrastructures close to the site are documented: transportation facilities (e.g. cableways, funiculars), accommodation facilities (hotels, camping grounds, mountain huts, etc.), restaurants, tourist office, etc.
Education	**Indicators**
Interpretive facilities	All existing interpretive facilities are documented. They concern both in situ (e.g. panels) and ex situ (booklet, website, flyer, virtual visit, etc.) facilities as well as guided visits. The general quality of the set of facilities is assessed qualitatively (good, medium, high quality)
Education interest	The potential for interpretation is documented qualitatively. The evaluation takes into account the type of visitors (e.g. is the site adequate for the education of scholars?) and the "readability" of the site (are the landforms and the geomorphological processes sufficiently simple to be understood by non-specialist visitors?)

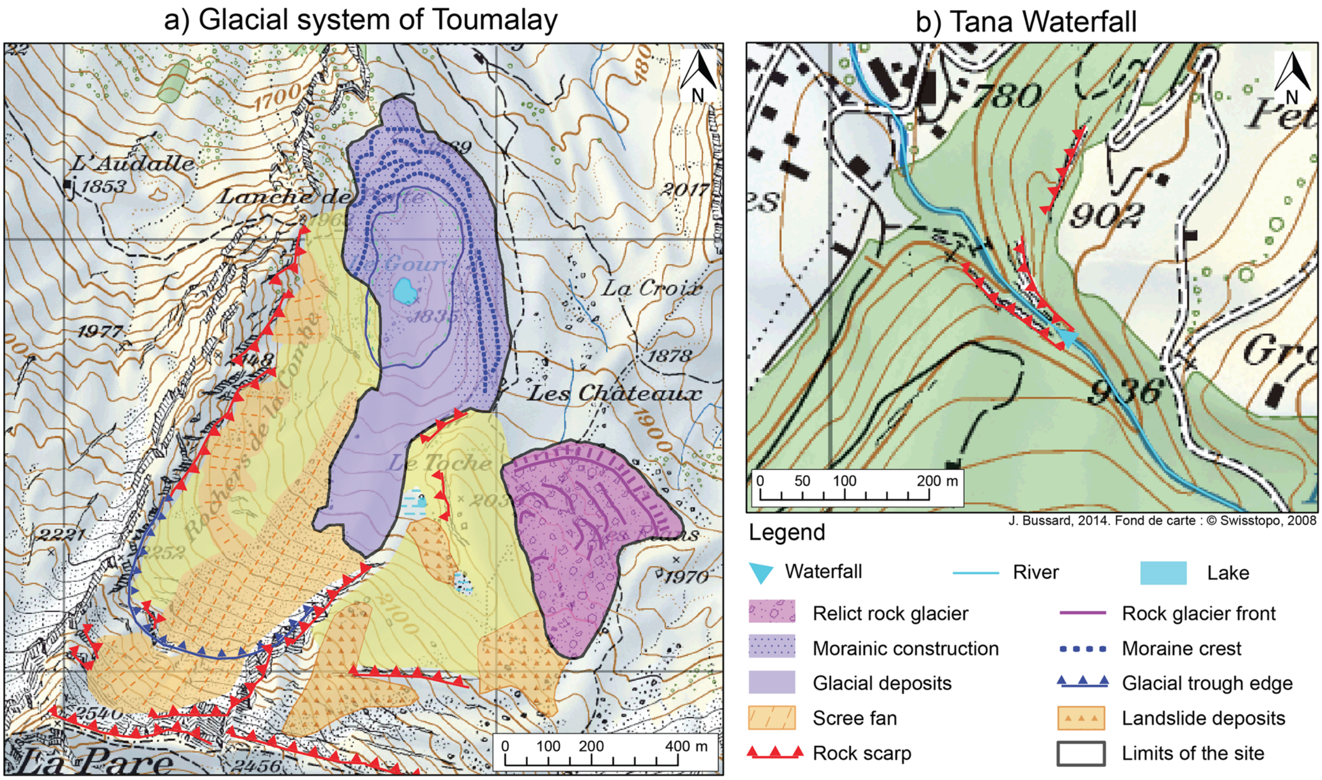

Fig. 4 Simplified geomorphological map representing the geomorphological features of a complex geomorphosite (**a**) and the geomorphological context of a small geomorphosite (**b**), after Bussard 2014 (modified). We have used the mapping legend of the University of Lausanne (Lambiel et al. 2015)

2013; Bussard 2014). The procedure is divided in four main steps (Fig. 3): (1) the description of the site, in two parts (general data and descriptive data); (2) the assessment of the intrinsic value, in two parts (the central or scientific value and additional values, which are divided into three kinds of characteristics—cultural, ecological, aesthetic); (3) the documentation of the present use and management of the site, also divided in two parts: the protection issues (protection status, property, damages and threats) and a series of factors influencing the (tourist) use of the site (visit conditions and educational interest); (4) synthesis.

Compared with other methods, only the intrinsic value is considered as a value and, therefore, assessed numerically. The central value is always assessed numerically by calculating the mean or a weighted average of its criteria, which allows the site comparison and classification. The additional values can be evaluated numerically or not. If they are assessed numerically, they can be averaged or not.

The use and management characteristics are not considered as a site's value (unlike Serrano and González Trueba (2005), Bruschi and Cendrero (2005), Pereira et al. (2007) and Pereira and Pereira (2010)); data is just collected and stored in a database and can be used as a basis for the site classification, comparison and management. Indeed, we consider that the potential for educative activities or geotourism as well as the needs for protection are not part of the "quality" of the site and are not, therefore, to be considered as a value. We speak, therefore, of "use and management characteristics".

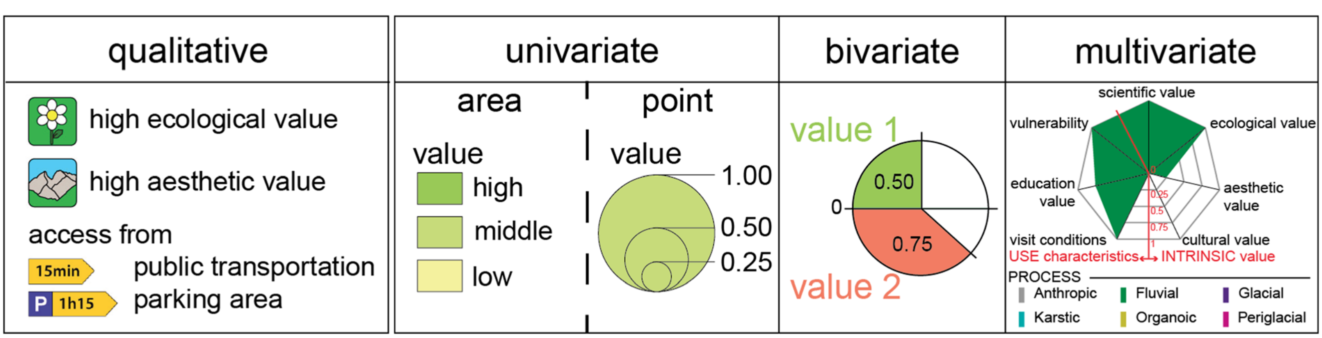

Fig. 5 Four representation types used for synthetic maps of regional geoheritage

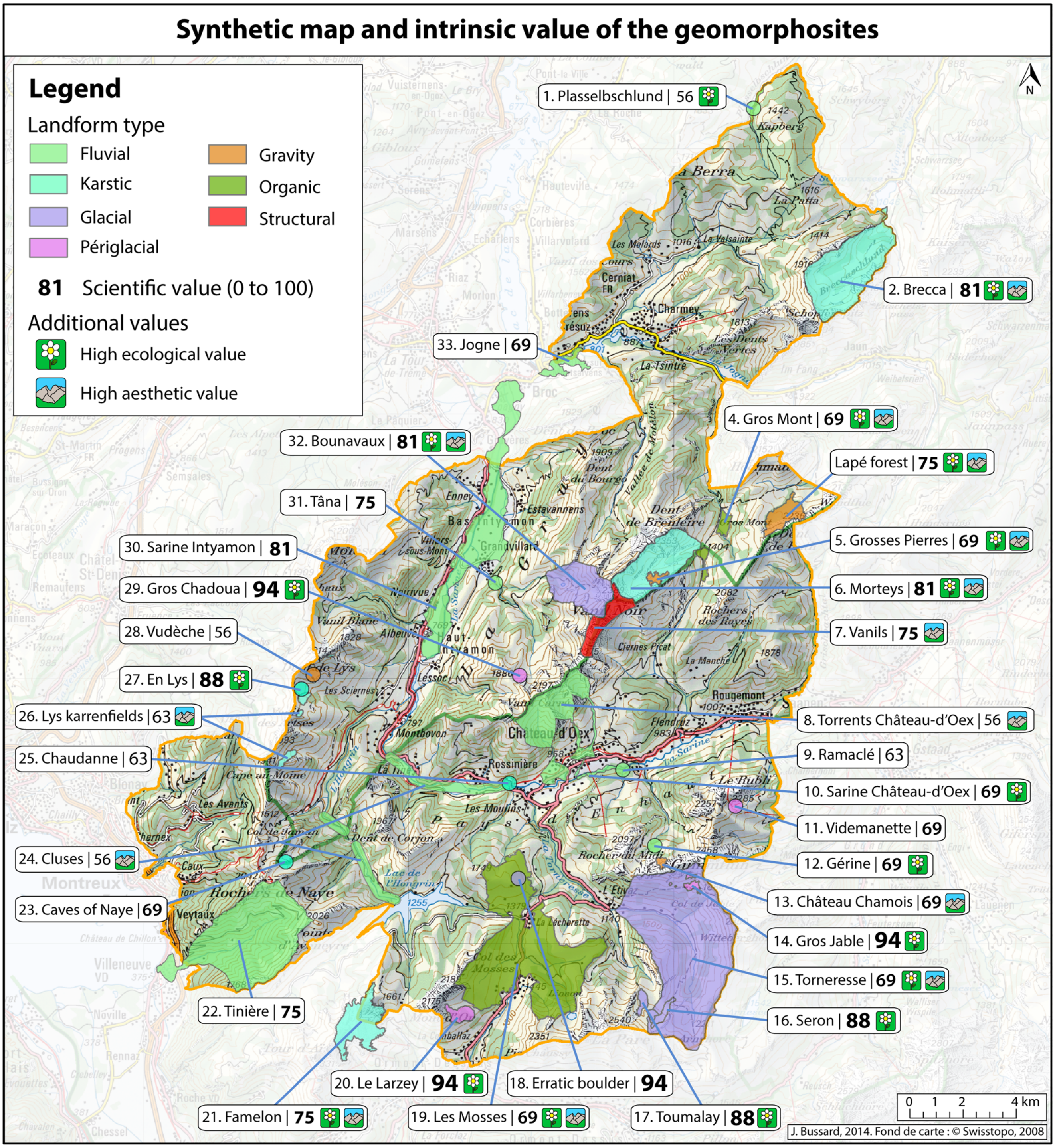

Fig. 6 The 33 geomorphosites inventoried in the Gruyère Pays-d'Enhaut Regional Nature Park

Site Documentation

The site documentation is divided into two parts: general data and descriptive data. The general data has 12 pieces of information (Reynard et al. 2007) (Table 1): (1) code divided in three parts: three capital letters for the name of the project, three small letters for the geomorphological context or process, three digits (site identifier); (2) name; (3) location; (4) coordinates; (5, 6) minimum and maximum altitude; (7) type, divided into three categories: point (e.g. spring, sinkhole), line (e.g. moraine ridge, river) and surface (e.g. glacier forefield, karren), useful information for GIS processing; (8) size; (9) property status, divided into four categories (public, private, common, association), following Reynard (2005b)

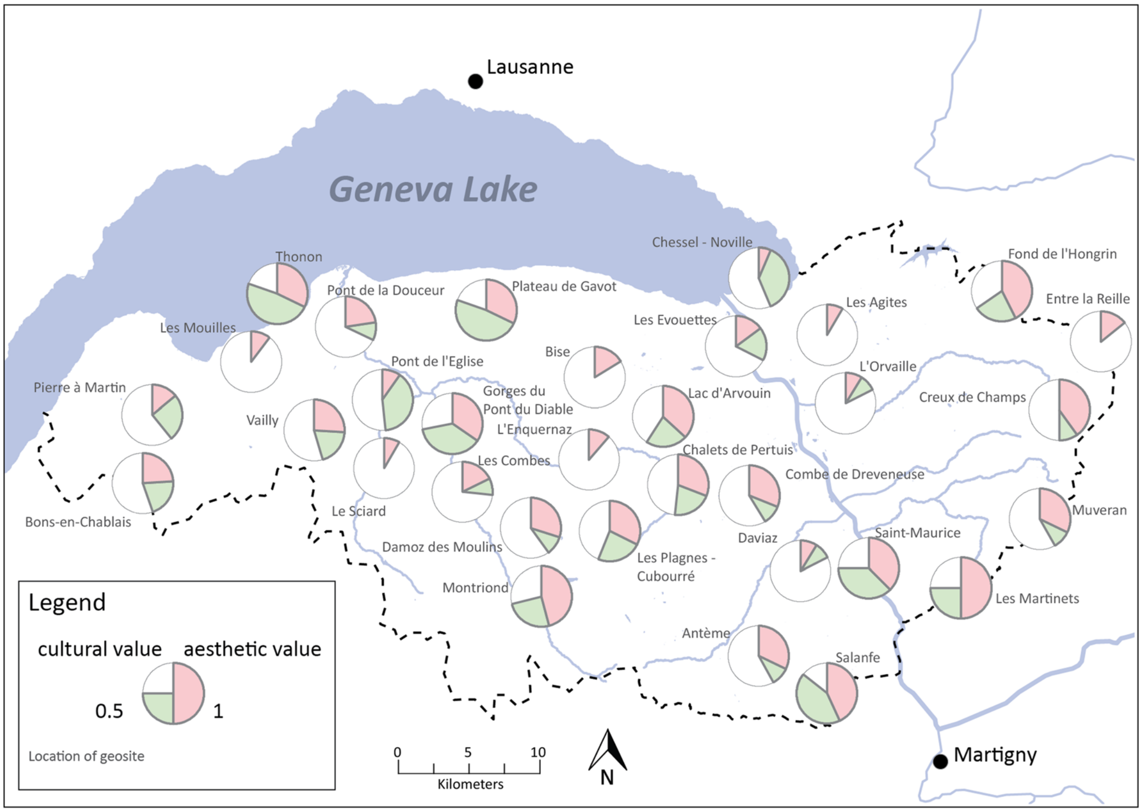

Fig. 7 Cultural and aesthetic value of glacial geosites in the Chablais area

analysis; (10) simplified geomorphological map containing the site perimeter and other useful geomorphological information; (11) photographs; (12) schemes.

The descriptive data is divided into two parts: the description and the morphogenesis. The description is based on observations made by the assessor during fieldwork as well as on document analyses (maps, air photographs) and literature survey. The description not only presents the geomorphological features but also archaeological findings, human infrastructures, biotopes, etc. The morphogenesis analysis emphasises the processes responsible for the landform genesis and development and can include temporal information (dating) and information about landform activity. In a second phase, human transformations, if existing, are also analysed.

Assessment of the Intrinsic Value

The second step of the approach is the assessment of the intrinsic value, divided into the central and additional values. The central value is the value of the site for the geosciences. It is evaluated relatively to the studied area. As suggested by Grandgirard (1999) and Reynard et al. (2007), it is assessed according to four criteria: rareness, representativeness, integrity and palaeogeographic interest (Table 2). The last one is included "to encourage greater context sensitivity in analysis in terms of Earth and climate history" (Reynard et al. 2007, p. 149). The term "palaeogeographic" must be considered in a very broad perspective. A site giving information about very old processes does not have more importance than a site referring to recent or current processes. What is important is the fact that the site documents a stage (old or recent) of the Earth and climate history.

The additional values are more difficult to define (Giusti and Calvet 2010). In the first version of the method (Reynard et al., 2007), following the typology by Panizza and Piacente (1993) and Reynard (2005a), we proposed to assess four values (ecological, aesthetic, cultural and economic). In this version, we consider only three values (ecological, aesthetic and cultural). The reason is that the economic interest of a site is not intrinsic but related to the use by Man; for this reason, we consider now that the economic interest is part of the cultural values. In assessing the additional values, the aim is not to give an exhaustive analysis of the site in terms of ecology, culture or aesthetics but to highlight the possible links between geomorphology and other aspects of nature and culture (see Pralong 2006). Reynard et al. (2007) give an extended description of the criteria used for assessing the additional values (Table 3).

The ecological value corresponds to the arithmetical mean of the "ecological impact" and the "protected site" criteria. The ecological impact is assessed qualitatively based on literature and/or discussions with specialists and concerns the impacts of the geomorphological context on the development of specific species or habitats. Moraines damming wetlands,

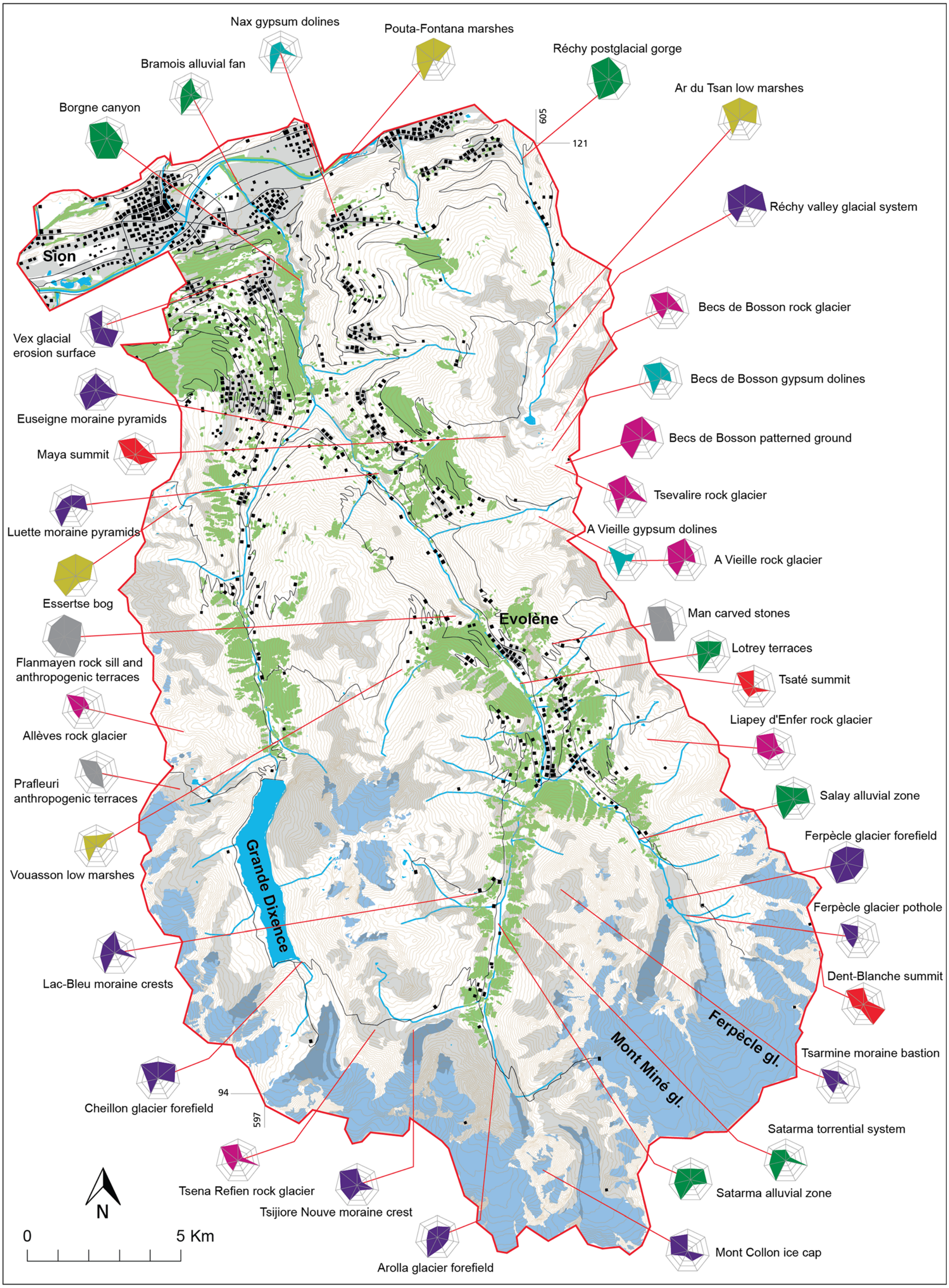

Fig. 8 Geomorphosites of the Hérens and Réchy valleys

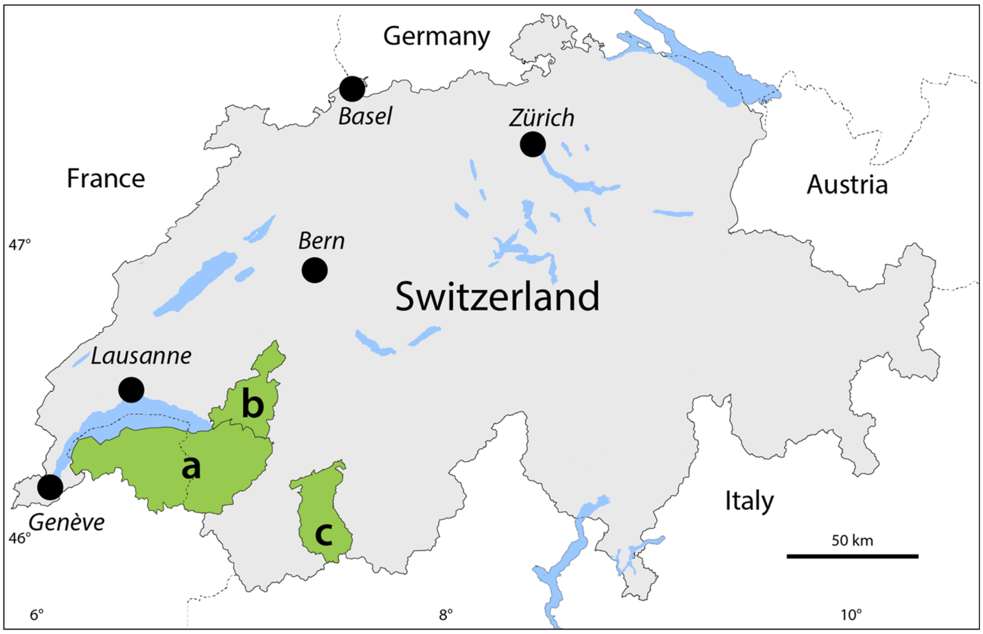

Fig. 9 Location of the three study sites. **a** Chablais area, **b** Gruyère Pays-d'Enhaut Regional Nature Park, **c** Hérens/Réchy Regional Nature Park project

karren fields provoking the development of specific species or gravel islands of braided rivers used by birds for nesting are examples of positive impacts of geomorphological landforms on ecology and biodiversity. The second criterion takes into account the possible protection of the site by national or regional regulation. In previous research, it was noted that this criterion is ambivalent for large protected areas such as nature regional parks. In this case, a regional inventory at the scale of the park would give a high score on this criterion for all sites. We recommend, therefore, to consider as "protected site" only the landforms specifically protected—for various ecological reasons—and not all the landforms included in a large natural protected area. The aesthetic value is difficult to evaluate and quite subjective. Based on the works of Grandgirard (1997), Droz and Miéville-Ott (2005) and Pralong (2006), this value is assessed using two criteria: the presence of viewpoints and the colour contrasts, vertical development and space structuration by the geomorphosite. The "cultural value" criterion is more heterogeneous in character. It is made up of five independent sub-criteria: religious importance, historical importance, artistic and literature importance, economic importance, and geohistorical importance (that is the importance for the history of geosciences) (for examples of these sub-criteria, see Reynard et al. (2007)). As it is rarely the case that a geosite has all the five values, here the numerical assessment considers only the most important one.

Use and Management Characteristics

The third part concerns the use of geomorphosites by society. Its aim is to collect the maximum amount of data allowing us to characterise the site in view of its protection and/or promotion (Fig. 3). It documents the current protection of the site, as well as the presence of interpretive material, the visit conditions and the educational interest of the site. The objective is to prepare the second part of the approach, which is the site management.

Protection is documented using two criteria: the protection status and the damages and threats. The "protection status" concerns the site's protection against damages. It can be a legal protection (protected site) and/or a physical one (presence of fences). It can also relate to more informal rules such as maintenance works to protect the site against enforestment or erosional processes or even social rules such as religious taboos. Finally, the protection status also relates to the property regime statement documented in the "General data" part. The "damages and threats" section documents all the threats—active and potential—that concern the site. For the damages, that are effective, the objective is to document the extension of the damage (expressed for example as a percentage), the origin (natural or anthropic) and the temporality (past or active). Note that the damage is not always located on or in the site itself. For example, in fluvial contexts, a reduction of flow upstream, due to water extraction or river damming, may modify the river capacity and, therefore, the sediment transfer and channel style of the river. This is considered as a kind of damage. The threats concern the potential damage in the future. Here, the question of temporal scale is an issue. Only the potential damage in a short and medium term (i.e. 5 to 20 years) related to concrete changes is documented. This is the case of sites close to fast-growing urban areas, sites situated in areas concerned with tourism or transport infrastructures or sites subject to active erosional processes. Long-term potential threats (more than one human generation) are not documented.

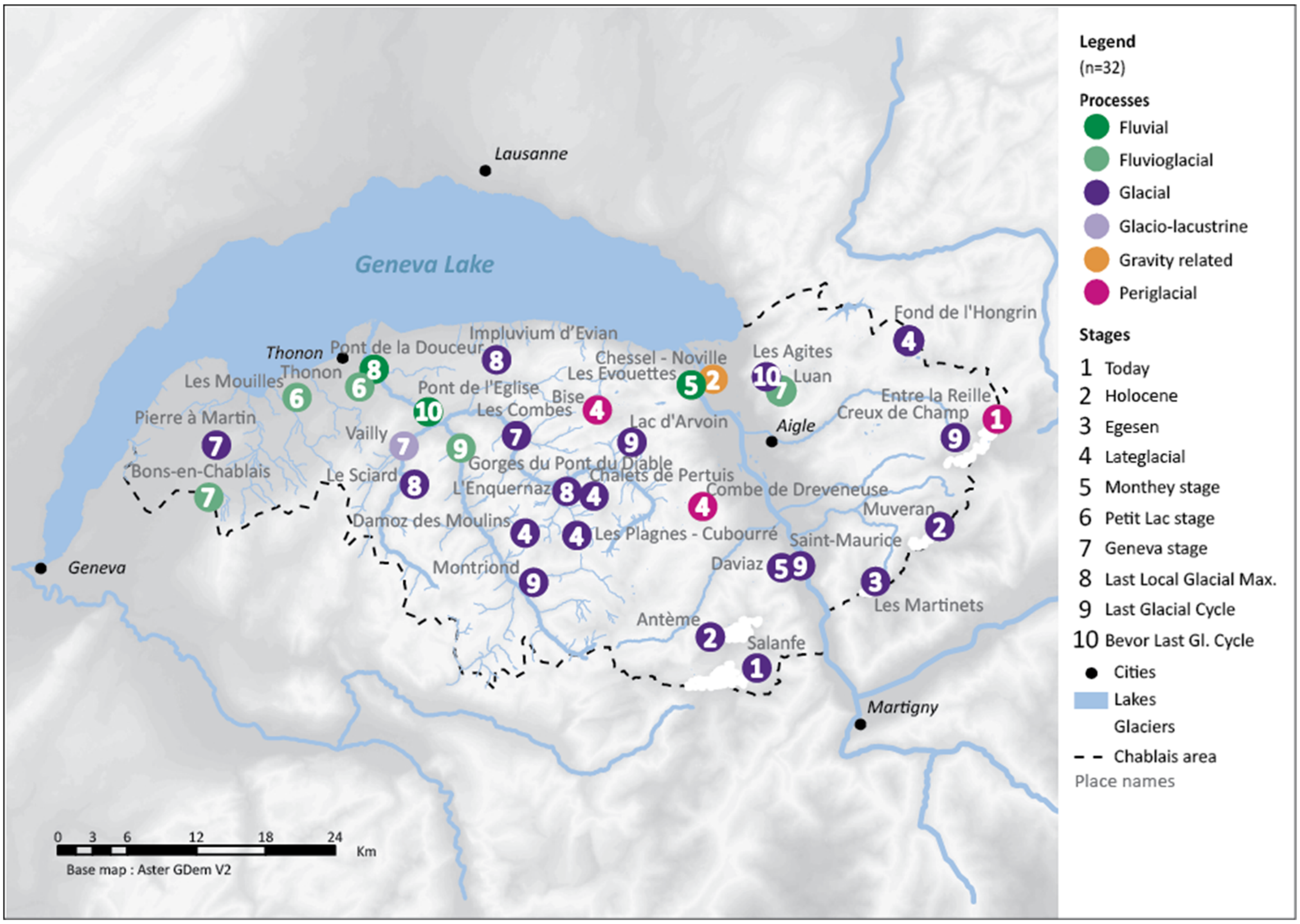

Fig. 10 The 32 retained geosites out of 102 points of interest based on chronological (glacial stages) and representativeness (geomorphological context) criteria

Promotion is also divided into two parts: the visit conditions and the educational aspects. The visit conditions are documented using four indicators (Table 4). They concern the physical visit of the site, not the case of virtual visits (Barbieri et al. 2008; Liberatoscioli et al. 2011; Barton et al. 2014; Cayla 2014). The educational interest of the geomorphosite is documented through two indicators (Table 4).

Synthesis

This last part of the assessment process is divided into three parts. The first one gives a global intrinsic value of the site and makes a global comment on the central and additional values of the site. The second describes briefly the situation concerning the use and management issues (protection and promotion). The last one, called "Management measures proposals" allows the assessor to propose protection (e.g. technical measures such as fencing, institutional measures such as protection decree, management policy) and promotion measures (e.g. educational programme, interpretive facilities development, networking with other sites). The "Synthesis" part also contains information about scientific references, assessor's information as well as possible annexes (graphs, maps, photographs, etc.).

The Cartographic Representation of Results

Good cartographic representation is particularly important to communicate results (Coratza and Regolini-Bissig 2009), especially to the stakeholders (public authorities, decision makers, park managers) and non-geoscientists (Carton et al. 2005). Maps are used at two levels: at the level of the geosite, within the assessment procedure, and at the regional scale, as a tool for synthetic representation of results. For the assessment phase, unlike some authors (Serrano and González Trueba 2005; Sellier 2010), we do not advocate a complete coverage of the studied area with a geomorphological map—this can be time-consuming for large areas—but we propose to use simplified geomorphological mapping to represent geomorphological features (for complex geomorphosites, Fig. 4a) or the geomorphological context (for small geomorphosites, Fig. 4b).

At the regional scale (synthetic maps), four representation modes were tested (Fig. 5):

- The qualitative legend is used to represent geosites assessed without numeric scores (Fig. 6) and to present some use characteristics (e.g. access).
- The univariate mode is used to present numeric scores (e.g. qualitative categories, such as low, middle or high importance, or values on a scale from 0 to 1). In this case, the size of the circles is proportional to the value.
- The bivariate mode is used to present two values (Fig. 7) on a scale from 0 to 1 (e.g. the central value and the average of the additional values). In this case, the size of the circles is identical for all sites; it is the proportion of each value that varies.

Table 5 Glacial ‘witnesses’ taken into account in the selection

Geomorphological context	Point	Linear	Areal	Deposit
Glacial	Erratic boulder	Lateral morainic crest	Glacier	*Lodgement till*
		Latero-frontal morainic crest	Glacier patch	*Melt-out till*
		Frontal morainic crest	Covered glacier	*Fluted moraines*
		Morainic amphitheatre	Regenerated glacier	(Subaqueous till)
			Proglacial margin	
			Glacial valley	
			Hanging glacial valley	
			Glacial cirque	
			Roches moutonnées	
			Roches moutonnées with striae	
			Lock and glacial basin	
			Glacial U-shaped valley	
			Drumlin	
Fluvioglacial	*Glacial pothole*	Subglacial gorge	Kame terrace	Stratified deposits
		Fluvial gorge	*Sandur*	
		Fluvioglacial channel	*Fluvioglacial deposit*	
Glacio-lacustrine			Moraine dammed	*Laminated fine deposits*
			Proglacial lake	Deltaic deposits
			Rock-dammed proglacial lake	
			Perched delta	
Gravity related			Landslide	
			Postglacial rockslide	
			Subglacial rockslide	
			(Rockslide)	
Periglacial			Fossil rock glacier	
			Active rock glacier	
			Protalus rampart	
			Kettle	
Fluvial			Pyramid	Conglomerates
Organic			*Marsh, peat*	
Hydrographic	(Spring)			
Karstic	(Sinkhole)			

Upright characters are ‘witnesses’ represented by a geosite; italics are ‘witnesses’ included in a geosite; parentheses are ‘witnesses’ not included in the final list of geosites

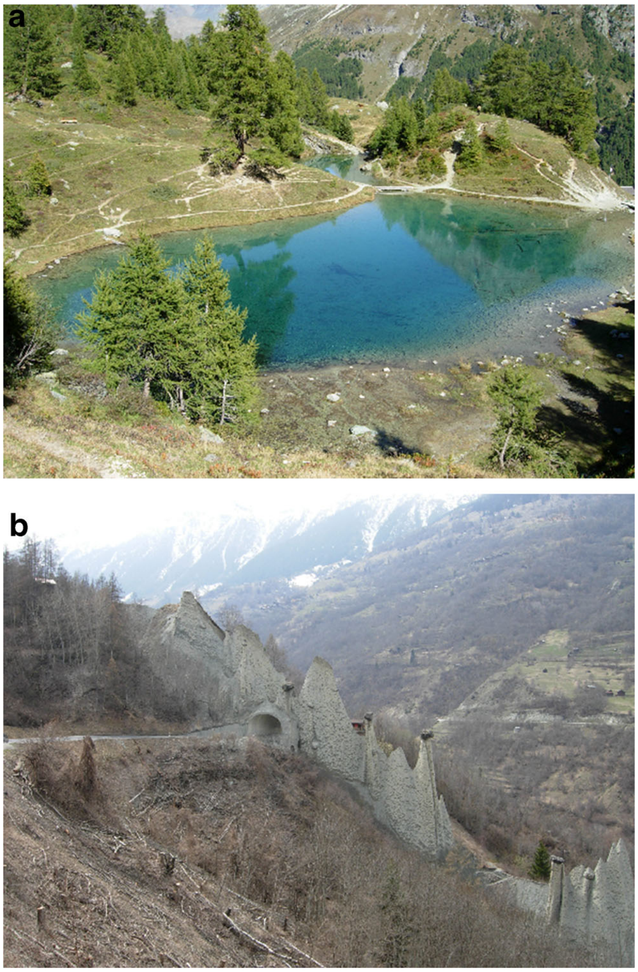

Fig. 11 **a** Trampling due to tourist walking on the Lac Bleu morainic system. **b** Morainic Pyramids near Euseigne (photographs by E. Reynard)

– The multivariate representation was tested by Grangier (2013). Several criteria are represented simultaneously on a scale from 0 to 1; in this case, the form of the representation allows us to compare different sites rapidly (Fig. 8). Note that in this case, a graphical bias is introduced related to the surface covered by the evaluation; in fact, if a geosite has high scores for adjacent criteria, it will cover a larger surface than if adjacent criteria have high and low scores. This bias can be avoided by using column charts.

The Management

The management phase comprises two parts (Fig. 1). The first one is the elaboration of a management strategy that can be done directly by the scientists (e.g. the assessor) or by site management bodies (e.g. geoparks, nature parks, public administrations, private companies, associations). This strategy should comprise both protection and promotion measures and should be based on the synthesis of the inventory. It can concern one individual geomorphosite or several networking sites. The educational and geotourist products should follow specific guidelines, such as, for example, the ones proposed by Martin et al. (2010). The second one is the management itself that should have sufficient financial, personal and jurisdictional means. To ensure good quality, the users themselves should assess the management strategy. This is particularly the case for the educational and geotourist products. As we have not carried out a long-term survey of geomorphosite management strategies, we do not discuss this issue further in this paper.

Examples

Three examples are presented briefly. They illustrate three main issues: the selection process and bivariate representation of results (example 1), a geotourism-oriented inventory and the multivariate representation of results (example 2), a geotourism and protection-oriented inventory and the qualitative representation of results (example 3).

The first one (Fig. 9a) is an inventory of glacial geosites (Perret 2014) carried out within a project dealing with the promotion of natural and cultural heritage in the Chablais area (Interreg IVA project 123 Chablais, www.123chablais.com, accessed 05/01/2015) and linked to the creation of the Chablais Geopark (Hobléa et al. 2011). In a context of development of smart forms of tourism, the objective was to develop a strategy promoting the glacial heritage to a wide public in an area where the glaciers have almost completely disappeared. For this, an inventory of glacial geosites was carried out. The inventory was realised following the above presented method with small adaptations: (a) for the scientific value, the focus was put on the importance of the selected geosites for representing the main stages of the regional glacial history; (b) not only the landforms (glacial geomorphosites) were assessed but also glacial deposits were taken into account; (c) the evaluation of additional values focused on cultural and aesthetic values. In the cultural value, some criteria linked to the use of glacial witnesses by the population were included: gravel extraction, mineral water exploitation, and leisure activities. A particular attention was put on the selection of potential geosites. The first step was the creation of a list of "points of interest" (102 sites) established using different sources: literature review, fieldwork and use of GIS to cross information.

The selection was then performed according to two criteria (see Fig. 2): correspondence with a glacial stage (time axis) and belonging to a type of forms/deposits (spatial axis). For the time axis, ten stages were retained: today, Holocene, Egesen, Lateglacial (before Egesen), Monthey stage (regional stage), Petit Lac stage, Geneva stage, Last Local Glacial Maximum, Last Glacial Cycle and Before Last Glacial Cycle (Fig. 10). For the spatial axis, each point of interest was classified according to 9 geomorphological contexts (Table 5). The selection was then performed qualitatively based on two criteria: to represent the regional glacial geodiversity and to be representative of the regional glacial chronology. Finally, 32 geosites out of 102 points of interest were retained for the assessment (Fig. 10). The assessment of additional values was useful in identifying geosites with strong heritage interest. The bivariate cartographic representation (Fig. 7) was useful to identify possible synergies between geosites.

The second example is an inventory realised in 2011 (Grangier 2013) within the framework of a regional nature park project in the Hérens and Réchy valleys (Fig. 9c). Thirty-eight sites were identified and evaluated. In addition to the evaluation of the intrinsic value, the work assessed numerically the use characteristics of each site in terms of visit conditions, education value and protection value. Criteria used to evaluate the conditions of visit were the access (type—public versus private transport, walking time and difficulty), safety and the environmental context; the educational value was assessed using three criteria: the visibility and readability, the presence of interpretation means and the potential for educational activities. The protection value was assessed by combining two criteria: threats and degree of protection. The multivariate cartographic representation (Fig. 8) allows easy comparison between the geomorphosites: the colours indicate which are the main processes in the area (glacial, periglacial and fluvial) and their localisation; the form of the cartograms indicates groups of geosites (e.g. geosites with high intrinsic value but bad visit conditions). The inventory was then used to propose a strategy for the development of geotourism to the local stakeholders.

Most geosites have a high intrinsic value, which constitutes a good base for geotourism development. However, several sites suffer bad visit conditions due to access difficulties or safety problems (e.g. Prafleuri anthropogenic terraces, Tsarmine moraine bastion, Allève and Liapey d'Enfer rock glaciers, Tsaté and Dent Blanche summits, Ferpècle glacier potholes), which reduce their geotourism potential. On the contrary, other sites, intensively visited, are particularly vulnerable to tourist overexploitation—e.g. Lac Bleu morainic system where trampling is an issue (Fig. 11a) or Euseigne moraine pyramids where current exploitation of the site threatens it (erosion, trampling) (Fig. 11b). Based on the use characteristics of geosites, a focus on geotourism promotion near Evolène and Arolla could be proposed.

The third example is also an inventory (Bussard, 2014) carried out in a nature park, the Gruyère Pays-d'Enhaut Regional Nature Park (Fig. 9b). The research dealt with two main issues: the protection of the geomorphological heritage and the promotion of geotourism in the protected area. Thirty-three sites were selected and inventoried. Most of them (27 sites) are related to three main geomorphological processes: karst formations, relicts of glacial/periglacial processes and fluvial landforms. The inventory was very useful to highlight three main results: (1) The study area has a high diversity of landforms and presents a large set of geomorphosites with an important scientific value. Most of them (24 sites) also have a high ecological value. (2) The majority of the sites have a good protection status and only three of them are threatened by human activities because they do not benefit from sufficient protection. This good protection is, however, more related to the ecological or landscape value of the sites than to their geomorphological characteristics. (3) There are almost no geotourism activities or valorisation panels in the park and the population is not aware of its geomorphological richness. However, many sites have very good visit conditions, and the new dynamic generated by the creation of the park is an interesting opportunity to develop geotourism in the region. For this study, we have used a partly numerical representation of results (Fig. 6). Scores ranging from 0 to 100 express the scientific value. The additional values are represented with symbols (a flower for the ecological value and a mountain landscape for the aesthetic value) and the main processes are represented by colours.

Discussion and Conclusions

Inventories of geosites and geomorphosites are important tools for documenting and characterising the geo(morpho)logical heritage of an area or a country. During the last two decades, several methodologies were proposed, one of them by the University of Lausanne. This paper has presented a second version of the methodology proposed by Reynard et al. (2007). The main improvements concern four issues.

The first one is a clarification of the process of selection of potential geosites before their assessment. In fact, the methods proposed until now do not address this question; it is, therefore, impossible to know how the potential geosites were selected and it seems that in most of the cases they are just selected based on the assessor's experience, which is quite subjective, or on other external factors, such as time (a maximum number of sites preselected), which clearly constitutes a bias. Based on the Portuguese proposal of defining geological frameworks before every inventory and on the selection method proposed by Sellier (2010) in a context of education to geomorphological heritage, we propose a transparent procedure that combines two principles: a spatial one (the preselected geomorphosites should represent the main geomorphological processes present in the study area) and a temporal one (they should also document the main stages of the regional morphogenesis). The method was successfully tested in the Chablais area (Perret 2014; Table 5 and Fig. 10) and we hope that this simple and systematic approach will fill a gap in the inventory procedures.

The second improvement was to complete the existing method that evaluated only the intrinsic value (Reynard et al. 2007), to include new information about the use of the geomorphosites. In this sense, we followed proposals made by several authors, in particular Serrano and González Trueba (2005), Pereira et al. (2007), Pereira and Pereira (2010) or Bruschi and Cendrero (2005, 2009), who assessed the use values of geosites. But, unlike these authors, we do not consider that the use is a value but that it is a characteristic of each geosite, worth being documented qualitatively (Table 4) to help their management (protection and/or promotion).

Thirdly, we discuss mapping issues in this paper. Indeed, the representation of results is an important communication tool, in particular for discussions with decision makers or representatives of conservation, heritage or tourism sectors. Cartographic tools are used in two parts of the procedure: (1) during the assessment phase (simplified geomorphological maps are useful in highlighting geomorphological features of complex geomorphosites or to show the geomorphological context of small geomorphosites; Fig. 4); (2) when the inventory is finished, synthetic maps help to obtain a complete geographic overview of the studied geomorphological heritage. Four types of representation—qualitative and uni-, bi- and multivariate—are discussed in this paper (Fig. 5). They are not exclusive and can also be combined in the same study. Several cartographic examples are presented (Figs. 6, 7, 8, 10).

Finally, we consider that the assessment is just one phase of a larger process (Fig. 1), divided into two main phases—the inventory and the management—and four steps (selection, assessment, use, evaluation). In this paper, we have only discussed the two first steps. In the future, more attention should be paid to management strategies and evaluation by the stakeholders and by the users.

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