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Concepts and terminology for the risk of degradation of geological heritage sites: fragility and natural vulnerability, a case study

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ABSTRACT

This paper focuses on the conservation of geological heritage sites and specifically on the assessment of the risk of degradation. A review of the relevant literature shows (a) a lack of a standardised terminology used by different authors and (b) a lack of a standard methodology that supports the recognition and prevention of threats affecting a geosite. Three criteria (previous studies, the most common meaning of the words used and the use of terms in related disciplines) were used to select four terms with which to assess the risk of degradation: sensitivity, fragility, natural vulnerability and anthropic vulnerability. This paper provides a detailed description and discussion of these terms and their relevance. To test the use of these terms, an analysis of the fragility and natural vulnerability of geosites was performed in La Rioja (Spain), where more than one hundred outcrops bearing exceptional dinosaur footprints are located. The main factors that affect the fragility of these geosites are related to the lithology and to the location and typology of the ichnite. With respect to natural vulnerability, this study reveals several factors and processes that are involved in the degradation of these sites and establishes several field indicators that indicate deterioration. This research was intended to establish a common framework for specialists (both scientists and managers) working on geoconservation issues.

1. Introduction

Geological heritage (geoheritage) is a component of natural heritage that includes natural geological resources (such as geological formations and structures, landforms, minerals, rocks, meteorites, fossils and soils) that have scientific, cultural and/or educational value. The conservation of geoheritage (geoconservation) is defined as *action taken with the intent of conserving and enhancing geological, geomorphological and soil features, processes, sites and specimens, including associated promotional and awareness raising activities and the recording and rescue of data or specimens from features and sites threatened with loss or damage* (Burek and Prosser, 2008; Prosser, 2013). It is achieved through the coordination of four fields: (1) the inventory of sites of geological interest (geosites), (2) the creation of a legal framework that guarantees their preservation, (3) the dissemination of the importance of geoheritage to society and (4) the development of management plans and measures to ensure the protection and appropriate use of geosites.

Larwood et al. (2013) analysed the initial progress in geoconservation and concluded that much had been achieved in this field and that it is gaining recognition at a global level. These advances have been supported by the contributions of many researchers who have focused their efforts and scientific knowledge towards this goal. For example, the number of papers on this topic has greatly increased, especially in recent years (see all the papers in the journal *Geoheritage*, which is specifically devoted to this subject and has been published since 2009, and the Special issue of the *Proceedings of the Geologists' Association* edited by Prosser et al., 2013). Nevertheless, many researchers agree that key challenges remain for effective geoconservation (e.g., Carcavilla et al., 2009; Henriques et al., 2011; Larwood et al., 2013).

One of these challenges is the establishment of a standard and generally accepted methodology for assessing the risk of degradation of geosites. The evaluation of the threats to geoheritage is essential for geoconservation and forms the basis for the management and planning activities described above. Additionally, measuring the risk of degradation enables researchers to monitor the changes and the evolution of geosites over time. Therefore, this question is present in every conceptual study and

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Table 1
Review of the terms used in publications describing the risk of degradation of geoheritage sites. The definitions quoted from the different studies are shown in italics. The definitions that have been translated from other languages are not italicised. The abbreviations used in the second column of this table are as follows: Acceptable changes (AC), External Threats (ET), Fragility (F), Impact (I), Need of protection (NP), Risk of degradation (RD), Sensitivity (S) and Vulnerability (V).

References	Terms	Definition	Comments
Kiernan (1995)	*Vulnerability* *Sensitivity*	V: *potential for degradation of conservation values (whether or not hazards are thereby created)* S: *combination of both vulnerability and the scale of any hazards that may result from degradation (such as soil erosion, subsidence mass movement)*	Proposes a useful distinction between degradation due to the occurrence of hazards and other forms of degradation
Sharples (2002)	*Vulnerability* *Sensitivity*	V: *degree to which a feature, process or system is actually threatened with degradation due to disturbances caused by existing or likely human activities, given its inherent sensitivity* S: *inherent susceptibility of a feature, process or system to degradation resulting from disturbances caused by human activities, irrespective of any existing threats of such disturbances actually occurring*	Gives an interesting definition of sensitivity but is exclusively focused on anthropic threats and does not consider the sensitivity to natural changes
Gray (2004, 2013)	*Vulnerability* *Sensitivity*	V: *likelihood of damage given public access or lack of it* S: *refers to how easily features can be damaged*	Takes into account that the risk of degradation changes with the public accessibility of a geosite
Brilha (2005)	*Need of protection* *Fragility*	NP: probability of degradation of a geosite F: related to the capacity to resist degradation resulting from human activities	Links the risk of degradation to the fragility (which exclusively refers to human threats)
Pereira et al. (2007)	*Protection value* *Deterioration* *Vulnerability*	*Protection value includes both past threats (deterioration) and future threats (vulnerability)*	Classifies threats according to when they occur (past or future)
Carcavilla et al. (2007)	*Risk of degradation* *Vulnerability* *Fragility* *Sensitivity*	RD:probability of degradation due to internal or external factors. V = F = S: susceptibility to anthropic factors	The term risk of degradation is used as a general concept that brings together all possible types of degradation or damage Vulnerability, Fragility and Sensitivity are used as synonyms and refer to anthropic causes but may vary because of intrinsic characteristics
De Lima et al. (2010)	*Vulnerability*	V: *refers to natural and human processes that might affect the geosite (presently or in the near future)*	Separates degradation caused by natural and human processes
Fuertes-Gutiérrez and Fernández-Martínez (2010)	*Fragility* *Vulnerability*	F: *sensitivity to degradation due to natural threats under present conditions* V: *sensitivity to degradation due to anthropic threats*	Differentiates between natural and anthropic but not between intrinsic and extrinsic degradation
Vegas et al. (2011)	*Vulnerability* *Fragility* *External threats*	V:synonymous with risk of degradation Within Vulnerability, F and ET are distinguished as follows: F: sensitivity to degradation due to natural threats. ET: sensitivity to anthropic threats	Differentiates between natural and anthropic but not between intrinsic and extrinsic degradation
Fassoulas et al. (2012)	*Fragility* *Acceptable changes* *Impact*	F: *degree of resistance of a geosite physical features with respect to potential degradation* AC: *resistance of a geosite to changes without risking degradation of its physical features* I: *negative effects of existing human activities on the site*	Considers potential degradation that might affect the geosite
García-Cortés and Carcavilla Urquí (2012)	*Vulnerability* *Anthropic vulnerability* *Natural vulnerability* *Intrinsic fragility*	Vulnerability includes anthropic vulnerability, natural vulnerability, intrinsic fragility (synonymous with intrinsic vulnerability) and other factors	Vulnerability is a general term that includes different parameters. Fragility is synonymous with vulnerability The origin of the threat is considered (anthropic and natural vulnerability)
Rocha et al. (2013)	*Fragility*	F: *closely linked to the negative impacts of anthropogenic activities that can lead to a series of events, from minor damage or loss to partial or total destruction*	Takes into account exclusively anthropogenic activities

inventory of geoheritage. Unfortunately, each study adopts different methods, concepts, terms and parameters with which to assess the risk of degradation. As shown in Table 1, the same word can be associated with different meanings by different authors, and the same concept is sometimes given different names in different papers. According to Fuertes-Gutiérrez et al. (2013), this lack of consistency leads to two problems: (1) the results of the studies are not directly interpretable and are sometimes difficult to analyse, and (2) the results of different studies are isolated and cannot be compared with one another.

This paper presents a methodology for assessing the risk of degradation of geoheritage sites. The methodology is intended to be useful for management and is organised in two parts. First, the terms to be used are discussed. The most proposed concepts (sensitivity, fragility and vulnerability) are then discussed in detail and applied to a case study of the outcrops containing dinosaur footprints in La Rioja (Spain).

The region of La Rioja is known internationally for its outcrops of dinosaur footprints. The large number of sites (more than 150 outcrops containing more than 10,000 tracks) has made this region one of the most important areas for the global fossil record of dinosaurs (García-Ortiz and Díaz-Martínez, 2008). The many unique scientific features contained in outcrops (swimming dinosaurs, tail traces, herding behaviour) make this region an extraordinary location for palaeoichnological research (García-Ortiz and Pérez-Lorente, 2014). In addition to their scientific value, several of these sites have been included in a value-enhancement strategy that is focused on geotourism. However, despite their high heritage value, the outcrops at La Rioja are experiencing increasing levels of deterioration.

For these reasons, the tracksites at La Rioja were selected as a case study to test the validity of the proposed methodology. The intent of the study is to provide a tool that is useful for the management of geosites of all types and locations.

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