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Guidelines for geoconservation in protected and conserved areas

Crofts, R., Gordon, J.E., Brilha, J., Gray, M., Gunn, J., Larwood, J., Santucci, V.L., Tormey, D., and Worboys, G.L.

Craig Groves, Series Editor

Developing capacity for a protected planet

Best Practice Protected Area Guidelines Series No. 31

WCPA WORLD COMMISSION ON PROTECTED AREAS

Convention on Biological Diversity

Cultural Heritage Administration

IUCN WCPA's BEST PRACTICE PROTECTED AREA GUIDELINES SERIES

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IUCN PROTECTED AREA DEFINITION, MANAGEMENT CATEGORIES AND GOVERNANCE TYPES

IUCN defines a protected area as:
A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.

The definition is expanded by six management categories (one with a sub-division), summarised below.
Ia Strict nature reserve: Strictly protected for biodiversity and also possibly geological/ geomorphological features, where human visitation, use and impacts are controlled and limited to ensure protection of the conservation values.
Ib Wilderness area: Usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, protected and managed to preserve their natural condition.
II National park: Large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems, which also have environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.
III Natural monument or feature: Areas set aside to protect a specific natural monument, which can be a landform, sea mount, marine cavern, geological feature such as a cave, or a living feature such as an ancient grove.
IV Habitat/species management area: Areas to protect particular species or habitats, where management reflects this priority. Many will need regular, active interventions to meet the needs of particular species or habitats, but this is not a requirement of the category.
V Protected landscape or seascape: Where the interaction of people and nature over time has produced a distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
VI Protected areas with sustainable use of natural resources: Areas which conserve ecosystems, together with associated cultural values and traditional natural resource management systems. Generally large, mainly in a natural condition, with a proportion under sustainable natural resource management and where low-level non-industrial natural resource use compatible with nature conservation is seen as one of the main aims.

The category should be based around the primary management objective(s), which should apply to at least three-quarters of the protected area – the 75 per cent rule.

The management categories are applied with a typology of governance types – a description of who holds authority and responsibility for the protected area. IUCN defines four governance types.
Type A. Governance by government: Federal or national ministry/agency in charge; sub-national ministry or agency in charge (e.g. at regional, provincial, municipal level); government-delegated management (e.g. to NGO).
Type B. Shared governance: Trans-boundary governance (formal and informal arrangements between two or more countries); collaborative governance (through various ways in which diverse actors and institutions work together); joint governance (pluralist board or other multi-party governing body).
Type C. Private governance: Conserved areas established and run by individual landowners; non-profit organisations (e.g. NGOs, universities) and for-profit organisations (e.g. corporate landowners).
Type D. Governance by Indigenous peoples and local communities: Indigenous peoples' conserved areas and territories - established and run by Indigenous peoples; community conserved areas – established and run by local communities.

For more information on the IUCN definition, categories and governance types see Dudley (2008). *Guidelines for applying protected area management categories*, which can be downloaded at: www.iucn.org/pa_categories

For more on governance types, see Borrini-Feyerabend et al. (2013). *Governance of Protected Areas: From understanding to action*, which can be downloaded at https://portals.iucn.org/library/node/29138

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International Union for Conservation of Nature (IUCN)
IUCN is a membership Union uniquely composed of both government and civil society organisations. It provides public, private and non-governmental organisations with the knowledge and tools that enable human progress, economic development and nature conservation to take place together.

Created in 1948, IUCN is now the world's largest and most diverse environmental network, harnessing the knowledge, resources and reach of more than 1,400 Member organisations and some 15,000 experts. It is a leading provider of conservation data, assessments and analysis. Its broad membership enables IUCN to fill the role of incubator and trusted repository of best practices, tools and international standards.

IUCN provides a neutral space in which diverse stakeholders including governments, NGOs, scientists, businesses, local communities, indigenous peoples organisations and others can work together to forge and implement solutions to environmental challenges and achieve development.

Working with many partners and supporters, IUCN implements a large and diverse portfolio of conservation projects worldwide. Combining the latest science with the traditional knowledge of local communities, these projects work to reverse habitat loss, restore ecosystems and improve people's well-being.

www.iucn.org

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IUCN World Commission on Protected Areas (WCPA)
IUCN's World Commission on Protected Areas (WCPA) is the world's premier network of protected area expertise. It is administered by IUCN's Programme on Protected Areas and has more than 2,500 members, spanning 140 countries. WCPA is one of IUCN's six voluntary Commissions and its mission is to promote the establishment and effective management of a worldwide representative network of terrestrial and marine protected areas, as an integral contribution to the IUCN mission. WCPA works by helping governments and others plan protected areas and integrate them into all sectors, providing strategic advice to policy makers and practitioners to help strengthen capacity and investment in protected areas, and convening the diverse constituency of protected area stakeholders to address challenging issues. For more than 60 years, IUCN and WCPA have been at the forefront of global action on protected areas.

www.iucn.org/wcpa

Convention on Biological Diversity (CBD)
Opened for signature at the Earth Summit in Rio de Janeiro in 1992, and entered into force in December 1993, the Convention on Biological Diversity is an international treaty for the conservation of biodiversity, the sustainable use of the components of biodiversity and the equitable sharing of the benefits derived from the use of genetic resources. With 196 Parties so far, the Convention has near universal participation among countries.

www.cbd.int

Cultural Heritage Administration, Republic of Korea
The Cultural Heritage Administration was established to safeguard the integrity of the cultural traditions of Korea and enhance the cultural life of Korean people by preserving and promoting the use of cultural heritage. It operates under the aegis of the Ministry of Culture and Tourism. Its role is to contribute to the advancement of national culture through conservation and by creating values from cultural heritage and to promote Korea as one of the world's leaders in cultural heritage It funds research at institutes, prepares cases for submission to UNESCO for listing of properties and cares for properties in Korea. It also provides funds to enable international dissemination of knowledge, including funding for the publication of the IUCN WCPA *Guidelines for geoconservation in protected areas.*

english.cha.go.kr/cop/bbs/selectBoardList.do?bbsId=BBSMSTR_1205&mn=EN_03_01&ctgryLrcls=CTGRY209

IUCN WCPA Geoheritage Specialist Group
The Geoheritage Specialist Group (GSG) was established following broadening of the IUCN definition of a protected area to include all elements of nature, and therefore geodiversity and geoheritage, as requiring conservation. GSG's membership is drawn from those with expertise and knowledge of the Earth sciences and their application to protected areas planning, management and operations. The group has over 100 members and provides specialist advice on all aspects of geodiversity in relation to protected areas and their management, including caves and karst.

www.iucn.org/commissions/world-commission-protected-areas/our-work/geoheritage

Guidelines for geoconservation in protected and conserved areas

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Craig Groves, Series Editor

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Front cover photos: Front cover photos: Clockwise from top left: Yellowstone National Park (Wyoming, USA), viewing platform for geysers; Hohe Tauern National Park (Carinthia, Austria): Grossglockner mountain and Franz Josef glacier showing melting effects of climate change; San Bartolomé, Galápagos National Park (Ecuador): volcanic landforms being vegetated; Hotel in Serengeti National Park (United Republic of Tanzania) built sensitively around a granite landform. All photos © Roger Crofts

Back cover photos: Examples of the geoconservation in protected areas, clockwise from top left: Burgess Shale Cambrian explosion of life Yoho National Park, (Canada) © Parks Canada, Ryan Creary; Triglav National Park (Slovenia) represented on the national flag as a cultural icon of the country; Royal Natal National Park (KwaZulu-Natal, South Africa), part of the escarpment of the Drakensberg World Heritage site and the transboundary Peace Park; Jiuzhaigou National Park (Sichuan, China), very popular with Chinese tourists for its colourful lakes in limestone rocks. Latter three photos © Roger Crofts

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Contents

Boxes

Tables

Figures

Foreword

IUCN's World Commission on Protected Areas has been producing Best Practice Guidelines for many years. The intention is to help all those involved in protected and conserved areas activities around the world to have access to the most up-to-date information and well-informed practices derived from experts.

With the change in IUCN's definition of a protected area over a decade ago to incorporate geoconservation alongside and complementary to biodiversity conservation, and the mandates approved by three IUCN World Conservation Congresses in 2008, 2012 and 2016, there is an obvious requirement to provide guidance on geoconservation.

Conserved areas, as well as protected areas, are included in this guidance in recognition of the importance of other effective means of protecting geoheritage. Two are of particular importance in geoconservation: World Heritage Sites and Geoparks; the latter are an expanding global network under the aegis of UNESCO.

There is a view that geoheritage is robust and can look after itself. As these guidelines show, this is not the case. Many of the features are fragile and can be easily damaged by overuse or by exploitation for rock and minerals. Dealing with such threats is a constant challenge for managers of sites. The increasing effects of global climate change means it is even more important to ensure that geoconservation is effective in aiding understanding of how nature responded in the past to natural climate changes and how best to give it a helping hand now and in the future. A dynamic and flexible approach to site identification and management is, therefore, most appropriate.

Geoconservation focusses on protecting and conserving the best examples of particular fossils, rock formations and minerals, and particular landforms representing the different climatic regimes throughout the Earth's history. It also seeks to ensure that current natural, non-biological, processes are properly conserved and managed.

There is a vital link between conservation of biodiversity and conservation of geodiversity. As knowledge of this interaction increases, so does the need for ensuring that the whole ecosystem and all of its functioning parts are treated as an entity.

Often protected area staff are put off by the language of Earth science. In these guidelines, the authors hope to remove those barriers of understanding and comprehension for managers and their staff. Additionally, they have provided an easy to understand glossary of terms. Most important of all is the need for staff to inform the public about geoheritage in an easy to understand way that is inspiring and sparks interest and enthusiasm.

These guidelines are the result of an international cooperation within the recently formed WCPA Geoheritage Specialist Group. This group is expanding all of the time and has expertise and experience on all aspects of geoheritage and its conservation. Members are ready and willing to help protected and conserved area colleagues in their work.

I commend these guidelines on geoheritage to all involved in the establishment and management of protected and conserved areas to ensure that we protect our geodiversity as well as biodiversity heritage.

Dr Kathy MacKinnon
Chair
IUCN World Commission on Protected Areas

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This guideline is dedicated to Dr Graeme L. Worboys who contributed so much to its development and died before it was published.

Finally, many thanks for the encouragement of colleagues in the IUCN WCPA Geoheritage Specialist Group, to Tim Badman the budget holder and for the forbearance of my wife Lindsay.

Executive summary

These Guidelines are to help all of those involved in any aspect of protected area establishment and management and the stewardship of conserved areas to understand and address the conservation of geoheritage (termed *geoconservation* throughout these Guidelines). The explanatory chart in Section 1 guides the reader to those sections that are of most relevance to their role and activity.

The summary of each section includes the Best Practice Guideline(s) for users.

Section 1: Purpose, content and use of the guidelines
This section describes the purpose and the target readership for the guidelines, outlines the context of geoconservation, provides a table and diagram to guide the reader through the document and notes the key additional sources of guidance.

Section 2: Defining the context of geoconservation in protected and conserved areas: Key concepts and definitions
This section provides standard definitions of geoheritage, geodiversity and geoconservation; describes the five key values of geoheritage and geodiversity; explains the relevance of geoconservation for IUCN and for protected areas.. It also advises on the application of these Guidelines to Other Effective Conservation Mechanisms and "conserved areas".

We recommend that all users read this section as it provides essential context for the remainder of the guidelines.

Best Practice Guideline No. 1: To avoid confusion, use the definitions of geoheritage, geodiversity, geoconservation, geoconservation protected areas and geosites consistently.

Best Practice Guideline No. 2: These Guidelines should be applied to Other Effective Conservation Mechanisms and other "conserved areas", as well as protected areas.

Section 3: Applying general principles of geoconservation in protected and conserved areas management
This section describes nine general principles for geoconservation as the basis for establishing and managing geoconservation in protected areas. We recommend that all users read this section as it also provides essential context for applying the guidelines.

Best Practice Guideline No. 3: Use the nine principles for geoconservation in inventory, planning, objective setting, management and monitoring of geoheritage features and processes.

Section 4: Establishing geoconservation protected and conserved areas
This section describes the key steps in the establishment of new geoconservation protected areas or for protecting geological and geomorphological features and processes as part of existing protected areas: defining the purpose, deciding on the scale of operation (national, regional or local), developing an inventory of geoheritage features and processes, and defining site assessment criteria. Examples are provided. The section spells out the importance of incorporating geoconservation in national, regional and local planning documents. The relevance of different types of protection mechanisms, governance, ownership and tenure arrangements are described. Requirements for relevant expertise are discussed. The relevance of international approaches, such as World Heritage, Global Geoparks, as well as Biosphere Reserves and Ramsar sites, are briefly discussed.

Best Practice Guideline No. 4: Use the eight types of geoheritage interests (Table 4.1) to help define the purposes of a geoconservation protected area or geosite network.

Best Practice Guideline No. 5: Make a geosites inventory using the flow chart approach in Figure 4.1.

Best Practice Guideline No. 6: Ensure that clear geosite assessment criteria are utilised, covering scientific study, educational use, geotourism and recreational use.

Best Practice Guideline No. 7: Encourage the development of action plans at national, regional and local scales to ensure that geoconservation is included in key decision documents.

Best Practice Guideline No. 8: Use the WCPA guidance on protected areas and other effective area-based conservation measures to ensure the most effective protection mechanism for the geosite.

Best Practice Guideline No. 9: Use experts to ensure technical input to geoconservation planning, management and communication.

Best Practice Guideline No. 10: Consider whether the protected area and its geoheritage features and processes could meet the criteria for UNESCO status under the World Heritage Convention and/or the Global Geoparks Network.

Best Practice Guideline No. 11: Consider how geodiversity and geoheritage in Biosphere Reserves and Ramsar sites can be managed to achieve conservation of biodiversity and wetlands, respectively, and of geoheritage.

Section 5: Geoheritage management in protected and conserved areas

This section provides detailed guidance on all aspects of managing geosites in protected areas, including management planning, operational aspects, applying the IUCN Management Categories, incorporating spiritual and cultural values, and monitoring and evaluation systems. It concludes with examples of geoconservation management.

Best Practice Guideline No. 12: Follow the two-stage generic framework of conservation needs analysis and conservation planning and delivery to incorporate geoconservation into protected area management plans.

Best Practice Guideline No. 13: Use a systematic approach to guiding management operations, including suitability of materials for trails and buildings, safety reviews of major hazards and the effects of climate change.

Best Practice Guideline No. 14: Assess the relevance of each of the IUCN protected area management categories in establishing new protected areas for geoconservation or in improving the management of existing ones for geoconservation.

Best Practice Guideline No. 15: Include cultural and spiritual values in the purposes and management of geoconservation protected areas and, where appropriate, include geoheritage in protected areas designed for spiritual and cultural values.

Best Practice Guideline No. 16: Develop monitoring schemes to assess and evaluate critical features and natural processes, and adjust plans accordingly (in an adaptive management framework) to ensure geoconservation goals are achieved.

Section 6: Dealing with threats to geoheritage in protected and conserved areas

This section focuses on threats to geoheritage in protected areas and how to deal with them. The concepts of *sensitivity* and *vulnerability* of geoheritage are defined as a basis for making management decisions. The principal threats to geoheritage in protected areas are described. Guidance is provided on assessing risk and impacts. Generic site management guidelines for dealing with threats from nine particular sources are listed. Finally, the interaction between geodiversity and biodiversity conservation is discussed and the principal issues in management identified.

Best Practice Guideline No. 17: Use the concepts of *sensitivity* and *vulnerability* to guide assessments of threats and their potential impacts on geoheritage features and processes.

Best Practice Guideline No. 18: Take a multi-step approach to address threats to geoheritage, including identifying type of threat, sensitivity of site to threat, risk assessment and prioritisation of management actions.

Best Practice Guideline No. 19: Recognise both positive and negative interrelationships between biodiversity and geodiversity conservation to provide the best possible outcome for nature conservation.

Section 7: Geoheritage management in selected situations

Detailed advice is provided on landforms, processes and features; threats; and management principles and guidelines for four different situations: caves and karst, glacial and periglacial, minerals and palaeontology, and volcanic. Access to case studies is provided through URL links in the references section.

Section 8: Education and communication for geoconservation

This section sets out the general principles and practices for interpretation, education and public outreach for geoconservation. It deals with how both new media and traditional forms can be used effectively.

Best Practice Guideline No. 20: Determine the nature and characteristics of the target audience in designing effective public outreach on geoconservation.

Best Practice Guideline No. 21: Include interpretative planning, off-site environmental education outreach programmes and web-based or mobile app-assisted interpretation for geoconservation protected areas to attract visitors, improve understanding of geoconservation and to enhance the visitor experience

Best Practice Guideline No. 22: Use a variety of conventional media to inform the public about geoconservation.

Section 9: Overview

Key points for readers are described, stressing the important interaction and interdependency between geoconservation and biodiversity conservation, and the need for active management of geoheritage and for good communication.

© Penelope Figgis

This Best Practice Guideline is dedicated to Dr. Graeme L. Worboys, AM (1950-2020): an inspiring colleague, a leader on geoconservation and a campaigning conservationist.

Purpose, content and use of the guidelines

1

Travertine terraces and pools formed from deposition of calcium carbonate, Huanlong National Park and World Heritage Site, Sichuan Province, China. © Roger Crofts

This section provides:

- a summary of the purpose and content of the guidelines (1.1)
- a quick guide to using the guidelines and locating particular topics (1.2)
- key additional sources of information (1.3).

1.1 Purpose of these Guidelines

These Guidelines are to help professionals working in and for protected areas, and the custodians of conserved areas to incorporate conservation and management of geoheritage and geodiversity into their work at all scales from the system level to the site level. We recommend use of a simple definition of ***geoconservation:*** "the conservation of geodiversity for its intrinsic, ecological and geoheritage value" (Sharples, 2002).

These Guidelines provide links to related guidance on particular topics in the WCPA Best Practice Guidelines series, and to case studies from around the world illustrating best practices in geoconservation.

Many protected area professionals and custodians of conserved areas are not geoscientists and may find the language and concepts of the Earth sciences difficult to understand and incorporate in their work. This is understandable as the terminology is often complex, the concepts are quite different from those of biodiversity conservation (for which many protected areas have been established) and it is often felt that geological features are relatively static and need very little attention (Crofts 2014). For these reasons, geoheritage and geodiversity (as defined in Section 2.2) are often overlooked in protected area conservation and management, but may have high value as an integral part of nature and need to be understood and looked after. Moreover, the functional health of many protected areas depends on understanding the non-biological processes that have created the area, are operating at the present time, and may be influential in the future. In addition, in a protected area there may be significant geological features, which are of interest to visitors, and which might also represent significant natural hazards (such as volcanic activity) that must be properly addressed by management staff.

These Guidelines are intended to help improve the conservation and management of geoheritage and geodiversity in protected and conserved areas and recognition of the interrelationships and interactions with biological features and processes. They are not a textbook on geoconservation management practice, but rather set out the essential background, context and principles; summarise relevant material to make it more readily accessible to users in one volume; and provide links to the key literature and additional sources that include detailed practical guidance. The use of best practice examples from around the world will hopefully give users renewed confidence in looking after geoheritage and in connecting geoconservation with biodiversity conservation.

1.2 Using the Guidelines

It is unlikely that most users will need to read these guidelines from cover to cover, but will use them as a reference source for their particular needs and circumstances concerning geoconservation in protected area establishment and management.

These Guidelines are organised in nine sections (Table 1.1). Following two key contextual sections, they provide a progression from establishing a geoconservation protected area system at the national or regional scale, to establishing individual geoconservation protected areas or adding geoconservation protection to already existing protected areas, including managing and monitoring and arrangements for public outreach (Figure 1.1). Managers of existing protected and conserved areas may proceed directly to Section 5. We do, however, strongly recommend that everyone read Sections 2 and 3, as they provide essential contextual material for geoconservation. Table 1.1 and Figure 1.1 provide a quick guide to locating particular topics within the document.

1.3 Key additional sources

Several key additional sources give an overview of geoconservation in protected areas. Crofts & Gordon (2014, 2015) provide an introduction to the concepts, terminology and links between geoconservation and biodiversity conservation, and these are freely available. More comprehensive treatments of geodiversity and geoheritage and their assessment, protection and management are available in Gray (2013) and Reynard & Brilha (2018). The journal *Geoheritage* is the key international source for articles on all aspects of geoheritage. Most articles are available as open source or can be accessed through ResearchGate.

Table 1.1. Structure and layout of the guidelines.

No.	Section	Main topics (subsection)	Pages
1	**Purpose, content and use of the guidelines**	■ Purpose (1.1) ■ Using the guidelines (1.2) ■ Key additional sources (1.3)	2 2 2
2	**Defining the context: Key concepts and definitions**	■ Why is geoconservation needed? (2.1) ■ Definition of key terms (2.2) ■ Values of geoheritage and geodiversity (2.3) ■ IUCN's role in geoconservation (2.4) ■ Geoconservation and the IUCN definition of protected and conserved areas (2.5)	6 6 8 10 11
3	**Applying general principles of geoconservation in protected and conserved areas management**	■ Key guiding principles for geoconservation (3.1)	14
4	**Establishing geoconservation protected and conserved areas**	■ Defining the purpose and operational scale (4.1) ■ Making an inventory (4.2) ■ Determining site assessment criteria (4.3) ■ Examples of geoheritage inventories and site assessments (4.4) ■ Incorporating geoconservation into national, regional and local action plans (4.5) ■ Protection mechanisms (4.6) ■ Types of governance (4.7) ■ Expertise requirements (4.8) ■ International approaches to geoconservation (4.9)	22 24 25 29 29 32 32 32 32
5	**Geoheritage management in protected and conserved areas**	■ Management planning (5.1) ■ Geoconservation and protected area operations (5.2) ■ Application of the IUCN protected area management categories to geoconservation. (5.3) ■ Incorporating spiritual and cultural values of geoheritage (5.4) ■ Monitoring and evaluation of geosites (5.5) ■ Examples of geoconservation management (5.6)	40 50 50 52 57 58
6	**Dealing with threats to geoheritage in protected and conserved areas**	■ Concepts of sensitivity and vulnerability (6.1) ■ Principle threats (6.2) ■ Dealing with threats assessing risk and impacts (6.3) ■ Dealing with threats: best practice guidance on key topics (6.4) ■ Dealing with the interaction between geodiversity and biodiversity conservation (6.5)	64 66 66 66 85
7	**Geoheritage management in selected situations**	■ Karst and cave protected and conserved areas (7.1) ■ Glacial and periglacial protected and conserved areas (7.2) ■ Palaeontological and mineral sites (7.3) ■ Volcanic protected and conserved areas (7.4)	88 91 100 104
8	**Education and communication for geoconservation**	■ Interpretation (8.1) ■ Education (8.2) ■ Public outreach (8.3) ■ Communicating by new digital media (8.4) ■ Communication by conventional media (8.5)	111 111 114 117 119
9	**Overview**	■ Summary of key points	121

Figure 1.1. Key steps in establishing and managing geoconservation protected areas and the main topics covered in these guidelines.

Geoconservation concepts, definitions and principles (Sections 2 and 3)

Establishing geoheritage protected areas

Define the purpose, goals and scale **(4.1)**

↓

Site inventory and documentation **(4.2)**

↓

Site assessment and selection criteria **(4.3)**

↓

Incorporating geoheritage into national and local action plans **(4.5)**

↓

Protection mechanisms **(4.6)** Types of governance **(4.7)**
Expertise requirements **(4.8)** International approaches **(4.9)**

Managing geoheritage in protected areas

Incorporating geoconservation into protected management plans **(5.1)**

- documentation
- threat analysis
- management zoning
- management objectives
- site condition monitoring
- interpretation potential

↓

Geoconservation and protected operations **(5.2)**
Application of the IUCN protected area mangement categories **(5.3)**
Incorporating spiritual and cultural values of geoheritage **(5.4)**
Monitoring and evaluation od sites **(5.5)**

↓

Dealing with threats
Nature of the threats **(6.1)**
Sensitivity and vulnerability **(6.2)**
Assessing risk and impacts **(6.3)**
Dealing with threats from particular sources **(6.4)**
Dealing with the interaction between geodiversity and biodiversity conservation **(6.5)**

↓

Examples of geoconservation in selected environments **(7.1 - 7.4)**

Communication and education

Implement arrangements for public engagement and outreach **(8.1 - 8.5)**

Defining the context of geoconservation in protected and conserved areas: Key concepts and definitions

2

Siccar Point in Scotland is a key site in scientific discovery of the formation of the Earth. This Site of Special Scientific Interest is protected for the rock formations that James Hutton discovered in 1788, and reported in his 1795 treatise *Theory of the Earth*. The junction between the lower older steeply bedded rocks and the overlying younger gently dipping rocks represents a vast gap in the rock record with many cycles of erosion and deposition in between, and indicates the immensity of geological time. The people in the photo are Graeme L. Worboys (right) and John Gordon (left); both are authors of these Guidelines. © Roger Crofts

This section provides contextual material for geoconservation in protected areas. It addresses:

- why geoconservation is needed (2.1)
- definitions of key terms; (2.2)
- core values of geoconservation (2.3)
- the role of IUCN in geoconservation (2.4)
- geoconservation within the IUCN definition of a protected area (2.5).

2.1 Why is geoconservation needed?

There is a popular view that rocks and landforms are reasonably robust and not liable to change or damage by human activities and therefore do not need special measures for their conservation. This is not the case, as they are subject to both natural threats and human interventions. Geodiversity and geoheritage are undoubtedly part of the Earth's natural heritage, but compared with biodiversity their conservation and management only recently began to be considered in a more structured way. There are a number of reasons for this imbalance (Crofts, 2014, 2018). There is no equivalent of the Convention of Biological Diversity for geoconservation or geodiversity, although there are several international agreements or conventions, such as the UNESCO World Heritage Convention and the UNESCO Global Geoparks programme, that include geoconservation. There is low awareness within society about how important it is to protect key geological and geomorphological features and processes for their geoheritage values, and about the role of geodiversity in supporting biodiversity and ecosystem functions and services.

2.2 Definitions of geodiversity, geoheritage and geoconservation

As the practice of geoconservation has evolved, various terms and definitions have been introduced. For reasons of clarity, consistency and simplicity, and to assist communication, the following terminology is recommended (Crofts & Gordon, 2014, 2015).

Geodiversity is the variety of rocks, minerals, fossils, landforms, sediments and soils, together with the natural processes that form and alter them. It includes past and present geological and geomorphological features and processes that record the history of the Earth and the evolution of life forms as represented in the geological record, including plants and animals and their habitats. The elements of geodiversity provide the foundation for life on Earth, and they maintain natural capital and ecosystem services.

Geoheritage comprises those elements and features of the Earth's geodiversity, either singly or in combination, that are considered to have significant value for intrinsic, scientific, educational, cultural, spiritual, aesthetic, ecological or ecosystem reasons and therefore deserve conservation. Geoheritage constitutes a legacy from the past to be maintained in the present and passed on for the benefit of future generations. Geoheritage records the cumulative story of the Earth preserved in its rocks and landforms, as in the pages of a book, albeit fragmentary and with pages missing. It is represented in special places (*geosites;* see definition below) and objects (specimens *in situ* and in museum collections) that are fundamental to our appreciation of the history of the Earth and the evolution of life. The underlying philosophical basis is set out in the Digne Declaration on the Rights of the Memory of the Earth (Box 2.1), which outlines a rights-based approach to geoheritage and is a foundation of UNESCO Global Geoparks.

It is important to appreciate the range of features that comprise *in situ* geoheritage. They include:

- rock exposures that are unique or representative of particular geological processes or stages in the evolution of the Earth, either globally or in particular regions;
- landforms that are unique, classic or representative forms arising from particular processes at present or in the past (e.g. glaciation);
- active systems (e.g. rivers, deserts, glaciers and soils); or
- assemblages of all of these components.

Geoheritage in protected areas can, therefore, exist across a continuum of scales from small individual features, such as rock outcrops or boulders transported long distances by glaciers (e.g. The Pierre á Dzo, Monthey, Switzerland), to whole landscapes, such as mountain systems comprising assemblages of rocks, landforms and soils (e.g. Los Glaciares National Park, Argentina) or volcanic systems that host extremely diverse microhabitats (e.g. Yellowstone Caldera, USA, and the associated Greater Yellowstone Ecosystem, including charismatic megafauna and species that inhabit hot-springs). The only limit for site size is set by the management unit and the management scheme.

It is easy to be confused by what is a geoconservation protected area. It can entirely comprise a single feature of value or representation of a past or current natural process, and does not require a diversity of features or forms. For example, a thick sequence of apparently monotonous, deep-water limestones may appear relatively uniform, but may nevertheless represent an important part of the geological evolution of a particular region or the evolution of life. Equally, a particular layer of rocks may hide a rich diversity of fossil life forms that is not readily evident to the naked eye, but may be a crucial feature of an internationally important type section or reference locality for a particular evolutionary phase or change. Alternatively, a

Box 2.1

The Digne Declaration

Declaration of the Rights of the Memory of the Earth

1. Planets, like people, have their own life history – they are born, they mature and die. For planets, as for people, each life history is unique: the time has come to recognise the uniqueness of the Earth.
2. Our planet, the Earth, is the only bond which unites all mankind. We are, each and every one of us, linked to the Earth, and it is the link between us, and indeed all life.
3. The Earth is 4.5 thousand million years old and the cradle of life; life which has undergone many metamorphoses and renewals through geological time. Its long evolution, and slow maturation, have shaped the environment in which we live.
4. Our history and the history of the Earth cannot be separated. Its origins are our origins, its history is our history and its future will be our future.
5. The surface of the Earth is our environment. This environment is different, not only from that of the past, but also from that of the future. We are the Earth's companions for the present, but are only transient, and with time we will pass.
6. Just as an ancient tree retains the record of its life and growth, the Earth retains memories of the past inscribed both in its depths and on its surface, in the rocks and in the landscape, a record which can be read and translated.
7. We have always been aware of the need to preserve our memories – our cultural heritage. Now the time has come to protect our natural heritage. The past of the Earth is no less important than that of Man. It is time for us to learn to protect this Earth heritage, and by doing so learn about the past of the Earth, to learn to read this 'book', the record in the rocks and the landscape, which was mostly written before our advent.
8. Man and the Earth share a common heritage, of which we and our governments are but the custodians. Each and every human-being should understand that the slightest damage could lead to irreversible losses for the future. In undertaking any form of development, we should respect the singularity of this heritage.
9. The participants of the First International Symposium on the Conservation of our Geological Heritage, including over 100 specialists from more than 30 nations, urgently request all national and international authorities to take into consideration and to protect this heritage, by all the legal, financial and organisational measures that may be necessary.

Source: http://www.progeo.ngo/downloads/DIGNE_DECLARATION.pdf

protected area may include some geoheritage features, but have been designated primarily for other, non-geoconservation reasons. On the other hand, it may have a great variety of features, forms, and processes of geoconservation significance. All of these variations are valid, and it is essential therefore to ensure that the criteria for the selection of a geoconservation protected area or the management of geoheritage in protected areas are explicit. Guiding principles are provided in Section 3 and more detailed guidance on selection criteria is given in Section 4.

It is important to emphasise that geoheritage features must have special geological or geomorphological value (Section 2.3). There will be other cases, however, where geological or geomorphological features are not exceptional in themselves, but are important for cultural or archaeological heritage (e.g. a cave site with paintings or hominid fossils).

Sites or areas of high geoheritage value may exist across the full range of IUCN Protected Area Categories, either as primary interests or as components within a wider assemblage of natural features (see Section 5.4).

Geoconservation has been defined as "the conservation of geodiversity for its intrinsic, ecological and (geo)heritage values" (Sharples, 2002). Essentially, geoconservation in protected areas is the practice of conserving, enhancing and promoting awareness of geodiversity and geoheritage. Geoconservation is, therefore, concerned primarily with conservation of features and/or elements that have special geological or geomorphological value. Geoconservation can help to maintain biodiversity and the functioning of healthy ecosystems, as well as the conservation of geoheritage.

Geosite is used to refer to any site that has a single feature or a variety of geological or geomorphological features and processes worthy of protection on account of their scientific value (Brilha, 2018a). The term "geosites" is short-hand for geological sites or geomorphological sites.

To summarise, a hierarchy of terms is used through this Guideline: **Geodiversity** is the totality of abiotic nature**,** of which some elements have significant value requiring conservation, termed **Geoheritage,** which is managed in **geosites,** that are either formally protected areas or are "conserved areas", under the generic label **geoconservation.**

The overriding purpose of **Geoconservation in protected and conserved areas** is to conserve **geoheritage** and **geodiversity** located in **geosites**. The activity is geoconservation management in geoconservation protected areas, or as a component of protected area management in sites with other purposes as well.

Best Practice Guideline No. 1: To avoid confusion, use the definitions of geoheritage, geodiversity, geoconservation, geoconservation protected areas and geosites consistently.

2.3 Values of geoheritage and geodiversity

Geoheritage and geodiversity are not only tangible matters, but are underpinned with important values. Five basic geoconservation values are described to ensure that all of the facets of geoconservation are understood and recognised in practice.

First, geoheritage is important for ethical reasons, or what is generally termed **intrinsic value**. Too often in the recent past, the focus has been exclusively on the usefulness of diversity to society. However, there is ample ethical justification for protecting our geoheritage just because it is there: *for its own sake*. This reason is congruent with society's responsibility to conserve nature. It underpins the Digne Declaration.

Second, it is important to protect geoheritage as a **scientific and educational resource** that contributes to knowledge of the evolution of the Earth. For example, Hutton's Unconformity at Siccar Point, Berwickshire, Scotland, is one of the key sites where James Hutton, 'the founder of modern geology', advanced his theory of the Earth encapsulated in his timeless statement that 'we see no vestige of a beginning, – no prospect of an end' (see frontispiece photo). Similarly, the fossils in the Burgess Shale in Yoho and Kootenay National Parks, British Columbia, Canada, provide exceptional insights into the evolution of complex life forms on Earth over 500 million years ago.

Third, geoheritage in protected areas can be important for **aesthetic, cultural and spiritual heritage values** (Verschuuren et al., in press). This may include communities who identify fully with their local geoheritage, such as the mountain Triglav, in the National Park of the same name in Slovenia and which is represented on the national flag, or Mount Fuji, a cultural icon to Japan. Some sites with important geological features, such as Yosemite and Yellowstone National Parks in the USA, have a cultural and educational importance because of their role in the development of protected areas thinking and action, while many others have significant value for aesthetic reasons and for recreation and tourism activities. Similarly, there are many sacred sites, such as Christian monasteries of Meteora, Greece, and many cultural history sites, such as the caves with early paintings in KwaZulu-Natal, South Africa, that demonstrate the close connection between geoheritage and cultural and spiritual heritage.

Geoheritage and cultural heritage can also be linked in many other ways; for example, 'soft' rock formations form the settings for 'cave cities' in the World Heritage Sites at Petra in Jordan and Vardzia in Georgia.

Fourth, geodiversity has an important **ecological value** in supporting biodiversity and ecosystem functioning. The

Photo 2.1 Ngorongoro Crater, Ngorongoro Conservation Area, United Republic of Tanzania, is an example of intrinsic value: it is the crater of an extinct volcano of substantial size and also the home of many native fauna. © Roger Crofts

Photo 2.2. Burgess Shale, Yoho National Park, British Columbia, Canada, is an example of a site where research has enabled new knowledge to be developed about the evolution of life on Earth some 500 million years ago, during the time of the "Cambrian Explosion". A Parks Canada interpretive guide holds a large fossil specimen at Walcott Quarry, Yoho National Park, Canada.© Parks Canada Ryan Creary

Photo 2.3. Rock art from Royal Natal National Park, KwaZulu-Natal, South Africa, illustrating the use of sheltered natural sites for communicating symbolically in times past. © Sue Stolton

Photo 2.4. The use of natural materials *in situ* is exemplified in the Petra Archaeological Park and World Heritage site, Jordan. Multi-coloured sandstone rocks have been carved into many types of buildings (especially temples, tombs and civic buildings) over the centuries of Nabatean and Hellenistic presence. © José Brilha

diversity of substrates, landform mosaics and soil formations, together with processes such as water flow regimes, sediment supply, erosion and deposition, provide the foundations for habitats and species and ecosystem functioning. In many environments, the complex patterns of micro- to macro-scale topography, soils and geomorphological processes and disturbance regimes provide conditions for high species richness and diverse mosaics of habitats.

The relationship between the geo- and bio-diversity elements is essential to the concept of ecosystems. The recently coined term 'conserving nature's stage' is based on flora and fauna being the 'actors' with geodiversity as the 'stage' on which they thrive. As a coarse filter approach, the conservation of biodiversity is seen as best achieved by conserving the stage, particularly in times of climate change when having a range of habitats for plants and animals to relocate to may be crucial to their survival (Anderson & Ferree, 2010; Gross et al., 2016).

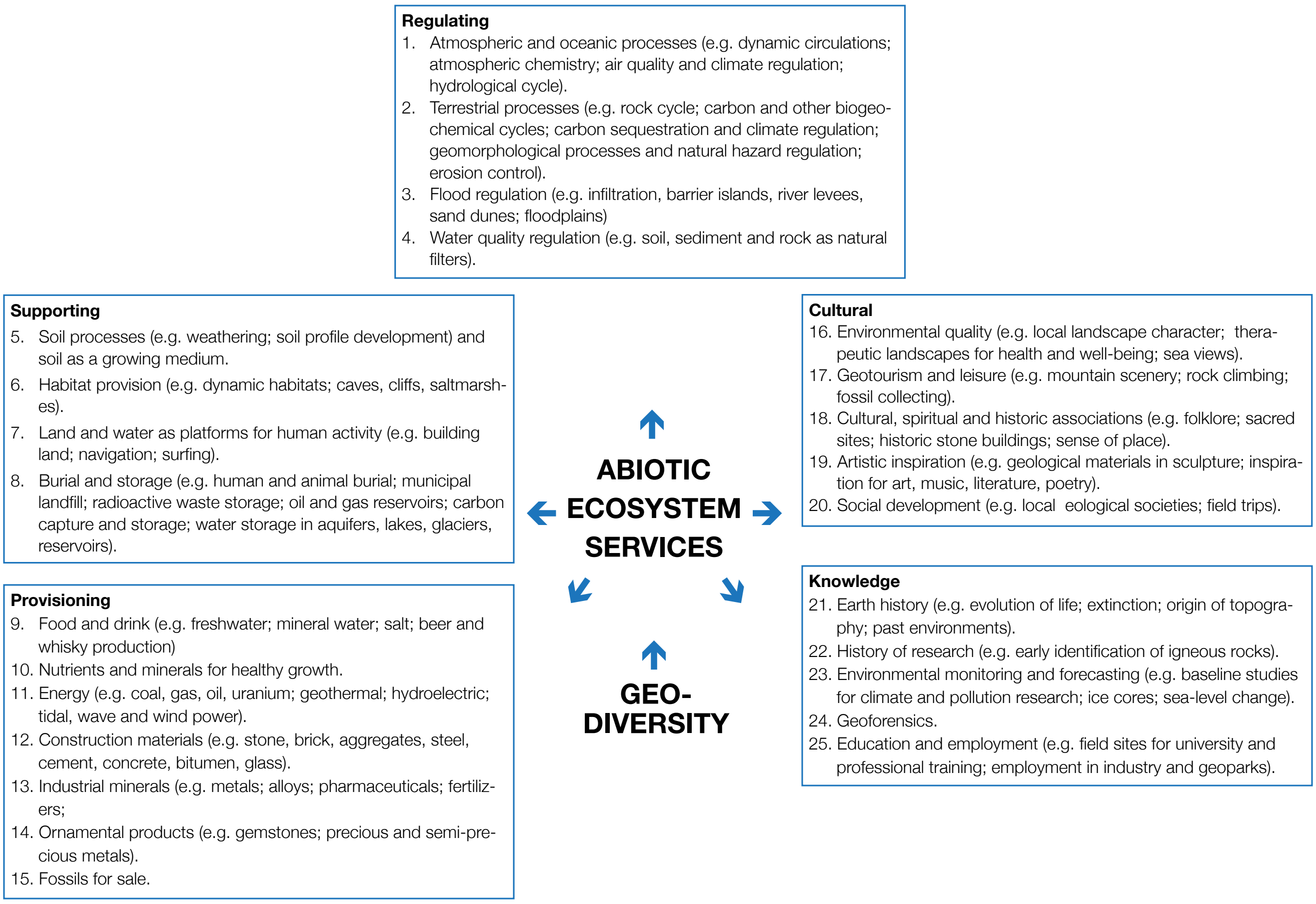
Fifth, geodiversity is a critical component of ecosystems, and specifically provides many **environmental goods and ecosystem services**, which are the direct and indirect benefits that humans receive from the natural environment and properly functioning ecosystems (Figure 2.1; Table 2.1). To support the provision of these services, managers must work with nature, rather than against it, and seek to maintain the natural systems and processes, as a fundamental role of protected areas. It also means that all elements of ecosystems must be seen as a whole, rather than, for example, considering only biodiversity or only geodiversity. In other words, we should think of *nature's services* or *nature's contribution to people* (Díaz et al., 2018). There is no doubt about the integrated approach to ecosystems as defined in Article 2 of the Convention on Biological Diversity: "'**Ecosystem**' means a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit." Neugarten et al. (2018) provide a useful compendium.

2.4 IUCN's role in geoconservation

IUCN has played a leading role in geoconservation for many decades, notably through its role as the statutory advisory body on natural heritage to the UNESCO World Heritage Committee. The World Heritage Convention recognises geoheritage as an integral component of the Outstanding Universal Value of World Heritage Sites, notably through World Heritage criterion (viii), which is explicitly related to geoheritage (see Section 4.8 (i)).

In recent years IUCN's mandate for geoconservation has been further established in two ways. First, IUCN WCPA's *Guidelines for Applying Protected Area Management Categories* state clearly that all protected areas should aim where appropriate to 'conserve significant landscape features, geomorphology and geology' (Dudley, 2008). Second, resolutions approved at three IUCN World Conservation Congresses place geoconservation in the Union's programme (IUCN, 2008, 2012, 2016a). Resolutions 4.040 of 2008 and 5.048 of 2012 state that geodiversity is part of natural diversity and geoheritage is part

Figure 2.1. **Ecosystem services from a geodiversity perspective.**



Source: Gray, 2018.

of natural heritage. Resolution 6.083 of 2016 promotes and supports national and international initiatives directed towards the conservation and sustainable use of moveable geoheritage (e.g. fossils, meteorites and volcanic bombs).Together, these resolutions represent a benchmark in recognising the integrative role and relevance of geoheritage and geodiversity, which must also be considered in the planning, design, governance and management of protected areas.

2.5 Geoconservation and the IUCN definition of a protected area and of 'conserved areas'

IUCN defines a protected area as:

A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Dudley, 2008).

The key points for geoconservation are:

- "long-term conservation of nature" including geoconservation;
- sub-surface rocks and minerals, as well as surface features, are included;
- management can, in practice, mean doing nothing in order to retain natural processes;
- managers should ensure that geoheritage features are not damaged and the processes forming them are not impaired; and
- managers must consider geoconservation and biodiversity conservation together.

IUCN also recognises the existence of "conserved areas", namely areas that are not protected areas, and may not have conservation as a primary objective, but which nevertheless conserve nature in the long-term (IUCN-WCPA Task Force on OECMs, 2019). The Convention on Biological Diversity has also defined "other effective area-based conservation measures" or OECMs as: 'A geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the *in situ* conservation of biodiversity, with associated ecosystem functions and services and, where applicable, cultural, spiritual, socioeconomic, and other locally relevant values' (CBD Decision 14/8).

It should be noted that most areas that qualify as OECMs have not yet been identified and included in national or international databases. Furthermore, as OECMs are defined within the context of the CBD, there may also be conserved areas governed by autonomous governance authorities (local communities, indigenous peoples, first nations etc.) who do not wish to be recognised under the CBD definition, and some states that may not accord them this recognition. These conserved areas nevertheless contribute towards long-term outcomes for the in-situ conservation of biodiversity (Borrini-Feyerabend and Hill, 2015), and should fall within the scope of interest of these Guidelines.

These Guidelines can therefore be applied in respect of protected areas, OECMs and other "conserved areas", as many sites for geoheritage may occur across these different forms of governance of nature. Indeed, many territories and areas conserved by Indigenous peoples and local communities may be founded on geoheritage values that have cultural and spiritual significance.

Best Practice Guideline No. 2: These Guidelines should be applied to Other Effective Conservation Mechanisms and other "conserved areas", as well as protected areas.

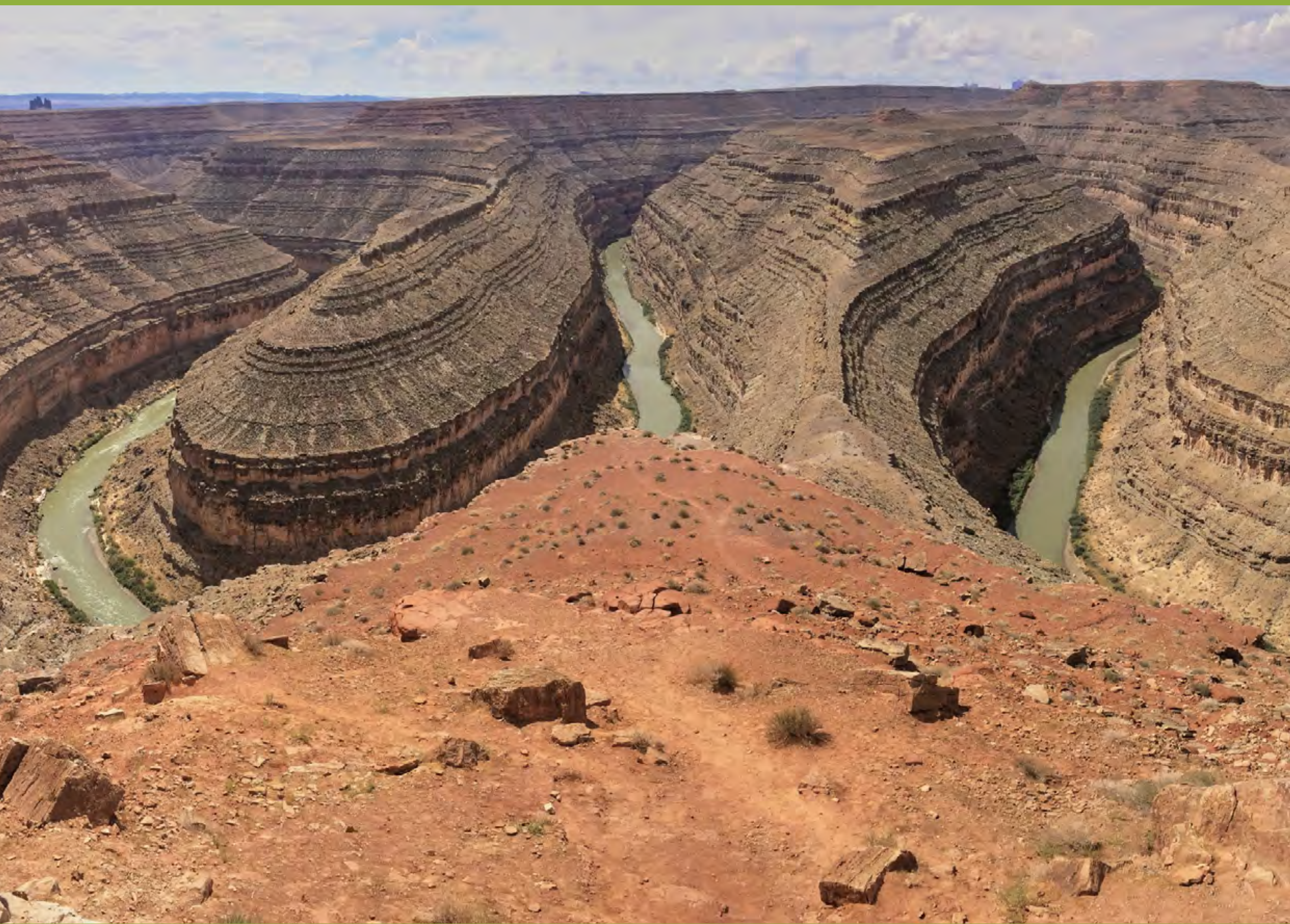
Table 2.1. Example of goods and services provided by geodiversity in the coastal region of São Paulo State, Brazil.

Ecosystem	Regulation	Supporting	Provisioning	Cultural	Knowledge
South Brazil Shelf	■ Oceanic circulation promoted by marine landforms ■ Global climate regulation and carbon storage by marine sediments	■ Part of hydrological cycle ■ Habitat provision for both animal and plant species	■ Food supply by providing habitats for edible sea species ■ Oil and gas supplies	■ Recreation and tourism in coastal islands, rocky shores, beaches, trails, waterfalls ■ Sense of place and spiritual values, especially for traditional communities ■ Promotion of voluntary work on nature conservation on NGOs and other institutions dealing with the Atlantic Forest and marine environments ■ Health and well-being promoted by scenic beauty and good environmental conditions	■ Scientific research into several branches of geosciences, and coastal and marine topics ■ Field resources for geoscience students ■ Records of past climates ■ Education about geosciences
Rocky shore	■ Long-term carbon cycle regulated by chemical weathering of silicate rocks	■ Habitats for various species ■ Places for anchorage ■ Foundations for buildings ■ Shelters for ancient settlements	■ Natural and cultivated food production		
Dune	■ Water infiltration and recharging of aquifers, and as part of the hydrological cycle ■ Control of water quality	■ Control and storage of water	■ Growth of specific plant species related to sand sediments		
Mangrove	■ Storage of blue carbon ■ Control and storage of water ■ Wave-energy dissipation	■ Part of hydrological cycle ■ Habitats for various species	■ Terrestrial or transitional shelter or nursery ■ Natural and cultivated food production		
Beach	■ Erosion control ■ Wave-energy dissipation and shoreline protection	■ Natural retention and sediment transport ■ Water filtration	■ Fishing		
Estuary and lagoon	■ Natural hazard regulation by erosion control	■ Part of hydrological cycle	■ Refuge and/or marine nursery ■ Natural and cultivated food production		
Coastal plain	■ Erosion control ■ Recharge of aquifers	■ Typical resting vegetation	■ Terrestrial or transitional refuge or nursery		
River	■ Water flow and flood regulation ■ Draining ■ Participation in water cycling and ocean circulation	■ Part of hydrological cycle ■ Water pathways for transportation	■ Water supply by several river basins with sources in the Serra do Mar and in the Atlantic Plateau ■ Sand mining ■ Energy supply from hydroelectric plants		
Serra do Mar	■ Local climate regulation by the Serra do Mar Mountain Range	■ Soil formation as support to the Atlantic Forest vegetation and to banana cultivation	■ Rocks, saprolite and sands as ornamental and construction materials		

Source: modified from Garcia et al., 2018.

Applying general principles of geoconservation in protected and conserved areas management

3



Goosenecks, technically river meanders cut or incised into the landscape, on the San Juan River Utah State Park, USA. © José Brilha

This section describes nine general principles that should inform both the establishment of new geoconservation protected and conserved areas and the management of existing ones.

The principles apply to the protection of geodiversity and geoheritage across the full range of IUCN Protected Area Management Categories, including those where geoheritage is not the primary reason for designation.

3.1 General principles

A number of general geoconservation principles should underpin all protected and conserved areas management (Table 3.1). These principles should be incorporated in national, regional and local geodiversity action plans where they exist, and into protected area system and management plans in general. Specific applications in geoconservation protected area management plans must match local conditions, legislation and management systems. The principles also apply to the management of protected areas in all IUCN Protected Area Management Categories, even where geoheritage is not the primary reason for designation. Geoconservation should be an integral part of the management plan (Sections 5.1, 5.2 and 5.3).

Principle 1. The multiple values of geoheritage and geodiversity should be recognised.

Conservation of all the values of geodiversity and geoheritage identified in Section 2.3 should be an integral part of protected area management.

Principle 2. Effective geoconservation requires a rigorous and systematic approach to all aspects of site identification, assessment, management and monitoring.

Inventories of geoheritage interests and an assessment of their values are required, followed by effective conservation management, monitoring and, where appropriate, use of interpretation and stakeholder outreach to enhance awareness and education. Clear management objectives should be tailored appropriately for different categories of geoconservation protected area, recognising the different requirements of 'exposure', 'integrity' and 'finite' sites (Section 5.2). Protection of the geoheritage interest will normally be the primary objective, but complementary objectives such as geotourism and conservation of biodiversity may be included where they do not conflict. Periodic monitoring of the condition of geoconservation protected areas is essential to establish the condition and state of the features of interest; whether these are changing and, if so, how; and whether the conservation targets are being met (Section 5.5).

Principle 3. Management of natural systems should 'work with nature', allowing for natural processes to operate over their full range of variability.

There is growing focus on the value of nature-based solutions and the promotion by IUCN and others of the role of healthy ecosystems in addressing existing and emerging global challenges, such as climate change, disaster risk reduction, food and water security, and human health and well-being (Cohen-Shacham et al., 2016; Griscom et al., 2017; IUCN, 2020). As far as possible, natural systems and processes (e.g. flow regimes in streams) should be allowed to maintain natural rates and magnitudes of change and their capacity to evolve uninterrupted across most or all of their range of variability. If intervention is essential, solutions that work in sympathy with natural processes are more environmentally sustainable and effective than trying to impose engineered solutions that seek to control or halt natural processes. For example, along coastlines building fixed structures to stem sediment loss might result in starving adjacent beaches, dunes and salt marshes and

Table 3.1. Key guiding principles for geoconservation in protected areas management.

1.	The multiple values of geodiversity and geoheritage should be recognised.
2.	Effective geoconservation requires a rigorous and systematic approach to all aspects of site identification, assessment, management and monitoring.
3.	Management of natural systems should 'work with nature', allowing for natural processes to operate over their full range of variability.
4.	Natural systems and processes should be based on sound understanding, and managed in a spatially integrated manner.
5.	Geoconservation strategies should include vulnerability and risk assessment.
6.	The inevitability of natural change should be recognised.
7.	The effects of global climate change should be assessed and acted on as far as achievable.
8.	Natural systems should be managed within the limits of their capacity to absorb change.
9.	The interaction and interdependency of geodiversity, biodiversity and cultural heritage should be recognised.

Source: adapted from Crofts and Gordon (2014, 2015).

Photo 3.1. Shilin Stone Forest, in Yunnan Province, forms part of the South China Karst World Heritage site and is a UNESCO Global Geopark. The remarkable pinnacle karst and related landforms have important aesthetic and cultural values, celebrated in poetry, painting, folklore and local customs, and represent a significant asset for geotourism. © John Gordon

Photo 3.2. Cape Mondego, Portugal, is a geosite valued for education and geotourism within a Natural Monument. © José Brilha

Photo 3.3. Removal of mangroves for cultivation makes coastal areas more vulnerable to erosion, as in this area north of Guayaquil, Ecuador. © Roger Crofts

Photo 3.4. Mangrove restoration on Cat Ba Island, offshore of Vietnam, seeks to restore natural vegetation, which in turn provides protection to habitats and to the land from erosion by the sea. © Nigel Dudley

Photo 3.5. Sand and gravel extraction from a protected Ice Age esker in Scotland has permanently destroyed the integrity of the landform. © P & A Macdonald/SNH

their associated habitats. Instead, alternative approaches, including beach nourishment, managed realignment or use of 'green infrastructure' to enhance natural forms of defence, such as sand dunes, salt marshes or mangroves, are recommended (Temmerman et al., 2013; Pontee et al., 2016).

Principle 4. Natural systems and processes should be based on sound understanding, and managed in a spatially integrated manner.

Conservation management of active systems should be based on a sound understanding of the underlying abiotic processes. This includes, for example, an understanding of coastal sediment circulation dynamics (erosion and deposition, including sources, transport pathways and sinks) within individual coastal units (coastal cells) in the preparation of shoreline management plans; integration of river, soil and slope processes in river catchment management plans; and monitoring of active processes.

Management of part of a natural system in isolation from other elements of the system should be avoided. For example, along a coastline or in a mountain area or a river basin, management should recognise the effects of connectivity and the dependencies between different parts of the system at the landscape scale (e.g. the dependency of beaches and sand spits on sediment supply from rivers, along the coast or offshore sources, or the consequences for downstream habitats resulting from changes in sediment transfer between hillslopes and river channels upstream) (Bruneau et al., 2011). More generally, spatially connected management should recognise the patterns of geodiversity and the links with biodiversity and ecosystem services as part of landscape-scale conservation (Anderson et al., 2014; Theobald et al., 2015; Zarnetske et al., 2019; Hilty et al., 2020).

Principle 5. Geoconservation strategies should include vulnerability and risk assessment.

Geoconservation management should include risk assessment, involving assessment of site vulnerability and resilience to a range of human pressures and natural changes, as well as geological risks to humans such as volcanic activity. Geoheritage features vary in their degrees of sensitivity to different types of human activity and natural changes (Section 6.1). Some may be relatively robust (i.e. the degree to which they can withstand disturbance) and therefore require relatively little management intervention. Others, however, are highly sensitive (i.e. susceptible to damage or degradation from human activities from which they may recover only over a very long period, if at all) (Sections 5.2 and 6.1). Except in the case of active glacial, river and volcanic systems, for example, the features in most geosites are relicts, so that damage or destruction is irreversible.

Principle 6. The inevitability of natural change should be recognised.

The inevitability of natural change should be recognised. No element of a natural system is static and changes will

Photo 3.6. Morrich More, in the Dornoch Firth, Scotland, is designated as a Site of Special Scientific Interest and a European Union Special Area of Conservation. A great variety of coastal landforms have developed in a highly dynamic environment over the last 7000 years and support a diversity of species-rich coastal habitats, including vegetated sand plains, intertidal flats, salt marshes, dunes, brackish pools and heath. © P & A Macdonald/SNH

occur naturally. The common approach of maintaining or enhancing the current state to preserve features may be valid where these are unlikely to be significantly affected by the natural changes. For example, in iconic mountains and resistant rock features, or in the case of some small, high-value sites where protective measures can be effectively implemented. However, in many circumstances, where natural processes are a key element of maintaining or protecting the features of interest, working with natural changes to allow geomorphological processes to adapt to the changed conditions may be the only effective strategy. This may mean the loss of some features, changes in their locations (possibly outside the boundaries of the protected area), or their realignment. Where protection is deemed necessary (e.g. to protect valuable infrastructure), it may require some form of artificial approach mimicking nature as far as possible, rather than seeking to modify substantially or destroying the geoheritage feature.

Principle 7. The effects of global climate change should be assessed and acted on as far as achievable.

The effects of climate change will inevitably challenge the management objectives of protected areas (Groves et al., 2012; Gross et al., 2016). Careful consideration will be needed where, for example, features are lost and/or processes are curtailed or intensified, thus changing the basis for protection. It may mean that the area's protection status can no longer be justified at all or that features elsewhere now merit protection. Site boundaries may also need to be altered to take account of coastal erosion or shifts in the location of dynamic features of interest. A risk-based approach should help to prioritise sites and features for monitoring (Wignall et al. 2018).

Principle 8. Natural systems should be managed within the limits of their capacity to absorb change.

The sensitivity of natural systems should be recognised, and they should be managed within the limits of their capacity to absorb change (see Section 6.1 for more detail on sensitivity). It is rarely the case that natural systems are so robust that they can absorb any change imposed upon them. Some will be more resistant to change (e.g. a rock outcrop on a hillside), whereas others will be very fragile with low thresholds for change (e.g. vegetation on a coastal sand dune, which can be lost due to trampling, leading to erosion). If limiting thresholds are crossed, the conservation effort will be negated as the original features and processes will have been irreversibly changed. For example, installation of 'hard' coast defences may interrupt sediment supply to beaches, sand dunes and salt marshes downdrift, resulting in a switch from deposition to erosion and the consequent loss of landforms and habitats.

Photo 3.7. Climate change and sea-level rise will likely lead to changes in geomorphological processes and the distributions of land-forms, habitats and species as the coastal edge moves landwards, even if 'hard' engineering solutions are used, as here in the St Kilda National Nature Reserve and World Heritage site, Scotland. © Roger Crofts

Photo 3.8. A heavily managed river system: the Yangtze above the Three Gorges Dam, China, showing the effect of the fluctuating shoreline on soil and vegetation removal, and the exposure of the rock structures. © Roger Crofts

Photo 3.9. Understanding the interaction between vegetation growth and visibility of geological features is important, as here in Jade Dragon National Park, Yunnan Province, China. © Roger Crofts

Principle 9. The interaction and interdependency of geodiversity, biodiversity and cultural heritage should be recognised.

The interaction and interdependency of geodiversity and biodiversity should be recognised in conservation management. Many sites protected for biodiversity will have a high dependency on geodiversity, and at other sites there will be a significant interrelationship between the biotic and abiotic elements (e.g. sand dunes) (Section 6.5). Managers should take into account these interdependencies in managing sites, as well as cultural heritage issues.

Best Practice Guideline No. 3: Use the nine principles for geoconservation in inventory, planning, objective setting, management and monitoring of geoheritage features and processes.

Establishing geoconservation protected and conserved areas

4

The importance of modern natural processes, for example new volcanic landforms resulting from activity at tectonic plate margins, is illustrated on San Bartolome, Galápagos National Park and World Heritage site, Ecuador. © Roger Crofts

This section sets out the key steps and protocols to establish geoconservation protected and conserved areas at national, regional or local scales where none exist or have not been established in a systematic way. The guidance can also be used by managers of individual protected areas to establish the geoheritage interests and values of their protected areas. The guidance addresses:

- Defining the purpose and operational scale (4.1)
- Making an inventory (4.2)
- Determining site assessment criteria (4.3)
- Examples of geoheritage inventories and assessments (4.4)
- Incorporating geoheritage into national, regional and local action plans (4.5)
- Protection mechanisms (4.6)
- Types of governance (4.7)
- Expertise requirements (4.8)
- International approaches (4.9).

The key steps in the development of a geoconservation strategy for a protected area comprise site inventory, assessment, management and protection, monitoring, and interpretation and promotion. The following guidelines address each of these in turn. . The approach broadly follows the adaptive management approach set out in the Open Standards for the Practice of Conservation and used by many conservation organisations worldwide for conserving biodiversity through protected areas and other means (Conservation Measures Partnership, 2013). This section provides guidance on site inventory and assessment. It addresses both the establishment of a network of geosites and the assessment of geoheritage within existing protected areas. Section 5 provides guidance on conservation and monitoring. Section 6 provides specific guidance on threats to geoconservation and how to deal with them. Section 7 provides examples of geoconservation in different environments. Section 8 focuses on interpretation and promotion.

At the outset, establishing a systematic framework is essential for the identification, categorisation, assessment and selection of geosites that merit conservation at all levels from international to local. This is best accomplished with a three-step approach: (1) defining the purpose and operational scale; (2) applying the most appropriate method of inventory in a rigorous manner; and (3) determining the site assessment criteria.

4.1 Defining the purpose and operational scale of a geosite or system of geosites

Geosites are identified primarily on the basis of their special scientific value. Educational, spiritual, cultural, aesthetic and values may provide additional support, as can other non-geodiversity scientific values such as ecological values. The following principles apply both in the establishment of a geoheritage site system and in the assessment of geoheritage interests or geosites within existing protected areas.

A key decision at the outset in the planning of geoconservation in protected areas is to specify the scale of operation. Is the requirement to establish a protected area system for geoconservation at a broad scale (e.g. for the whole nation, a region, or a smaller but still extensive area), or to determine the geoheritage interests and values within an individual protected area? Both are essential requirements for effective geoconservation. The guidance below applies to both situations.

The purpose of a geosite or geosite system will determine the geoheritage values to be assessed. Some geosites will have a relatively narrow purpose – to protect, for example, their features of special scientific interest (Table 4.1). Others may be multi-purpose, based on scientific value but with supporting educational, aesthetic, cultural, geotourism or ecological values.

Broadly, the geoheritage interests in Table 4.1 fall into three main categories: type sites and key reference sites, sites with unique or outstanding examples of particular geological features, and sites representative of the geology or geomorphology of an area, region or country.

Type sites and key reference sites

Stratigraphy is a fundamental component of geoscience. It involves the subdivision of the rock record, correlation of mappable rock units and establishment of their time relationships to interpret successions of events through time. It requires the identification of type sections and reference points to define the boundaries of the stages in the geological timescale according to internationally agreed standards. The International Commission on Stratigraphy (ICS), a commission of the International Union of Geological Sciences (IUGS), is working to reach international agreement on the definition of global standard units. A standard unit is referred to as a Global Boundary Stratotype Section and Point (GSSP) (Cohen et al., 2013; Smith et al., 2015; Finney & Hilario, 2018).

Geoconservation is fundamental to ensure that these sites remain accessible as reference sites for the future. Despite the stipulation in the GSSP criteria for conservation and protection (Gradstein & Ogg, 2012), there are no international legislation or conservation measures to ensure the protection of these

Table 4.1. Key geoheritage interests to be considered for geoconservation protected areas.

Geoheritage interest	Significance of sites and features	Geoconservation protected area example	Photo
Key stages in Earth's history	These include major intervals or boundaries in Earth's history, such as the internationally agreed Global Stratotype Section and Point (GSSP) locations, which define the lower boundary of a geological stage in the geological time scale. Some of these GSSPs are marked with a 'golden spike'.	The GSSP site for the base of the Precambrian Ediacaran Period is located at Enorama Creek, Flinders Ranges National Park, South Australia. This is the only GSSP 'golden spike' in the Southern Hemisphere.	 © ediacaran.org/flinders-ranges-southaustralia
Major structural and tectonic features	These may include features associated with tectonic plate collisions, such as mountain chains that are accompanied by thrusting, folding and compression of strata. They may also include the formation of island arcs, central volcanic complexes and lava flows.	Banff, Jasper, Kootenay and Yoho National Parks, Alberta and British Columbia, Canada, help protect the intensely folded southern section of the Canadian Rocky Mountains, a mountain area uplifted as a consequence of tectonic plate collision.	 © Roger Crofts
Types, occurrence and formation of minerals	Some sites include rare mineral deposits and significant crystals that may have been recognised as the type locality for these minerals.	Uranium-based minerals found in secondary and enriched water table deposits at Mount Painter in the Arkaroola Protection Area, South Australia, have yielded outstanding research and museum display specimens.	 © Mindat.org
Rare rock types and rock structures	Whatever their process of formation, rare rock types and rock structures may be recognised as geoheritage for their special values. Determination of rarity will depend on the spatial scale of the inventory (for example, 'rare' locally may not be 'rare' internationally)	Mount Gee, the 'crystal mountain', which lies within the Arkaroola Protection Area of South Australia, is a product of volcanic activity. The silica rich rock structures are where the molten rock flowed within the system a and include caverns and cavities containing internationally rare crystals.	 © Mindat.org
Evolution of life	Some sites include fossils and fossil assemblages that represent stages in the evolution of life on Earth. They can include gradations and interruptions in life sequences in the fossil record reflecting evolutionary trends and catastrophic events, such as meteorite impacts and eruptions of super volcanoes.	Bletterbach Gorge in northern Italy, a protected area, includes a rock sequence that marks the Permian extinction event, the greatest mass extinction of life in Earth's history.	 © Geopark Bletterbach
Contemporary Earth processes	These sites include modern Earth processes, such as volcanism, aridarea processes, coastal processes, fluvial processes and glacial and periglacial activity.	Hawai'i Volcanoes National Park, USA, hosts a continuously active volcano with its basaltic pahoehoe and aa lavas.	 © José Brilha
Representative surface and subsurface features	These sites are representative of particular periods of Earth's history, or of particular rock formations or Earth's processes, or contain distinctive or unusual features, such as caves.	Deer Cave in the Gunung Mulu National Park in Malaysia is a World Heritage site that protects outstanding karst resources and provides visitor access to a suite of caves.	 © John Gunn
Records of past environmental conditions	These sites record past environmental conditions, such as glacial phases of the Quaternary Period, and include landforms, sediments and rock sequences from all periods of Earth's history.	Kosciuszko National Park in Australia features the Australian mainland's highest mountain and rare evidence of Pleistocene glaciation in the southern hemisphere, with five glacial lakes, a glacial cirque and glacial moraines	 © Roger Crofts

Source: adapted from Crofts and Gordon, 2015 Table 18.2.

Photo 4.1. The Global Stratotype Section and Point at Luoyixi Town, Guzhang County, Hunan Province, China: an internationally recognised type site and reference site that is protected and forms part of the Xiangxi UNESCO Global Geopark. © John Gunn

sites. There is, therefore, a strong case that GSSPs should be regarded as a third internationally recognised geoconservation site network to run in parallel with World Heritage Sites and Global Geoparks (Gray, 2011). Such recognition would help to raise awareness among national governments of the need to protect GSSPs. Irrespective of this long-term goal, protection of such sites should be a high priority for protected area managers.

National systems of reference sites for geoscience also have been established in most countries. These type sites for particular time periods or events in the Earth's history are also a high priority for geoconservation. For further information, protected area managers should consult with appropriate experts in their national geological survey, geological societies or research institutes.

Sites with unique or outstanding examples of particular geological features

Certain sites include unique, rare or outstanding examples of particular rock strata, deposits, landforms or geomorphological processes. Internationally known examples include the Grand Canyon (Grand Canyon National Park, USA), Uluṟu (Uluṟu–Kata Tjuṯa National Park, Australia), and Hutton's Unconformity section at Siccar Point and the glacial lake shorelines of Glen Roy (both in Scotland).

Sites that are representative of the geology or geomorphology of an area, region or country

The majority of sites deemed to have geoheritage value will be representative of the geological history of a region or country. They comprise the key localities and best examples that are fundamental to understanding the past and present processes and events preserved in the rock record and that have shaped the landscape. Normally such sites will form part of a coherent network of related sites that collectively represent a particular time period, event or set of geomorphological processes and landforms (e.g. sites representing the key facets of the Devonian geological period or the coastal geomorphology of a nation).

Best Practice Guideline No. 4: Use the eight types of geoheritage interests (Table 4.1) to help define the purposes of a geoconservation protected area or geosite network.

4.2 Making an inventory

The vast majority of protected areas in the world were established to conserve biodiversity and/or iconic landscapes and seascapes. The absence of information about the occurrence of geoheritage inside protected areas means that important natural features are not always included in management strategies. Therefore, undertaking geoheritage inventories in protected areas is of paramount importance. They are of equal importance as the next step in developing a national or regional system of geoconservation protected areas.

Where possible a comprehensive inventory of all geoheritage elements – geology, geomorphology and soils – should be undertaken for the protected area, region or country, depending on the scale of operation under consideration. Practical issues, such as sensitivity to damage and linkage to key habitat areas, should be assessed if resources allow. An inventory of sites can assess their potential value for science, education, recreation and/or geotourism, as well as their risk of degradation (Brilha, 2016). This information assists with the establishment of management priorities and opportunities.

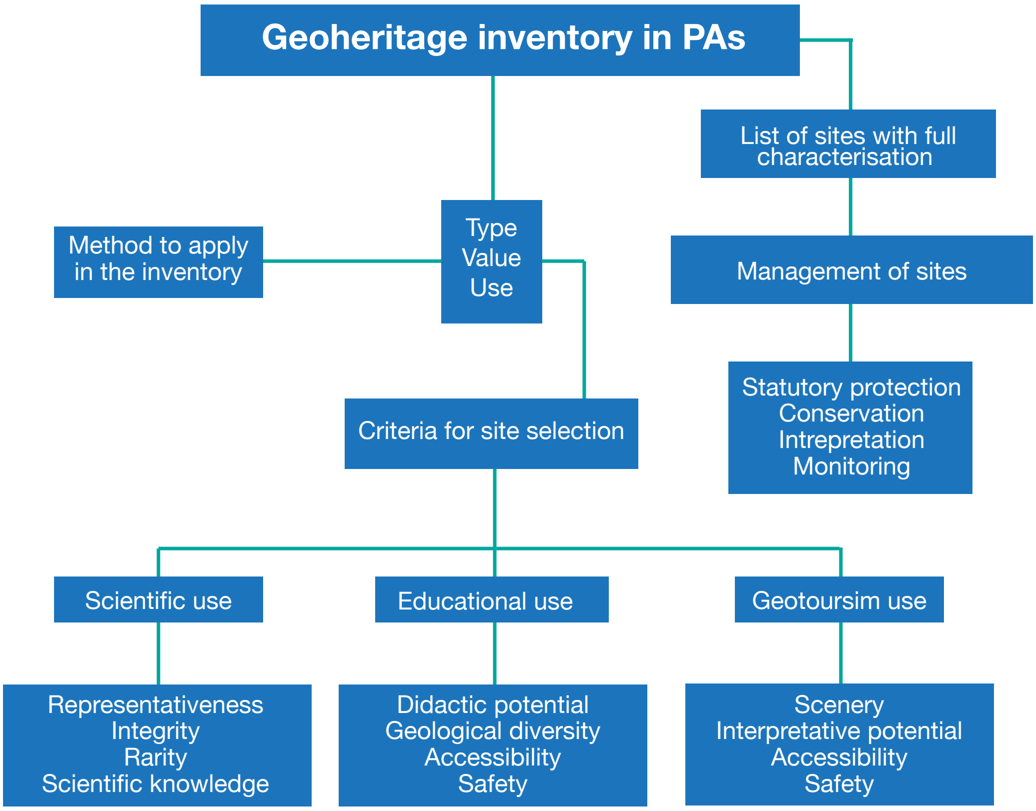
Geoheritage inventories should provide protected area managers with crucial information and data to be included in management plans, and to answer simple questions, such as:

- How many geosites exist in the protected area and where are they located?
- What is their main value (scientific, aesthetic, cultural, educational, and relevance (international, national, local)?
- Are they at risk of damage or loss by human and/or natural factors, either now or in future?

A critical decision must be taken about what sites and features to select and why. It is best to use tried and tested methods as set out in Table 4.1. This requires expert help. The most common solution for protected area managers is to get external support to develop a geoheritage inventory, which can be done by geological surveys, universities, private companies or individual experts.

There are a number of steps involved in a geoheritage inventory (Figure 4.1; Box 4.1). The first is to define the aim of the inventory based on the type, value and use of geoheritage.

Figure 4.1 Geoheritage inventory and management process in protected areas



Source: © José Brilha

Sometimes partial inventories can be made, such as those of palaeontology (fossils), geomorphology (landforms and their landscapes), mineralogy (minerals), or petrology (rocks). Normally, however, a full inventory will be required to ensure that all key elements of the geoheritage are identified and protected. The values of a geosite will determine the type of use allowed there.

Each site selected during the inventory should be fully characterised with the following details (Brilha, 2016):

1. name;
2. geographical location, including GPS coordinates;
3. ownership, including that of subsurface materials;
4. present statutory protection;
5. accessibility;
6. fragility and vulnerability;
7. observed condition of the main geodiversity features and processes;
8. geological description;
9. most remarkable features justifying a geosite;
10. features with potential educational and/or geotourism uses;
11. links with ecological and cultural assets;
12. limitations and restrictions on scientific access and use;
13. limitations on visitor numbers, if any ; and
14. safety conditions for all types of users.

This information is crucial for the establishment of an appropriate geoheritage action plan and incorporating the inventory results into protected area management plans. The inventory may include geosites of international, national, regional or even local relevance. This has implications in setting management plan priorities and should be determined by the technical team responsible for the inventory.

A good example of the involvement of geoscience students and professionals in protected areas is the Geological Society of America's programme 'Geoscientists in Parks'. It provides participants with a unique opportunity to contribute towards the conservation of America's national parks and enables the US National Park Service to better understand and manage its natural resources (Geological Society of America, 2019).

Best Practice Guideline No. 5: Make a geosites inventory using the flow chart approach in Figure 4.1.

4.3 Determining site assessment criteria

It is well-established practice to consider geosite assessment according to the three main types of use – scientific, educational and geotourism/recreational.

Four criteria are recommended for the selection of geosites important for **scientific study**:

1. **Representativeness:** how well the geosite illustrates an Earth process or feature and makes a meaningful contribution to the understanding of the topic, process, feature or framework (Photo 4.2);

Photo 4.2. Example of representativeness - folded sedimentary rocks forming mountain ranges where tectonic plates have collided, such as in the Andes, Himalayas, Rockies and European Alps, the latter illustrated here in Ecrins National Park, France. © Roger Crofts

Photo 4.3. Example of rarity: *Spriggite*, a rare yellow mineral named after geologist Reg Sprigg. Its type locality is Mount Painter within the Arkaroola Protection Area, Flinders Rangers, South Australia. © Joel Brugger

Photo 4.4. **Example of the development of scientific knowledge from study of rock formations and their origins: an ancient glacial deposit from global glaciation some 700 million years ago, often called 'Snowball Earth'. Tillite Gorge, Arkaroola Protection Area, South Australia. © Graeme L. Worboys**

Photo 4.5. **Example of educational potential: Old Faithful Geyser and geothermal area, Yellowstone National Park and World Heritage site. © Graeme L. Worboys.**

2. **Integrity:** the present conservation status of the geosite, taking into account both natural processes and human factors (Photo 4.6);
3. **Rarity:** the number of geosites representing similar geological features (Photo 4.3); and
4. **Scientific knowledge:** the extent of scientific information already published about the geosite (Photo 4.4).

Five criteria are recommended for the selection of sites for **educational use**:

1. **Educational potential:** the capacity of a feature to be easily understood by students of different educational levels (primary and secondary schools, universities) (Photo 4.5);
2. **Geodiversity:** the number of different types of geodiversity features and processes present in the site (Photo 4.6);
3. **Accessibility:** the conditions of access to the site in terms of difficulty and safety, and the amount of time students and visitors would need to spend on foot in order to learn about the site (Photo 4.7);
4. **Safety:** related to the visiting conditions, taking into consideration minimum risk for students and visitors (Photo 4.8); and
5. **Cultural and spiritual connection:** link to cultural and spiritual values held by indigenous communities (see Photos 5.12 to 5.16).

Photo 4.6. Example of a geodiversity site: represented by tension cracks at Eurasian/North American tectonic plates margin, a small rift valley, and a deep lake with lake-bed volcanic vents in Thingvellir National Park, Iceland. The area has significant cultural heritage interest as the location of Iceland's first parliament and is a World Heritage site. © Roger Crofts

Photo 4.8. Example of safety: waterfall view from board walk and viewing platform. Fulufjällets National Park, Sweden. © Roger Crofts

Photo 4.7. Example of accessibility: roadside access to view sea stacks at the Twelve Apostles Marine National Park, Victoria, Australia. © Roger Crofts

Photo 4.9. Example of the links between geodiversity and scenic value: the juxtaposition of folded sedimentary rocks, snow and ice, and alpine flora provide a scenic justification for protection. Vanoise National Park, France. © Roger Crofts

Photo 4.10. Example of interpretative potential: an unusual rock formation at the Elephant Rock, Topes de Collantes Nature Park, Cuba. © Roger Crofts

Three criteria are recommended for the selection of sites for **geotourism/recreational use**:

1. **Scenery:** the visual beauty of the landscape or feature (Photo 4.9);
2. **Interpretive potential:** the capacity of the feature to be easily understood by non-experts (Photo 4.10); and
3. **Accessibility:** the conditions of access to the site in terms of difficulty and safety, and the amount of time the general public would need to walk the site (Photo 4.7).

Once these criteria have been established, the geographical level of significance can be established (Brocx & Semeniuk, 2007; Crofts & Gordon, 2015). Brocx & Semeniuk (2007, 2015) provide a globally comparative method to enable the systematic identification and categorisation of regions, areas, geosites or features of geoheritage significance at all scales; allocate them to a conceptual category of geoheritage and scale of reference; and assess their level of significance (Figure 4.2).

Protected area managers should use the outputs from the site assessment to inform the conservation management of particular geosites and their potential uses. For example, internationally important sites will likely require a higher level of management and protection than others.

4.4 Examples of geoheritage inventories and site assessments

To assist protected area managers, there are numerous examples in the published literature of geoheritage inventories and site assessments at national, regional and local scales, and for individual protected areas. At a national level, examples include those from the USA (Santucci & Koch, 2003), Spain (Carcavilla Urquí et al., 2007), Portugal (Pereira et al., 2009) and Great Britain (Ellis, 2008 and 2011). Examples for particular protected areas include Cilento Vallo di Diano National Park, Italy (Santangelo et al., 2005), Montesinho Natural Park, Portugal (Pereira et al., 2007), Regional Park of Picos de Europa, Spain (Fuertes-Gutiérrez & Fernández-Martínez, 2012), Pyrénées National Park, France (Feuillet & Sourp, 2011) and Lena Pillars Nature Park, Russia (Gogin & Vdovets, 2014). Several exemplars are outlined in Boxes 4.1, 4.2 and 4.3. Such inventories also help identify key sites for geoconservation within marine protected areas (e.g. Gordon et al., 2016).

Best Practice Guideline No. 6: Ensure that clear geosite assessment criteria are utilised, covering scientific study, educational use, geotourism and recreational use.

4.5 Incorporating geoconservation into national, regional and local action plans

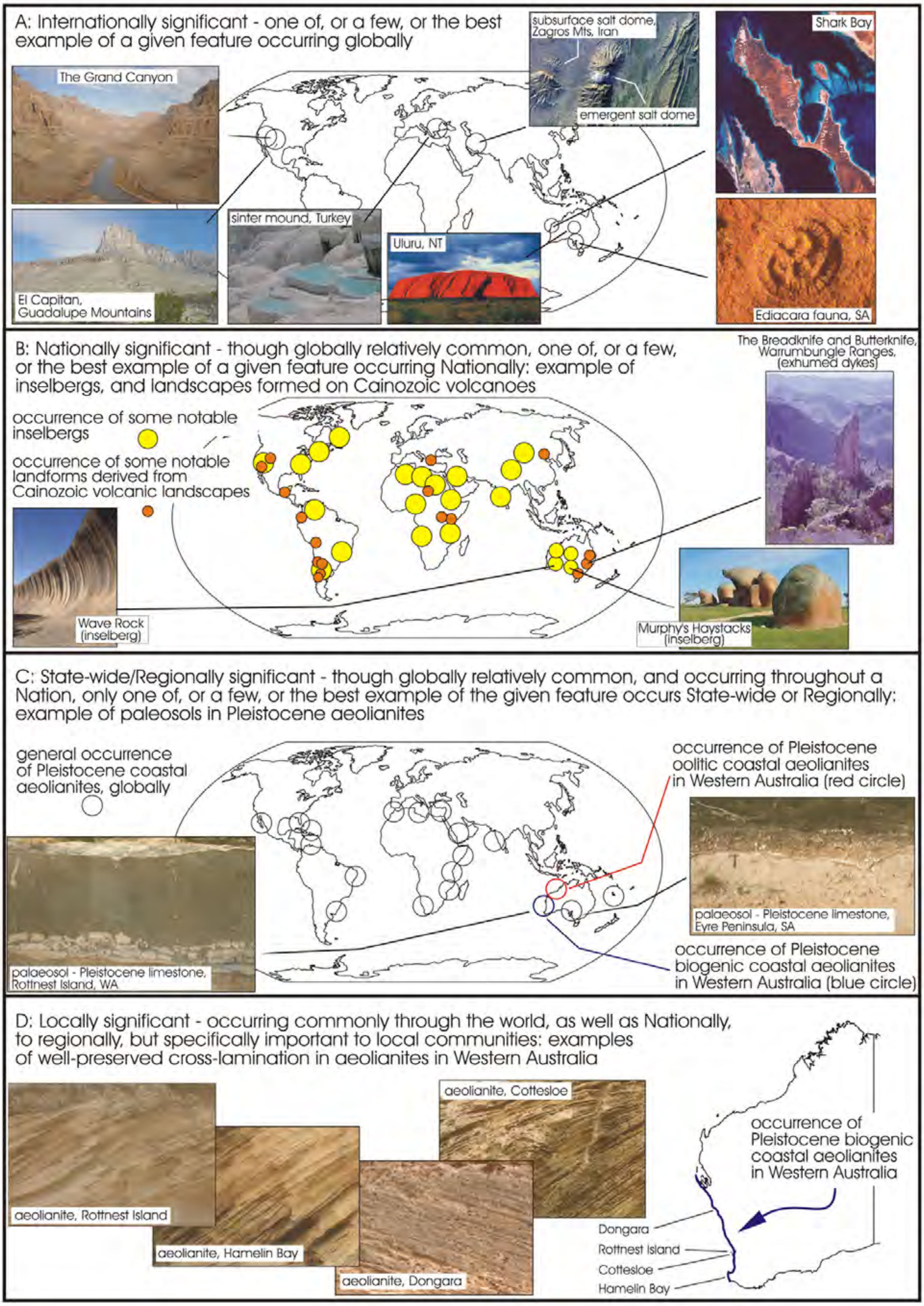
Geoconservation in protected areas will be considerably enhanced if plans at national, regional and local levels incorporate geoconservation (see Crofts, 2018). For example, a national framework or action plan can help to deliver a broad, strategic approach to geoconservation, setting out high-level objectives and actions (Gordon & Barron, 2011). Martín-Duque et al. (2012) demonstrate how such inventories and geoheritage mapping can inform local land-use planning. They can be used to measure and report on progress, help to enlist partners and coordinate their activities, and promote geoconservation at a national level and in subnational policies and strategies. An example of a national framework is the UK Geodiversity Action Plan; subnational examples include the Geodiversity Strategy of Basque Country and the Andalucía Strategy for the Management of Geodiversity The CBD's briefing note on National Biodiversity Strategy and Action Plans can provide a helpful template.

A geodiversity action plan builds upon an inventory to determine management requirements for different elements. The action plan defines clear long-term aims and objectives, sets out measurable short-term targets and actions to conserve and enhance the geodiversity and geoheritage of a particular area, and identifies human and financial resources necessary to achieve them. Such plans can also assist the integration of geodiversity and geoheritage into the conservation management of different categories of protected area.

In Italy, the multidisciplinary PROGEO-Piemonte programme (PROactive management of the GEOlogical heritage in the Piemonte) is developing action planning for geoconservation in the Piemonte region to meet the needs of local communities in respect of tourism, sustainable development, education and

Figure 4.2. Representation of the levels of significance applicable to geoheritage features

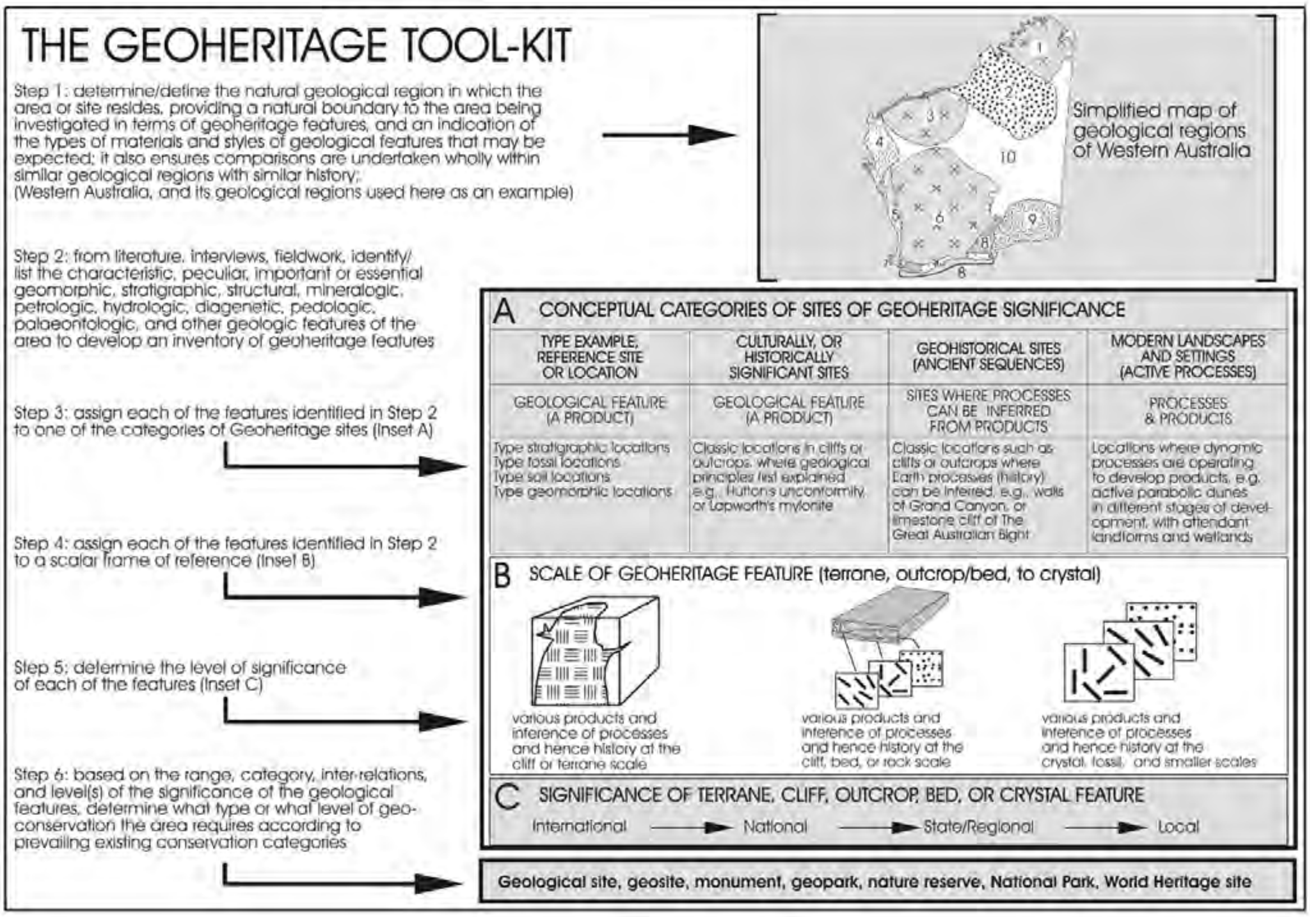
A: International; B: National; C: State-wide to regional; and D: Local. This approach can be used for developing new protected areas and adding geoheritage interests to existing protected areas.



Source: Brocx & Semeniuk, 2007.

Box 4.1
Geoheritage Tool-kit

The following conceptual diagram summarises the steps used to identify and assess sites of geoheritage significance for their management and/or conservation status. Geoheritage features within the site are assessed by category (A), scope and scale (B) and level of significance (C). This approach can be used for developing new protected areas and adding geoheritage interests to existing protected areas. The Geological Tool-kit (Box 4.1), devised in Western Australia, has been successfully applied (Brocx & Semeniuk, 2011; Brocx et al., 2019) and in Morocco (Errami et al., 2015).



Steps in the use of the Geoheritage Tool-kit used to identify and assess sites of geoheritage significance from Brocx & Semeniuk (2011).

Contributor: Margaret Brocx

geohazard awareness (Ferrero et al., 2012). The programme is based on a systematic audit of geosites and an assessment of their geoheritage value from scientific, educational, cultural and aesthetic points of view. It involves the participation of local partners and considers not only the geological features of the region but its physical, geographical, political, economic, historical and cultural components. Other examples of regional networks of geosites include those in Spain (Fuertes-Gutiérrez & Fernández-Martínez, 2010), Switzerland and Portugal.

In Great Britain, Local Geodiversity Action Plans (LGAPs) set out a framework, guiding principles and priorities to ensure conservation of geoheritage and the networks of geosites at a regional scale (English Nature, 2004; Dunlop et al., 2018). LGAPs set clear aims and objectives, with measurable targets, for local geoconservation. Typically, they include the following elements:

- an inventory of geodiversity resources within an area;
- public communication and education;
- encouragement of protection of geodiversity through local government plans and guidance;
- management and conservation goals for geosites, natural processes and landscape geodiversity; and
- clear objectives for the resourcing of the action planning process in order to sustain momentum into the future.

Once completed, Geodiversity Action Plans should be incorporated into protected area management plans at the appropriate scale, i.e. national, regional or for an individual protected area. These plans should then be fed into the nation's system for decision-making on development and land use. This can be done either independently or through integration with local biodiversity plans. This enables development plan policies and development control planning decisions to be based upon up-to-date information about the geodiversity of an area. Audits and action plans should help to underpin work on development planning, strategic environmental assessment (SEA), environmental impact assessment (EIA), local biodiversity plans and tourism-based activities. As well as conserving important examples of local geoheritage, LGAPs can contribute to the quality of local environments, provide opportunities for informal recreation, and contribute to the public health agenda. Community involvement in the care and enjoyment of local geosites will also help to foster a sense of pride in local geoheritage and thereby help to conserve it.

Best Practice Guideline No. 7: Encourage the development of action plans at national, regional and local scales to ensure that geoconservation is included in key decision documents.

4.6 Protection mechanisms: Statutory or other effective means

All protected areas, including geosites, should be 'gazetted' (recognised under statutory civil law), recognised through an international convention or agreement, or managed through other effective means. In practice, protected areas can be governed and managed by governments, private organisations, indigenous peoples and local communities or combinations of these (termed 'shared governance'). But, there are also other "conserved areas" that are not protected areas where conservation is a primary goal, and which may be stewarded in other ways, which nevertheless result in the long-term conservation of nature. Included are the" other effective area-based conservation measures (OECMs) defined by the Convention on Biological Diversity (CBD Decision 14/8). IUCN WCPA has published Guidelines for Identifying and Reporting Other Effective Conservation Measures. These conserved areas and OECMs may also be effective in achieving geoconservation.

Best Practice Guideline No. 8: Use the WCPA guidance on protected areas and other effective area-based conservation measures to ensure the most effective protection mechanism for the geosite.

4.7 Types of governance

Two examples of different governance situations relating to geoconservation in protected areas are provided in Boxes 4.2 and 4.3. More general guidance on protected area governance can be found in Borrini-Feyerabend et al., (2013).

4.8 Expertise requirements

The needs of geoconservation management should determine the type and level of expertise required either in the protected area itself or in its managing agency, or through special arrangements with expert external bodies such as research institutes. Ideally, for suites of sites where there is a strong Earth science component, or a site where geoconservation is a major objective, it is preferable to employ a range of relevant experts within the managing agency for the protected areas. However, resources will not always allow this approach and therefore informal arrangements should be made with experts from academic institutions or with private individuals who can work as volunteers. Their role should be as specialist advisers to the protected area managers on defining objectives and developing management regimes and educational programmes. In addition, they should be expected to communicate best practice from similar situations in other parts of the world.

The choice of expertise will depend on the interest of the site (e.g. palaeontology, mineralogy, stratigraphy, geomorphology). It is generally preferable to involve people that have both the specific knowledge needed as well as a more general knowledge of geodiversity and specific training on geoheritage and geoconservation. Ability to communicate with colleagues, non-specialists and the general public is essential if there is a strong public education focus on geoheritage and geoconservation.

Some protected areas instead will have a strong research and scientific focus. Here, a coordinated programme of scientific activity should be developed between the protected area's managers and the scientific community, with an agreed programme of work. A protected area management agency may find it more effective to engage with scientists in universities and research institutes rather than employ its own scientific expertise. It is essential, however, that there is a clear agreement that the results from the research are made available to protected area managers and the general public in an understandable and usable way.

Citizen science (public participation in scientific research) is now often used to increase the capacity of knowledge and information gathering. It is a valuable approach provided that there are protocols for its use and for the recruitment and training of volunteers (Irwin, 2018, spells out the pros and cons).

With the likelihood of new staff being employed and staff moving from one protected area to another during their career, it is essential that induction on geoheritage and geoconservation is undertaken (Table 4.2).

Best Practice Guideline No. 9: Use experts to ensure technical input to geoconservation planning, management and communication.

4.9 International approaches to geoconservation

It is important to recognise the specific international instruments that exist in support of geoconservation.

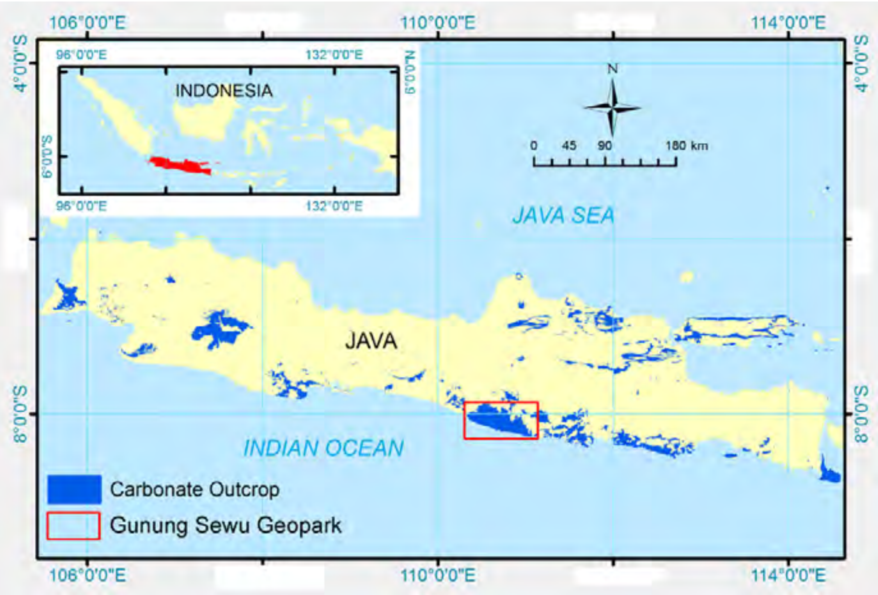
The UNESCO Convention for the Protection of the World Cultural and Natural Heritage focuses on the concept of "Outstanding Universal Value" as the basis for recognition of World Heritage Sites. The Convention recognises geodiversity as part of nature through its criterion (viii), which states that sites constituting "outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features" may qualify for World Heritage status (UNESCO, 1972).

Box 4.2

Community-based geoconservation management in Gunung Sewu UNESCO Global Geopark, Indonesia

Gunung Sewu Geopark was designated as a UNESCO Global Geopark in October 2015. The geopark has an area of 1,802 km^2 and includes 33 geosites within a classic tropical karst landscape (Figure 4.5), eight of which were initiated by local communities. The management of the geopark is under a joint agreement among three provincial administrations and is rotated among them. Management of most of the geosites is by the local communities, initiated and organised by local people under the umbrella of a community-based tourism management group.

The community-based geoconservation management protects the geopark's geosites and generates income for the local people and for regional development through ecotourism. As an example, the geoconservation management carried out by the village of Nglanggeran demonstrates responsible, inclusive and sustainable tourism destinations, products and behaviour. Nglanggeran's community-based geoconservation best practices have been recognised through national and regional awards.



Contributor: Eko Haryono

Table 4.2. Briefing considerations for the induction of protected area staff.

Geological mapping	Briefing about the geology of the protected area and the extent and quality of the geological mapping available.
Special geological heritage	Identification of the location and nature of geosites and any special management operations in place to protect that heritage. Written research material about the features should be provided.
Visitor safety	Briefing on any geological hazards or phenomena that may provide a safety issue with visitors. A history of safety incidents in the protected area should be presented, including actions taken to enhance safety.
Materials	Description of geological materials used to assist operations (such as road materials), their source and the appropriateness of their use.
Monitoring	Outline of the geological phenomena being monitored, the basis for monitoring and the logistics associated with it. Costs of the monitoring and how that information is used should be included.
Geological incident planning	Outline of any planning that is in place to deal with possible geological incidents. This should include the status of planning response documents, their currency and their revision schedules.

Box 4.3
Brymbo Fossil Forest Site of Special Scientific Interest, Wrexham, UK

Brymbo Fossil Forest is an important palaeobotanical site situated near Wrexham, north-easten Wales, UK. The fossil feature of interest was discovered in 2005 during reclamation of a derelict steelworks site and comprises a 14 m-thick sequence of Coal Measure sediments. The rich assemblage of plant fossils, many being in life position, give the site high scientific and geoheritage value.

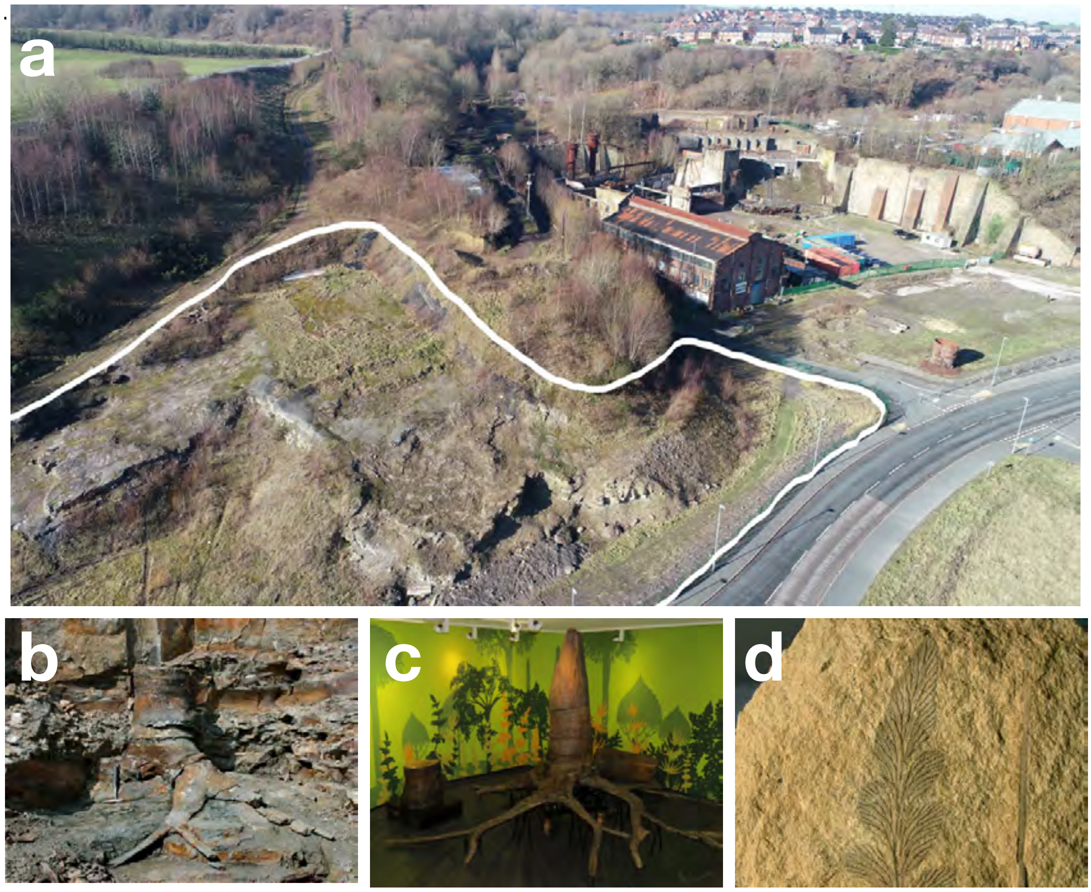
The site is currently owned by Brymbo Development Ltd, with the intention of transferring the land to the Brymbo Heritage Trust. The Trust and key partners have focused on preparing a master plan to develop the site into a world-class visitor attraction. Funds secured will allow stabilisation work on the industrial heritage and conservation of the fossil forest.

Conservation challenges

Although notification as a Site of Special Scientific Interest (SSSI) provides legal protection, the conservation and management of the fragile features remain a challenge. The aim is to develop on-site facilities to conserve and showcase many of the fossils in situ, with construction of a building to cover part of the fossil forest. A full-time fossil coordinator will lead on the excavation and has been training volunteers to recover, prepare and catalogue the many specimens stored during the initial ‘fossil rescue’ phase.

Brymbo Fossil Forest is an exemplar of partnership working to protect and manage a fragile, finite geological resource and promote the connections between geoheritage and industrial heritage. The building will include facilities for scientific research, be open to the public and will form the centrepiece of a wider visitor attraction looking at centuries of industrial heritage.

For further information see Appleton et al. (2015) and Roberts et al. (2016).



a. Oblique aerial view of Brymbo Fossil Forest SSSI (outlined). Immediately adjacent is the suite of industrial buildings charting more than 200 years of iron- and steel-making at Brymbo © Brymbo Heritage Trust

b. Giant in situ lycophyte © Peter Appleton

c. The lycophyte in (b) rescued from the site, cleaned and reconstructed in life position for display at Wrexham Museum © Nigel Larkin

d. Specimen of Neuropteris semireticulata © Peter Appleton

Contributor: Raymond Roberts

Photo 4.11. Some internationally important geosites are in private ownership, as was the world famous Geysir geothermal site in Iceland until recently. Management tensions do occur, but generally speaking the relative resistance of the site to damage of the geoheritage interest means that its integrity remains intact and visitor access is well managed. © Ragnar Th. Sigurdsson

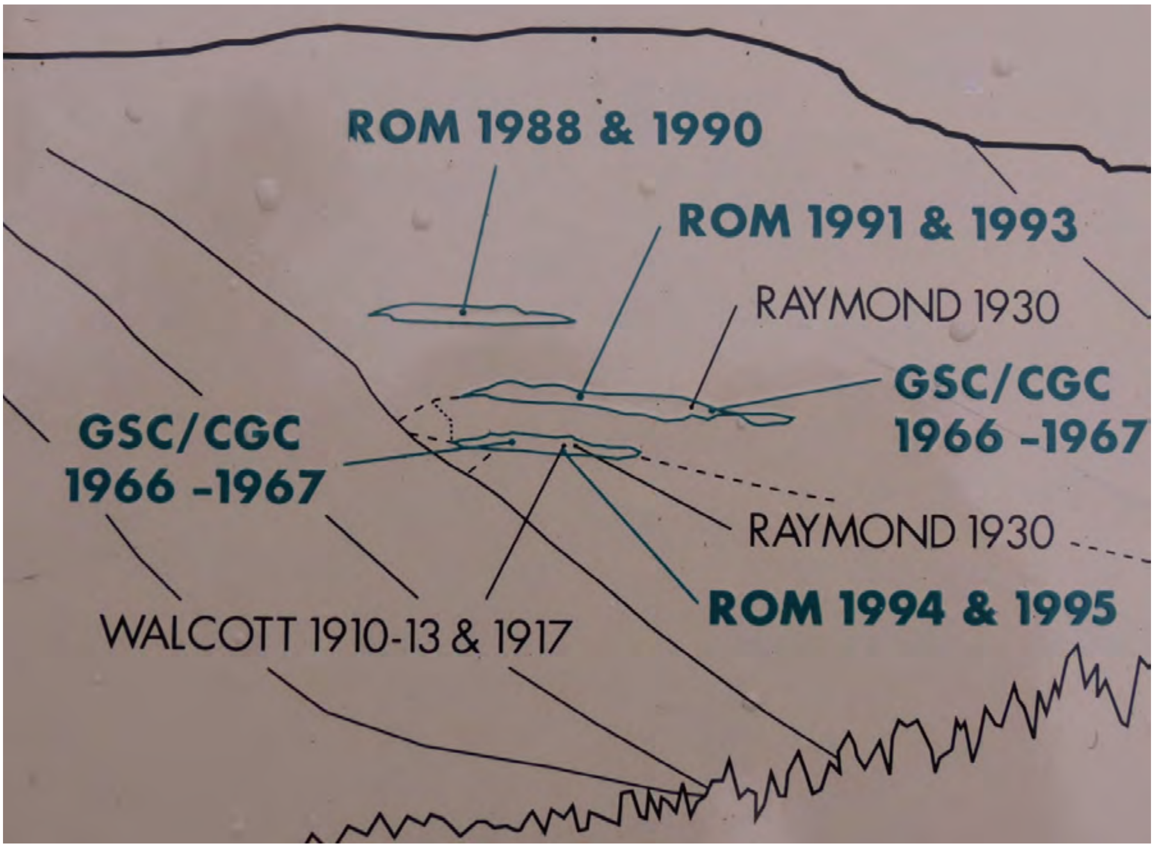


Photo 4.12. New minds with new ideas results in new knowledge that can be applied to protected area assessment and management. The photo shows the locations of successive research projects on the Burgess Shales, Yoho National Park, Canada. © Roger Crofts

Photo 4.13. Aletsch Glacier is one of the early sites designated under World Heritage criterion (viii) in the Jungfrau-Aletsch World Heritage site, Switzerland. © Roger Crofts

Photo 4.14. The aptly-named Mirror Lake, Jiuzhaigou National Park, China. Kishore Rao, UNESCO World Heritage Centre, said on evaluating this site: "this is a truly outstanding national park, fully deserving world heritage status. I am very impressed by the scenic and natural beauty of the area, as well as the high degree of management attention and commitment of staff". © Roger Crofts

Photo: 4.15. Ensuring that all international designations which are relevant are applied to a geoheritage area. Huanlong National Park, China. © Roger Crofts

More detail on the application of criterion (viii) can be found in the IUCN thematic framework (Dingwall et al., 2005), which analyses the different aspects of geodiversity covered in the criterion, establishes 13 themes that characterise how the main geological and geomorphological ideas translate to identification of sites. More detail is found on deserts in Goudie and Seely (2011), on caves and karst in Williams (2008), and on volcanoes in Wood (2009) updated by Casadevall et al. (2019). A useful overview of World Heritage Sites and geoheritage is given by Migoń (2018).

In 2015, the 195 Member States of UNESCO ratified the creation of the UNESCO Global Geoparks designation to express international recognition of the importance of managing outstanding geological sites. UNESCO Global Geoparks are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development. Four fundamental prerequisites for an area to become a UNESCO Global Geopark are:

- geological heritage of international value;
- a legally recognised management body and a comprehensive management plan;
- visibility to promote sustainable local economic development, mainly through geotourism; and
- networking with local people living in the Global Geopark area and cooperating with other global geoparks through the UNESCO Global Geoparks Network (GGN).

Best Practice Guideline No. 10: Consider whether the protected area and its geoheritage features and processes could meet the criteria for UNESCO status under the World Heritage Convention and/or the Global Geoparks Network.

In addition, the Ramsar Convention on Wetlands of International Importance and the UNESCO Man and the Biosphere Programme both establish global systems and global recognition to areas of importance for biodiversity (Ramsar sites and Biosphere Reserves, respectively) where there are links with geoconservation.

Best Practice Guideline No. 11: Consider how geodiversity and geoheritage in Biosphere Reserves and Ramsar sites can be managed to achieve conservation of biodiversity and wetlands, respectively, and of geoheritage.

Photo 4.16. A Ramsar site that is protected for its geoheritage interest as a seasonal lake in the globally classic Karst area of Slovenia. Cerknisk Jezero. © John Gunn

Photo 4.17. Linking World Heritage, Ramsar and geoheritage at Neusiedler See National Park, Austria. © Roger Crofts

Geoheritage management in protected and conserved areas

5

Challenging management in the mountains of the Rila National Park, Bulgaria due to long standing water supply intakes, unsightly redundant infrastructure and skiing development all affecting negatively on the geoheritage value of the area. Independent evaluations by international experts helped management to focus on the necessary action. © **Roger Crofts**

This section provides detailed guidance on all aspects of managing geoheritage , including management planning, operational aspects, incorporating spiritual and cultural values, monitoring and evaluation, and research. It addresses:

- management planning (5.1)
- geoconservation and protected area operations (5.2)
- applying the IUCN Management Categories to geoheritage (5.3)
- incorporating spiritual and cultural values of geoheritage (5.4)
- developing a site monitoring and evaluation system (5.5)
- examples of geoconservation management in protected and conserved areas (5.6).

This section focuses on the managing geoheritage, There are four functions: planning, organising, leading and evaluating. All are relevant to geoconservation in a protected area. Readers are encouraged to consult Worboys et al. (2015, chapter 8) which spells out these points in more detail.

5.1 Incorporating geoconservation into protected area management plans

Prosser et al. (2018) provide a helpful generic framework for geoconservation. Following site inventory and selection, this involves two stages: (1) a conservation needs analysis, which requires assessment of a site's use, character and threats/ sensitivity; and (2) conservation planning and delivery.

Essentially, these two stages involve six key requirements to be addressed in incorporating geoconservation into the preparation of comprehensive management plans for the geosite and its incorporation in the protected area management plan in cases where a geosite is nested within it. This broadly follows the approach exemplified by Wimbledon et al. (2004). Management plans should be reviewed and updated regularly and should be incorporated within protected area or OECM management plans, as appropriate.

1. Site inventory and documentation of key interests

There are a variety of geoheritage features , including rock exposures, landforms and soils, and spans a variety of geographical scales from small rock outcrops to landscapes comprising assemblages of rocks, landforms and soils. These must be accurately located and documented within the geosite. Depending on the size of the geosite, this will usually be achieved by a combination of field survey and annotated photography carried out by specialists. However, the outputs must be presented in a form that is accessible to non-specialist staff (Box 5.1). The geosite inventory and documentation process must be conducted in sufficient detail to catalogue and map the precise locations of each feature within the geosite, and provide details of sediment exposures and annotated photos to show protected area managers exactly what the interest is and where it is within the geosite. In some cases, this may be a two-stage process: initial inventory of all candidate sites within an area to establish the interests and their significance (Section 4.2); and more

Box 5.1.
Site documentation reports and management plans

All 900 geosites identified as nationally and internationally important in Scotland are supported by a detailed assessment of their scientific value documented in the Geological Conservation Review (Ellis, 2011). In addition, to assist site managers, landowners and occupiers, each site has a Site Document Report and a Site Management Statement produced by Scottish Natural Heritage (SNH).

Site Documentation Reports identify and locate the key features of interest within sites. They are aimed both at SNH geoscience staff who are tasked with providing detailed management advice, as well as non-geoscience staff who are required to manage the sites. The reports are based on field surveys and are written in non-technical language or with technical terms clearly explained. Typically, the reports include simplified but scientifically accurate explanations of the Earth science interests, a geological or geomorphological map showing the locations of the features of interest, and annotated photographs of these features and their locations within the sites. The reports also contain management recommendations. They are available to owners, managers and tenants of land as well as to other interest, but they are not published online. Where the sites are large and complex, more detailed reports are produced as part of the SNH Commissioned Reports Series (e.g. Gemmell et al., 2001).

Site Management Statements are public statements prepared by SNH for owners, managers and tenants of land of SSSIs. They outline the reasons a site is designated as an SSSI and provide guidance on how its special natural features should be conserved or enhanced. They include a brief description of the features of interest in plain English, an assessment of their condition, an outline of past and present management and a set of management objectives. For example, the latter might be to maintain the geological exposures in favourable condition so that they are clearly visible and accessible for the purposes of research and education, and to encourage responsible visitor access to the site for the purposes of recreation, education and interpretation. Site Management Statements are available online through SNH SiteLink.

Table 5.1. Classification of geoheritage site types, typical threats and conservation objectives (Prosser et al., 2018 reproduced with permission).

	Type of site	Site code	Typical threats	Typical conservation and management objectives
Exposure or extensive	Active quarries and pits	**EA**	Backfill against quarry faces	Secure access for recording and collecting Secure conservation-friendly restoration with retention of exposed quarry faces
	Disused quarries and pits	**ED**	Restoration through in-filling Degradation of faces through weathering and vegetation encroachment	Maintain exposed quarry faces Control vegetation encroachment
	Coastal cliffs and foreshore	**EC**	Coastal protection schemes Cliff re-profiling Marinas or foreshore development	Maintain natural processes Discourage development in front of or on top of geological exposures in cliffs
	River and stream sections	**EW**	River management and bank stabilisation River damming Vegetation encroachment	Maintain natural processes Control vegetation encroachment
	Inland outcrops	**EO**	Vegetation encroachment Inappropriate recreational activity	Discourage development against exposures Control vegetation encroachment
	Exposure underground mines and tunnels	**EU**	Features inaccessible Flooding and collapse	Secure access for recording and collecting Seek long-term solutions to flooding and mine collapse
	Extensive buried interest	**EB**	Development on top of the buried features Agricultural practice that damages the buried features, e.g. deep ploughing	Ensure there are no physical obstacles to restrict excavation of features when required
	Road, rail and canal cuttings	**ER**	Exposures obscured through stabilisation work using concrete or rock-fall mesh Degradation of exposures through weathering and vegetation encroachment	Ensure exposures are retained if road is widened Control vegetation encroachment
Integrity	Static (fossil) geomorphological	**IS**	Mineral extraction Vegetation encroachment or tree planting	Maintain integrity of the feature Discourage quarrying or tree planting
	Active process geomorphological	**IA**	Coastal protection schemes River management schemes Quarrying and dredging	Maintain natural processes Discourage development in areas likely to be affected in future as processes migrate
	Caves	**IC**	Quarrying and mining Pollution Irresponsible specimen collecting	Maintain hydrological systems Promote good practice with caving groups
	Karst	**IK**	Quarrying Vegetation encroachment	Maintain integrity of features Control vegetation encroachment
Finite	Finite mineral, fossil or other geological	**FM**	Quarrying and mining Irresponsible specimen collecting	Manage collecting to ensure maximum scientific gain
	Mine dumps	**FD**	Re-profiling or levelling Irresponsible specimen collecting Vegetation encroachment	Manage collecting to ensure maximum scientific gain Control vegetation encroachment
	Finite underground mines and tunnels	**FU**	Flooding and collapse Irresponsible specimen collecting	Secure access for recording and collecting Seek long-term solutions to flooding and mine collapse
	Finite buried interest	**FB**	Quarrying or mining Development on top of the buried features Agricultural practice that damages the buried features, e.g. deep ploughing	Ensure there are no physical obstacles to restrict access to features when required Manage collecting to ensure maximum scientific gain

detailed documentation of confirmed geosites building on the initial site inventory.

2. Specification of generic management objectives and performance indicators

Geoconservation, like any protected area or conservation project, requires clear management objectives that reflect the different types of geoheritage interest and their potential uses and are identified to ensure that management is focussed on achieving the objectives. Specific objectives should be set for each site reflecting the generic guidance, but targeted for the specifics of the geosite as exemplified by Wimbledon et al. (2004). These should set out the vision of favourable condition for the site (e.g. at least 50% of the site will have clean and accessible exposures of a particular rock sequence and its key features). The factors that may impact on the condition of a site (e.g. talus accumulation, vegetation growth, dumping of waste material, damaged from unrestricted public access) should be identified. In addition, measurable attributes that will be used to trigger a management response should be specified (e.g. if less than 70% of a key horizon is no longer visible due to deterioration of the exposure).

In Great Britain, generic conservation management principles have been developed for different categories of site, with an important distinction between ‘exposure’ (or ‘extensive’), ‘integrity’ and ‘finite’ sites (Table 5.1) (Prosser et al., 2006, 2018). The scheme is based on the premise that different categories of site have different conservation requirements; for example, the management issues in disused quarries are different from those for coastal sites. This approach should have wider applicability. Prosser et al. (2006) provide specific case studies under each of these categories.

Exposure sites

Exposure sites contain geological features (rock units or sediments) that are spatially extensive below ground level, so that if one site or exposure is lost, another could potentially be excavated nearby. They include exposures in active and disused quarries, coastal and river cliffs, road and rail cuttings, and natural rock outcrops. The basic conservation principle is that removal of material does not necessarily damage the resource as new exposures of the same type will be freshly exposed. The principal management objective for such sites is to achieve and maintain an acceptable level of exposure of the features of interest, but the precise location of the exposure is not crucial. Exposure sites are not usually damaged by quarrying or erosion, but the exposures can be obscured by landfill and dumping of rubbish or deterioration through slumping and vegetation growth. However, loss of exposures may be offset by mechanical excavation of new conservation exposures at appropriate locations elsewhere.

Integrity sites

Integrity sites are geomorphological sites that include both static (inactive) features (e.g. Pleistocene glacial landforms) and active features such as those formed by river, coastal, karst and contemporary glacial processes. Such sites may be large and include assemblages of both static and active features. Damage

Photo 5.1. Example of *Exposure site* seen from the sea, Dale peninsula, Pembrokeshire Coast National Park, Wales. © Roger Crofts

Photo 5.2. Example of *Exposure site* with the natural collapse of cliff faces revealing new rock exposures. Jasmund National Park, Germany.© Roger Crofts

Photo 5.3 Example of an active *Integrity Site* where glacial river Jökulsá á Fjöllum emerges from Dyngjujökull glacier. Vatnajökull National Park, Iceland. © Roger Crofts

Photo 5.4 Example of inactive *Integrity Site.* Limestone pavement near Doolin in the Burren and Cliffs of Moher UNESCO Global Geopark and The Burren National Park, Ireland. © John Gunn

Photo 5.5 Example of a *Finite Site*. Extremely rare occurrence in Iceland of plant fossils buried beneath younger lavas. Ytritunga Tjornes, Iceland. © Roger Crofts

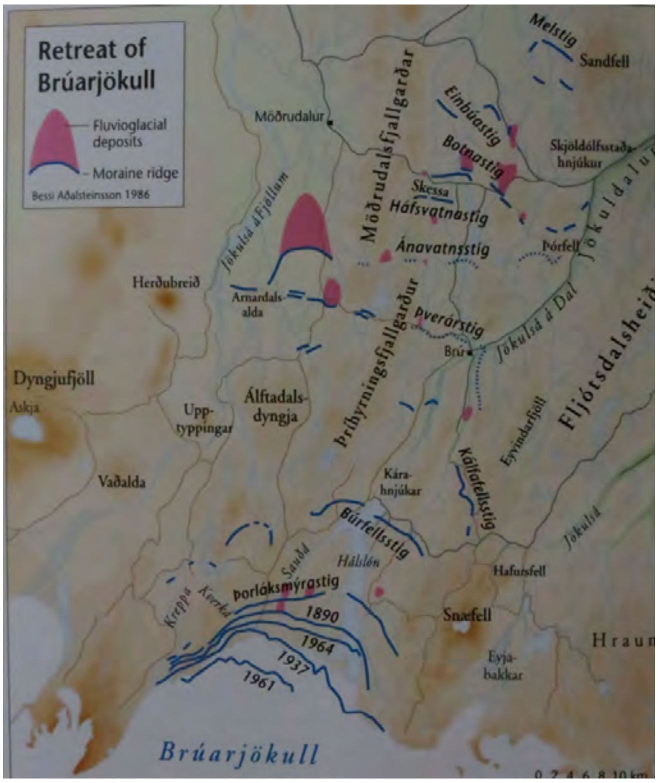


Photo 5.6 Documenting natural change is an important element of protected area planning and management. Retreat maps of an Icelandic glacier in the Vatnajökull National Park. © Roger Crofts

to one part of an integrity site is likely to impact on the value of the whole site. The prime management objective for static features is to protect the integrity of the resource: if damaged or destroyed, the features cannot be reinstated or replaced since they are unique and the processes that formed them are no longer active. They are also susceptible to partial damage and fragmentation of the interest, so that the integrity of important spatial relationships between individual landforms may be lost. There are usually few options for reconciling conservation and development through management or offsetting. Mitigation will depend on local circumstances and may include re-siting of parts of the development to avoid key landforms. Occasionally, landform reconstruction or replication may be possible for aesthetic or educational purposes, although integrity will be lost. In other situations, restrictions on access by the public or even refusing to publicise the existence of a site because of its fragility can be justified.

The principal conservation management objective for integrity sites is to maintain the capacity of the active processes to evolve naturally, allowing them to operate across most or all of their natural range of variability and hence to maintain natural rates and magnitudes of change and the connectivity between different features (e.g. between rivers and their floodplains). A consequence is that the landforms produced by them may change over time, and some may be transitory. They may also re-form in different locations. For example, gravel bars in a river bed may be destroyed in a large flood but may re-form as the discharge and sediment transport readjust to 'normal' flow conditions. Active process sites are also susceptible to changes outside the conservation site boundary (e.g. through upstream changes that affect river discharge and sediment inputs). This is more likely to occur on sites with river, coastal, cave or slope processes and their associated features. Some active sites may also contain inactive landforms that form part of the total landform assemblage.

Finite sites

Finite sites comprise features of limited extent that will be depleted and damaged if any of the resource is removed or lost. Examples include geological sites with fossil-bearing rocks. They may occur in a range of locations, including active and disused quarries and coastal and river sections. In some cases, the interest may become buried because of practical difficulties in maintaining exposures in soft sediments, or intentionally as a practical conservation measure to protect a particularly vulnerable interest. Finite sites require close control over the removal or loss of material. They include many mineral and fossil deposits, mine dumps, underground mines and buried interests (where the interest is known to occur under the ground and can only be exposed by excavation). Generally, mitigation or offsetting measures will rarely be possible. Where a site is primarily used for research purposes, it may not be practical or necessary to maintain an exposure. In such cases, access should be maintained for excavation as required for study.

In general, there must be a presumption against development in a protected area that would damage it and undermine the reasons for its protection. Where a development would result in significant damage to a geoconservation protected area and cannot be prevented or adequately mitigated, suitable alternative sites should be sought for the development. In the absence of any such alternatives, development that would adversely affect the site should only be permitted where there are overriding reasons of sustainability or national importance. In such cases, compensation measures should be sought, including exposure creation or site enhancement elsewhere if practical, to maintain, restore and wherever possible enhance the geoheritage value of the site or area. Section 6 provides more detailed guidance on specific threats and how to deal with them.

3. Threat analysis: Assessment of risk and vulnerability to pressures and threats

To help prioritise management action, analysis of threats and assessment of risks from different types of human activity and natural changes will need to be undertaken (see Section 6 for details). The principles and methodology of strategic environmental assessment and environmental impact assessment and the application of the precautionary principle provide valuable templates (Cooney, 2004; Cooney & Dickson, 2005).

4. Site condition monitoring

Periodic monitoring of geoconservation protected areas is essential to establish the condition and state of the features of interest, whether and how they are changing, and whether the conservation targets are being met. This element is not easily accomplished and is often ignored, especially if resources are limited.

Photo 5.7 Plotting the historical changes in the river mouth is essential for developing future management of the protected area. Skjern Å National Park, Denmark. © Roger Crofts

This section deals with relatively simple and rapid site condition monitoring that can inform conservation management. More detailed approaches to protected area monitoring and monitoring related to safety issues are considered in Section 5.5.

Several site monitoring schemes exist or are proposed, for example in Great Britain (Werritty et al., 1998; Ellis, 2004), Spain (Garcia-Cortes et al., 2012), and Tasmania, Australia (RPDC, 2013). More specifically, the US National Park Service has established guidelines for monitoring geological and palaeontological resources (Santucci & Koch, 2003; Santucci et al., 2009). Protocols for monitoring need to be set up, including the establishment of a baseline, a list of key attributes measured and the targets (Table 5.2). Site integrity indicators apply to sites of particular geoconservation significance, where the degree of physical integrity or degradation of the sites and features have been identified as an issue for geoconservation; this has been done in the Tasmanian example cited above. Process integrity indicators measure the degree of integrity or degradation of geomorphological and soil processes: these processes govern the long-term integrity of sites, features and systems of geoconservation (and general) significance. Process integrity indicators provide a measure of the sustainability of natural landform and soil processes (RPDC, 2013). A suite of geoindicators has also been developed for Canada's national parks (Welch, 2004).

The frequency of monitoring is determined by the degradation potential of the site. Monitoring must be followed by appropriate remedial action in partnership with site owners and managers as part of the management plan revision (Wimbledon et al., 2004). Photography will be an important tool. For example, a five-year monitoring cycle is probably justified for fragile features, such as travertine, with a much longer cycle of over ten years for hard-rock features.

In Spain, a novel approach to site monitoring and stewardship has been implemented. This involves a national programme, 'Apadrina Una Roca' ('Adopt a Rock'), in which volunteers enlist to visit sites annually and to report to the Geological Survey of Spain on any threats or incidents (http://www.igme.es/patrimonio/ApadrinaUnaRoca.htm). While not replacing formal site condition monitoring, such an approach can provide early warning of threats or significant site condition deterioration.

Another example of a successful programme is the site condition monitoring undertaken for protected areas in Great Britain. It is based on a set of common standards (JNCC, 2019). Wignall (2019) provides details of the methodology as applied to geoheritage features in SSSIs in Scotland over the period 1999–2019. Of 666 geoheritage features monitored, 3% have been irreversibly damaged, and 10% have required remedial action to restore them to favourable condition.

5. Identification of zones to facilitate management

Every portion of the protected area will not be of the same conservation value and therefore some may need different management regimes, provided these support the overall conservation goal. We recommend the use of the IUCN Protected Area Management Categories (Section 5.4) as an appropriate tool for zoning. For example, a Protected Area

Photo 5.8 Getting the message about hazards across in a simple way to everyone. A comic produced by the Cotopaxi National Park, Ecuador. © Roger Crofts

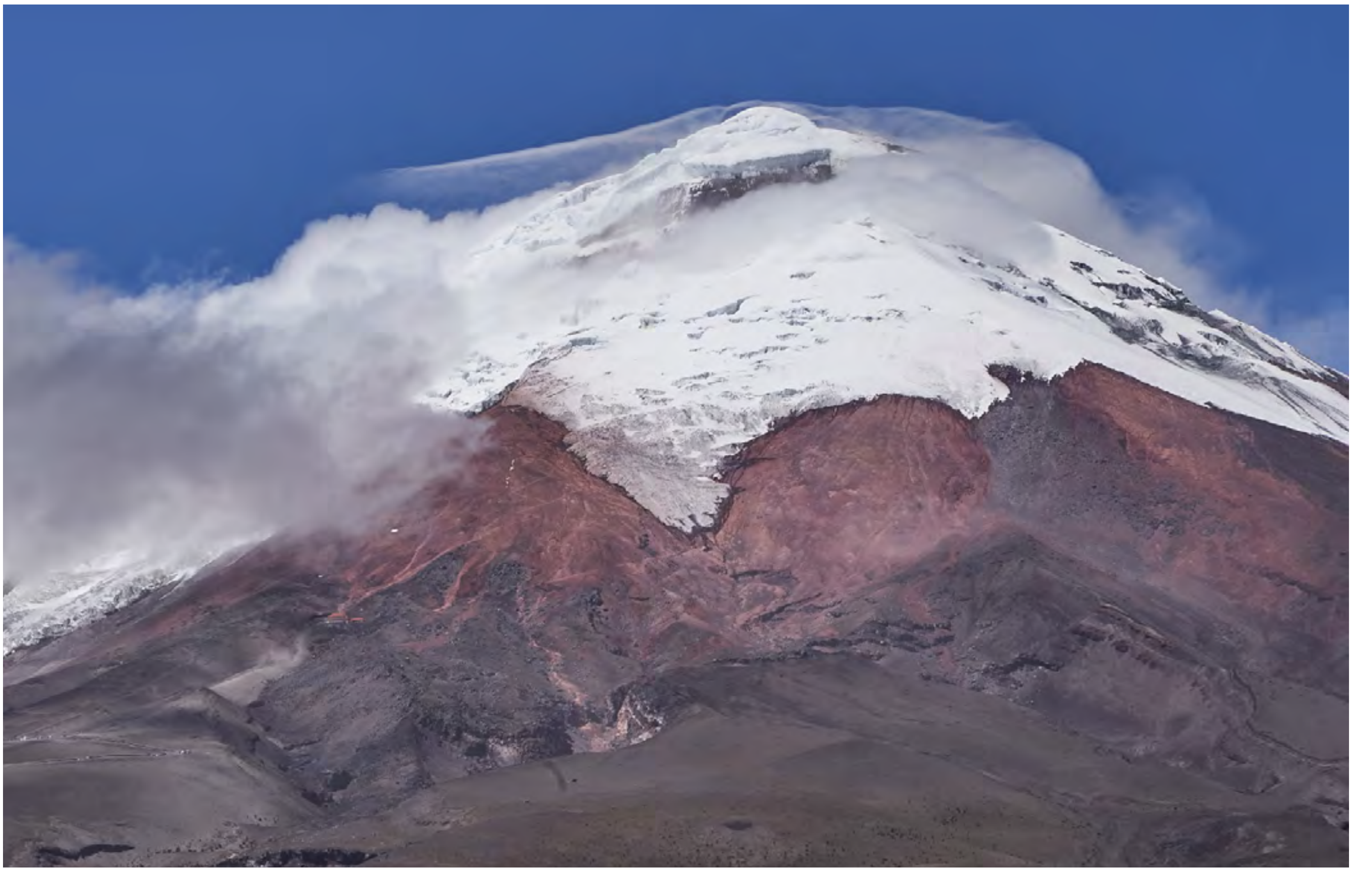
Table 5.2. Recommended site condition monitoring attributes and generic targets (adapted from Ellis, 2004; RPDC, 2013; Wignall, 2019).

Attribute	Description	Generic target for favourable condition
Site integrity: physical attributes	This attribute refers to the physical condition of the features that form the basis of the selection of the site, including the absence of disturbance, physical damage or fragmentation of the interests. The physical attributes of the key features include the extent, composition and structure of the features and, where relevant, their quantity and morphology. For active process sites, physical attributes also include the presence of land-forms and other physical characteristics (e.g. erosion or deposition), which indicate that the processes remain active.	The physical attributes of the key features and the physical integrity of the site remain intact and undisturbed.
Site integrity: visibility	This attribute refers to the absence of concealment (e.g. from vegetation, talus build-up, engineering con-structions or buildings) of the key features that form the basis for the selection of the site and whether suitable close-up and/or distant views are available and safely accessible.	The key features of the site remain visible in close-up and distant views, as appro-priate.
Process integrity: pro-cess dynamics	This attribute is monitored for active-process geomor-phology features only. It refers to the capacity of the geomorphological processes that form the basis for the selection of the site to evolve naturally and unimped-ed. There should be no artificial constraints (e.g. from coastal defences or river bank protection). Activities such as extraction of sand and gravel may also disrupt natural processes. and are relevant to this attribute as well as to physical attributes. In addition, factors outside the site may also affect the process dynamics within it (e.g. installation of upstream dams on a river).	The natural geomorphological processes that are the key features of the site, in-cluding their levels of activity and spatial extent, are not disrupted or impeded.
Negative indicators	This attribute refers to the presence of any factors, ac-tivities or changes in the vicinity of the site that might adversely affect it in the future (e.g. dumping of waste, growth of self-seeded trees or enhanced erosion likely to lead to the demand for coastal defences). Negative indicators can be used to determine if a review of site management is required. Issues already affecting the other attributes above will also be relevant here if they are likely to require a review of site management to pre-vent them becoming ongoing issues.	There are no activities or changes evident in the vicinity of the site that might in the future affect one or more of the above attributes.

Category III geoconservation site might be surrounded by much larger areas of Category II or V. In reality, there will be situations where there are a number of significant geoheritage elements requiring conservation within a protected area, and multiple core zones and surrounding buffer zones will be the most appropriate approach. Identification and management of core and buffer zones for geoconservation protected areas depend on the specific reason for designation and therefore the type of area being protected. There is likely to be a substantial difference between the definition of core and buffer zones for small, discrete areas – for example, to protect a particular geoheritage feature, such as a national monument – and large geosites that combine many features and where maintaining the effective functioning of Earth processes is critical. The latter case requires consideration of abiotic processes at the larger, ecosystem scale. For example, conserving the features of a river valley because of the biodiversity and geodiversity interest and importance cannot be sustained without ensuring that the water regime upstream of the protected area is not radically changed unnaturally or significantly damaged by human activity. Similarly, in the case of geomorphological features such as caves, management of human activities in the wider water catchment may be necessary to safeguard features of interest in cave systems downstream.

6. Evaluation of potential opportunities for interpretation, promotion and geotourism

As part of promotion, interpretation and education, provision for managing visitors at sensitive sites should include appropriate assessment of risk and carrying capacity (see Section 8 for more details). Not all geosites are appropriate for geotourism, for example because of the sensitivity of the interest, particular hazards or other management constraints. Some sites will be very sensitive. For example, those with rare fossils and minerals need protection from the activities of commercial collectors and irresponsible fossil collecting,



Photos 5.9 and 5.10 Lahar, a volcanically induced mudflow, from the eruption of Cotopaxi, Ecuador causing devastation and often loss of life. 5.9 © José Brilha 5.10 © Roger Crofts

Table 5.3. Protected area operations benefiting from Earth science expertise.

Protected area operation	Nature of the action	Contributions of Earth science expertise
Road and access track construction and maintenance	Selection of material types for roads and tracks	Externally sourced materials need to be assessed for their environmental and geological compatibility within the protected area, their engineering suitability as a road material and their cost effectiveness. Materials sourced internally need to be assessed both for the impact of potential quarrying in the protected area and for the engineering suitability of the materials.
Walking track construction	Track selection	Knowledge of the sensitivity of the ground surface to damage (e.g. soft volcanic deposits, tundra with summer surface melting) is required, whether natural surface or artificial materials are needed (e.g. boardwalk) and whether single-way or return routes are appropriate.
Walking track construction	Selection of material types for walking tracks	Assessment of parent material for a walking track route should identify suitable construction techniques and the nature of future maintenance management for the track. In a volcanic landscape, successive lava flows of varying chemistries may present track material types with different suitability.
Building materials	Selection and use of rock materials for building	Assessment of the compatibility, engineering and environmental suitability of rock building material sourced externally for use within the protected area should be undertaken. Any rock extraction from within the protected area should be carefully considered and subject to an environmental impact assessment.
Water dams	Construction of in-park water dams for fire operations or for wildlife watering points	Assessment of the geological parent material's suitability to host a water dam should be undertaken.
Water bores	Provision of water bores for human or wildlife consumption or for firefighting operations	Assessment for the optimum placement of water bores based on the substrate should be undertaken.
Erosion control structures	Construction of erosion control structures	Technical contributions should be provided towards the design and placement of erosion control structures installed for landscape restoration and other work.
Safety: rock stability monitoring	Rock stability monitoring	Routine monitoring should be completed of natural structures that have safety issues, such as the potential to collapse. These could include overhanging cliffs, caves or unstable rock screes in steep mountains.
Safety: dangerous volcanoes	Facilitating monitoring of active or dormant volcanoes	Routine monitoring data for volcanoes, including potential for eruptions, should be completed in collaboration with geological survey organisations.
Safety: epithermal environments	Facilitating monitoring of geyser and superheated groundwater fields	Routine monitoring of these extreme environments should be completed for visitor safety management. Specific responsibilities should be defined for the protection of extremophile species.
Safety: lahar flows	Monitoring to provide warning for these dangerous events	Routine monitoring to identify warning of fast-moving events is needed to protect the public.
Safety: dangerous gases – volcanoes	Facilitating monitoring of dangerous gas levels, such as that of sulphur dioxide in volcanic landscapes	Routine monitoring of these extreme volcanic environments should be completed for visitor safety management, preferably with geological survey organisations.
Safety: dangerous gases – caves	Monitoring within caves for gases, such as carbon dioxide and radon	Monitoring of within-cave atmosphere is undertaken to ensure the safety of users. High carbon dioxide concentrations pose a health risk and may, in exceptional instances, reach lethal levels. Staff may accrue a radiation dose from exposure to radon gas.
Safety: karst catchments	Excessive rainfall in karst catchments	Tracking of local weather conditions is undertaken to prevent any impacts to visitors, including speleologists, caused by extreme weather events, excessive rainfall and extreme subterranean water flows.
Safety: seismic activity and tsunamis	Collaborative monitoring of seismic activity	Seismic activity information is gathered to provide protected area managers data to predict potential impact of tsunamis on visitors and staff. Tsunami potential should be factored into the planning, design and location of potentially vulnerable coastal walking tracks.

Table 5.3. Protected area operations benefiting from Earth science expertise. (continued)

Protected area operation	Nature of the action	Contributions of Earth science expertise
Climate change: ice	Monitoring of the seasonal freezing and thawing of lakes	Tracking of the annual "first freezing" and "first thawing" of ice on mountain lakes should be undertaken to identify any long-term changes due to climate change.
Climate change: glaciers	Monitoring the reduction in size of mountain glaciers	Tracking should be undertaken of the extent and rapidity of recession of mountain glaciers, glacial lake meltwater build-up and lake-outburst flooding potential due to climate change. Assessment should be undertaken of the risk of increased hazards from rockfall and destabilised moraines following glacier retreat and permafrost melting.
Climate change: coastal process changes	Monitoring change in condition of coastal features	Assessment should be undertaken of the effects of rising sea level and saltwater incursions inland, and predicted enhanced storms on coastal features, including increased hazards from rockfalls or landslides on steep coasts as the basis for potential management responses.
Climate change: fluvial process changes	Monitoring change in condition of river systems	Monitoring should be undertaken of the effects of more severe storms in catchments and downstream to assist in determining any management response to changing landforms, erosion rates or other effects.
Climate change: permafrost changes	Monitoring change in the condition of permafrost areas	Tracking should be undertaken of the melting of permafrost and the effects on the protected area landscape, access systems and structures, including assessment of increased hazards from rockfall or landslides and the implications for public safety.

which can damage the scientific interest and reduce the opportunities for more research. Other sites may be vulnerable to trampling, which will damage and perhaps wreck fragile forms such as new lavas. Managing access through permit systems or through accompanied visits are obvious ways of dealing with sensitivity that protected area managers will be well familiar with. Where there is a cultural and/or spiritual interest in a site, consideration also needs to be given to the maintenance of traditional access. In the case of sites, where the interest is in active processes or where mitigation of hazards to visitors is impractical, an assessment of the enhanced risk will be essential, as will be the implementation of appropriate actions, including exclusion or rerouting of visitor access and management of visitor expectations (see Sections 5.3, 5.6, and 6.4).

Best Practice Guideline No. 12: Follow the two-stage generic framework of conservation needs analysis and conservation planning and delivery to incorporate geoconservation into protected area management plans.

5.2 Geoconservation and protected area operations

Management operations for a protected area are described in detail in Jacobs et al., 2015. This includes guidance on programming, planning and delivering operations. Operations are described as the "tactical implementation of projects associated with strategically focused programs", which basically covers most actions in a protected area. An understanding of Earth science interests is especially important during the planning stages of an operation. Most tertiary-level-qualified protected area staff have had some background training in Earth science, either in secondary school or as an undergraduate subject. Some rangers may be trained as an Earth scientist and work alongside botanists, zoologists, anthropologists and other specialist colleagues in protected areas. There are many operational areas where their geological expertise and training may be used (Table 5.3).

Best Practice Guideline No. 13: Use a systematic approach to guiding management operations, including suitability of materials for trails and buildings, safety reviews of major hazards and the effects of climate change.

5.3 Application of the IUCN protected area management categories to geoconservation

IUCN identifies six categories of protected area (one with a subdivision), depending on how the area is managed; Dudley (2008) provides rationale and Stolton et al. (2013) provides further details. Important geoheritage features and processes may occur in all categories of protected areas (Table 5.4).

Protected areas important for geodiversity and geoheritage exist in all the categories, although some management categories are more likely to be applied to areas solely or primarily set aside for their geological or geomorphological importance. Category Ia, strict nature preserve, may be an important option for sites with a very fragile geoheritage. Rocks and landforms are sometimes more fragile than living vegetation because they are less easy to replace once degraded. Reserves protecting fossil beds that are important in the charting the history of the Earth could be Category Ia, where visitors only have access on restricted pathways or boardwalks. Some large Category II national parks are designated primarily for their geoheritage features. Category III, national monument, is likely to be useful for geosites because it is generally assigned to places with one particular feature, such as a cave, a rock formation or an outcrop of minerals. Category IV, aimed at protecting species and habitats, will not usually be as suitable for geosites, but may nevertheless include sites with rock outcrops, cliffs or other features that provide habitats; areas

Table 5.4. Geoheritage and the IUCN protected area management categories.

No.	Category Number; Name	Description	Geoheritage example	Photo
Ia	(Ia) Strict nature reserve	Strictly protected for biodiversity and also possibly for geological/ geomorphological features, where human visitation, use and impacts are controlled and limited to ensure protection of the conservation values	Surtsey, Iceland: Volcanic island that emerged in 1963, with access strictly limited for scientific research	 © Roger Crofts
Ib	(Ib) Wilderness area	Usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, protected and managed to preserve their natural condition	Petrified Forest Wilderness Area, USA: Large area of fossilised trees	 © José Brilha
II	(II) National park	Large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems, which also provide environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities	Kilimanjaro National Park, Tanzania: Large central volcano in the East African Rift Valley	 © Roger Crofts
III	(III) Natural monument or feature	Areas to protect a specific natural monument, which can be a landform, sea mount, marine cavern, geological feature such as a cave, or a living feature such as an ancient grove	Jenolan Karst Conservation Reserve, Australia: Important caves with Silurian marine fossils	 © Anne Musser
IV	(IV) Habitat/ species management area	Areas to protect particular species or habitats, where management reflects this priority; many will need regular, active interventions to meet the needs of particular species or habitats, but this is not a requirement of the category	Isle of Rum, Scotland, UK: Volcanic formations and periglacial landforms	 © Roger Crofts
V	(V) Protected landscape or seascape	Areas where the interaction of people and nature over time has produced a distinct character with significant ecological, biological, cultural and scenic value, and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values	El Hierro Geopark, Canary Islands, Spain: a geologically young island with well-preserved volcanic features and comprising several Category V protected areas	 © http://c0.thejournal.ie/media/2014/04/el-hierro-390x285.jpg
VI	(VI) Protected areas with sustainable use of natural resources	Areas that conserve ecosystems, together with associated cultural values and traditional natural resource management systems; generally large, mainly in a natural condition, with a proportion under sustainable natural resource management and where low-level non-industrial natural resource use compatible with nature conservation is seen as one of the main aims.	Great Barrier Reef National Park, Queensland, Australia: General Use Zone Gross Morne World Heritage Site and National Park, Canada: Community Area (over 180,000 ha in extent; ancestral home of the Mi'kmag people)	 © fairfaxstatic.co.au

with particular minerals, soils or rock types (e.g. limestone) that support specialised habitats and species; or landforms and geomorphological processes that support a diversity of habitats and species or disturbance regimes. Protected landscapes and sustainable use areas (Categories V and VI, respectively) are also less likely to be used for sites dedicated primarily to geoconservation, although they might be suitable in instances where geology or the traditional use of rocks or minerals, for example, has contributed to the development of a cultural landscape.

More broadly, protected areas with many values that also coincidentally *include* geoheritage can be found in any category. Thingvellir National Park, Iceland (Category II), is noted as an area where the North American and Eurasian tectonic plates are moving apart, but it also has enormous cultural value in Iceland as the setting of the first parliament, the *Althing,* and for that reason is inscribed on the World Heritage List (see Photo 4.6). The Isle of Rum, Scotland (Category IV), was initially purchased as a nature reserve for its unique geoheritage values, but is also a critically important breeding colony for Manx shearwater (*Puffinus puffinus*) and has an important and much-studied herd of wild red deer (*Cervus elaphus*). Zona Volcànica de la Garrotxa, Spain (Category V), has a unique landscape of extinct volcanoes alongside its important role in conserving traditional cultural landscapes and associated wildlife.

Some of the finest natural landscapes on the planet are dominated by spectacular geological formations or geomorphological phenomena and many of these are protected areas. For instance, the spectacular 180,000-ha Torres Del Paine National Park in southern Chile is an exemplary glaciated landscape that has exposed a dramatic white granitic laccolith capped by a metamorphosed sedimentary rock. Other protected areas that have impressive geological features, such as Uluṟu–Kata Tjuṯa National Park in Australia, Sagarmatha (Mount Everest) National Park in Nepal, Tongariro National Park in New Zealand and the Los Glaciares National Park in Argentina, are inscribed on the World Heritage List.

From the perspective of geoconservation, consideration of the six IUCN protected area management categories provides a shorthand way of thinking about how a particular site might best be managed to maximise its potential without destroying the values for which it was designated. In sites with mixed values, it can be a way of reminding managers of the full range of values.

Best Practice Guideline No. 14: Assess the relevance of each of the IUCN protected area management categories in establishing new protected areas for geoconservation or in improving the management of existing ones for geoconservation.

5.4 Incorporating spiritual and cultural values of geoheritage

Cultural and spiritual values, which in many cultures are indistinguishable, have been significantly related to geological features all over the world (see Verschuuren et al., in press, for details). For much of human history, the dominant values attributed to what is currently considered geoheritage have basically been cultural and spiritual. This is also the case with use values related to extracted materials, such as rocks, minerals or precious stones.

The cultural and spiritual symbolism of rocks and stones – such as monoliths, megaliths, and lightning stones – is extraordinarily rich and diverse across the Earth. Moreover, a vast array of precious stones and gems is used in numerous rituals and ceremonies. For all these reasons, numerous geological features have been, and in many instances still are, extremely significant in cultures all over the world (Chevalier, 1969). The stability and durability of most geological features makes them a symbol of what lies beyond the short cycles of nature; and what is beyond the human experience of the flux of time, reflecting other eons, or the eternity. In many cultures, stones are also symbolically related to wisdom. Ice in its varied forms adds to these meanings the symbolism of purity and rigor.

Sacredness, holiness, and spiritual power or significance has been attributed to numerous mountains, caves, wells, rivers, rocks and other features. For example, in Finland alone, at least 76 hills, 74 lakes, 38 mountains, 36 bays, 22 peninsulas, 18 ponds, 16 islands, 15 rivers, and 12 gorges have either the prefix 'pyhä' or 'hiisi' or the genitive 'hiiden', meaning 'sacred' or 'holy' (Lounema, 2003).

The following paragraphs provide some examples of the cultural and spiritual attributes and values related to geoheritage, chosen from around the world and diverse spiritual traditions. More detail can be found at the Silene Documentation Centre.

Sacred mountains, often with limited vegetation and fauna, occur on all inhabited continents (Bernbaum, 1997). They include most of the highest and most elegant volcanoes (e.g. Mauna Kea, Hawai'i, USA; Ol Doinyo Lengai/Sabuk, Tanzania; and Fuji-San, Japan). The great monolith of Uluṟu, Australia, is sacred to Aboriginal people. Mont Kailas, Tibet, China, is revered by Buddhists, Hindus and Jaïns. The Sierra Nevada de Santa Marta range, Colombia, is considered a 'heart of the world' by its traditional custodians. Machapuchare, Annapurna range, Nepal, consecrated to Shiva, has never been allowed to be climbed. Sri Pada (Adam's Peak), in Sri Lanka, receives Buddhist, Hindu, Christian and Muslim pilgrims. Jabal ar-Rahmah (Mount of Mercy), Saudi Arabia, is part of the Muslim Great Pilgrimage (Hajj). Tur Sinâ/Jabal Mûsâ (Mount Sinai), Egypt, is a holy mountain for Judaism, Christianity and Islam, related to the revelation to the prophet Moses. Agios Oros/Mount Athos, is part of a unique living Christian monastic republic within Greece, its slopes populated by hermits and monks devoted to prayer and contemplation.

Many important caves and karstic phenomena have been used as natural sanctuaries preserving, in some cases, the oldest and most impressive paintings and sculptures of humanity, such as Pont d'Arc, France, dating to around 30,000 BCE. The Maya civilisation used numerous caves and wells for rituals, such as Actun Tunichil Muknal (Cave of the Stone Sepulchre), Belize. In Sri Lanka, Dambulla Caves, a complex of five Buddhist cave shrines, have been receiving pilgrims for over two millennia.

Photo 5.11 Spectacular landscape where glacier action has exposed underlying igneous and metamorphic rocks. Torres del Paine National Park, Chile. © Graeme L. Worboys

Photo 5.12 Uluru sacred mountain in central Australia. © John Gordon

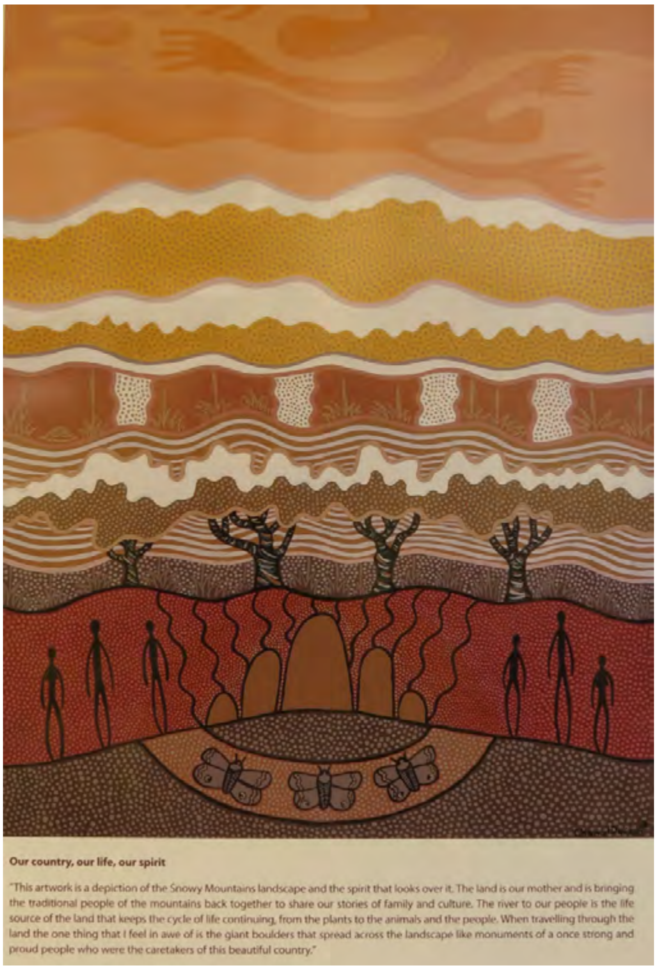


Photo 5.13 Aboriginal depiction of the Snowy Mountains landscape, New South Wales. © Roger Crofts

Innumerable Hindus, Buddhist and Christian hermits and monks have been living in caves to gain wisdom in remote natural places of Asia, Africa and Europe.

Troglodytic temples and shrines carved in rocky formations are another striking feature found all over the world. Examples from vanished civilisations include those of the Nabateans (e.g. in Petra, Jordan), or of the Achaemenid Kings (Naqsh-e Rostam, Iran). Impressive troglodytic temples are still in use (e.g. the monolithic churches of Lalibela, Ethiopia). Cut into the Xiangshan and Longmen Shan hillsides above the Yi River, China, an impressive treasury of Buddhist carvings comprise over 2,300 caves and niches and 43 pagodas, the earliest dating from the fifth century AD, the same period of the Elephanta Caves in Gharapuri Island, India.

Rocks with special morphologies are considered spiritually and/or culturally significant in many cultures and traditions. Examples range from large rocky features, like those of Monument Valley, Utah–Arizona, USA, to mesas (such as those associated with certain Native American Pueblos,, New Mexico, USA), to cliffs such as Bandiagara Cliff, Doggon country, Mali. In northern Scandinavia and Russia, numerous rock formations and offering stones have a long history of sacredness and continue to be meaningful for indigenous peoples.

Gorges and waterfalls have been considered spiritually significant around the globe. The Iguazu Falls, Brazil–Argentina; the sacred Ganges waterfalls, India; the Three Gorges of the Yangtze river, China; the Angel Falls in Canaima National Park, Venezuelan Amazonia; and the Victoria Falls, Zimbabwe, are just a few outstanding examples.

Precious or semi-precious stones, gems and metals with numerous cultural and/or spiritual associations have been used since prehistoric times, especially for religious, medical and magical purposes, in very diverse cultures. The Ayurvedic gemstone therapy is still widely used in India. For all these reasons, evidence of long-distance transportation of precious stones, volcanic glasses, gold, silver, etc. has been documented around the world since prehistoric times (Piccardi & Masse, 2007).

In numerous sacred scriptures, which influence over 85% of humankind, some geological elements have prominent roles. Both the Bible and the Quran were written in arid or desert ecosystems, where geological features dominate the landscape. No wonder that geological symbols and metaphors are often used. In the Bible, the word "rock" is used some 150 times, being more often a reference to God than anything else (Wellman, 2015). "God the Rock" appears in the Psalms, Deuteronomy, and several prophetic books. In the New Testament references to "drinking from a spiritual rock" and "the rock was Christ" (1 Corinthians 10:4) occur. The Kaaba, the cubic shaped sanctuary, attributed to the prophet Abraham/Ibrahim, is located in the centre of the sacred mosque of Mecca, the holiest city of Islam. In the eastern corner of the Kaaba lies the famous Black Stone, probably a meteorite, which "fell from heaven" and has been held in reverence by pilgrims for centuries. The revelation of the Quran is said to have begun in a small cave of the mount An Nur, where Muhammad used to take retreats. The purity attributed to clean stones and sands in the Islamic tradition is attested to by the fact that both can be used for ritual purifications when water is lacking.

Overall, a vast variety of cultural and spiritual values provide added significance to many geologic features, from individual gems or stones to entire rangelands, both on and below the Earth's surface. These values connect the life of current cultures and communities to the meaning and symbolism of the most permanent features of our terrestrial home, and through them to the past and the future generations. The cultural and spiritual connections between local communities and cultures and their geological heritage has a deep significance, which should not be neglected by conservationists.

There are many management mechanisms for ensuring that cultural and spiritual values at sites are adequately protected. These include the use of on-site watchmen from the local community to guard the site and to act as interpreters of the cultural and spiritual interest to visitors, for instance at Gwaii Haanas National Park with its S'Gang Gwaay World Heritage Site, British Columbia, Canada, and restrictions on access to safeguard the spiritual values of the site, such as at Uluru in Australia. More details are given in Verschuuren et al (in press).

Photo 5.14 Buddhist shrine in a cave at Wat Tham Sri Wilai, Thailand. © John Gunn

Photo 5.15 St Archangel Michael Rock Monastery, Bulgaria. © Roger Crofts

Photo 5.16 Symbols of life, including hunting scenes and livestock enclosures, carved into bedrock at the Alta World Heritage site, Finnmark, Norway. © Roger Crofts

Photo 5.17 Musicians have been inspired by natural phenomena, such as Fingal's Cave, Staffa, Scotland which inspired Mendelssohn to compose his *Hebrides Overture*. © Roger Crofts

Box 5.2

The geoarcheosite of the San Giuliano Etruscan Necropolis, Italy

The Etruscan tombs dug into the rock in the area of Barbarano Romano, 60 km north of Rome, are a good example of the interrelationship between geoheritage and archaeological heritage. The layered volcanic rocks were relatively soft and readily worked for cutting tracks and digging tombs. Dating from the sixth century BCE are numerous Etruscan necropolises known collectively as 'San Giuliano'.

The Caiolo tumulus and the tombs called 'Chariots' and 'Beds' are among the first features encountered by following the trail that descends into the deep valley, before arriving at the

'Tomb of the Queen', with its 10m-high façade. Above a lateral staircase at the 'Deer's Tomb' is a singular sculpture in bas-relief, representing a fight between a deer and a wolf. All of the tombs and tracks are protected as the Marturanum Natural Reserve by a special governmental agency for the preservation and care of the region's archaeological heritage. The management objective combines environmental protection and the conservation of archaeological remains. The remains are being eroded by water runoff and plant roots. Any intervention should, therefore, be balanced between safeguarding the overall system and the individual elements. The archaeological component makes the site more accessible to the public, improving understanding of the geosite as a cultural asset. The presence of geoarcheosites also has improved geotourism development.

Contributor: Dario Mancinella

Best Practice Guideline No. 15: Include cultural and spiritual values in the purposes and management of geoconservation protected areas and, where appropriate, include geoheritage in protected areas designed for spiritual and cultural values.

5.5 Monitoring and evaluation of geosites

Monitoring of geosites or geoheritage features may be conducted for a number of intended uses, including to:

- evaluate and report on the current condition and long-term trends of specific geosites or features, and processes (see Section 5.1);
- evaluate the management effectiveness of a site or of specific geoheritage features and processes; and
- provide management information on the surveillance, protection and safety of the site and specific features and processes.
- The monitoring data and subsequent evaluation information may then be used by management for:
- official accountability reporting against the management plan and reporting to funders and management, as well as the public, in annual reports and other documentation;
- safety reporting and the management of access; and
- reviewing the effectiveness of management or for specific characteristics of the geosite.

Many monitoring "use" types have been developed by protected area organisations (Tables 5.5 and 5.6). These are presented here as generic monitoring and evaluation considerations, with specific examples provided. It should be noted that many geological features and processes are monitored by specialist organisations (such as a government geophysical survey organisation or a volcanology team) who have working partnerships with protected area organisations. It is unlikely that protected area organisations will have either the resources or the technical capability to undertake these specialist monitoring operations themselves; instead, they will depend on voluntary input by experts from accredited sources. In addition, a great deal has been written about monitoring and evaluation in relation to nature conservation projects and initiatives, including the different purposes of monitoring, its relationship to adaptive management, and the challenges to doing successful monitoring programs. Much of what has been written is applicable to the monitoring of geoheritage features. For a summary of monitoring and evaluation related to nature conservation, see chapter 10 in Groves & Game (2016).

The methods used to monitor geosites and their features and processes need to be carefully thought through and planned. They are typically underpinned by a monitoring plan that identifies the purpose of the monitoring, the protocols and procedures that will be used and how the monitoring information will be used. Indicators will be selected to suit the information collection to be used by an organisation (i.e. utilisation-based evaluation). A common trap for people considering evaluation is that they start the process by attempting to choose indicators. Indicator selection is undertaken *after* decisions have been finalised on what information will be utilised. Indicators can then be selected to suit the information needed. Typically, indicators chosen will be 'SMART': Specific, Measurable, Achievable/Attainable, Relevant and Timely. Another trap is that a monitoring plan is prepared well after a project has commenced. It needs to be an integral part of the initial project planning.

High-level management support in the protected area organisation is needed to ensure the ongoing success of

Photo 5.18 Linking geoheritage to the national currency can help to enhance recognition of protection. Guilin Karst, South China Karst World Heritage Site. © Roger Crofts

effective monitoring. Governance support considerations for both small- and large-scale monitoring projects include:

- Organisations have fully endorsed a monitoring and evaluation plan.
- Ongoing funding has been committed.
- Personnel with the right skills are employed to manage and conduct the monitoring.
- Systems have been put in place to utilise the monitoring information.
- Induction and training has been put in place for staff responsible for the system.

This approach stresses the functional relationship between an organisation's statutory responsibilities and monitoring, such as the ongoing protection of the geosite and all of its important aspects, as well as the safety of visitors.

Best Practice Guideline No. 16: Develop monitoring schemes to assess and evaluate critical features and natural processes, and adjust plans accordingly (in an adaptive management framework) to ensure geoconservation goals are achieved.

5.6 Examples of geoconservation management in protected and conserved areas

Boxes 5.3, 5.4 and 5.5 provide examples of geoconservation management. There are many examples published elsewhere; see chapters 19 to 24 of Reynard & Brilha (2018) for examples from Ethiopia, Brazil, Republic of Korea, Tasmania (Australia), Colorado (USA) and Spain. The journal *Geoheritage,* published by Springer and produced jointly by ProGEO (The European Association for the Conservation of the Geological Heritage) and IUGS (International Union of Geological Sciences), has articles on case studies from around the world.

Table 5.5. Monitoring types and their utilisation.

Monitoring use type	Monitoring information collected	Evaluation and utilisation	Rationale
Context	What is the condition of the geoheritage site or phenomenon and what is its trend in condition? Is it threatened?	Used to determine if management intervention is needed to protect the geosite or phenomena present.	Needed for all geosites and specific features and processes.
Planning	Identifies goals and objectives and how to achieve them.	Used to carefully identify and assess strategic management objectives and associated actions needed for the protection of the geosite or phenomena present.	Evaluation of the effectiveness of the planning objectives should be a routine management assessment, taking place perhaps every 5 to 10 years.
Inputs	Geoconservation actions need resource inputs that typically include people, funds and materials.	Evaluation is used to ensure that the right financial investments and human resources are directed to the right locations and the right materials for the task to be delivered in a timely and cost-efficient manner.	Such assessments ensure the right human and financial resources have been allocated to ensure the monitoring is successful as well as ensuring the allocation has been effective.
Process	Assessing systems of management and procedures is an important part of geoconservation.	This may apply to emergency incident management procedures, such as dealing with incidents such as volcanic eruptions, lahars and earthquakes.	Monitoring the appropriateness of procedures and systems for managing events and incidents on geosites is a critical part of management.
Outputs	Given the planning, organisation of inputs and processes, the effectiveness of geoheritage outputs can be assessed.	What was done and what products and services were achieved for the effort and inputs involved can be evaluated.	The monitoring of individual actions provides important feedback for managers, especially at the task completion stage. It provides a basis for adaptive management.
Outcomes	The measurement of outcomes is normally assessed against the original planning objectives, but it should also take into account "big picture" appraisals of how geoconservation has been advanced by the management actions undertaken.	Outcome measurement may be quantified and as such it provides invaluable information for organisations to demonstrate success as well as for use by independent audits of management effectiveness required by government or a board of management.	Conservation progress for the management of a geoheritage site or phenomena may be identified, and published within an organisation's annual report or used for other statutory reporting requirements.

Box 5.3

Geoconservation and management strategies: Components for success from two Spanish UNESCO Global Geoparks

Examination of the geoconservation and management strategies of two Spanish UNESCO Global Geoparks, Las Loras and Molina de Aragón-Alto Tajo , highlights six crucial components for the success of any geopark. First, is the establishment of a database with all actions and activities organised in the geopark, by management and partners. Second, the presence of geoconservation experts within the geopark's staff helps to raise the profile of geoheritage and to better inform other staff. Third, the creation and implementation of a geoconservation action plan provides a new base for management planning and action. Fourth, the existence of a multidisciplinary staff team creates a new dynamic. Fifth, management and strategic plans covering key activities of geoparks– namely, education, tourism, communication and sustainable development – are completed. Sixth, the promotion of participative management with stakeholders and the local population provides a tool for the development of the whole territory.

For further information, see Canesin et al. (2020).

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Table 5.6. Examples of geoheritage monitoring, evaluation and reporting.

Category	Monitoring information	Utilisation	Examples
Seismic activity	Frequency and severity of seismic activity	Used for: research, determining visitor access or closures, and emergency responses.	Point Reyes National Seashore and Hawai'i Volcanoes National Park (USA), US Geological Survey
Volcanic eruptions: acid volcanics	Seismic activity; change in epithermal behaviour; content of gas emissions; rising or falling terrain	Used for: research, determining visitor access or closures, and emergency responses.	Yellowstone National Park (USA), US Geological Survey
Volcanic eruptions: basic volcanics	Seismic activity; lava dynamics; eruption activity	Used for: research, determining visitor access or closures, and emergency responses.	Hawai'i Volcanoes National Park (USA), US Geological Survey
Glacier condition	Satellite remote sensing monitoring information of the characteristic and condition of glaciers	Used for: inventory and research, climate change impact and precautionary reporting of glacier dams and potential for collapse	ICIMOD (International Centre for Integrated Mountain Development) undertakes whole-of-Himalaya evaluation, including for many protected areas
Tsunami: undertaken by specialist organisations, but linked to protected area organisations	Severe earthquake in a marine environment	Used for: visitor safety and emergency response actions	Hawai'i coastal parks (USA) that are subject to frequent tsunamis
Volcanic gas emissions	Gas content and concentrations	Used for: research, determining visitor access or closures	Hawai'i Volcanoes National Park (USA), US Geological Survey
Lahar define	Monitoring for active lahars post eruption events	Used for: emergency evacuation and road closure actions	Tongariro National Park (New Zealand)
Slope stability	Monitoring of unstable slopes including cliffs and cracks in rock formations	Used for: visitor safety and park closure actions	Dolomite serial World Heritage sites, (European Alps) monitors for climber safety in a climate change environment of higher temperatures affecting high-altitude cliff faces
Cave roof stability	Monitoring the stability of cave roof	Used for: visitor safety and cave closure decisions	Manjanggul lava tube cave (Republic of Korea). Rockfall was monitored using high-resolution gear or glass plate
Cave speleothems	Identifying any change in speleothems from a known baseline	Used for: research and for protection from the threat of vandalism	Baegnyong Cave (Republic of Korea), where before-and-after photographic monitoring identified change
Cave atmosphere	Monitoring of the level of carbon dioxide within a cave used by visitors	Used for: the safety of visitors, especially in show caves	Waitomo glow worm caves protected area, (North Island, New Zealand), uses an automated, continuous air quality monitoring system.
Cave radioactivity	Monitoring the level of radioactive radon gas within caves	Used for the safety of within cave workers, especially cave guides	Carlsbad Caverns National Park (USA)
Mistaken Point World Heritage property fossil beds coast morphology	Lidar (satellite) monitoring of the condition and trend in condition of the coastal fossil beds	Conducted every 10 years to monitor the long-term erosion of the site	Mistaken Point World Heritage property (Newfoundland and Labrador, Canada)
Mistaken Point foot traffic erosion of fossil beds	Fixed point and fixed position photography to assess foot traffic erosion	Conducted every two months and after major storms.	Mistaken Point World Heritage property (Newfoundland and Labrador, Canada)
Great Barrier Reef condition and trend in condition	Monitoring of the physical condition of the Great Barrier Reef	Conducted after major events such as tropical cyclones and extreme heat bleaching events by university and research organisations. Provides public reporting on the condition of the reef.	Great Barrier Reef Marine Park (Queensland, Australia)

Box 5.4

Protection work in volcanic landscapes

Active volcanoes are spectacular geological and geomorphological features. Many are located within protected areas and some have been inscribed on the World Heritage List, such as Hawai‘i Volcanoes National Park (USA). Protected area managers responsible for volcanic phenomena appreciate the distinction between acid and basic volcanicity, and are aware of highly volatile and dangerous acid rock volcanoes that feature rhyolite, trachyte and andesite lavas and can include pyroclastic *nuée ardente* events. These fast downslope-moving clouds of superheated fine shards of volcanic material enveloped ancient Pompeii and killed many of its residents. Managers responsible for volcanic protected areas are constantly managing for the safety of visitors in the dynamic volcanic environment (Table 5.7).

Table 5.7. Visitor safety in volcanic landscapes.

Eruptions	Erupting volcanoes are fascinating and inspiring and can be a major attraction for visitors. Volcanoes with basic lavas, such as the Kilauea Volcano in Hawai‘i (USA), are relatively safe and may erupt steadily in between more vigorous eruptions. Active volcanoes with more viscous and silica-rich lavas are highly dangerous and visitors would normally not be allowed in close proximity to them. Protected area closures are made when conditions are potentially or actually unsafe. Typically, there is a close working partnership between volcanologists and protected area managers.
Lahars	The mix of volcanic eruptive material and water high on a volcano is very dangerous and can lead to the rapid downslope movement of this muddy material, known as a lahar. In Tongariro National Park, New Zealand, lahars have historically emanated from the Mount Ruapehu crater lake. The volcano is monitored, and safety warning systems have been established downslope where the public could be impacted.
Earthquakes	Earthquakes of varying intensity are typically associated with eruptions. It may mean that some protected area locations need to be closed as access roads or steep slopes have become unsafe from destabilised boulders, slope movements and collapsed or fractured roads.
Explosions	Unpredictable explosions during volcanic eruptions may occur as primary eruption events or even as an interaction between groundwater and hot magma. This is a reason many protected areas are closed during eruptions. Managers need to work closely with volcanologists to ensure that the public and staff are safe.
Gases	Carbon dioxide, sulphur dioxide, methane and other gases may be present at volcanoes whether they are erupting or not. The concentration and extent of these gases is a safety issue for visitors and areas may need to be monitored, with closures occurring as necessary.
Navigation	Stone cairns are used to assist visitors with navigation on walking tracks in Hawai‘i Volcanoes National Park, given the dual issue of regularly occurring thick mountain fog and magnetic fields associated with recent basalt lava and subterranean molten lava, which render a compass useless. The authority supplies good maps, trail routes are marked and visitors are warned about navigation issues.
Signs and safety handrails and fencing	Managers need to consider the corrosive nature of a combination of volcanic gases such as sulphur dioxide and rain when installing signs and safety handrails and fencing. The selection of materials is critical, for many metals have a short life span in these extreme conditions, and safety barriers of the wrong type of material can become unsafe over time.

Box 5.5
Jenolan Karst Conservation Reserve, New South Wales, Australia

Jenolan Karst Conservation Reserve (JKCR), on the eastern flank of Australia's Great Dividing Range, is a 3,085-ha protected area, wildlife sanctuary and tourist operation. JKCR features an extensive cave system in Silurian limestone visited by over 200,000 people yearly.

JKCR is jointly managed by the Jenolan Caves Reserve Trust and the New South Wales National Parks and Wildlife Service (NPWS). It is part of the Greater Blue Mountains World Heritage Area (GBMWHA), listed for the diversity and uniqueness of cave-dwelling invertebrates (specific to JKCR). It has the largest tourist caves in Australia and provides critical habitat for rare, endangered and relict species and unique or endemic troglobitic/stygobitic faunas.

Conservation issues

Two features are of critical importance. First, cave-dwelling invertebrates are of special conservation value and include troglobitic and stygobitic faunas completely dependent on the cave environment and adapted to the current conditions within the caves; deleterious changes in the cave environment thus have the potential to seriously impact these faunas. Second, McKeowns Valley (the Jenolan River Valley) is a globally significant example of excavation of valleys through karst by surface rivers.

Threats to geodiversity and biodiversity include the potential for pollution to affect the karst and groundwater, fire, alterations to hydrology, development pressures and risks from climate change. Cave-specific threats include artificial lighting, changes in temperature and humidity, noise, gating, public interference, and, in the case of bats, potential for introduction of white-nose syndrome. Aging infrastructure, silting and gravel accumulation in the human-made Blue Lake, maintenance of water treatment and sewage treatment facilities all pose challenges.

Management objectives and innovations

The current management plan (Office of Environment and Heritage New South Wales, 2019) has benefited from new survey information, and coupled with additional resources, enables many of the threats to be overcome. To manage cave-specific threats, lighting systems have been upgraded to minimise light and temperature impacts; 'best practice' is followed for cave infrastructure (including the installation of non-ferrous stainless steel railings); cave access permits are strictly monitored (access to caves is by site- and date-specific NPWS permit for accredited caving organisations only); and plans have been developed to prevent the introduction of white-nose syndrome at important bat/wallaby sites.

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Dealing with threats to geoheritage in protected and conserved areas

6

Removal of a dam on the Elwha River, Olympic National Park, Washington, USA, has allowed the river to return to its natural state with the formation of sedimentary features and reinstatement of natural processes. © US National Park Service

This section focuses on threats to geoheritage in protected and conserved areas and how to deal with them. The following topics are addressed:

- concepts of sensitivity and vulnerability(6.1)
- principal threats(6.2)
- guidance on assessing risk and impacts (6.3)
- generic site management guidelines for dealing with threats from nine particular sources (6.4)
- interaction between geodiversity and biodiversity conservation (6.5).

Many human activities have an impact on Earth's land surface. Hooke (1994) used data on natural and human-induced sediment transport to conclude that "humans are geomorphic agents. They move vast quantities of soil and rock, and have a major visible impact on the landscape…. Humans are arguably the most important geomorphic agent currently shaping the surface of Earth". In this section, the main human threats to geoheritage features and processes are described, and advice on how to deal with them set out. Analysis of threats is a major element of the management planning process described in Section 5.

6.1 Concepts of sensitivity and vulnerability

A common misconception about the natural world is that, whereas plants and animals are frequently endangered and susceptible to many threats, rocks and landforms are solid, robust abundant and therefore not in need of protection. This is far from the case. There are many physical features that are highly fragile and susceptible to human disturbance, one example being the ease with which thin cave stalactites can be snapped off, either intentionally or accidently, by geotourists in show caves. Much here depends on two concepts – *sensitivity* and *vulnerability*. 'Sensitivity' refers to a feature's susceptibility to damage and the degree to which it is affected or will respond, whereas 'vulnerability' refers to the likelihood of damage because of actual or potential human intervention. Some sites are highly sensitive yet not vulnerable because of their remote location or physical protection.

The evaluation of the sensitivity of relict features (i.e. those resulting from past processes that have now ceased) is relatively straightforward, based on a simple assessment of the likely scale of impact and loss of the feature of interest (Table 6.1). For active geomorphological systems, additional factors to be considered are resilience of the system and its potential dynamic response, including prolonged readjustment (that may or may not lead to recovery) or change in state (for example, from a braided to a meandering river) (Kirkbride & Gordon, 2010).

Table 6.1 shows the 10-point Tasmanian geosensitivity scale ranging from 1 (highly sensitive) to 10 (highly robust). Activities that cause severe damage to sensitive sites may have little impact on more robust ones. Some systems are capable of repairing themselves (e.g. footprints on a beach eroded by the next high tide), whereas other changes are irreversible because the processes that created them no longer operate in that area (e.g. glacial landforms in areas where glaciers no longer exist). Overall, the greatest need for careful management and protection is at sites that are both sensitive and vulnerable to human disturbance.

Many natural processes operate on the land surface, eroding, transporting and depositing sediment. These natural physical processes will also often need protection because geoconservation is not just about protecting static sites: it is also about making space for dynamic processes to continue

Table 6.1. The 10-point Tasmanian geosensitivity scale (modified after Kiernan, 1996; Sharples, 2002).

1.	Values sensitive to inadvertent damage simply by diffuse, free-ranging pedestrian passage, even with care (e.g. fragile surfaces that may be crushed underfoot).
2.	Values sensitive to effects of more focused pedestrian access (e.g. footpath erosion).
3.	Values sensitive to damage by scientific or hobby collecting or deliberate vandalism or theft (e.g. some fossil or mineral collecting).
4.	Values sensitive to damage by remote processes (e.g. hydrological changes upstream).
5.	Values sensitive to damage by higher-intensity linear impacts (e.g. vehicle tracks).
6.	Values sensitive to higher-intensity but shallow disturbance on site (e.g. soil erosion due to poor land management).
7.	Values sensitive to deliberate linear or generalised shallow excavation (e.g. removal of tree stumps, construction of small bunds).
8.	Value sensitive to major removal or addition of geomaterials (e.g. quarrying).
9.	Values sensitive only to very large-scale contour change (e.g. reservoirs or major river channelisation schemes).
10.	Values sensitive only to catastrophic events (e.g. major landslides or tsunamis).

Table 6.2. Principal human-induced threats to geoheritage in protected areas (adapted from Gordon & Barron, 2011; Brooks, 2013; Gray, 2013; Crofts & Gordon, 2015).

Threats	Examples of impacts on geoheritage in protected areas
Urbanisation, construction (including commercial and industrial developments inland and at the coast), infrastructure and renewable energy installations	■ destruction of landforms and exposures of sediments and rocks ■ fragmentation of site integrity and loss of relationships between features ■ disruption of geomorphological processes ■ destruction of soils and soil structure ■ changes to soil and water regimes
Mining and mineral extraction (including extraction from open-cast mines, pits, quarries, dunes and beaches, river beds, marine aggregate extraction and deep-sea mining)	■ destruction of landforms and exposures of sediments and rocks ■ fragmentation of site integrity and loss of relationships between features ■ disruption of geomorphological processes ■ destruction of soils and soil structure ■ changes to soil and water regimes
Changes in land use and management (including agriculture and forestry)	■ landform damage through ploughing, ground levelling and drainage ■ loss of landform and outcrop visibility and access to exposures ■ stabilisation of dynamic landforms (e.g. sand dunes) ■ soil erosion ■ changes to soil chemistry and soil water regimes ■ soil compaction and loss of organic matter
Coastal protection and river management and engineering (including dams and water abstraction)	■ damage to landforms and exposures of sediments and rocks ■ loss of access to exposures ■ disruption of geomorphological processes ■ inhibition of erosion allows exposures to become degraded
Offshore activities (including dredging, trawling, renewable energy developments, hydrocarbon exploitation and waste disposal)	■ physical damage to seabed landforms and sediments ■ disruption of nearshore and offshore geomorphological processes
Recreation and geotourism	■ physical damage to landforms, rock outcrops, processes and soils (compaction) through visitor pressure ■ fragmentation of site integrity ■ footpath erosion and other localised soil erosion and loss of soil organic matter
Climate change	■ changes in active system processes ■ changes in system state (stabilisation or a move to an active state) ■ loss of features, such as ice caps, glaciers and periglacial processes
Sea-level rise (from anthropogenic causes)	■ loss of visibility and access to coastal exposures and outcrops through submergence ■ loss of exposures through enhanced erosion ■ changes in coastal landforms ■ loss of all or substantial parts of protected areas ■ new features developed (e.g. from storm surges)
Restoration of pits and quarries (including landfill)	■ loss of exposures and natural landforms
Stabilisation of rock faces (e.g. road cuttings) with netting and concrete	■ loss of exposures
Irresponsible fossil and mineral collecting and rock coring	■ physical damage to rock exposures and loss of fossil records and context

operating within their natural range of variability. However, human activities can have an impact on the rates of these processes, for example by clearing vegetation and thus increasing run-off rates into rivers and increasing soil erosion. In these cases, geoconservation should seek to return the processes to within their natural range of variation through sustainable land and water management (Section 6.3).

Best Practice Guideline No. 17: Use the concepts of *sensitivity* and *vulnerability* to guide assessments of threats and their potential impacts on geoheritage features and processes.

6.2 Principal threats

Natural processes can result in the loss of geodiversity (e.g. coastal erosion leading to collapse of a sea stack or natural arch). This should be accepted as part of the natural evolution of the landscape – continued operation of the processes will create new stacks or arches. Of greater concern for managers are human-induced impacts that can lead to one or more of the following generic impacts:

- complete destruction of a geosite;
- partial loss of or physical damage to a geosite;
- fragmentation of the feature of interest;
- loss of visibility (e.g. through vegetation growth);
- loss of access;
- interruption of natural processes and off-site impacts;
- pollution;
- loss of naturalness; and
- visual impacts (e.g. graffiti).

Table 6.2 gives a list of specific threats, with examples of the impacts on geoheritage in protected areas. The remainder of this chapter outlines the threats, pressures and impacts, and provides recommended management approaches and sources of practical guidance. For more detail see Gray (2013).

6.3 Dealing with the threats: Assessing risk and impacts

Sites and features will have varying degrees of sensitivity to different types of human activity. Determining the likely impact and the options for responding to potential threats is an important component of site management. Risk assessments and prioritisation of management action will need to be undertaken to determine the likelihood and potential effects of different types of human activity and natural changes. Here, the principles and methodology of strategic environmental assessment and environmental impact analysis should be applied. Note that in the case of dynamic systems, activities beyond the protected area may impact on it.

6.4 Dealing with the threats: Best practice guidance on key topics

The effects of specific threats to geosites are outlined below, together with advice on management principles and approaches. For practical guidance and working examples, refer to Prosser et al. (2006), who set out comprehensive guidance on managing sites based on the conservation objectives for the three main categories of geosite: exposure/extensive, integrity and finite (Section 5.2 and Table 5.1). Examples of the application of this guidance to protected areas for cave and karst, glacial and periglacial (i.e. those formed by freeze/thaw processes) areas, palaeontological and mineral interests, and volcanic areas are given in Section 7. In the text below, reference is also made to additional sources of guidance, where these exist (e.g. for the management of rivers and coasts). In addition, several case studies are included (Boxes 6.1–6.7; and see also Box 4.5). Consideration should always be given to Nature-based Solutions (i.e. those seeking to mimic nature or restore it where appropriate and possible). IUCN has published the first edition of a Global Standard for Nature-based Solutions (IUCN, 2020).

Mineral extraction and restoration of quarries

Old mines within protected areas can pose safety and environmental problems. Often vertical shafts and mine entrances are left exposed and these dangerous historical features need safety fencing or safety caps to protect visitors from accidents. Many mines exploited sulphide mineral ores, such as lead, copper and zinc, and groundwater run-off from these old workings is typically acidic and toxic to stream life and animal life. Arsenic-rich sulphides pose a particular problem because of their toxicity. Typically, protected area authorities may be involved with other organisations, such as a mines department or an environmental protection authority, for the clean-up of such toxic water pollution. Old mine dumps rich in sulphides pose a similar pollution run-off problem.

Minerals are needed in modern society and their extraction often leads to important exposures of rock strata. There is little problem where the material being extracted is extensive and where the landscape impact of a quarry is limited. The most serious situations are where rare soils, important landforms or fossil-bearing sites of limited extent are destroyed by surface quarrying. Unfortunately, illegal or uncontrolled digging also occurs in some parts of the world, leaving landscapes devastated and unrestored.

As well as direct geoheritage and landscape impacts, other possible effects of quarrying include the production of waste material/spoil heaps, pollution via mine tailings, acid mine drainage or failure of dams where waste material is stored, noise, vibration or traffic/access, road impacts and visual impacts of plant and machinery.

In most nations, mining is excluded from protected areas. This includes all forms of mining exploration, such as drilling and geophysical surveys. This prohibition extends to the centre of the Earth for protected areas legislated in this fashion, or it may be depth restricted. Some protected areas, including water catchment areas over gently dipping coal seams near Sydney, Australia, were depth restricted in their proclamation, which meant the coal could be mined at depth. Protected

Photo 6.1 Quarrying provides new exposures for geologists to research, especially rare ocean mantle rocks, as seen in the Troodos National Park, Turkish Cyprus. The debris can be dangerous and access needs to be managed. © Roger Crofts

Photo 6.2 A illustration demonstrating that quarrying approved before a site is given protected area status can be stopped or extensions refused permission if the geoheritage interest is sufficiently important. Eldon Hill Quarry in the Peak District National Park and the Castleton Site of Special Scientific Interest, England. After the quarry closed in 1999 access was granted to cavers who have discovered important speleothem and sediment deposits (see person at cave entrance). © John Gunn

BOX 6.1

Horn Park Quarry Site of Special Scientific Interest and National Nature Reserve, UK

Horn Park Quarry, a disused quarry near Beaminster, Dorset, UK, is an example of retaining the conservation interest for visitors and scientists to study after quarrying is completed and new use of the quarry approved.

Horn Park Quarry SSSI and National Nature Reserve is one of the most famous and richly fossiliferous localities in the Middle Jurassic Inferior Oolite Formation of south-west England, particularly noted for the unique metallic bed and diverse, well-preserved fossil invertebrate fauna, in particular ammonites.

Conservation issues and actions taken

Horn Park Quarry presents two significant conservation challenges (Larwood & Chandler, 2016). First, as the limestone has largely been quarried out, the remaining fossil resource is finite and particularly vulnerable to over- and illegal collecting. Second, development of a business park has required careful and sensitive planning to retain representative and accessible exposures through the relevant stratigraphy.

Following a detailed survey, the main faces in the upper quarry were re-exposed and stepped, enabling the retention of a complete stratigraphical sequence. This area was securely fenced to restrict access, thus protecting both the fossil resource and demarcating the most sensitive area of the site during the construction of industrial units. Access to the site is by prior permission only.

Working with volunteers and the Jurassic Coast Trust, the lower part of the sequence has been extended and the upper part, including fossils, re-exposed. A secure box (with a weld-mesh lid) has been placed over this area. This allows visitors to view in detail the diverse fossil fauna without disturbing it or losing fossils. Surplus material from the site investigation and clearance works has been left on site for visitors to collect from. Also, specimens have been donated to the nearby Beaminster Museum, where they have been incorporated into a geology exhibition and fossil educational boxes for work with local schools.

Boxed weld-mesh cover protecting exposed fossil beds © Jonathan Larwood

area staff were left with surface management problems, such as disappearing streams and leaking methane gas, problems which necessitated a government response.

Collaboration between IUCN and the International Council on Mining and Metals has resulted in codes of practice (ICMM, 2003). The key commitment is: “Respect legally designated protected areas and ensure that any new operations or changes to existing operations are not incompatible with the value for which they were designated” (ICMM, 2003). IUCN considers that no mining activities should take place in a protected area (IUCN, 2016b).

An example of concern about mining operations in or near protected areas is the Los Frailes mine in Aznalcóllar, near Seville, Spain. In 1998, a tailings dam burst, and 5 million cubic metres of toxic sludge flowed into the Guadiamar River, narrowly avoiding the important wetlands of Doñana National Park, a World Heritage Site. A €240 million clean-up operation was needed. As a result, the mine closed, but was allowed to reopen in 2015, with the construction of a new tailings dam being prohibited.

Some protected areas suffer from illegal mining, such as gold mining. Corcovado National Park in Costa Rica is one example where artisanal gold on the river banks was being mined and the extensive activity prompted authorities to act. Usually such response actions involve the police. With protected area managers understanding the geoheritage of their area at a detailed level, there is the potential to anticipate illegal activity and put in place protective measures in advance. Illegal mining damage, once stopped, will also require clean-up and restoration measures that can benefit from geological and restoration expertise.

At Kakadu National Park in Australia, uranium mining was started in 1980, but when the national park was established the following year, the Ranger and Jabiluka mines were excluded from the park but are completely surrounded by it. Concerns here include the leaking of 100,000 litres of contaminated water each day from a mine tailings dam into rock fissures beneath the Ranger mine as recently as 2009.

Planning conditions normally require restoration and landscaping, and often involve landfill. The result is the loss of geological exposures. Early dialogue between stakeholders (e.g. quarry operators, local authorities, academics and geoconservation bodies) is essential to ensure that, where practical, geoheritage interests are incorporated into restoration schemes through the establishment of places where the geological features can be conserved, viewed and interpreted for research, education and geotourism (Boxes 4.5 and 6.1). These may include conservation sections, or spoil heaps that contain important mineral specimens. Where applicable, restoration for geoheritage should be integrated with that of mineral workings for biodiversity and habitat gain (e.g. the Nature After Minerals programme in England, operated jointly by Natural England and the Royal Society for the Protection of Birds along with the mining community). In the absence of legislation, Prosser (2016) highlights the value of "developing mutually beneficial partnerships that celebrate the positive contribution of the mineral extraction industry to geoscience, education and conservation, while at the same time conserving geological features, specimens and data that may arise from their operations."

Recommendations for quarry management and restoration:

- ensure early dialogue between stakeholders so that geoheritage interests are incorporated into restoration schemes;
- secure access for recording and collecting in working quarries;
- integrate geoheritage and biodiversity restoration;
- secure and maintain key exposures or spoil heaps as conservation areas, using appropriate techniques;
- control vegetation encroachment; and
- develop opportunities for interpretation.

Land development and urbanisation

The development of land for the building of roads, houses, industry and other uses can have huge impacts on geoheritage by remodelling natural topographies, damaging soil structures, interrupting geomorphological processes and altering the hydrology of the area, for example by the installation of low-permeability surfacing. Where new buildings are to be constructed in protected areas, careful attention should be paid to their siting and design so they fit harmoniously with the local landscape. Where roads are to be constructed, they should try to flow with the existing topography and be designed to avoid extensive cuttings and embankments. But where cuttings are necessary, any revealed geological strata should be left exposed for future research and study, following guidance in Prosser et al. (2006). In certain cases, partial restoration may be possible after damage caused by development.

Recommendations for management and restoration:

- ensure early dialogue between stakeholders so that geoheritage interests are incorporated into development and restoration schemes;
- secure access for recording and collecting during development work;

Photo 6.3 Road making provides easier access for tourists to the Ngorongoro Conservation Area, Tanzania and its important wildlife, but creates greater pressures on the conservation management of the area. © Roger Crofts

- integrate conservation of geoheritage with landscape restoration;
- secure and maintain key exposures or landforms as conservation sections or sites using appropriate techniques; and
- develop opportunities for interpretation.

Coastal management and engineering

The installation of hard coastal defences can have several important effects on geodiversity. First, they are designed to prevent the natural evolution of the coastline. Second, they can obscure important coastal geological exposures and thus make them inaccessible for future study. Third, they can lead to stabilisation of active coastal landforms, such as dune systems. and prevent the interchange of sediment between beaches and dunes. At Burnie, in Tasmania, Australia, for example, a protected geological monument (comprising Precambrian dolerite dykes) was covered during a coastal reclamation scheme (C. Sharples, pers. comm.). Where coastal protection is necessary, the use of "soft" engineering methods is recommended, such as beach sand replenishment.

More strategic approaches are being increasingly adopted, based on understanding processes at the scale of regional coastal systems or coastal cells. This enables possible wider adverse effects to be considered, areas of conflict to be identified and resolved, and more integrated management progressed through shoreline management plans. While hard protection is likely to continue to be needed to secure essential infrastructure, more natural solutions are being increasingly discussed and deployed elsewhere, both on environmental and cost grounds (Spalding et al., 2014; Cohen-Shacham et al., 2016; Williams et al., 2018; Morris et al., 2019); (see also Section 5, and the IUCN/WCPA Natural Solutions website). A good example of climate change mitigation and adaptation in mangrove swamps is Case Study 1.1 in Gross et al. (2016). The Science for Nature and People Partnership's team on coastal defences has excellent material to aid protected area managers.

Beach nourishment by bringing sand from down-drift locations or offshore and depositing it on the beach (often in combination with other approaches) is also being increasingly employed. There is an extensive literature on sustainable solutions to coastal management; Williams et al. (2018) provide an up-to-date review.

Nearshore and offshore activities may also have a detrimental impact on coastal, as well as offshore, geoheritage features through damage to landforms or the disruption of natural processes. See Spalding et al., 2014 and Pontee et al., 2016 for further advice.

- Recommendations for coastal management and restoration:
- adopt a coastal cell management approach;
- adopt natural flood management and coast protection techniques;
- work with natural processes using minimal intervention (e.g. managed realignment, beach re-charge and restoring connectivity between sediment sources and sinks), rather than 'fix and control';
- integrate geodiversity and biodiversity objectives; and
- locate or re-locate infrastructure away from active coastal edges.

River management and engineering

Like coastal engineering, river engineering also impacts natural features and processes. Many rivers have been "channelised, straightened, embanked, dammed, diverted, culverted, dredged and isolated from their floodplains" (Gray, 2013). In any one of these cases or in combination, the river dynamics are changed, and the natural river bed, bank or floodplain habitats are adversely affected.

Dam construction is the most serious action in altering the downstream flow regime and impacting on the landscape. One of the most controversial dams in a protected area is the O'Shaughnessy Dam, built in 1913 across the Hetch Hetchy Valley in Yosemite National Park, California, USA, to provide water to San Francisco. Its construction was controversial, and the controversy still rages. A more positive example is the opposite action – dam removal – such as has been undertaken in Olympic National Park, Washington, USA. Two dams, the Elwha and Glines Canyon, have been removed. They were built in the early 1900s to provide hydropower for timber industry and local towns. However, construction of the dams also blocked the migration of salmon upstream, disrupted the flow of sediment downstream and flooded the historic homelands and cultural sites of the Lower Elwha Klallam Tribe. In 1992 the river's story changed when the US Congress passed the Elwha River Ecosystem and Fisheries Restoration Act, authorising dam removal. After two decades of planning, the largest dam removal in US history began in 2011 with the Elwha Dam, and was followed by removal of the Glines Canyon Dam in 2014. Today, the Elwha River and its sediment load once again flow freely from its headwaters in the Olympic Mountains to the Strait of Juan de Fuca (see frontispiece photo to this section).

Conventional approaches to river management usually involve hard engineering through the use of rock armour or gabions to stabilise channel margins. Such approaches not only constrain the natural dynamics of the river system, but can also damage river bank and in-channel habitats and species, and may lead to the transfer of problems downstream. From a conservation viewpoint, hard engineering should be restricted to protecting essential utilities, buildings and infrastructure. New approaches increasingly recognise the importance of catchment-scale management and the value of Nature-based Solutions that involve working with nature through measures to re-establish natural flow regimes, such slowing water flow into rivers and encouraging enhanced floodplain storage of floodwaters (Poff et al., 1997; Poff, 2018; Palmer & Ruhi, 2019). Specific guidance on natural solutions together with examples is available from a range of sources, including the River Restoration Centre, and the IUCN/WCPA Natural Solutions website. Box 6.2 provides a specific example.

Photo 6.4 Hard engineering with a sea wall to halt cliff erosion and groynes to capture sand might be necessary in places, but alternative soft engineering approaches should be tried first. Folkestone, England. © Roger Crofts

Photo 6.5 Sand stabilisation by planting native grasses is an excellent method. Doolough dunes nature site, Mayo, Ireland. © Roger Crofts

Photo 6.6 The highly controversial O'Shaughnessy Dam, across the Hetch Hetchy Valley in Yosemite National Park, California, USA. Construction of dams and flooding of land is a long standing problem in many mountain protected areas. Mitigation is very limited unless the structures can be removed. © Murray Gray

Photo 6.7 Some of the finest examples globally of terraces formed by glacial meltwater are now submerged beneath the waters of the Hálslón reservoir, Iceland affecting both upstream and downstream water and sediment movement. There was very strong opposition to the building of the dam. The site is now excluded from the Vatnajökull National Park, Iceland, despite intense opposition. © Roger Crofts

Photo 6.8 Donau River and canal downstream from Vienna, Austria have been straightened to improve navigation. New measures have been taken to restore the natural flood channels of the river in the Donau-Auern National Park. © Roger Crofts

Yosemite National Park, California, USA, experienced the largest flood in at least 100 years in January 1997. As devastating as the flood was on a human scale, it provided an opportunity for positive restoration. The protected area authority was committed to relocating as many facilities as possible outside of the floodplain of the Merced River or outside of Yosemite Valley entirely. The new facilities are located outside of the floodplain and away from sensitive wetlands, meadows, woodlands and the river bed itself. Flood recovery projects had been estimated to be complete in four to five years, but a series of lawsuits challenging specific projects, court ordered injunctions and the preparation of park planning documents expanded the restoration time-frame to 15 years. The final report of the restoration activity is available online (US National Park Service, 2013).

Recommendations for river management and restoration:

- adopt a catchment management approach;
- adopt natural flood management techniques (e.g. river and floodplain restoration);
- re-establish natural flow regimes;
- work with natural processes using minimal intervention, rather than 'fix and control', making space to reconnect rivers and their floodplains and restoring upstream and downstream connectivity;
- seek agreement for the removal of obstructions to natural flow and sediment transfer, such as dams;
- integrate geodiversity and biodiversity objectives; and
- locate or re-locate infrastructure outside active floodplains.

Forestry and vegetation

The principal impacts of forestry and vegetation are their potential to obscure rock exposures, individual landforms or landform associations over an area, reducing visual continuity and obscuring viewpoints. In the case of planting operations, the use of large-scale mechanical equipment can compact soils, alter soil hydrology and destroy subtle landforms. The same is true of logging operations, which need to be carried out with as much environmental sensitivity as possible. Tree removal can also increase overland flow, soil erosion and sediment input to rivers.

Large-scale afforestation is generally incompatible with conservation management objectives for large geomorphological sites. In the 1970s, the Great Britain Forestry Commission had plans for conifer plantations in the Glen Roy National Nature Reserve where the famous Parallel Roads of Glen Roy are continuously visible over several kilometres. These glacial lake shorelines would have been totally obscured by this planting, but fortunately the scheme was abandoned when the impacts were pointed out by the geoscience community. Where sites are already planted for commercial forestry, opportunities may exist through dialogue with the forest operators to clear specific landforms or viewpoints. In the case of small landforms and rock exposure sites, the principal management requirement is to leave the features unplanted and to maintain access and viewpoints.

Photo 6.10 Landforms left by the retreat of an ice age glacier cannot be seen by most visitors as they are obscured by the plantation forestry seen in the top of the photo. Viewers have to climb a steep hill to gain the view in the photo. Clearly no thought was given by the tree planters about the visibility of the geoheritage interest. Coire Fee National Nature Reserve, Scotland. © Roger Crofts

Natural regeneration of woodland on large geomorphological sites is potentially even more intractable. While it will not be possible to retain all the landforms as open country, the most representative and valuable sites should be identified and kept visible and accessible through management intervention, bearing in mind the issues discussed in Section 6.5 (See Box 6.3).

At a fine scale, vegetation encroachment is frequently a concern in the management of small landforms and rock exposure sites. Management intervention to clear the vegetation may be required as specified in the site management plan and objectives (e.g. if more than 50% of the exposure is covered; see Section 5.2). This will depend on the nature of the feature of interest (e.g. repeated clearance of soft sediment exposures may progressively damage the interest) and the type and frequency of use (e.g. a research site may require only occasional clearance when new studies are undertaken, whereas a robust and heavily visited site used for geotourism may require regular clearing).

Information and guidance on dealing with conflict between biodiversity and geodiversity conservation is provided in Section 6.5.

Recommendations for management of forestry and vegetation encroachment:

- avoid large-scale afforestation of sites that obscure key features;
- maintain access to and visibility of key exposures and landforms;
- undertake site condition monitoring to inform decisions on the need for vegetation clearance at a site in line with management objectives; and
- integrate geodiversity and biodiversity management objectives as far as possible.

Agriculture

Agriculture has the potential to transform soils, resulting in erosion, compaction, contamination, salinisation, and changes in soil hydrology and ecology. Ploughing of slopes can increase runoff and soil erosion and have detrimental effects on protected features downstream. Ploughing can also destroy delicate landforms, such as periglacial features (i.e. those formed by freeze/thaw processes), low sand dunes or abandoned channels on river terraces. A particular issue arises when agriculture is practiced in karst areas, where its impacts can include pollution or sedimentation of cave systems and waters through farmyard runoff or overuse of agrichemicals, changes in karst hydrology through surface farming operations or tipping of farm waste into karst hollows and cave entrances. In some landscapes, whole hillsides and their soils have been transformed by the construction of terraces for rice or vine cultivation.

Box 6.2

Improvement in water quality of the Reka River, Škocjanske jame Regional Park, Slovenia

Škocjanske jame Regional Park is situated in the Kras Plateau of south-west Slovenia. The protected area of 413 ha conserves an exceptional limestone cave system which comprises one of the world's largest known underground river canyons, cut into the limestone bedrock by the Reka River. The buffer zone covers 45,000 ha and encompasses the entire Reka River basin.

Škocjanske jame has been protected as a natural monument since 1980 and was inscribed on the World Heritage List in 1986. The 1996 Škocjanske jame Regional Park Act established a public service agency to manage the protected area. The caves were included on the Ramsar List of Wetlands of International Importance in 1999. Since 2004, the park has also been recognised by UNESCO's Man and the Biosphere Programme as a Karst Biosphere Reserve.

Photo 6.9 Reka River flowing through the Škocjanske jame cave. © Borut Lozej

The pollution of the Reka River began with industrialisation in 1960. The biggest polluters were the local wood processing and organic acid factories and an associated landfill. Poor water quality resulted from decomposition or intensive anaerobic digestion processes, with micro-organisms consuming the organic substance that served as a source of nourishment and energy, producing in particular residual biomass and gaseous or highly volatile products. These micro-organisms (such as mucilage, algae and filamentous bacteria) used to be attached to the bottom of the river's bed and banks during times of low stream flow, after which a rise in the flow rate would wash them away. The flood wave carried the sedimentary particles, the compounds decomposed during the digestion processes and biomass downstream, where they were deposited. In the karst underground, they were subject to an anaerobic digestion process, which has thus shifted from one section of the Reka River to another.

The quality of the river improved after 1990 when one of the factories closed down. Even prior to that, certain pre-treatment measures were introduced at the local wood panel production facility, such as closing the circuit of waste water, reclaiming a part of the wood mass to be reused in the production and constructing a water treatment plant within the facility.

According to the Slovenian Environment Agency, the ecological and chemical status of waters in the buffer zone is good. Occasionally, water pollution and foam appear on the surface current before the Reka River enters the cave into the Škocjanske jame.

In 2017, the Ministry of the Environment and Spatial Planning, together with the Škocjan Caves Park and the Municipality of Ilirska Bistrica, started the remediation of the industry landfill. A study precisely documenting the condition of the landfill, the structure and quantity of waste, and the leachate analysis, has just been completed and represents the first step on the way to beginning remediation.

The agency is also actively involved in various educational and awareness-raising activities within the buffer zone, and encourages the resolution of old ecological issues and actions to prevent new pollution.

Contributor: Rosana Cerkvenik

Box 6.3
Tors and vegetation management

Tors are distinctive upstanding rock landforms, rising as much as 20-30 m above upland summits or mountain ridges. Tors commonly occur on granites, but other types of crystalline rock (gneiss and quartzite, in particular); some types of sandstone also support tors. Tors not only have considerable scientific value for interpreting the geomorphological evolution of an area, but also have cultural value, being associated with ancient settlements, folk tales, art, early tourism and landscape interpretation (Migoń, 2006).

A significant issue for conservation management in areas below the treeline is the growth of bushes and trees, which obscures the tors. The experience from countries such as Austria, Czech Republic, Germany, Hungary and Poland, where tors are mostly within the limits of forest growth, illustrates various approaches to the issue and differing policies of stakeholders.

The tors of Kogelsteine, Austria, occur within largely treeless terrain, with scattered bushes, grassy surfaces with steppe vegetation and vineyards in the surroundings being of considerable aesthetic appeal. In 2009, a nature reserve was established, covering 2.5 ha, to protect valuable plant steppe communities. Conservation management includes removal of invasive species, such as acacia, and introduction of grazing. Thus, the primary motivation for periodic vegetation removal is to sustain dry grasslands, but this management has also proved beneficial for the visibility of the geoheritage. This example illustrates how management requirements for biodiversity and geoheritage do not necessarily conflict, but instead may lead to mutual benefits.

Elsewhere the primary motivation is to keep tors exposed and visible, mostly because of their cultural significance. The Teufelsmauer locality in Harz, Germany, where a sandstone crag has remained in open terrain since the 19th century, is recognised as a regional landmark. By contrast, other granite tors in Waldviertel have slowly disappeared from sight due to either spontaneous and uncontrolled or planned afforestation. The Steingarten locality near Litschau includes tors with spectacular minor weathering forms (pits, flutes and tafoni) and boulders with classic examples of flared slopes, indicative of their gradual emergence from the soil. However, no conservation measures are applied and a considerable part of the area is under newly planted forest. Some tors are already hidden in the forest and a number of emergent boulders will shortly be completely overgrown. While it is not possible to retain all tors in open terrain conditions, landform inventory and comprehensive geoheritage evaluation should inform forestry policies in order to keep the most valuable sites visible and accessible.

Contributor: Piotr Migoń

Recommendations for managing threats and pressures from agriculture:

- review the type of agriculture adjacent to the protected area to assess threats to geoheritage features and processes within it;
- provide guidance to farmers and land managers to ensure that they understand the need for changes in practice to protect geoheritage features and processes; and
- secure management agreements where appropriate to restrict detrimental agricultural activities and secure agricultural land management benefiting geoconservation.

Recreation and tourism

Some environments are particularly vulnerable to visitor impacts. These include sand dune areas, where dune stability can be affected by vehicle or pedestrian movement, and volcanic sediments or brittle lavas, where off-road driving and visitor trampling leaves long-lasting scars across the landscape. At Craters of the Moon National Monument and Preserve in Idaho, USA, the lava is brittle and easily crushed underfoot and visitors are asked to stay on the designated trails. One solution is to provide alternative means of access which reduces damage. For example, access to the volcano in Teide National Park, a World Heritage site on Tenerife, Canary Islands, Spain, is largely by gondola and a visitor centre has been located immediately outside the park boundary.

In limestone caves fragile speleothems (deposits formed in the caves by solution of rocks and subsequent deposition) can be easily damaged and even touch, breath and light can encourage algal growth. Areas like these need very careful management. In mountain environments, impacts on geodiversity can include the use of bolts on rock climbing pitches, footpath and soil erosion from hill walking and mountain biking, soil compaction from camping, inadequate disposal of human waste, blackening of land from campfires and the movement of rocks to build fireplaces, windbreaks or cairns. At Yellowstone National Park, USA, visitors have been found throwing coins, stones, branches, articles of clothing and other objects into geysers. On the other hand, at the fumaroles (thermal vents) on some of the Portuguese islands of the Azores archipelago in the Atlantic, families have a custom of digging into the ground, placing large pots of meat and vegetables there and allowing the geothermal heat to cook the contents. At Furnas do Enxofre Natural Regional Monument on the island of Terceira, Azores, this disturbance of the ground is banned by legislation.

Not all geosites are appropriate for geotourism because of the sensitivity of their features of interest (e.g. the presence of rare fossils and minerals requiring protection from the activities of commercial collectors and irresponsible fossil collecting) or the risk of particular natural hazards (e.g. volcanic eruptions). There are a number of ways of controlling access, such as zoning

Photo 6.11 Tors in the Morne Mountains Area of Outstanding Natural Beauty, Ireland showing their structure and shape when not obscured by vegetation. © Bob Aitken

Photo 6.12 Example of the dramatic effect of land reclamation for agriculture on the functionality of a raised mire by surface peat layer removal, ground drainage and tree planting. It is now only possible to manage the remaining nature interest by raising the mire water table. Flanders Moss Natural Nature Reserve, Scotland. © Roger Crofts

Photo 6.13 Speleothems are particularly vulnerable cave deposits. In this Ethiopian cave a fine flowstone curtain was broken by local villagers to sell the pieces as souvenirs. Dissuading visitors from purchasing speleothem and persuading locals that protecting their caves and charging visitors to see them is a more sustainable practice. © John Gunn

certain areas as prohibited to visitors, or allowing entry only with a permit or accompanied by an accredited guide. In the case of other sensitive sites, an assessment of visitor carrying capacity may be required, both to protect fragile features and to maintain the quality of the visitor experience. Restricting access to parts of a cave system where there are fragile landforms and allowing visitors only with a guide is well practiced, for example, in the Aven d'Orgnac in the Ardeche region of France.

Geotourism should also be sensitive to the values and cultures of local communities, recognising that the latter may hold different norms, values and interpretations of the landscape, as well as incorporating local knowledge fundamental to sustainable management of the geotourism assets. For example, where geosites have cultural and/or spiritual features of interest, consideration should be given to particular sensitivities and the maintenance of traditional access. Management zoning or employment of local guides, both in sensitive areas and to present indigenous interpretations of the landscape, may also be considered.

Risk assessment of actual and potential hazards must be taken into account fully in evaluating the potential use and management of sites for tourism. The IUCN WCPA Best Practice Guidelines on Tourism and Visitor Management in Protected Areas is a valuable source (Leung et al., 2018). Visitors to inherently dynamic sites may be exposed to hazards, with risk of injuries or death. Some of these risks may be increased by climate change; for example, increased slope instability due to landslides and rockfalls arising from more intense rainfall or melting permafrost. There are a growing number of case studies in relation to hazard mapping on geotourism trails in different environments (e.g. Pelfini et al., 2009; Brandolini & Pelfini, 2010; Bollatti et al., 2013). For example, mountain glacier environments have significant geoheritage interest from scientific, cultural, aesthetic, scenic and educational viewpoints. Many are popular visitor attractions accessible via hiking or interpretation trails. However, they are dynamic and unstable environments that can present many hazards to visitors, including rockfalls from cliffs, debris falling from high lateral moraines, glacier calving into lakes and river erosion. Some of these hazards are exacerbated as a consequence of climate change. Hazard assessments have been used to inform suitability for different users of tourist trails linking geomorphological sites near the Miage glacier in the Italian Alps (Bollati et al., 2013). In New Zealand, access to the fronts of the Fox and Franz Josef glaciers has been closed since rapid glacier retreat has significantly increased the rockfall hazard, while modelling indicates the risk of increased runout of rockfall debris across the lowered surface of Fox Glacier affecting heli-hiking tours on the glacier (Purdie et al., 2018).

Volcanic areas offer a good example of the risks posed to humans in geoconservation protected areas. If a volcanic protected area is not established for its geological attributes, there is the potential that the risk of hazardous conditions (e.g. eruptions, gas emissions, landslides and other volcanic hazards) may not be adequately addressed in the site's management plan, or that protected area staff may not be adequately trained in hazard identification, mitigation and evacuation. Drawing visitors to active volcanic areas carries a responsibility to monitor volcanic activity and develop risk contingency plans as essential parts of the management process, perhaps leading to restrictions on access. However, if the site's geological features are not adequately identified, the management plan may not cover these hazard considerations, and the site's key volcanic features may not receive adequate emphasis or protection by the managing authority.

In the case of dynamic geomorphological sites, where the interest is in active processes or where mitigation of hazards to visitors is impractical, an assessment of the enhanced risk will be essential, as will appropriate actions, possibly including exclusion or re-routing of visitor access and management of visitor expectations. At the same time, education campaigns are needed to increase the knowledge of visitors, site operators and employees of hazards and emergency response measures. Good communication between scientists and risk managers is essential for robust and defensible decision-making by managers.

Recommendations for managing geotourism threats and pressures :

- undertake risk assessment of all threats and hazards to visitors and identify actions required;
- assess the level of visitor pressure that the geoheritage features or processes can absorb without damage to them, and take action to minimise damage;

Photo 6.14 Ski development at the boundary of protected areas can cause slope erosion if not properly managed, and affecting the integrity of the site. Kosciuszko National Park, Australia. © Roger Crofts

Photo 6.15 Large numbers of visitors can detract from the experience of visitors. Five Coloured Lake, Jiuzhaigou National Park, China. © Roger Crofts

Photo 6.16 Allowing vehicles to drive through coastal sand dunes and onto beaches creates erosion which is difficult to repair where there is sand blowing. Vehicular access should be prohibited. Vadehavet National Park, Denmark. © Roger Crofts

- restrict access in part or in whole depending on the risk to the geoheritage interests of the site or the risk to visitors; and
- establish effective communication to visitors of management measures to protect the geoheritage features and processes (see Leung et al., 2018 for more detailed recommendations).

Irresponsible collection of specimens

Visitors often like to collect geological specimens, whether attractively coloured stones, pieces of stalactites or fossils. Where the geological resource is extensive there may be no problems in controlled collection activities, which can even be encouraged in order to stimulate geological education and enthusiasm. Fossil collection is also to be encouraged where the material is threatened by coastal erosion, quarrying or other unavoidable losses. The main problem arises where there is a limited amount of a geological resource or where there are very rare or scientifically valuable specimens.

A major issue arises when commercial collectors use power tools to remove fossils illegally from protected sites without proper recording of their finds. Geologists themselves are capable of over-collecting, as has happened at the Ediacara Fossil Reserve in South Australia. The naming of this and other protected areas can even draw attention to the importance of these fossil sites. Geologists have also caused damage to sites by removing rock cores for palaeomagnetic research.

Photo 6.17 Fossil collecting on the Jurassic Coast World Heritage site, England is managed by a specifically appointed warden and a code of practice. © Sam Rose

More detailed guidance, recommendations for management and links to codes of conduct is given in Section 7.3 and especially Table 7.4.

Climate change and sea-level change

Human-induced climate change is happening and is likely already causing significant changes to weather patterns and hence impacting on physical systems and geoheritage features and processes. This is clearly highlighted in the latest IPCC reports (IPCC 2019a, 2019b). In particular, the predicted increase in the frequency and magnitude of extreme events is likely to bring rapid changes, including soil erosion, severe flooding, sediment movement and increased solution of calcareous rocks. Small mountain glaciers are likely to disappear as the climate warms, resulting in reduced summer river flows in these areas. In periglacial areas subject to alternate freezing and thawing, the warming may result in disruption of the permafrost and consequent subsidence and erosion of the melted areas and higher incidence of rockfalls. Changes in wave conditions may exacerbate coastal erosion, while rising sea levels may result in coastal flooding, loss of salt marsh areas and saline water intrusion.

Climate change is now recognised as an emerging issue for geoconservation (Gross et al., 2016; Wignall et al., 2018). For example, reviews of the impact of climate change on protected geosites in Great Britain concluded that the impacts would be greatest on active soft-sediment coastal and fluvial features, finite Quaternary sediment exposures, landforms in coastal and river locations, active periglacial features, sites with records of past environments, and sites with finite or restricted rock exposures and fossils (Prosser et al. 2010; Wignall et al. 2018). Sharples (2011) investigated the impacts of climate change on the geodiversity of the Tasmanian Wilderness World Heritage Area, Australia. These include the degradation of moorland organic soils, peat, swamps, and bogs, increased channel erosion and sedimentation, and more flash flooding and sedimentation in caves. Such systematic assessments of the impacts on geoheritage would allow risk-based prioritisation for monitoring and management action as part of a climate change action plan. A key part of this process will be the prior setting of thresholds for change, which, if crossed, will activate management interventions to mitigate threats where that is practical.

It is likely that active geomorphological, hydrological and soil systems, in particular, will undergo major changes in response to climate change. As well as alteration to geomorphological features per se, these changes may result in erosion or depositional burial of other geoheritage features (Table 6.3). Furthermore, dynamic geomorphological features may migrate outside the boundaries of existing protected areas. Related threats may arise from the effects of sea-level rise and increased storminess in some parts of the world, and particularly from the human responses (for example, in the form of demands for the installation of 'hard' flood protection along rivers and at the coast) that conceal exposures and disrupt natural processes. Since protection against potential loss of property or infrastructure is likely to be considered more important than loss of geoheritage, these threats present particular management challenges that will require collaboration among governments, planners, decision makers and local communities to ensure sustainable management of geoheritage as part of wider, long-term adaptation strategies to protect ecosystem services. However, in a landmark legal case in England, the fundamental principles of site designation and geoconservation, including allowing natural processes to run their course on an eroding coast where property was threatened, were upheld by the courts (Prosser, 2011). In many cases, Nature-based Solutions or intermediate 'soft' solutions, such as managed realignment, have additional benefits of reducing the risks from natural hazards such as coastal erosion, flooding, landslides and soil erosion and the impacts of climate change. In other cases, relocation of activities or infrastructure inland from the coast may ultimately be the only cost-effective option. Where some form of protection is required to protect capital interests (e.g. essential infrastructure), and where space allows or can be created, 'natural' forms of intervention should be the first option (see above for examples of river and coastal management).

It will be possible to prevent loss or mitigate deterioration of some specific sites, but in other cases it may be necessary to accept the loss or deterioration of the features of interest. In the latter case, it may be appropriate to implement detailed recording for posterity or to recover particular features, such as fossils, for curation in museum collections or archives ex situ. Mitigation measures might include the burial of some sites to protect highly vulnerable finite interests. In exceptional cases the construction of hard defences to protect some unique features may be called for. In the case of exposure sites, excavation of replacement sections may be appropriate.

Table 6.3. Impacts of climate change on geosites.

Impacts on exposure, integrity and finite sites
(–) accelerated weathering, erosion and vegetation growth, requiring increased frequency of management intervention
(–) loss of features through enhanced erosion or burial by enhanced deposition
(–) sealing of exposures by increased requirement for hard coast/river defences
(–) submergence of exposures
(–) changes in land use affecting visibility and access
(+) new exposures created by erosion and landslips
(+/–) repositioning of exposures due to changing patterns of erosion

Impacts on active process sites
(–) human responses to increased hazards that disrupt natural processes
(–) changes in land use that affect sediment/water discharges
(+) enhanced rates of process activity – greater dynamism and diversity
(+/–) repositioning of features due to changing patterns of erosion
(–) negative impact; **(+)** positive impact; **(+/–)** impacts may be positive or negative

Photo 6.18 Sea level change will have a profound effect on the functionality of coastal systems with coastal erosion and loss of natural buffers, such as beaches and sand dunes, allowing the sea to penetrate inland and loose the geoheritage interest. East Sandy Coast Site of Special Scientific Interest, Orkney, Scotland. Hard engineering does not provide a solution, and managed retreat of the coastline is probably the only mechanism that is practicable. © Roger Crofts

Photo 6.19 Land uplift after the release of the weight of glaciers continues in many parts of the world and will continue to do so, especially with melting of ice sheets. New land will be revealed as in Kvarken Gulf of Bothnia, Finland World Heritage Site. New sites for protection will therefore arise. Conversely, some coastal sites may be submerged as a result of sea level rise.© UNESCO

Box 6.4

Restoration following the eruption of Mount St. Helens, USA

The 1980 eruption of Mount St. Helens – which began with a series of small earthquakes in mid-March and peaked with a cataclysmic collapse of the mountain side, avalanche and explosion on May 18 – was not the largest nor the longest-lasting eruption in the mountain's recent history. But, as the first eruption in continental USA during the era of modern scientific observation, it was uniquely significant. A vast, grey landscape replaced the once forested slopes of Mount St. Helens. In 1982, the President and Congress created the 110,000-acre Mount St. Helens National Volcanic Monument for research, recreation and education. Inside the protected area, the environment is left to respond naturally to the disturbance. In the decades since the eruption, Mount St. Helens has given scientists an unprecedented opportunity to witness the intricate steps through which life reclaims a devastated landscape (Brantley and Meyers, 2000).

Box 6.5

Restoration of the Alto Vez geosite, Peneda Mountain, Portugal

The Alto Vez geosite comprises one of the most remarkable fields of granite glacial erratic boulders in Portugal. These and other glacial features, such as a U-shaped valley and moraines, justify the inclusion of Alto Vez as one of the most important geosites in the Portuguese geoheritage inventory. Despite its scientific relevance, it is located just outside the contiguous Peneda-Gerês National Park, the most important protected area in Portugal. This national park was founded in 1971 and its limits were defined before the discovery of the glacial features.

In 2012, a horse-racing track was constructed in the geosite by the local village administration, with the removal of erratic boulders from their original places, affecting the natural landscape and the integrity of the geosite. After an alert from a citizen, legal and administrative actions taken by the Portuguese Institute of Nature Conservation and Forests and by the municipal authorities resulted in the closure of the track, an assessment of the degradation and definition of a strategy to mitigate the damage. A restoration plan was developed in 2017, using aerial photos captured by autonomous aerial vehicles, GPS and GIS procedures. The initial topography was restored using earth-moving machinery and the buried erratic boulders were identified and carefully relocated to their original positions. A management plan of the geosite is being produced in order to protect it more efficiently through a statutory designation and to promote its use for tourism and education. This case study shows that a well-informed society is essential to help authorities protect geoheritage and that restoration of a geosite is possible when the main features of interest are not fully destroyed.

Contributors: Paulo Pereira, José Brilha, Diamantino Pereira and Renato Henriques.

At a landscape scale, the prevention of widespread changes in geomorphological processes will be impractical. The most appropriate, and cost-effective, approach should be to allow active geomorphological processes to adapt naturally to changing climate conditions. This may require creating space (e.g. through removal of flood banks to enable rivers to fully utilise their floodplains) and managing the consequences of change (e.g. adapt site boundaries) rather than attempting to stabilise and control the active system.

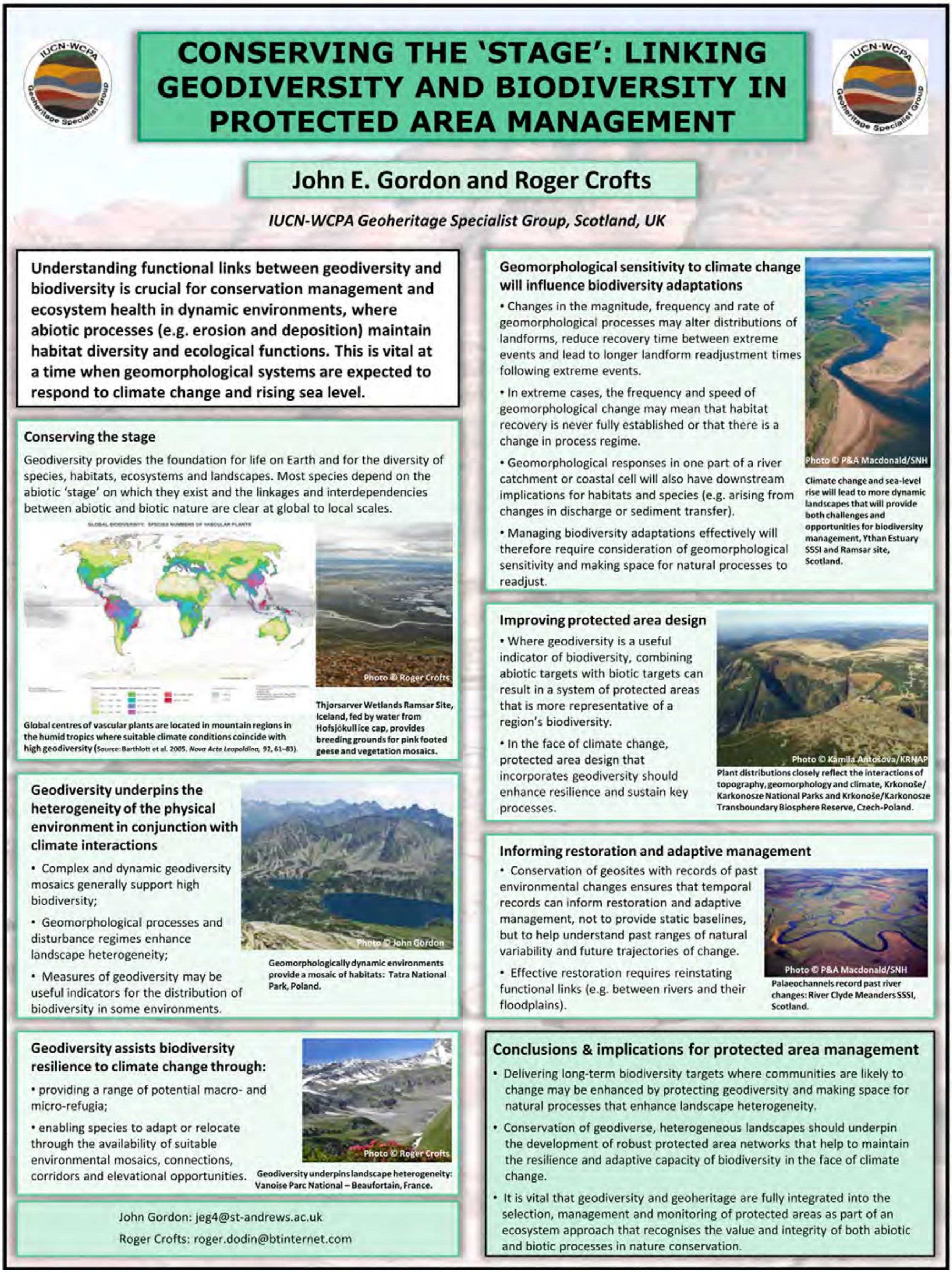
Monitoring of changes to the sites and their features of interest is a fundamental part of the management process to help decide at what point intervention is required and the type of intervention required. More general actions include communication with planning authorities and local communities to integrate geoconservation into wider climate change adaptation strategies and plans.

Summary recommendations for managing the effects of climate change:

- conduct risk assessment of vulnerable sites;
- adopt Nature-based Solutions and allow active geomorphological processes to adapt naturally to changing climate conditions;
- revise protected area boundaries where necessary;
- identify mitigation measures or potential replacement exposures for sites at high risk;
- implement posterity recording and, where appropriate, recover particular features, such as fossils, for curation in museum collections;
- monitor changes to inform decision-making; and
- communicate with planning authorities and local communities to integrate geoconservation into wider climate change adaptation strategies and plans.

Best Practice Guideline No. 18: Take a multi-step approach to address threats to geoheritage, including identifying type of threat, sensitivity of site to threat, risk assessment and prioritisation of management actions.

Figure 6.1. "Conserving the stage" explanatory poster.



6.5 Dealing with the interaction between geodiversity and biodiversity conservation

Geodiversity supports a diversity of habitats across a wide range of temporal and spatial scales (Table 6.4). At a global scale, for example, research suggests that centres of vascular plant diversity coincide with mountain areas in the humid tropics and subtropics with high geodiversity (Barthlott et al., 2005). At regional and local scales, geodiversity supports habitat heterogeneity arising from the characteristics of the physical substrate, soil properties and soil stability, geomorphological processes and landforms, topographic effects on microclimate, water availability and disturbance regimes arising from continual and episodic processes. Consequently, habitat diversity and species richness are often greater in areas of high geological and geomorphological heterogeneity (e.g. Tukiainen et al., 2019).

Geoconservation in protected areas is, therefore, crucial for sustaining living species and habitats, both to maintain the setting or ‘stage’ and the natural processes (e.g. floods, erosion and deposition) necessary for habitat diversity and ecological functions. This is particularly relevant for protected area design and management in the context of climate change since geodiversity can provide a degree of resilience and enable the survival of species through the availability of suitable environmental mosaics, corridors and elevational ranges that provide a range of macro- and micro-refugia. Where species and communities are likely to change, robust protected area networks that are founded on the conservation of geodiverse, heterogeneous landscapes should help to optimise the resilience and adaptive capacity of biodiversity and key ecosystem processes under the current climate and in the future (Anderson et al., 2014; Comer et al., 2015; Knudson et al., 2018). Hence, integrating conservation of geodiversity and biodiversity is vital not only in developing protected area networks that are representative of different ecosystems and habitats, but also in supporting the management of biodiversity in individual protected areas.

Interactions between geodiversity and biodiversity conservation can be both positive and negative (Crofts and Gordon, 2015; Crofts, 2019; Table 6.4). Positive interactions arise where there is convergence of geodiversity and biodiversity interests, as in dynamic coastal and river systems with strong interdependencies between vegetation and geomorphological processes, or where geodiversity provides the foundations for biodiversity. Negative interactions may occur where there is narrower geoheritage interest that is not functionally dependent

Photo 6.20 Specialist plants, termed extremophiles, thrive on the hot chemical cocktails emanating from geothermal areas below the ground. Lake Manyara National Park, United Republic of Tanzania. © Roger Crofts

Table 6.4. Examples of links between geodiversity and biodiversity.

Geo/bio interdependency	Examples
Specialist plants reflecting chemistry of rocks and water	Giant Prismatic Spring, Yellowstone National Park, USA; Waimangu volcanic valley, Rotorua, New Zealand.
Niches for animals in rocks	Jenolan Karst Conservation Reserve, Australia; White Desert National Park, Egypt; Galapagos National Park, Ecuador.
New habitats due to emerging land from glacier melting and associated land rise	Kvarken World Heritage site, Finland; Skeidarásandur, Vatnajökull National Park Iceland.
Rock strata significant for tracing biological evolution	Burgess Shales, Yoho National Park, British Columbia, Canada; Joggins Fossil Cliffs, Nova Scotia, Canada,
Ecosystems totally dependent on adequate supply of water and nutrients	Shaumari Reserve Jordan for Arabian Oryx reintroduction. Flow Country SSSIs Scotland blanket peat formation for habitats and bird protection.

Source: Crofts, 2019.

Photo 6.21 Many species of bats roost in caves. In the temperate zone, caves are commonly used as winter hibernacula. Gufo Cave Jinfoshan, part of the South China Karst World Heritage site. © John Gunn

on biodiversity, such as a rock exposure illustrating the geological history of an area or delicate rock formations and landforms associated with karst or glacial areas. Although the rock or features may provide valued habitat, vegetation growth may impede visibility or access to the geological features in situations where the primary geoconservation requirement is to maintain their visibility. Such negative interactions need to be recognised and solutions found by protected area managers (Box 6.3). The essence of the resolution should be recognition of the interconnections between the biotic and abiotic features and the processes that brought them into existence and those that maintain them.

Key questions are:

- What is the basis of the conflict between the conservation of the geoheritage and biodiversity values in and around the protected area?
- Is the conflict capable of resolution without undermining one or both sets of values, or is it more fundamental?
- If the latter, is one of the sets of values more important in the long term to nature conservation, and so needs to be safeguarded and the other sacrificed?
- Should the geodiversity interest be taken off-site or allowed to be obscured by vegetation growth provided that it can be periodically re-exposed for re-examination in the light of new knowledge?
- Is the only available resolution beyond the protected area and within the bioregion?

Finally, it is important to discourage attempts to maximise habitat/species diversity by landscape modifications or restoration that result in the creation of incongruous landforms/landscapes (e.g. through raising the land surface by infill in areas of flat topography or creation of ponds with shapes that are atypical of local natural features).

Best Practice Guideline No. 19: Recognise both positive and negative interrelationships between biodiversity and geodiversity conservation to provide the best possible outcome for nature conservation.

Geoconservation management in selected situations

7

A unique combination of geothermal activity and glaciation given enhanced protection in 2020 at Kerlingarfjöll Nature Reserve and Landscape Protected Area, Iceland. © Roger Crofts

Detailed advice is provided for the management protected and conserved areas:

- caves and karst areas (7.1)
- glacial and periglacial areas (7.2)
- minerals and palaeontological sites (7.3)
- volcanic areas (7.4).

Guidance on management for particular types of geoheritage interest in protected and conserved areas is given with reference to caves and karst landscapes and features, glacial and periglacial features, mineral and palaeontological sites, and volcanic sites. For each of the four geoheritage types, information is provided on landforms, processes and features; threats, and management principles and guidelines. The four environments are selected to represent the range of the site types presented in Section 5.3 and to illustrate the types of management approach required. Sections on glacial and periglacial illustrates all three site types (exposure, integrity, finite), while the sections on caves and karst, and on and minerals and fossils, illustrate particular types of integrity and finite sites, respectively.

7.1 Managing karst and cave protected and conserved areas

Landforms, processes and features of value

Some of the Earth's most dramatic landscapes are in karst areas where landforms commonly include sinking streams, blind and dry valleys, closed depressions, underground drainage and caves. They are largely a product of a process called *dissolution* (i.e. dissolving) acting on rocks that have a high solubility in natural waters (see Photo 3.1). Solubility alone does not guarantee that a karst system will evolve. Other processes, most notably mechanical erosion and collapse, contribute to karst landform development, but dissolution is an essential precursor. Two groups of rocks are widely recognised as being karstifiable: the carbonate rocks (limestone, dolostone and marble) and the evaporite rocks (gypsum, anhydrite and salt). Surface and near-surface outcrops of these rocks occupy about 20% of the Earth's ice-free land surface. The emphasis in this account is on carbonate karst, but many of the threats, management principles and guidelines also apply to evaporite karst.

A cave is a naturally formed void in an earth material that is large enough for human entry. This definition distinguishes caves from artificial tunnels and other constructed underground voids that are sometimes incorrectly referred to as 'caves'. Caves are found in many lithologies and settings, but globally the majority are formed by dissolution of carbonate rocks. Caves formed by dissolution are also found in evaporite and, more rarely, silicate rocks. There are also a substantial number of volcanic caves (also called lava caves). Only caves that occur in karst settings are considered here.

A well-developed surface karst landscape is dependent on the development of underground drainage. In carbonate rocks, groundwater flows through dissolutionally enlarged channels. When the channel diameter becomes large enough for turbulent flow it is commonly referred to as a 'conduit'; those conduits that grow large enough for human access are called 'caves'.

The development of karst landforms is driven by water flowing over, into, through and out of rocks with high solubility. Hence, karst landforms may be broadly assigned to input, throughput and output roles (Williams, 2008). Greater detail is given in books such as Ford & Williams (2007), Gillieson (1996), Gunn (2004), Palmer (2007) and White & Culver (2012).

Internally draining closed depressions (dolines and larger flat-floored poljes) are the surface landforms that are most typically karstic. They serve a similar function to the drainage basin in that they channel water, solutes and sediments to an outlet point or points and thence underground. An important distinguishing feature of karst is that water flows are at velocities several orders of magnitude faster than is common in non-karst groundwater systems. This means that sediment and pollutants can be transferred over long distances in a short time. A second distinguishing feature is that most karst areas have a zone of enhanced dissolution, and hence of permeability, in the uppermost bedrock. The scale and speed of these processes means that management of caves and karst as protected sites is quite different to other geoheritage types.

The majority of karst caves are formed by water descending from the land surface, but some were formed by rising groundwaters. Cave passages may be active (undergoing enlargement by flowing water) or relict (no permanent water flows). The global number of karst caves and their explored length and depth increase year on year and new discoveries outside protected areas may have greater geoheritage value than those in previously designated areas. In response, new protected areas may need to be designated or the boundaries of existing areas reassessed.

In some karst areas, none of the conduits reach sufficient size to be accessible by humans. Hence, there can be surface karst with distinctive landforms and rapid groundwater flow through conduits, but no caves. In contrast, in some areas where karstifiable rocks do not crop out (and hence there are no surface karst landforms) groundwater circulating at depth through carbonate or evaporite rocks forms channels, conduits and, in some cases, caves. It is, therefore, essential that a full survey of an area is undertaken before any decisions on protection are taken.

Photo 7.1 The entrance of Hang Son Doong Cave, Phong Nha-Kẻ Bàng National Park, Vietnam, first explored and surveyed in 2009 and as of 2020 the world's largest cave passage by volume (5000m x 145m x 200m). © Dave Bunnel

Photo 7.2 Intact speleothems (stalactites, stalagmites and flowstone) in Wild Boar Cave, Mulu National Park and World Heritage site, Sarawak, Malaysia. © John Gunn

Threats

As around 20-25% of the global population depend on drinking water from karst, there is a substantial literature on threats to groundwater in these areas (e.g. Drew & Hotzl, 1999; Kresic, 2013). Karst groundwaters are particularly susceptible to transmission of bacteria, for example from poorly designed waste-water systems, and of pollutants, such as pesticides and herbicides from agricultural land, hydrocarbons from roads and fuel storage facilities and sediment from agriculture, extractive industry and development. There are also many examples of over-abstraction of groundwater from karst, which commonly leads to subsidence or catastrophic collapse (e.g. Veni et al., 2001). There is a high degree of endemism in many karst areas and threats to limestone biodiversity, particularly from quarrying, have been discussed by Vermeulen & Whitten (1999) and BirdLife et al. (2014). The formation of underground voids by rock dissolution and rapid underground transmission of sediment by groundwater are distinctive features of karst areas and the threat they pose to infrastructure and surface development has been widely discussed (e.g. Waltham et al., 2005).

Less attention has been paid to threats to karst geodiversity, although many of the threats discussed in other contexts also impact on surface and underground landforms. The variety of karst settings and the integrated three-dimensional complexity of karst mean that karst landforms in protected areas commonly face site-specific threats, such as extraction of rock. Also, an area that has low surface geodiversity may be underlain by significant cave passages and sediments of high geodiversity value. Hence, the potential presence of underground landforms should always be considered in evaluating development proposals.

Development of caves to allow visitor access may result in significant damage to features of Earth science interest, but if undertaken sensitively can provide improved access for scientific study. For example, when Poll an Ionain (Doolin) Cave in Ireland was developed, the existing cave passage was selectively enlarged to retain as much of the morphology as possible and the new passage allowed scientists to transport coring equipment to a chamber with deep sediments that was previously only accessible via a low, narrow passage.

In addition to direct impacts, any changes to the flux of water, sediment or carbon dioxide on and through karst represent a potential threat to geodiversity, for example by infilling or burial of features by modern sediments or changes in percolation water chemistry that lead to cessation of speleothem deposition. The main activities producing such changes are agriculture and forestry, extractive industry, water exploitation, construction/urbanisation, and tourism/recreation. Agriculture and forestry are the commonest human activities in, and on the boundaries of, karst protected areas, and both have a range of impacts. Changes to surface vegetation, for example as a result of fire, commonly lead to soil erosion and in extreme cases to desertification, as well as to reduced soil carbon dioxide concentrations. Water exploitation commonly has indirect impacts on geodiversity; for example, by either water extraction

Photo 7.3 The gigantic Dashiwei Tiankeng sinkhole (doline) measuring 600m long, 420m wide and 613m deep, Leye-Fengshan Global Geopark, China. © John Gunn

lowering the groundwater elevation or by point recharge washing sediment into conduits. See Box 6.2 for a Slovenian example.

Management principles and guidelines

Karst areas receive protection at local, national or international levels for a variety of reasons of which geodiversity is commonly just one; in some cases, it is not even mentioned. For example, five of the 52 World Heritage properties identified by Williams (2008, and pers. comm.) as having internationally significant karst features (including two with karst of Outstanding Universal Value, as defined by the Convention) were inscribed on the World Heritage List solely because of their cultural interest; it is not clear whether the geodiversity receives any protection within these sites. Similarly, Gunn (2020) has identified 151 Biosphere Reserves in 62 countries (total area 42,181,357 ha) and 124 Ramsar Sites in 55 countries (total area 4,766,652 ha) that contain karst groundwater and most likely also significant karst geodiversity. Even in Global Geoparks that contain karst, the focus for conservation is commonly commercially operated tourist caves with little or no consideration for the management requirements of other caves nor, in some cases, for the wider karst geodiversity. Hence, *the most important principle in managing karst protected areas is to adopt a holistic approach that considers the entire karst system.* This comprises surface

Photo 7.4 Gough's Cave in the Cheddar Caves Site of Special Scientific Interest, Somerset, England has been open to the public for over 100 years. Unfortunately, poor use of lighting has encouraged growth of lampenflora in many parts of the cave. The pool is artificial and contains both speleothem brought in from other parts off the cave and coins thrown in by visitors to 'make a wish'. © John Gunn

and underground landforms, the water network, and the flora and fauna, as well as any spiritual, religious and other cultural values.

International guidelines for cave and karst protection were published by the IUCN (Watson et al., 1997), and Veni et al. (2001). Examples of best practice guidelines for cave and karst conservation at a regional or national level include Prosser et al. (2006) for England; the 2003 karst management handbook for British Columbia, Canada, with a linked online training module (British Columbia, 2003; 2020) and the Tasmanian Government guidelines for protecting and managing karst (Tasmanian Government, undated). Many national caving associations publish guidelines for responsible caving; for example, the British Caving Association (undated) and the National Speleological Society in the USA (2016). Woo and Kim (2018) provide examples from Korea. Table 7.1 outlines some key management considerations.

7.2 Managing glacial and periglacial protected and conserved areas

Landforms, processes and features of value

Glacial and periglacial (areas subject to alternate freezing and thawing at high altitude or near to glacier margins) protected areas include a wide range of active (modern) and inactive (relict Quaternary) features. Modern glacial environments associated, for example, with the ice sheets in Antarctica and Greenland; the ice caps and icefields in Patagonia, Alaska (USA) and Iceland; and mountain glaciers in the Alps, the Himalaya, Rocky Mountains and sub-Antarctic islands comprise assemblages derived from a variable combination of glacial, lacustrine, fluvial and marine processes. In these areas, there are also assemblages of inactive landforms and deposits that record longer-term glacier changes over time scales from decades to hundreds of thousands of years (Kiernan, 1996; Benn & Evans, 2010). Protected areas that represent these glacial types are frequently large and include many of the world's most spectacular landscapes and important biodiversity reserves (e.g. Sagarmatha (Mount Everest) National Park, Nepal; Aoraki/Mount Cook National Park, New Zealand; Los Glaciares National Park, Argentina; Torres del Paine National Park, Chile; Glacier National Park, USA; Northeast Greenland National Park, Denmark; Vatnajökull National Park, Iceland; Jotunheimen National Park, Norway; and Sarek National Park, Sweden). They invariably comprise complexes of landforms and dynamic geomorphological systems at different scales.

Inactive glacial environments comprise landforms and deposits formed principally during the Quaternary glaciations of the last 2.6 million years. They occur over a wide area of mid-latitude North America and Eurasia and as well as in the forelands and lower valleys of present-day ice sheet and mountain glacier systems (Ehlers et al., 2011). Protected areas range widely in size from a landscape scale with high geodiversity (e.g. the Tasmanian Wilderness World Heritage Area Australia, and the Lake District and Cairngorms National

Table 7.1. Key considerations in cave and karst geoconservation.

SURFACE MANAGEMENT In a karst protected area, any planned activity should be assessed to determine the potential impact on the flux of water and air (especially levels of carbon dioxide), which is the driver of karst processes.	
Catchment area	Many karst areas receive a substantial flux of water and sediment from adjacent non-karst catchments, and groundwater in karst commonly moves beneath topographic watersheds and may follow convergent and divergent pathways. Karst catchments are commonly dynamic, expanding and contracting in response to rainfall. Hence, it is essential that the whole catchment of existing or proposed protected areas in karst is defined using repeated water tracing experiments and cave mapping. In those areas where the catchment extends beyond the area with surface karst geoheritage, the additional land should form part of a buffer zone or there should be an integrated catchment management plan to protect downstream karst features of interest.
Extractive industry	There should be a general presumption against extractive industry in karst protected areas as there is inevitably loss of geodiversity and process modification. Where there is a need for a mineral that cannot be obtained outside of the protected area, potential extraction sites need to be assessed in terms of both surface and underground landforms and of hydrogeological connectivity to identify 'minimal impact' zones.
Large-scale construction	Protocols have been developed to reduce the risks that karst poses to the development of highways and railways, but the risks of such development to karst have not received as much attention. Where it is necessary to cross protected areas, surface terrain mapping, speleological investigations with detailed cave surveys and hydrogeological investigations are essential to identify a 'least-damaging' route. Karst-specific measures should include preventing direct entry to groundwater of road runoff containing hydrocarbons and sediment; careful sealing of voids on the surface, rather than infilling with grout; and provision of alternative access to any caves encountered.
Local construction and access	Similar considerations apply to construction of local roads and walking tracks within karst protected areas, but greater control should be possible over the routing. Cave mapping linked to surface terrain mapping is essential to identify least-damaging corridors. For larger projects, geophysical surveys should be undertaken to identify large voids. Drainage from roads and tracks should be channelled through sediment (and hydrocarbon) traps that receive regular maintenance.
Buildings	Any new buildings in karst protected areas, such as visitor centres, require prior surface and underground surveys to avoid construction over subterranean features.
Parking and visitor transport	Wherever possible, car parks should be well away from significant surface landforms. They should never be above caves, both to avoid infiltration and because car parks form an impervious 'cap' that restricts the infiltration of water and can cause the drying of caves. Increasingly, electric vehicles are used to transport visitors from large, well-designed car parks to features of interest.
Power generation and the storage of fuel	Visitor facilities in some karst protected areas are remote and off the electricity grid. Where possible electricity should be generated on-site using wind, water or solar units. If diesel power generators are essential, the fuel for them and for any other essential uses should be in purpose-built bunded storage with procedures to prevent spillage.
Water supplies	As karst areas are characterised by a lack of surface water, underground water is commonly exploited to obtain supplies for human use. Collection of percolation water entering a cave is likely to have little impact, but before any water is abstracted from cave streams it is essential to establish (by water tracing) where it is coming from and where it drains to. Informed decisions can then be made on the potential impacts from abstraction.
Grey water and sewage treatment	Untreated waste water should not be discharged into karst, as this will result in pollution potentially impacting on speleothems, cave biota and springs. Transfer of wastewater out of the karst may disturb the water balance and best practice is to treat water to a high standard before discharge into the karst at a point where there is natural point-recharge. For example, in the Marble Arch Caves Global Geopark (Ireland), waste water from the visitor centre flows through a small on-site treatment plant and high-quality treated water is discharged into the cave stream.
Plants and animals	Limestone areas, with their carbonate-rich soils, may favour some plant species and produce a distinctive flora. The geomorphology of karst may also influence floral assemblages. For example, dolines that act as cold-air sinks may include flora that is more distinctive of higher altitudes or past colder climates. Karst terrain also provides many ecological niches for surface animals. Management of karst areas protected for geoheritage should always take into account flora and fauna, and vice versa.

SUBSURFACE MANAGEMENT	
Catchment area	It is essential to protect the whole catchment, but caves that extend at depth beneath non-karst terrain present a particular difficulty. If it can be established that there is no connectivity between the surface and the cave, then nothing is gained by having a protected area above the cave footprint, but where there is limited connectivity, for example via caprock dolines, then it is important that the surface landforms are protected.
Visitor access	The vast majority of caves are undeveloped, but even these may receive many visitors undertaking unguided 'adventure caving', including cave diving. In protected areas, a permit system may be necessary to restrict visitor numbers. Locked gates are necessary to protect caves with a high geoheritage, biological or archaeological value. All visitors should sign-up to a minimal-impact caving code of conduct, and in heavily used caves preferred routes should be clearly but discreetly marked.
Within-cave zones	Surveys of caves in protected areas should include geoheritage detail to facilitate management by zoning. Those sections of a cave most suitable for visitor access should be identified, together with areas where access restrictions must be applied because of exceptional speleothem, sediment or archaeological deposits, or those with high concentrations of harmful gases, such as carbon dioxide or radon.
Existing tourist caves	Many tourist caves were developed before protected areas were designated and, unfortunately, in some there has been significant damage to geoheritage interest from destruction of sediments and speleothems to construct pathways, introduction of organic materials and development of lampenflora (algae, mosses and plants which grow in artificial light). Large visitor numbers may also increase carbon dioxide concentrations to levels where speleothems begin to dissolve. Tourist caves in protected areas should be assessed and a management plan developed to restore features of interest where possible and to protect against future damage. For example, old lighting systems should be replaced by modern LED systems. For further details see ISCA (2014).
Development of new tourist caves	Tourist caves are commonly an important source of revenue for a protected area and there may be pressure to open up new caves. This should only be allowed where a clear demand can be demonstrated and a suitable cave identified. A development plan should be drawn up with involvement from experienced speleologists to minimise damage to passage morphology, speleothems and sediments. Sensors should be installed to allow real-time monitoring of air quality.
Cave cleaning	Tourist caves vary in the amounts of cleaning required, the most common requirements being to remove accumulations of lint and human residue arising from visitors, and to control lampenflora. Where possible, water from within the cave should be used and high-pressure hot water should only be used if other options have failed. Lampenflora are best controlled by reduction in lighting and use of LED lights, but a 5% solution of sodium hypochlorite can be used to remove existing growth, provided that care is taken to avoid runoff entering cave streams.
Cave toilets	Visitors need to be clearly advised where their last toilet stop is prior to entering a cave and there should be a presumption against in-cave toilets, although they may be needed in extensive tourist caves where visitors are underground for more than an hour. Modern designs minimise waste, but to avoid pollution care is needed in emptying and cleaning.
Cave fauna	Caves are popular roosting sites for a range of different bat species. Their bat guano is of special importance to invertebrate decomposer species who inhabit such a cave ecosystem. In the past guano was commonly mined for its value as a fertiliser leaving some caves in need of restoration. Other species such as birds, snakes, mammals and amphibians inhabit cave entrances and their immediate entrance area and need to be protected. Some cave fauna species are found deep within the cave and have evolved in the absence of light.

Source: Compiled from a variety of sources, most notably Watson et al. (1997).

Parks, UK) to small geosites (<1 km^2) that contain exceptional or representative stratigraphic records of Quaternary glaciation and environmental change, often exposed by coastal or river erosion. Where natural exposures are rare, working and disused quarries often offer a highly valued resource for their exposures of sedimentary records.

Similarly, periglacial environments include both active and inactive landforms and deposits formed by cold-climate, non-glacial processes (Ballantyne, 2018). The former are widespread on glacier-free ground in polar and high-mountain areas, and also on many lower-altitude mountains in the mid- and low-latitudes that no longer support glaciers, or only small ones. Inactive periglacial features are also present at lower altitudes in the same areas and in mid-latitude lowland areas, particularly those in the northern hemisphere which lay beyond the margins of the Quaternary ice sheets.

Glacial and periglacial protected areas have high geoheritage value for a number of reasons. They are important for scientific research and understanding of glacier dynamics, past climate changes recorded in ice cores, glacial and periglacial landforms and deposits, and glacial lake and marine deposits. Such knowledge is key to enabling insights into the possible future dynamic responses of the Antarctic and Greenland ice sheets to global warming. Glacial and periglacial landforms and soils provide the physical underpinning, or 'stage', for biodiversity over large areas of the high- and mid-latitudes, and in the world's mountain environments at scales from whole ranges to the mosaics of habitats on individual mountain slopes. Many

Photo 7.5 The highly accessible Nigardsbreen glacier and moraines, an arm of the Jostedal glacier, the largest ice cap in mainland Europe. The site is in the Nigardsbreen Nature Reserve, part of the Jostedalsbreen National Park, Norway. © **José Brilha**

Photo 7.6 Recently deglaciated area by retreat of the Stanley Glacier is now subject to periglacial processes, Kootenay National Park, Canada. © Parks Canada, Zoya Lynch

glacial and periglacial protected areas also have significant value for tourism, educational and recreational activities, cultural heritage associations (e.g. through folklore and legends, and as national symbols), landscape aesthetics and as sources of inspiration for art and literature (Kiernan, 1996; Gordon, 2018). In addition, they are important sources of water for adjacent lowland areas and for hydro-electric power.

Threats

All of the threats in Table 6.2 potentially apply to the geoheritage interests of glacial and periglacial protected areas (Table 7.2). The principal impacts are:

- total or partial destruction of landforms and exposures of sediments;
- fragmentation of site integrity and loss of relationships between features, particularly where the interest lies in assemblages of landforms;
- disruption of geomorphological processes;
- loss of access to landforms or sediment exposures; and
- loss of visibility of key features (e.g. through vegetation growth or talus accumulation in front of sediment exposures).

Large, landscape-scale protected areas will tend, overall, to be relatively robust in the face of most small-scale developments and threats, although particular concerns will be the loss of integrity and naturalness, and the risk of significant damage to, or destruction of, specific features of outstanding value to facilitate developments, such as construction of skiing infrastructure (Reynard, 2009a) or levelling the surface of a rock glacier to create ski runs (Lambiel & Reynard, 2003). Hence, proper documentation of the geoheritage interests, and evaluation of their sensitivity and the impacts of any developments, are essential. Small geosites will tend to be more sensitive to developments and threats, and often with less scope for avoidance or mitigation of impacts depending on the characteristics of the site. Again, proper documentation of the features of interest and evaluation of their sensitivity and the impacts of any developments are essential.

Site management principles and guidelines

The following general principles apply, following the site classification in Table 5.2:

- integrity sites/static features – protect the physical integrity of the resource and prevent fragmentation (e.g. through quarrying, track construction), so that relationships between features are evident (e.g. between eskers and meltwater channels);
- active geomorphological sites/features – maintain natural processes and the capacity of the active processes to evolve naturally;
- exposure sites – monitor sediment exposures and undertake maintenance (e.g. clearance of vegetation), if required, depending on the level and type of use; and
- finite/unique features – maintain stringent protection to prevent loss of key interests (e.g. interglacial deposits); in some cases, where the interest is particularly vulnerable, it may require burial.

Some small protected areas may be managed as discrete entities, but generally glacial and periglacial features will occur as complex landform and process assemblages (Kiernan, 1996; Reynard, 2009b), and individual features will vary in their sensitivities to particular threats. The impacts of fragmentation and loss of integrity and context of the landform assemblages are therefore important considerations.

In modern glacial environments, geoconservation protected area management objectives should be to maintain the active processes and protect the integrity and context of the inactive landform assemblages that are present. The main threats are likely to be from tourism and recreation, hydro-electric power and forestry developments. Impacts may arise directly from the siting of buildings and associated infrastructure and indirectly from hazard mitigation measures deemed necessary to protect the developments (e.g. river bank protection). Both the direct and indirect impacts of the siting of new facilities on geoheritage features should be assessed, as well as risks to the public, particularly as accelerated environmental change increases glacier and permafrost hazards (Kääb et al., 2005). In some areas, such as the Himalaya, increased risk of glacier lake outburst floods represents a particular concern for communities and visitors downstream, necessitating installation of warning measures and engineered lowering of lake levels.

Inactive landforms and finite deposits are particularly susceptible to damage from a range of threats (Table 7.2) (see Photo 3.5). The main management objectives for such features are to maintain the integrity of the landforms and access to exposures or localities where sediments can be re-exposed easily for scientific research, and, where appropriate, interpretation. In the case of landforms, the main management requirement is to prevent damage from activities such as mineral extraction, development and afforestation (Table 7.3). In the case of working quarries, there are two main requirements: first, to ensure that access is allowed for scientific research (subject to reasonable health and safety considerations), particularly where scientifically important material (e.g. interglacial deposits) would be permanently lost; and second, to retain representative sections and undug reserves after working has ceased, where possible. The latter requires early negotiations with quarry operators and planning authorities (Prosser, 2016).

In the case of disused quarries and pits, there are two requirements for restoration and management when working ceases. First, access to sections should be maintained for purposes of study and cleaning (e.g. by hand or a mechanical digger). Provided that access is maintained, subsequent uses such as landfill, building development or woodland development can usually be accommodated around the conservation area through appropriate technical or planning design; it may be possible to combine geoheritage and

Photo 7.7 A perfectly shaped circle of stones formed by frost heave, Kvadehuksletta, Nordaust-Spitsbergen National Park, Svalbard, Norway. These landforms are extremely fragile to human trampling. © **Roger Crofts**

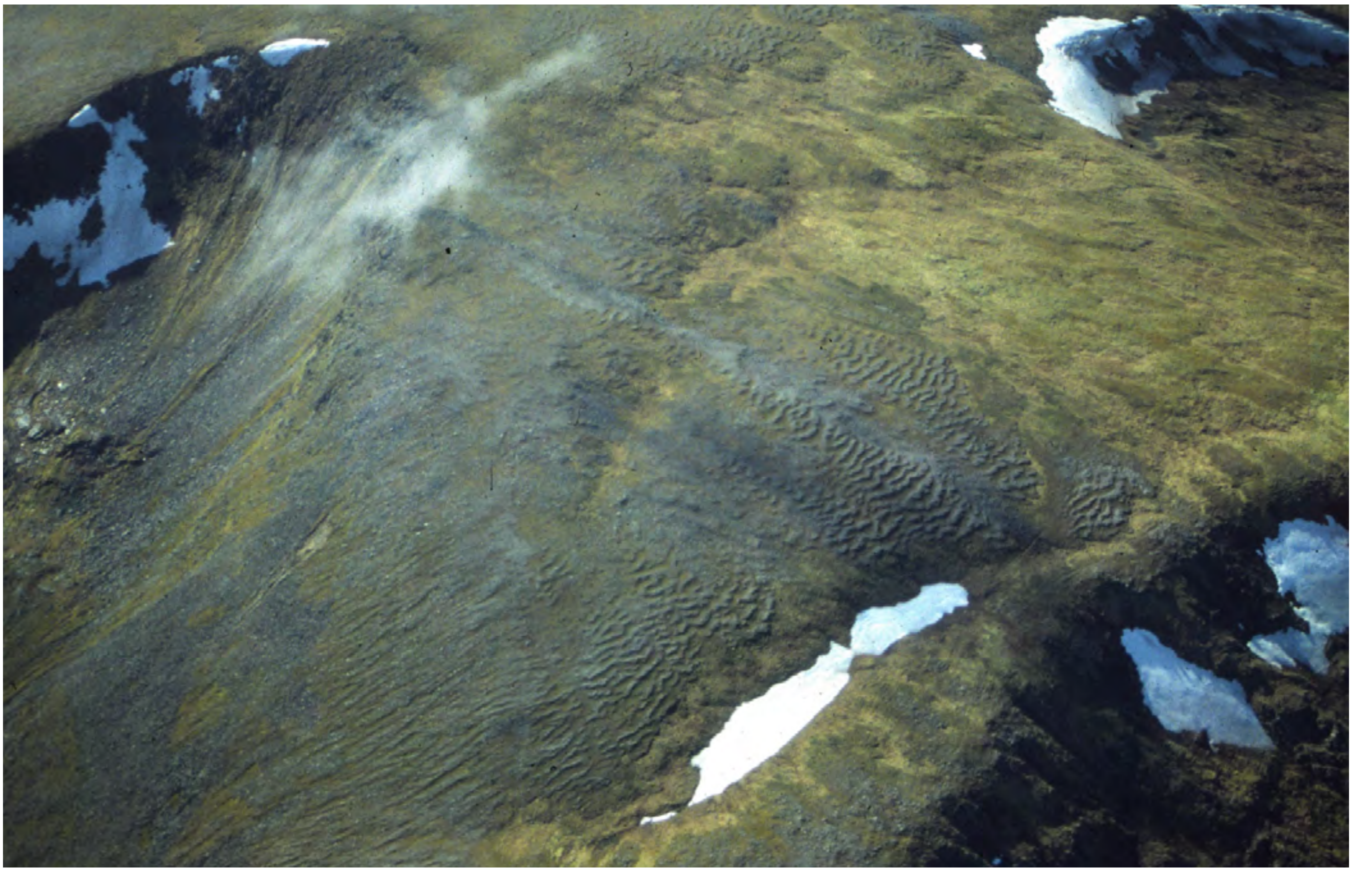


Photo 7.8 Periglacial lobes and terraces caused by downslope movement resulting from alternate freezing and thawing of the soil are highly fragile landforms and easily damaged by over grazing or by wheeled vehicles. Fannich Hills Site of Special Scientific Interest, Scotland. © Roger Crofts

Photo 7.9 **Suite of glacial landforms at the snout of the Battybreen glacier in the Nordre Isfjorden National Park, Svalbard, Norway. Remoteness means that they are likely to remain undisturbed, although the advent of small expedition cruising and use of fast boats to give access to remote places in Svalbard waters is a potential threat. © Roger Crofts**

Box 7.1
Restoration case study: Pitstone Quarry Site of Special Scientific Interest, Buckinghamshire, UK

Pitstone Quarry SSSI is a good example of the integration of geoheritage and biodiversity conservation as part of the planned restoration of a former mineral extraction site. The site displays evidence of two interglacial episodes, an intervening cold stage, and periglacial features with plant and animal remains indicating changing environments and processes. The site is a partly flooded former chalk quarry now managed as a local nature reserve by a local environmental NGO. Some of the key Quaternary deposits are presently obscured by vegetation and talus. As part of an integrated site management plan, the site owners, in partnership with local geologists, will undertake vegetation clearance, excavation of a fresh demonstration exposure in the periglacial deposits, development of new geoheritage educational and interpretation resources and improved access for visitors and researchers. Fixed-point photography will be used to monitor the condition of the site, which will help to inform its future geoconservation management.

Photo 7.10 **The key Quaternary deposits at Pitstone Quarry occur above the degraded chalk face on the right hand side of the image. © Eleanor Brown, Natural England**

Table 7.2. Principal threats and conservation management requirements for different categories of glacial and periglacial sites.

Earth Science Conservation Code	Type of site	Typical features of interest	Principal threats	Indicative conservation management
Exposure or extensive sites	Active quarries and pits	Exposures in glacial, periglacial and other Quaternary deposits	Restricted access for scientific studies; storage of quarry waste; backfill against exposures; over-extraction leaving no reserve of undug deposits for future research; post-working restoration and/or development	Consult with quarry operator to secure access for scientific study; consult with planning authority and quarry operator to incorporate geoconservation requirements during and after the working life of the quarry (including schemes for geological monitoring and recording, and retention of conservation sections and access as part of the restoration plan)
	Disused quarries and pits	Exposures in glacial, periglacial and other Quaternary deposits	Landfill; inappropriate restoration; inappropriate development; degradation of exposures; encroachment of vegetation	Negotiate long-term conservation sections and secure access; restrict development to non-core areas; manage vegetation encroachment; re-excavate sections for research studies where impractical or unnecessary to maintain continuous exposures
	Coastal cliffs and foreshore exposures	Exposures in glacial, periglacial and other Quaternary deposits	Coastal protection; dredging; degradation of exposures not maintained by coastal erosion; encroachment of vegetation; development of ports, harbours and marinas	Maintain natural processes (erosion); secure access; avoid installation of 'hard' engineering coastal protection; avoid development in front of cliffs and inland that may require future coast protection; on non-actively eroding coasts, manage vegetation encroachment and re-excavate sections for research studies as required
	River and stream exposures	Exposures in glacial, periglacial and other Quaternary deposits	River engineering and bank stabilisation; degradation of exposures not maintained by river erosion; encroachment of vegetation	Maintain natural processes; secure access; avoid installation of 'hard' engineering bank protection; avoid development on adjacent floodplain that may require future 'hard' protection; on non-actively eroding exposures, manage vegetation encroachment and re-excavate sections for research studies as required
	Extensive buried interest	Glacial, periglacial and other Quaternary deposits	Inappropriate agricultural and land-use practice (e.g. drainage of peat bogs); afforestation; development on top of buried features; quarrying	Avoid inappropriate activities in key areas so that they remain intact and accessible for scientific research
	Road, rail and canal cuttings	Exposures in glacial, periglacial and other Quaternary deposits	Stabilisation and grading of exposures; encroachment of vegetation; tree planting; road widening; development in disused cuttings	Avoid 'hard' engineering solutions, such covering exposures with concrete; manage vegetation encroachment and re-excavate sections for research studies; include conservation sections and secure access as part of final design of new cuttings

Earth Science Conservation Code	Type of site	Typical features of interest	Principal threats	Indicative conservation management
Integrity sites	Static (inactive) geomorphological features	Glacial and periglacial landforms and landform assemblages	Mineral extraction; urbanisation, commercial and industrial developments; dams; afforestation; vegetation encroachment; inappropriate recreational activities (e.g. land surface re-shaping for golf courses); inappropriate agricultural and land-use practice (e.g. infilling of natural kettleholes, construction of tracks) For offshore features: wind farms and energy production developments and associated infrastructure; dredging; trawling	Maintain integrity of landforms and landform assemblages; avoid quarrying and development; avoid afforestation, dumping and infilling of depressions; manage vegetation encroachment; avoid inappropriate recreational activities For offshore features: avoid developments that disturb the seabed
	Active process geomorphological systems	Glacial and periglacial processes and actively forming landforms	Development (e.g. skiing infrastructure and facilities); 'hard' engineering responses to hazard mitigation in tourism areas and downstream settlements and infrastructure; river engineering and dams	Maintain natural processes; locate developments away from active processes and in low-risk areas; re-route footpaths and interpretation trails as necessary
	Karst	Glacio-karst	Mineral extraction; development (e.g. skiing infrastructure and facilities); encroachment of vegetation	Maintain natural processes and integrity of landforms; avoid quarrying and development; manage vegetation encroachment
Finite sites	Features of limited extent in a range of situations (e.g. active and disused quarries, coastal cliffs, foreshore, river banks and caves)	Quaternary interglacial and interstadial deposits	Mineral extraction; development; inappropriate agricultural and land-use practice and recreational activities; afforestation; encroachment of vegetation	Avoid quarrying, development, afforestation, dumping and infilling, 'hard' engineering coastal and river protection, inappropriate recreational activities, irresponsible excavation of cave deposits; secure access; manage vegetation encroachment

Source: adapted from Prosser et al., 2006, 2018.

Photo 7.11 Fossil animal, *Dickinsonia*, Nilpena fossil site 560 Ma, Ediacara Conservation Park, South Australia. One of the early animals on Earth, it could move, and would feed on bacterial mats. © Graeme L. Worboys

biodiversity objectives. Second, where sections are not kept open, the option to undertake future temporary access must be maintained, such as to allow scientific meetings or research projects. After such events, the sections may be backfilled. Guidance on approaches and conservation solutions for a range of inactive situations is summarised in Table 7.2, with further details provided by Kiernan (1996), Prosser et al. (2006) and Kirkbride & Gordon (2010).

In exceptional cases (e.g. where the interest is extremely fragile and/or spatially very restricted), the most appropriate conservation method may be to bury the key interests and to re-excavate them for a specific purpose (e.g. scientific research or an organised visit by a professional body) (Bridgland, 2013). This may be done by placing a geotextile on the section and covering it with spoil. The spoil is allowed to revegetate but deeper rooted species are unable to penetrate the geotextile. This facilitates re-exposure whilst protecting the sediments in the interim.

Where inactive landforms have been damaged, appropriate restoration should be considered (see Box 7.1).

Pitstone Quarry SSSI is a good example of the integration of geoheritage and biodiversity conservation as part of the planned restoration of a former mineral extraction site. The site displays evidence of two interglacial episodes, an intervening cold stage, and periglacial features with plant and animal remains indicating changing environments and processes. The site is a partly flooded former chalk quarry now managed as a local nature reserve by a local environmental NGO. Some of the key Quaternary deposits are presently obscured by vegetation and talus. As part of an integrated site management plan, the site owners, in partnership with local geologists, will undertake vegetation clearance, excavation of a fresh demonstration exposure in the periglacial deposits, development of new geoheritage educational and interpretation resources and improved access for visitors and researchers. Fixed-point photography will be used to monitor the condition of the site, which will help to inform its future geoconservation management.

In some cases, it may be possible to mimic the original land surface (e.g. Gray, 2013). However, it is preferable to prevent the damage in the first place.

Interpretation should form a key part of the management objectives at appropriate sites, following best practice guidelines outlined in later in this section. Examples include Glacier National Park (USA) (https://www.nps.gov/glac/index.htm) and the Norwegian Glacier Museum (http://www.bre.museum.no/).

7.3 Managing palaeontological and mineral sites

Features of value

Sites with fossils and minerals are a very valuable part of geoheritage. Their conservation – indeed in some cases

Photo 7.12 Cavity with a quartz crystal lining, Mount Gee, Arkaroola Protection Area, South Australia. The surface epithermal area would have resembled modern Yellowstone with geysers and hot pools. © Graeme L. Worboys

their strict preservation – is necessary so that both sites and associated scientifically important specimens are not lost to present and future generations to study, learn from and enjoy.

Palaeontological resources (fossils) are the remains and evidence of past life preserved within a geological context; as such, they are a non-renewable resource. Fossils carry scientific and educational value by providing important data related to the history of life, palaeo-ecosystem evolution and past geological events. The science of palaeontology continues to expand as new fossil discoveries are made.

Minerals and mineralogical sites provide valuable evidence of the physical evolution of the Earth. They help us to understand the process of plate tectonics and the complexity of igneous intrusion (molten rock intruded below surface), volcanic eruption and metamorphism (temperature, pressure and chemical changes in original rocks). Minerals also provide a source of industrial raw materials and are among our most valuable commodities. Like fossils, minerals are widely collected, and research, particularly supported by modern analytical techniques, continues to develop our understanding of mineralogy.

The management of palaeontological and mineralogical resources and localities must be based upon scientific principles, strict resource management practice and legal authority, where necessary.

Threats

Natural processes and human activities may influence the stability of fossils exposed at the Earth's surface. Natural weathering and physical erosion, together with human activities, such as quarrying, are among the most important agents in revealing both fossils and minerals; for example, some of the most productive fossil localities are along actively eroding coastlines and in active quarries. Where these resources are limited in extent, however, the same natural processes may pose a threat, ultimately removing the fossil or mineral resource. Both inadvertent and intentional human activities, such as construction activities or intensive collecting, can threaten palaeontological and mineralogical resources and localities (Table 7.3) (Santucci & Koch, 2003; Santucci et al., 2009). A notable case is the degazetting by the US Congress of Fossil Cycad National Monument in South Dakota because collectors had removed all surface specimens and the main feature of interest was lost (Santucci and Hughes, 1998).

Management principles and guidelines

Useful guidelines and codes of conduct for conserving fossil and mineral sites and for responsible collecting have been developed (ProGEO, 2011) and applied in some countries, e.g. by the US National Park Service (Box 8.5). Other examples include guidelines for collecting geological specimens (including both fossils and minerals) in England, together with guidance on managing different types of fossil and mineral localities (Natural England, 2012); the West Dorset Fossil Collecting Code of Conduct (Dorset and East Devon Coast World Heritage site, 2011); and the Scottish Fossil Code for fossil collecting, conservation and storage (Scottish Natural Heritage, 2008).

The US National Park Service has devised palaeontological resource stability indicators comprising information on climate, rates of erosion, human attitudes and behaviour, and loss or gain of specimens at the surface (Santucci and Koch, 2003). These have been further developed into the five step Vital Signs monitoring system, comprising rates of natural change in geological and climatic variables, catastrophic geological processes, hydrology and bathymetry, and human impacts (Santucci et al., 2009). Table 7.4 sets out principles and Box 7.2 provides a case study.

There is a consensus that responsible fossil collecting can promote the science and contribute to research, as well as making a positive contribution to our understanding, conservation and experience of geodiversity, providing that a code of good practice is followed (as in the principles set out in Table 7.4). However, irresponsible collecting of rare fossil and mineral specimens represents a significant loss to science and can also incur damage to exposures and loss of other specimens. Mechanical excavators, explosives, crowbars and rock saws have all been used to remove fossil material and minerals, in a search for rare, valuable or high-quality specimens. It is important to work constructively with different collecting groups. For example, in the Jurassic Coast World Heritage site (UK), local collectors (including commercial collectors) are encouraged through the West Dorset Fossil

Table 7.3. Protecting palaeontological sites from threats.

Potential threat sources	Preferred management action
Amateur collectors	Fossil collecting is typically banned from a protected area where all natural phenomena are protected. There are some exceptions to this, but only under strict controls and after the management authority has determined that the benefits of allowing collecting (as a way to promote interest in palaeontology among the public) outweigh the costs of resource removal. The Jurassic Coast World Heritage Area near Lyme Regis, England, for example, permits the collection of fossils eroding from a cliff face at the high tide mark (see Photo 6.15).
Professional thieves	Methods used to thwart the theft of rare fossils by professional thieves include: the presence of rangers on-site, use of electronic surveillance, construction of protective structures that enclose the site, and, as a last resort, relocation of precious fossils to museum collections.
Research collectors	Scientific research in protected areas is usually managed through a permit system, with researchers granted permission to excavate fossils with minimum impact as part of their investigations. There will be many cases where researchers are not permitted to disturb the site, such as one that has a priceless array of fossil shells. There will also be many sites where scientists are actively encouraged to complete excavations, such as those with fossils found on an eroding coastal wave platform. In practice, protected area managers should develop a strong working relationship with the permitted research group, and have liaison rangers/wardens actively ensure that the rules are enforced and information exchanged, and also ensure that new knowledge gained is included into natural history descriptions and interpretive programmes.
Visitor management	Visitors often will be encouraged to visit fossil sites and to appreciate an 'extract of Earth's history' that is on display. Depending on the nature of the fossils, visitor access to open-air exposures is usually organised with fixed walking routes. For especially sensitive sites, guided tours are normally provided; many outcrops/specimens may be located behind protective structures. Some specimens are so sensitive that they may be relocated from an outcrop to an on-site visitor centre.
Visitor centres	Some fossil sites are so dramatic that they have been protected within large purpose-built structures that combine a visitor centre and museum. The Dinosaur National Monument quarry building (Utah, USA), for example, houses an excavation of a jumble of dinosaur bones. The structure serves as a workshop and excavation site for palaeontologists and a display site for the public.

Table 7.4. Summary of practical principles for conserving fossil and mineral sites.

- Always encourage responsible collecting practice from protected areas.
- Make conservation management measures proportionate to the scientific importance of the protected area and the fossils/minerals present.
- Adapt conservation management to local conditions, considering issues such as the extent of the collecting resource, its rate of renewal and the likely pressure from collecting, and so on.
- Permit *bona fide* site-based research and study in order to facilitate the development of geoscience.
- Conserve the fossil and mineral resource *in situ* wherever possible. In extreme circumstances, consider removal and conservation in a museum, but taking care to record all contextual information before removal.
- Limit any collecting to parts of the site that are the least vulnerable, or to sites that are of lesser importance and encourage collecting from loose and waste material.
- Consider burial (where the threat from weathering, erosion or collecting cannot be managed) of some key sites to conserve the fossils and minerals in context so they are available for future study.
- Develop protocols to conserve fossil and mineral sites and agree a code of conduct for responsible collecting that includes amateur, academic, institutional and commercial collectors.
- Develop specimen recording schemes for key sites, encouraging collectors to share information.
- Encourage regular communication between landowners and managers, collectors, museums and researchers.
- Ensure that regular site visits and monitoring are in place to assess overall condition and whether damage is occurring, with instigation of an appropriate management regime.

Photo 7.13 Petrified Forest National Park, Arizona. Fossilised remnants of the tropical forest of Triassic period c 225 Ma. © José Brilha

Photo 7.14 Safeguarding rare specimens in a carefully controlled environment is a tried and tested approach. Berne Natural History Museum, Switzerland. © Roger Crofts

Box 7.2

Case study of paleontological sites in the US National Parks

The US National Park Service (USNPS) manages at least 242 park units where palaeontological resources have been documented through baseline inventories.

The overriding principle for non-renewable palaeontological resources in US National Parks, as set out in the law that created USNPS, is to preserve and protect them "in such manner and by such means as will leave them unimpaired for the enjoyment of future generations". The Palaeontological Resources Preservation Act 2009 is the principal legal authority in the United States for the management and protection of fossils. The USNPS and other federal land-managing agencies have developed regulations, policies and procedural guidance to support science-based management for non-renewable palaeontological resources. Specific management activities associated with fossil localities include: inventory, monitoring, research, fossil collecting, museum curation, data management, site conservation, protection, interpretation and education. Some fossil sites warrant the development of a palaeontological resources management plan to provide a strategic approach for the management of palaeontological sites.

Palaeontological resource inventories (also referred to as 'fossil surveys') are important management tools to establish the scope, significance and distribution of palaeontological resources. Drawing from published and unpublished literature, a 10-year effort to compile baseline palaeontological resource inventories for the entire USNPS was completed in 2011 (Santucci et al., 2012). These systematic inventories more than doubled the number of parks identified as having fossils. The inventories also uncovered new scientific information previously unrecognised by park staff, resulting in increased stewardship of park fossils and new opportunities for public education and research.

Fourteen US National Park units were established wholly or in part for their fossil resources. One of the best known fossil parks is Dinosaur National Monument (Colorado and Utah), which preserves the world-famous Douglass Dinosaur Quarry and is considered a real-life "Jurassic Park" Dinosaur skeletons from the park are found in museums around the world. Petrified Forest National Park, Arizona , is another popular fossil park that provides visitors the opportunity to step back in time 200 million years to view the remnants of a Triassic terrestrial ecosystem. In addition to the beautifully preserved petrified logs, the park has yielded the remains of early dinosaurs, along with a diverse assemblage of other prehistoric vertebrates, invertebrates, plants and trace fossils. The park sustains an active geology and palaeontology research program, maintains significant fossil collections and provides a popular educational experience for park visitors from around the world.

Given the non-renewable nature of fossils, the long-term impacts of unauthorised fossil collecting activities represent a significant resource management and protection issue. This issue is clearly demonstrated by the unfortunate history of Fossil Cycad National Monument, South Dakota, which existed from 1952–1957 .Unauthorised collection of the fossil cycads at the park resulted in the complete removal of all the ancient plants exposed at the surface. The loss of the fossils at this site led to the degazetting of Fossil Cycad National Monument, which was abolished as a unit of the USNPS in 1957. The lessons learned from Fossil Cycad help to shape modern resource management practices at palaeontological sites on public lands (Santucci and Hughes, 1998).

Collecting Code of Conduct to work with specialists and museum curators to ensure that material is recorded and studied and that the most scientifically valuable specimens are kept in public institutions for common use.

One solution where very rare fossil and mineral sites are threatened is to remove the specimens and/or the fossil or mineral-bearing resource for curation in a museum where they are available for the public to see and scientists to study. At geosites where it is difficult to remove specimens, an alternative approach is to make high-quality moulds and casts (Williams and Edwards, 2013). This provides detailed replicas and a resource that can be used off-site for research and education, reducing on-site pressures. It is particularly valuable for recording trace fossils.

7.4 Managing volcanic protected and conserved areas

Landforms, processes and features of value

Volcanic landscapes demonstrate geological and geomorphological processes fundamental to understanding how the dynamic Earth works, from the global to the local scale and linking processes in the Earth's interior with those on its surface. In addition to their core geoscience values, volcanoes provide one of nature's most dynamic stages, which has expressions in the great biodiversity found in many volcanic landscapes, the cultural connections between people and their environment, and as a record of human developments on every continent. This management guidance is drawn primarily from Wood (2009), supplemented by Casadevall et al. (2019).

Volcanic landforms vary greatly in shape and size, ranging from small cinder cones to enormous volcanoes. Volcanoes may be long-lived phenomena, formed from repeated episodes of volcanic activity that may have taken place over hundreds of thousands to millions of years (e.g. the island of Iceland may have been shaped over a period of some 20 million years; the Las Cañadas caldera, Tenerife, Spain, may have an age of over 3.5 million years; the activity that built Jeju Island (Mount Halla), Republic of Korea, began about 0.8 million years ago; while the island of St. Lucia in the Caribbean is an example of complex and explosive overlapping collapses). This means that older volcanic centres can be complex overlays of different landforms and lava compositions through time, including collapses. In addition to contemporary volcanic processes and landforms,

Photo 7.15 Semeru Volcano, Java's highest volcano, in eruption on the skyline. In the foreground is Tengger Caldera with the ribbed post-caldera cone of Batok in the centre foreground and the steaming cone of Bromo in the left foreground. © Lee Siebert, Indonesian National Park

Photo 7.16 A mega caldera lake formed after the eruption at the transboundary protected area of Mount Changbaishan/Mount Paekdu Volcano, China/Democratic People's Republic of Korea. © Kayla Iacavino

scientists are interested in the remains of ancient volcanoes that are preserved at the surface. Evidence of former volcanic activity may be found in vertical geological sections exposed in cliff faces and valley sides, or in the patterns made by rock structures on the ground surface.

Volcanic landscapes may also host hydrothermal phenomena, such as hot springs, geysers, mud pools and fumaroles. Hot springs occur where geothermally heated groundwater emerges from the Earth's crust. They are found all over the planet, including the ocean floors.

Threats

There are many threats from volcanic geoheritage to people, and threats of people to volcanic geoheritage. Some protected areas do not recognise that beautiful volcanic features may be active. Therefore, there is the potential that the risk of hazardous conditions (e.g. eruptions, gas emissions, fumarolic activity, landslides and other volcanic hazards) may not be adequately addressed in the site's management plan. Drawing visitors to active geophysical areas carries a responsibility to monitor volcanic activity and develop risk contingency plans as essential parts of the management process. Many volcanic areas include site monitoring, communication and emergency response systems designed for residents. However, these may not address specific hazards of protected areas, such as a warning system for tourists and an orderly method for evacuation or protection. Protected areas offered a good venue for providing such information, but it is frequently omitted from management planning. There is also an educational value to raising awareness of volcanic hazards in a scientifically valid manner.

A good example of a successful hazard reduction scheme in a volcanic World Heritage site is New Zealand's Tongariro National Park. The threat of lahars (mud flows) caused by water spillage from Mount Ruapehu's summit lake has been of particular concern for the safety of skiers and ski infrastructure on its slopes, and for surrounding roads, farmland and settlements. Sophisticated crater-lake monitoring and lahar warning systems have been installed, and these proved to be of vital importance in reducing loss of life and property damage during a recent lahar event.

In addition to working with scientists to document the possible threats from a volcano, managers must also work with civil and emergency authorities and local communities to prepare a contingency plan in the event of a serious incident. Contingency planning is now recognised to be very important in safeguarding the public in a wide range of risk situations, although in addition to public risk, managers of volcanic protected areas will also wish to understand and mediate against the risks to natural assets of high conservation value. Japan's Mount Fuji has such management plans, and has conducted evacuation drills. Similar plans exist in south Iceland in preparation for the eruption of the Katla volcano and were deployed in 2010 when the adjacent volcano of erupted.

In managing threats of people to volcanic geoheritage, it is important that protected areas plans and management provide adequate protection of the complete volcanic system, including evidence of its eruption styles, products and landforms (Table 7.5). While there is a general belief that volcanic geology is usually quite robust, many young volcanic features, such as hydrothermal deposits and delicate eruptive products, are quite fragile. In addition, there are human-made threats to geological values that may require management intervention. In most cases, these threats also impact on the site's ecology and cultural values, and where these values are important such sites should be managed as integrated systems.

Site management principles and guidelines

Volcanic sites have other natural values that frequently depend upon the special abiotic factors of volcanic terrain. The ecology of a volcano will be influenced by, or in some cases depend upon, the rock type, soil, geomorphology, and such features as micro-terrain, aspect, altitude, aridity and sometimes even volcanic disturbance. Volcanoes also frequently have strong cultural importance.

In general, because of their large size, long eruptive lifetimes (usually spanning many hundreds of thousands of years), and inherent dangers, the most active volcanic systems are relatively undisturbed and little influenced by human behaviour. On many occasions the interaction between humans and volcanoes is the reverse of that influencing other natural systems, because volcanoes can and do pose substantial hazards to life and property, and indeed to the conservation of important geological, biological and cultural features. Nevertheless, human activity does pose threats to many volcanic protected areas. These threats include illegal dumping, pollution of groundwater, inappropriate highway development, erosion of wilderness quality, commercial tourism (including ski development), recreational overuse, off-road driving, and mineral extraction.

Education and interpretation

Management objectives can also be achieved through education and interpretation programmes. Volcanoes are some of the world's most visited tourist destinations. For example, Fuji-Hakone-Izu National Park, Japan, (i.e. the area around Mount Fuji) may receive as many as 100 million visits annually, while an estimated 300,000 people climb to the volcano's summit each year. The most visited volcanic World Heritage site is Teide National Park, Tenerife, Spain, with 3.2 million visits a year. All volcanic World Heritage ites provide some access for tourists. For example, on Kilauea, Hawai'i Volcanoes National Park,, USA, and Stromboli, Aeolian Islands, Italy, casual visitors are able to safely view active volcanism as it is taking place. The educational value of the experience of viewing either a dormant or active volcano is immense, because like nowhere else on Earth they demonstrate the power and importance of geology and the magmatic processes by which the planet was made.

Excellent interpretive facilities are now being developed in many volcanic World Heritage sites and in many other of the world's

Photo 7.17 Holuhraun fissure eruption October 2014, Vatnajökull National Park, Iceland. The largest flow of lava for over 200 years in Iceland. Danger to visitors and residents was reduced by closing off the area to passenger and vehicular traffic, although planes were allowed to fly over the site as in the photo. © Roger Crofts

Photo 7.18 Eruption cone of 1910, part of the Teide volcano (summit shadow in right foreground), Teide National Park, Tenerife, Canary Islands, Spain. Access to the fragile and potentially unsafe summit area is now managed through a cable car and a permit is required to enter the crater. © Roger Crofts

Table 7.5. Risk management issues to be considered in volcanic areas.

Catchment area	Volcanic hazards can extend many tens of kilometres from the centre of activity by means of landslides, mudflows, lahars, and slope collapse. Evaluate municipal volcanic hazard assessment and incorporate recommendations into the management plan.
Extractive industry	There should be a general presumption against extractive industry in protected areas as there is inevitably loss of geodiversity and modification of processes. Where there is a need for a mineral that cannot be fulfilled outside of the protected area, potential extraction sites need to be assessed in terms of their potential impacts on the key geosites.
Fragile volcanic features	Many hydrothermal areas, young volcanic features, and soft volcanic rocks are subject to damage and destruction if not properly managed. An inventory should be undertaken to prioritise areas in need of protection. Measures to keep visitors away from these features may be required. For particularly sensitive features, consideration should be given to prohibiting access or not advertising their location.
Unauthorised collection	Many volcanic products are prized by collectors, including glassy obsidian, volcanic bombs and other deposits. Managers should emphasise that these are non-renewable resources.
Buildings	Any new buildings in volcanic protected areas, such as visitor centres, require prior surface and underground surveys to avoid construction over subterranean features, such as lava tubes, as well as areas subject to hazards to building stability.
Parking and visitor transport	Wherever possible car parks should be well away from significant surface landforms and geosites.
Power generation and storage of fuel	Visitor facilities in some volcanic protected areas are remote and off the electricity grid. Where possible, electricity should be generated on-site using wind, water or solar units. If diesel power generators are essential, then the fuel for them and for any other essential uses should be in purpose-built bunded storage with procedures to prevent spillage.
Visitor Management	
Visitor access	The vast majority of protected volcanic areas are undeveloped, but still may receive many visitors hiking and backpacking. In protected areas, a permit system may be necessary to restrict visitor numbers. All visitors should sign-up to a minimal impact visitation code, and heavily used areas preferred routes of paths should be clearly but discreetly marked.
Within the protected area	Surveys of volcanic areas should inventory key geosites and geoheritage detail to facilitate management by zoning. Those sections of the area most suitable for visitor access should be identified, together with areas where access restrictions must be applied because of exceptional fragility or hazards.
Existing facilities	Many volcanic areas were developed before being designated as protected areas, and, unfortunately, in some there has been significant damage from destruction of volcanic features and viewpoints. These places may still serve the purposes of the protected area, but managers should consider whether removal and restoration of features may be preferable. In some cases, after a volcanic event such facilities may be damaged or destroyed, which provides an opportunity to not rebuild.
Scientific research	Volcanic areas typically have active scientific research owing to the valuable record of processes occurring from the Earth's interior to the surface. Particularly after volcanic events, research interest may be high. While research is to be encouraged, protected area managers should be mindful that some kinds of research involves drilling cores, or removal of relatively large volumes of rock. For these types of research, a permit system is recommended, with emphasis on protecting the integrity of geosites and the larger geoheritage area. In places where such research has destroyed or defaced features of geoheritage importance, restoration should be implemented to minimise the long-term damage.

volcanic protected areas, notable examples being at Thingvellir National Park, Iceland, and Heimay in the Vestmann Islands off the south coast of Iceland; Hawai'i Volcanoes National Park and Yellowstone National Park, USA; Teide National Park, Tenerife, Spain; and Tongariro National Park, New Zealand. At the very innovative Stone Park on Jeju Island, Republic of Korea, superb graphical, 3D and interactive exhibits explaining the volcanic geology of the island are also linked with artistic interpretation of the basaltic rock and the island's folklore. Such exhibits, and associated interpretive publications and guiding services, fulfil an essential role in raising awareness, understanding and appreciation of the beauty and interest of volcanoes, and the importance of protecting this geological resource.

Monitoring

The methods used to monitor the behaviour of a volcano are quite sophisticated and involve both remote sensing and measurements on and around the volcano to detect movement of magma at depth. Instrumentation measures underground seismic activity, geophysical and thermal profiles, ground deformation, the geochemistry of emitted gases, hydrological data, and the chemistry, heat and viscosity of lava. In most cases, protected area managers will need to consult with volcanologists and other geological experts in the development of these monitoring methods.

In addition, many Holocene volcanoes now have undergone a volcano hazard assessment, which is a descriptive summary of potential hazards, complete with a map showing areas that might be affected by future volcanic activity. The latter is useful to site managers, scientists, civil authorities and people living on or near the volcano to judge for themselves the relation between potentially dangerous areas and their daily lives. The assessments are also critical for planning long-term land use and effective emergency-response measures.

Education and communication for geoconservation

8

There is no substitute for getting students out into the field with a trained educator, Dan Tormey one of the authors, as here at La Brea Tar Pits fossil site, a National Natural Landmark, California, USA. © Dan Tormey

This section focusses on education and communication for geoconservation. The following topics are addressed:

- general principles and practices for interpretation (8.1)
- education (8.2)
- public outreach (8.3)
- communication by new digital media (8.4)
- communication by conventional media.

This section describes several types and levels of communicating geoheritage, with the vision that the physical and digital visitor centres will be the hub for this communication. Communication for three purposes is described: interpretation, education and public outreach. Following this, communication tools are presented, divided into new digital media techniques and traditional media techniques.

8.1 Interpretation

Interpretation is a method of communication that aims to reveal the significance of a protected area's resources, rather than just to convey factual information. The guiding principle of effective interpretation is "through interpretation, understanding; through understanding, appreciation; through appreciation, protection". Interpretive programmes traditionally have targeted visitors to parks, but interpretation can now occur anywhere, including environmental education outreach programmes and web-based or mobile app-assisted interpretation. On-site interpretation, however, can be particularly powerful as it can complement the public's direct experiences with geoheritage values, and how they support biodiversity and cultural values. A good perspective on communicating the relationship between geodiversity and biodiversity can be found at Santucci (2005).

A classical holistic guide of heritage interpretation is Freeman Tilden's *Interpreting Our Heritage* (1957). Tilden defines *heritage interpretation* as an educational activity that aims to reveal meanings and relationships through the use of original objects, by first-hand experience, and by illustrative media, rather than simply to communicate factual information.

The US National Park Service has a 'crash course in interpretation' based on Tilden's principles (Smaldone, 2003; Ham, 2013). The US-based National Association for Interpretation also has an abundance of online information and tools with excellent examples of successful interpretative materials. Bruno & Wallace (2019) provide practical guidance on designing interpretive panels for geoheritage.

Interpretation can enhance appreciation of geoheritage resources in many ways, particularly by highlighting the connections between the scenery and underlying geology, and by delineating the relationships between bedrock geology and a protected area's flora, fauna and human history. Additionally, viewing rocks and landscapes from different perspectives and scales further enables the understanding of the value of geologic resources as integral parts of park environments. In many ways, effective communication, including interpretive programmes, allows the public to connect to the importance of geoheritage values within societies and communities at large and can foster a greater appreciation of its significance. This, in turn, can promote a conservation ethic towards geoheritage.

Interpretive planning is an initial step in the planning and design process for geosites and similar properties where interpretation is used to communicate messages, stories, information and experiences. It is a decision-making process that blends management needs and resource considerations with visitor needs and desires to determine the most effective way to communicate a message to a targeted audience. The goal is to relate content in a meaningful way to a visitor's own experience, provoking emotion, thought or further inquiry into a subject. Most interpretive plans are based on defining themes that are important to communicate to various audiences. Interpretive planning may also guide how audiences will react to and interact with a particular site or exhibit. This planning identifies and analyses interpretation, education and visitor experience goals and issues and recommends the most effective, efficient and practical ways to address them. The plan guides the further design and development of the project, becoming a resource for communication, outreach and fundraising. General details are provided in the IUCN WCPA Best Practice Guidelines on Tourism and Visitor Management (Leung, et al. 2018).

A good comparison of using geotourism as a complete contextual communication system in China and the United States is presented by Fang et al. (2013), who compared the interpretation systems of two global geoparks in China to those of Zion National Park in the USA. From lessons and experiences, this paper suggests utilising geotourism as a complete contextual communication system, in which staff of a geosite (the source) delivers information about its unique cultural and natural values to target tourists (the receivers) through tourism activities (the channels).

8.2 Education

Raising wider awareness and increasing involvement through education and interpretation are key parts of geoconservation. Telling the geological story of a protected area is the equivalent of telling people about a slice of Earth's history. It is typically fascinating and, prepared in an interesting way, can be compelling. One of the challenges is to make the story innovative and easy to understand, as geoheritage statements can be quite complex. The purpose should be to inform and entertain as well as to educate, as recognised in the far-sighted aspiration of James Hutton (1795) that study of the Earth 'may

Phone 8.1 Classical style interpretation: highly accessible with clear graphics and simple statements about the Burgess Shales and evolution of life in the Cambrian period. Yoho National Park, Canada. © Roger Crofts

Photo 8.2 A good way to show the relationship between the underlying rocks and the landscape is in a three-dimensional model. Berne Natural History Museum, Switzerland. © Roger Crofts

Photo 8.3 Another method to improve understanding by visitors is to annotate photos of rock faces with easily understood information, as here in the Canadian Rockies. © Roger Crofts

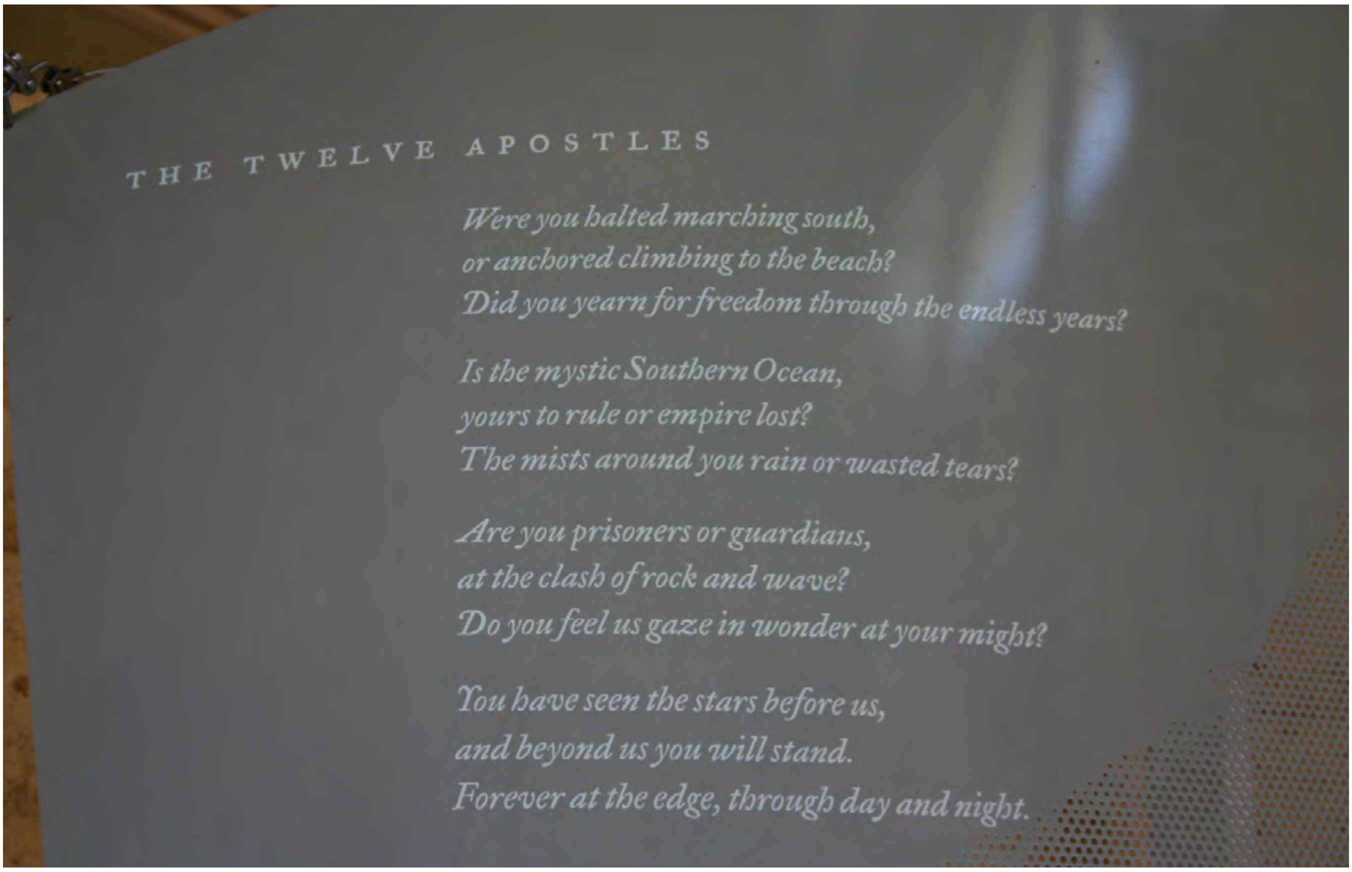


Photo 8.4 Using poetry can help to stimulate interest and to evoke reaction to the landscape. Poem at the Twelve Apostles Marine National Park, Victoria, Australia. © Roger Crofts

Photos 8.5 and 8.6 Elaborate and costly interpretation centres of geoheritage are unnecessary. It is cheaper and more effective to tell the story simply in an outdoor facility as at the Bogong National Park, Victoria, Australia. © Roger Crofts

afford the human mind both information and entertainment'. Effective geoconservation will ultimately depend on better public awareness, understanding and support.

One of the biggest challenges is to communicate the immensity of geologic time to a non-technical audience. Torres Del Paine National Park, Chile, has prepared an interesting account of its extraordinary geology (http://www.parquetorresdelpaine.cl/en/patrimonio). The visitor centre provides panels with very clear explanations of the park's geology, supported by an outside display of actual rock types found in the park, mounted and presented for visitors to walk around and touch. It is the type of display that communicates the special geology of a special park well.

Interpretation of geodiversity through geotourism is not new, as demonstrated by the longstanding appeal of and cultural interest in show caves, glaciers, sacred mountains and other natural geological wonders. In the 18th and 19th centuries, people engaged with the physical landscape in an experiential way, and natural features, places and past events inspired a sense of wonder through connections with landscape, literature, poetry, art and tourism. Today, it is less important to possess knowledge than to be able to find it, select it and apply it – and do all this swiftly. The emphasis is on finding and using information to address issues and questions; teaching people how to think (IUCN, 2015).

A relevant example of an excellent geoheritage education programme is one developed in the USA by the US National Park Service that is focused on palaeontology – National Fossil Day in October of each year. Since establishing the day as part of Earth Science Week in 2010, a partnership has grown steadily to include over 360 partners across the USA in every state. These partners are able to provide local fossil education and outreach to children, families, schools and other interest groups. Although much of the partnership is dedicated to getting children further interested in the fossil record, there is also outreach to other target populations, and over 100,000 Junior Palaeontologist booklets have been distributed.

8.3 Public outreach

Although all communication and education could be considered 'public outreach', in this section the term means reaching out to communities, tourist businesses, and stakeholders who may have influence or vested interests in preserving the site, but may have little or no understanding of geodiversity. Protected areas, by definition, imply that uses which undermine the conservation goals will not be allowed. Therefore, a protected area's outreach to local communities and other regional stakeholders is often paramount to getting political officials and competing local economic interests supportive of conservation goals.

An excellent example of public outreach, at the global level, is the IUCN Commission on Education and Communication; many of its programmes provide valuable examples for public outreach related to geoheritage. The material provides elements often absent in scientific research and conservation policy: how best to communicate, how to motivate action through behavioural science and how to have your message heard in a noisy world.

A more local example is provided by the Geological Society of Spain (SGE) which organises a nationwide public outreach activity every June 5: *Geolodía,* or the Day of Geology. Geolodía is an initiative for public outreach and environmental education based on geoheritage interpretation and the explanation of geological processes in nature. *Geolodía* was born as a result of an analysis which showed that the public's understanding of geology is inadequate. Participation has increased since the first time the event was organised in 2005. The event mainly consists of field trips guided by geologists. The SGE, an IUCN Member, decided in 2010 to make *Geolodía* a national initiative after several years of success at the local level.

Best Practice Guideline No. 20: Determine the nature and characteristics of the target audience in designing effective public outreach on geoconservation.

Photo 8.7 Even experts need an expert guide. Yellowstone National Park, USA members of the IUCN WCPA Global Steering Committee being briefed by a US National Park Service geologist. © Roger Crofts

Photo 8.8 and 8.9 Getting over the immensity of geological time is not easy. Two methods used at the Knockan Crag National Nature Reserve, Scotland are shown. The upper photo shows upside down rocks where the older rocks above younger ones. © Roger Crofts. In the lower photo, the user turns a handle to show how one part of the Earth's crust, Scotland, has moved over time from the southern to the northern hemisphere. © Roger Crofts

Box 8.1
Joggins Fossil Cliffs, Canada

A fine case study of education and interpretation is the Joggins Fossil Cliffs, a World Heritage site located on the Bay of Fundy in Nova Scotia, Canada (see Photo 1.2). Joggins Fossil Cliffs have been described as the ‘Coal Age Galápagos’ due to their wealth of fossils from the Carboniferous period (354 to 290 million years ago). The rocks of this site are considered to be iconic for this period of the history of Earth and are the world’s thickest and most comprehensive record of the Pennsylvanian strata (dating back 318 to 303 million years), with the most complete known fossil record of terrestrial life from that time.

Photo 8.10 Quoting eminent authorities who have visited a site in the past can be helpful. At Joggins Fossil Cliffs and World Heritage Site, visits by Lyell, one of the most eminent geologists of the mid nineteenth, and Darwin, have been used effectively in the visitor centre. © Roger Crofts

The local economic development association and three levels of government have collaborated to establish the Joggins Fossil Institute to present, promote and manage the cliffs through a state-of-the-art research and interpretive centre. The institute has addressed challenges in communicating volumes of often complex scientific knowledge to varied audiences in a short period of time. In collaboration with various stakeholders and concurrent with the application for World Heritage site status, interpretive planning and design were conducted to define the approach to telling the story of the natural and cultural history at Joggins. Interpretive planning promoted free-choice learning through varied delivery mechanisms that support individuals in developing their own conclusions. The institute has developed educational materials that permit the teaching of science in a way that prepares lay people not only to understand geology but also to approach it critically. Ongoing research at the new Joggins Fossil Centre further supports visitors in appreciating the degree of uncertainty in palaeontology and engages them in the scientific method. Scientists, educators, designers and lay people provided validation of the messaging and approach in communicating the significance of the Joggins Fossil Cliffs in innovative, engaging and even fun ways (Boon and Calder, 2008).

Photo 8.11 An easy to understand display of the formation of the fossil trees at Joggins Fossil Cliffs. © Roger Crofts

Box 8.2

Promoting education and training: An online course on global geoparks

A new online course has been developed at the University of Minho in Portugal (https://cursosonline.uminho.pt/EN/geoparquesed2/) to help protected areas' staff in UNESCO global geoparks to meet the need for more education about their principles and strategies. It is addressed both to those intending to be involved in geopark projects and a more general audience. . The four-week course comprises four modules: (1) general geopark concepts; (2) structures and strategies of geoparks; (3) geoparks as tools for sustainable development; and (4) UNESCO's International Geoscience and Geoparks Programme. The university awards a diploma for those who complete the course. The first edition of the course was held in Portuguese in April 2016, with 23 students from different countries (Argentina, Brazil, Chile, Ecuador, Italy, Mexico, and Portugal). In order to increase the number of potential students, English editions of the course began in October 2016. The online course is an efficient way to guarantee high-quality education for people who are interested in working in global geoparks and also to promote lifelong training of existing geopark staff, with the flexibility of studying from anywhere and at any time over the Internet.

8.4 Communication by new digital media

The audiences for communication range from the general public, for whom an all-inclusive approach to interpretation is needed; to groups of learners at various levels, for whom a more focused approach with educational objectives is required; to the community and stakeholder target groups for public outreach listed above (Section 8.3), for whom an even more focused approach is called for. This sub-section on digital media and the next sub-section on traditional media describe in more detail tools available for reaching all of these audiences.

Mobile apps

Mobile apps – software applications developed specifically for use on small, wireless computing devices – are particularly effective at communicating geoheritage. For example, many parks in the US national park system have developed mobile apps to assist and educate visitors through the USNPS Centre for Interpretive Media (US National Park Service, 2019). Mobile apps are also now playing a role in extending the reach of protected areas by connecting virtual-only visitors to learning material.

There is room for new ideas and growth in the utility of mobile apps applied to geoheritage values. For example, an app can link to ranger-developed content, such as narrative driving instructions that lead visitors to areas of interest. The app can also lead to additional content at the particular sites of interest in the protected area. The overall goal would be to have a virtual ranger-guide speaking to app users and linking them to more content if they are interested in going further.

Other digital approaches to communication

Digital tools have revolutionised science, and are driving new approaches to geoheritage and geotourism. Geoinformation, geovisualisation, digital monitoring and GIS systems have played an important role in the development of new methods of assessment and mapping, as well as aiding the development of geosites for tourism and education. Digital media have revolutionised direct interaction between an institution and its worldwide base of users. The June 2014 volume of *Geoheritage* was a special issue on 'New Digital Technologies Applied to the Management of Geoheritage' (Cayla et al., 2014). With respect to digital depiction, there is consideration of georeferencing and mapping of geoheritage, 3D digital imaging (including photogrammetry and laser scanning) and experiments in the promotion of geoheritage using augmented reality (a process which enriches discovery through digital media, or provides a virtual reality with which one can engage). Mountain and karst cave systems are used as case studies. Web mapping methods and techniques for geoheritage assessment and promotion are presented, using the web mapping application Google Maps API for disseminating geosite inventories established in Switzerland at both national and regional scales.

In another case study, four volcanic geosites in the Czech Republic were selected to showcase new technologies for communicating the recent results of scientific research to a wider non-professional public. The results from each volcanic site were summarised and transformed into images used for the 3D animation. The same sources used for 3D animations were also used for generation of virtual models of augmented reality. The outcomes were tested on school children, and the results indicate that the modern methods applied in popularisation of volcanic geoheritage are highly attractive (Rapprich et al., 2017).

Google's Street View is a rich resource for exploring geoheritage, since it visually transports us to many impressive sites across the country and around the world. Street View allows you to investigate a site, even one you do not know well, which can lead to important insights. The real power and fun of Street View is that it allows you to explore by moving your visual perspective around the image; very useful instructions for the application of this tool to geoheritage can be found at: (http://www.earthsciweek.org/classroom-activities/geoheritage-google-street-view).

The advent and rapid manifestation of social media and Internet communications have revolutionised the dissemination of information, including information on geoheritage and geoconservation, as well as the ability of people to correspond and connect. One-to-one, one-to-many and many-to-many communication has never been easier, from hyper-local to global scales. The public is no longer reliant on receiving news and information from traditional mass media sources.

Photo 8.12 Control room at Yuntaishan Global Geopark, Henan, China. Logging all activity in the protected area and other information. © Dan Tormey

Photo 8.13 and **8.14** Placing signs at viewpoints and on trails, provided it is done discretely, provides added benefit to users as shown in the two photos. Kosciuszko National Park, New South Wales, Australia and Mount Baker National Park [inset top right], Washington State, USA (right). © Roger Crofts

Best Practice Guideline No. 21: Include interpretative planning, off-site environmental education outreach programmes and web-based or mobile app-assisted interpretation for geoconservation protected areas to attract visitors, improve understanding of geoconservation and to enhance the visitor experience

8.5 Communication by conventional media

The conventional news media (print, television, radio) will be vital in reaching a larger audience, but there is often much more work to be done communicating geoheritage to the public and key stakeholders well before you provide any information to the media (Cohen, 2015). In relation to conventional media, it is important to first inform those people or groups who feel directly affected by anything being done or said. This means that key stakeholders should not be reading about plans for the first time in a newspaper without having prior knowledge. This requires a broader communication plan that identifies objectives and communication actions, whereby the media is but one element in the communication process – and not the first, and certainly not the only, one.

Protected area managers use the media to reach a wide audience with messages and information that support management objectives either by creating awareness and understanding of the rationale behind actions, or to achieve compliance and cooperation from the public because they understand and support the goals. The mass media is very important to how conservation messages and the agency's reputation are managed and received in the wider world.

The media will play an important role in building the case or argument on a subject of importance to the management of protected areas. It might be about fire or pest management or issues related to visitor access, but a carefully considered media plan can be very helpful in swinging public opinion in the direction needed. The aim is to find situations and circumstances related directly to the issue and promote them in the media over an extended period in a way that continues to validate and strengthen your argument.

Take the example of geohazard communication and restricting access to protected areas. Geological processes result in earthquakes, volcanic eruptions, tsunamis and other geological hazards that can affect access to protected areas. To emphasise and promote the agency's commitment to safe enjoyment of the area, key messages should be prepared supported by updated facts and figures, video, photos and a solid social media presence wherever possible. This transforms the negative aspect of restriction to a positive aspect of interpretation, education and appreciation of the natural forces protected as geoheritage.

Best Practice Guideline No. 22: Use a variety of conventional media to inform the public about geoconservation.

Some general principles for geoheritage interpretation and education in given in Table 8.1.

Table 8.1. Some general principles of geoheritage interpretation and education.

1.	Build interpretive planning into the design of geoconservation protected areas.
2.	Avoid complex geoscience terminology and favour using everyday language, and make it informative, interesting and entertaining.
3.	Design interpretation around the user's capacity to understand the complexity of Earth history and processes that are represented in a protected area.
4.	Enhance understanding by linking what people see to the underlying rocks and structures.
5.	Enhance connections by linking rocks and soils in the protected area to the overlying flora nd surface cover.
6.	Provide easy-to-understand descriptions of the origins of geoheritage features in the protected area.
7.	Provide information giving the Earth history context of the area to enhance understanding of the natural forces that have been formative in its evolution.
8.	Provide visual perspectives of landscape and what lies underneath at different scales.
9.	Provide connections between geoheritage in the protected area and human cultural and economic history.

Overview

9

Integrated approaches to protected area management illustrated in Hohe Tauern National Park, Austria. Spectacular scenery of the Grossglockner, the highest mountain in Austria, scientific interest in glacier retreat due to climate change on the Pasterze Glacier, providing facilities for visitors to enjoy the area and learn about it, and opportunity to climb the mountain and visit the glacier. © John Gordon

This Best Practice Guideline on geoconservation in protected and conserved areas sets out the reasons for protection, how to establish a system, how to develop management, how to deal with threats from natural and human causes, and how to communicate with the public. It is the first IUCN guideline on this subject, following the broadening of the definition of a protected area in the revised *Guidelines for Applying Protected Area Management Categories* (Dudley, 2008) to include all of nature by embracing abiotic elements.

Geoconservation has been increasingly recognised as an important component of protected and conserved area establishment and management, particularly through resolutions at successive IUCN World Conservation Congresses, through the development of the UNESCO Global Geoparks programme and action on the ground. Although lacking an international convention akin to the Convention on Biological Diversity to give it formal recognition, the Digne Declaration (quoted in Section 2) is the nearest best thing. The establishment and work of the IUCN WCPA Geoheritage Specialist Group provides a central point of reference and a body of expertise for all involved in protected areas to use. That expertise is the basis of the material in this guideline

The guideline presents approaches that may be unfamiliar to protected areas staff and their specialist advisers. Hence, we have provided a detailed contextual introduction on geoconservation in Sections 2 and 3, which we hope will improve understanding and everyone will read. We have also provided a glossary of terms to help the reader understand the often complex terminology and concepts.

The starting point for geoconservation in protected and conserved areas should be recognition that, while geoheritage seems eternal and immutable, this is definitely not the case. Geoheritage can be damaged in many ways by human carelessness, as we set out in Section 6, for example vandalised to remove fossils or other valuable components, or inadvertently destroyed by quarrying for roads or other construction. It can also be naturally fragile because of the materials it is made of, such as easily erodible soils and lavas, changing river courses and changes in sea level, and the now ever-present effects of global climate change.

The consequence of these changes and threats means that geoheritage requires active management based on sound knowledge and in the context of effective management planning, monitoring and evaluation.

As we describe, there is a robust theoretical and practical framework for geoconservation in protected and conserved areas. To date, it has not always been recognised as an essential part of protected and conserved area establishment and management. This guideline seeks to bridge that gap by helping managers, staff and their advisers to readily access this large body of work in a systematic way throughout their conservation efforts.

Geoconservation is important in its own right. There are many sites around the world where it is and can be the sole or primary propose of a protected or conserved area. It takes on perhaps even greater importance when its links to biodiversity conservation are recognised and acted upon. That is why we repeatedly emphasise the integration of biodiversity and geodiversity conservation planning and management in protected and conserved areas. The evolving concept of geodiversity as 'nature's stage', underpinning many biological process and functions and its application in practical management, will help further to bring together the two components of bio- and geo- conservation. This is classically the case of the whole, i.e. all of nature in a protected or conserved area, being greater than the sum of its individual parts. In other words, it emphasises the vital importance of protecting and managing ecosystem functionality in its entirety.

For much of human history, the dominant values attributed to what is currently considered geoheritage have basically been cultural and spiritual. This is also the case with use values related to extracted materials, such as rocks, minerals or precious stones. Hence, the importance we attach to this linkage in our description of values and in the practical management in Section 5.

There is a great deal of available expertise on geoconservation. It is increasing all the time, as the articles in the journal *Geoheritage* and the increasing importance of geoconservation in the work of professional geological and geomorphological bodies, such as the International Union of Geological Sciences and the International Association of Geomorphologists, testify. Within IUCN WCPA, the size and expertise of the Geoheritage Specialist Group is expanding as a source of advice and guidance to colleagues within the Commission, as well as a source of geoconservation contacts to others working within the IUCN family.

Geoconservation approaches are systematic in their rationale and their application, as we hope that the foregoing sections of this guideline demonstrate. It means that a systematic management approach is not only called for, but is relatively straightforward to implement. As we have suggested, you, the reader, are not on your own given the wealth of expertise around. Most experts are likely to be willing to help and offer advice, so this should be a cost neutral engagement.

The approach to geoconservation in protected areas is different from the biological conservation norm. For example, geological timescales can be very long, and effective management requires recognising that some features and/or processes dating to many hundreds of millions of years ago are important in their own right. Protecting special sites that demonstrate how the Earth has evolved is, therefore, an important component of geoconservation. A well-known phrase in geology: 'the past is the key to the present', means that learning from the past is relevant to understanding the evolution of landscapes and ecosystems today. Another difference is that fragile features might need to be covered over to protect them from human interference, but maintaining the ability to exhume them for scientific purposes at an appropriate time in the future. In a rapidly changing natural world, it is also important to protect modern processes and the features they create. This dynamic element provides a 'living laboratory' and necessitates an active, rather than a strictly protective, approach to the management of sites. It may require making space for natural processes to evolve by expanding the size of sites or designating new ones, rather than attempting to fix and control them. With changing climate, preservation of specific abiotic and biotic nature may not be possible, so that an adaptive approach is essential, allowing for evolution of the system and the building of resilience within it.

If protected areas managers stop at the management stage of the process, they miss a very important element: communicating geoheritage and its conservation. We recognise that this is a major challenge because the language is all too often obscure, the geological features may be of too great a scale for easy comprehension, and specialists are not always good communicators to the general public and even to protected areas' colleagues. Using modern communications approaches, as we set out in Section 8, is the way forward. Also vital is the use of able communicators to be interpreters and storytellers of the natural landscape. They may not be experts in geoconservation, but will be adept at demystifying the science and putting the listener within the scene.

Throughout this publication we have set out Best Practice Guidelines. They are deliberately phrased as 'must dos' and are listed in the Executive Summary.

Glossary

Italicised words in the definitions refer to items elsewhere in the Glossary.

Active processes: natural abiotic processes that are active in the formation and evolution of landforms and materials, such as deposition of sand along the coast, deposition of sands and gravels at the margins of glaciers and ice caps, volcanic eruptions, landslides and erosion.

Active systems: features and forms, such as sand dunes, river valleys, mangroves and soils, that are still developing and evolving due to natural processes.

Beach nourishment: the artificial supply of material, usually sand, to a beach from another source, often offshore, to help to maintain the stability of the beach and reduce erosion of the coastline.

Cambrian Explosion: period of geological time (see *Geological timescale*) when a major increase in species was recorded in the rocks of that age.

Carbonate rocks: See *Rocks.*

Catchment: the whole area of a river system from its source to its mouth, including all of its of tributaries and the land between the water courses.

Cirque: a large amphitheatre-like form at the head of a mountain valley formed by glacial erosion and the action of frost and the consequent failure of the adjacent rock walls.

Coastal cells: a unit of subdivision of the coast where the sediment circulates within fixed boundaries, usually defined by headlands.

Conserving nature's stage: a relatively modern concept based on flora and fauna being the 'actors' with geodiversity as the 'stage' on which they thrive. It underlines the importance of the interdependence between biodiversity and geodiversity and their coordinated conservation.

Crystals: a homogeneous solid with naturally formed plane faces. Minerals may present crystals of various sizes and geometric shapes.

Crystalline rocks: old term referring to rocks comprising crystals formed by slow cooling after being subject to intense heat and/or pressure. They can be either *metamorphic rocks*, such as *gneiss*, or *igneous rocks*, such as *granite* (see definitions of the specific rock types in this glossary).

Deposition: (a) the dropping of particles due to gravity that were being carried by water, ice or wind**;** (b) precipitation of a mineral from a solution.

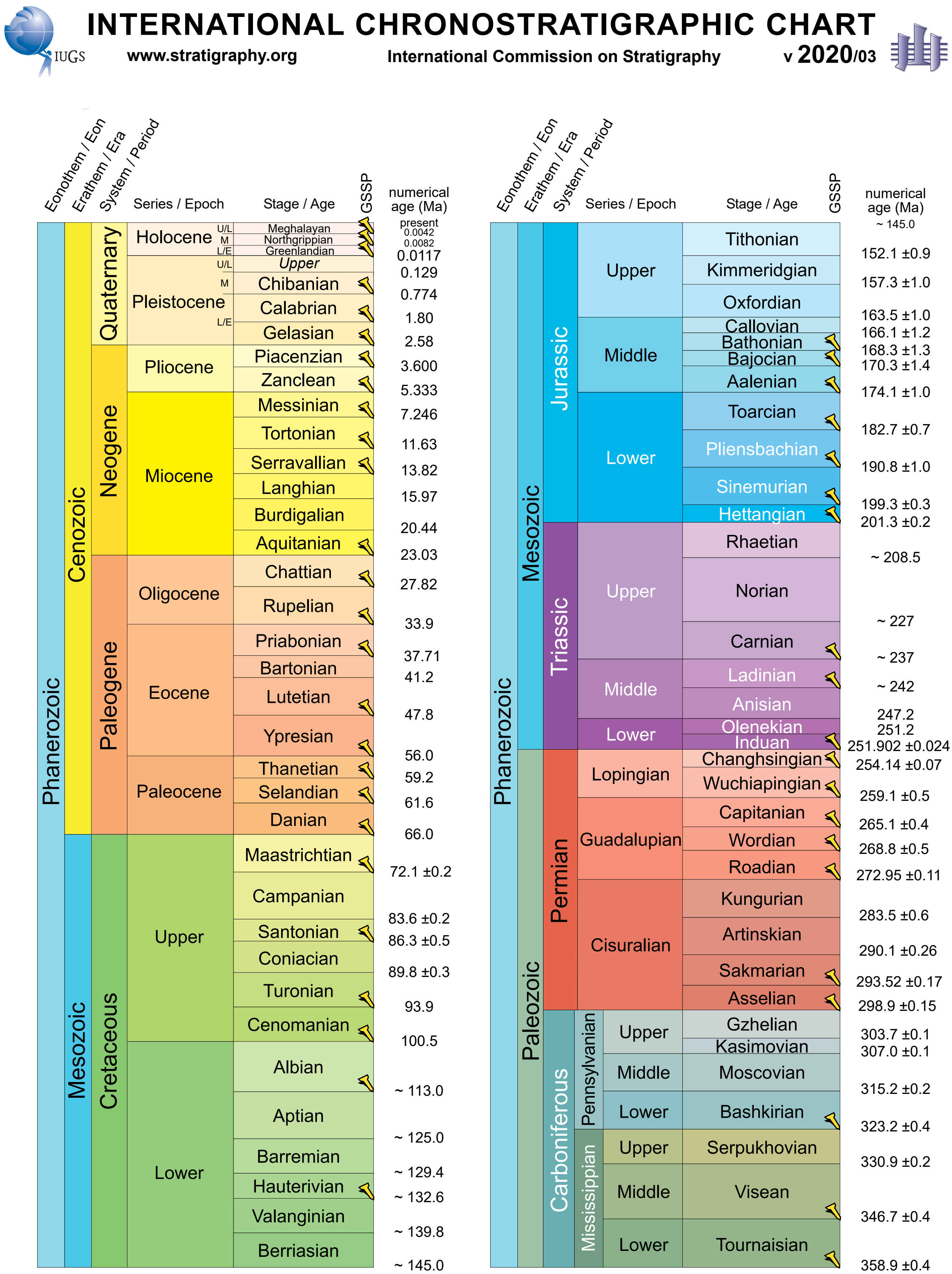
Devonian: see *Geological timescale.*

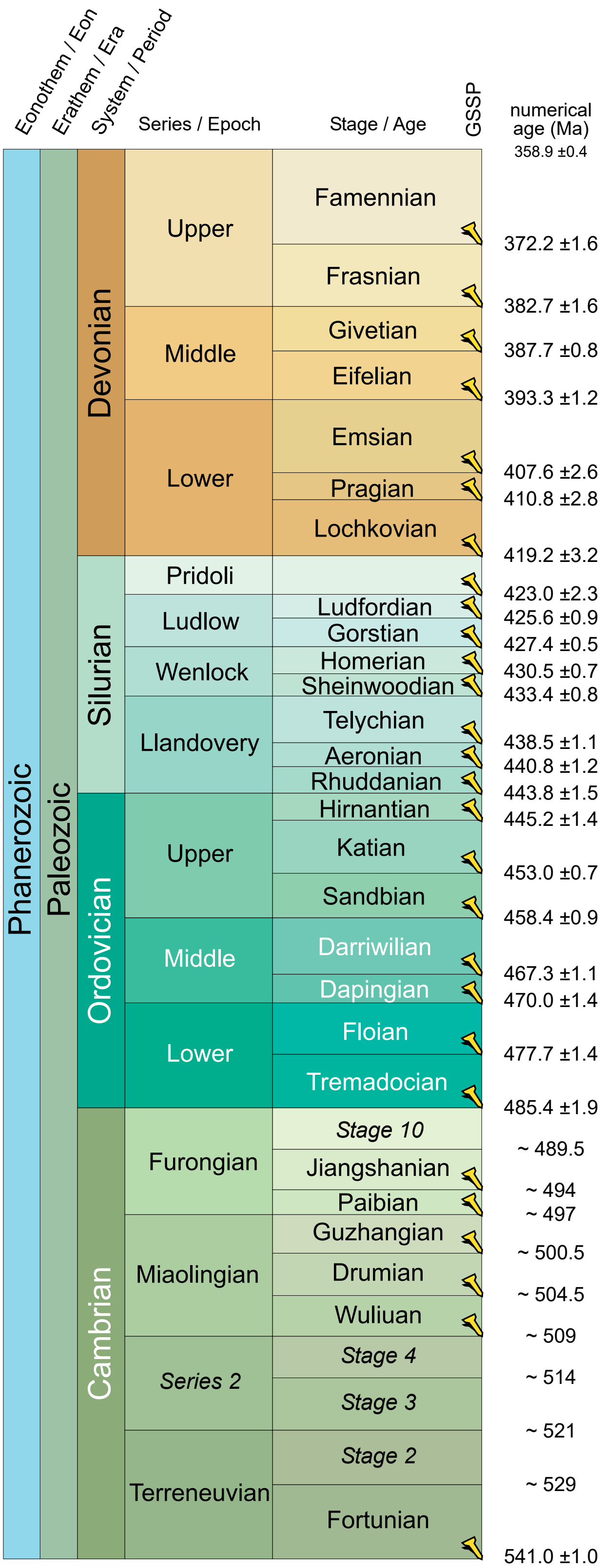
Dissolution: dissolving of minerals and rocks in natural waters.

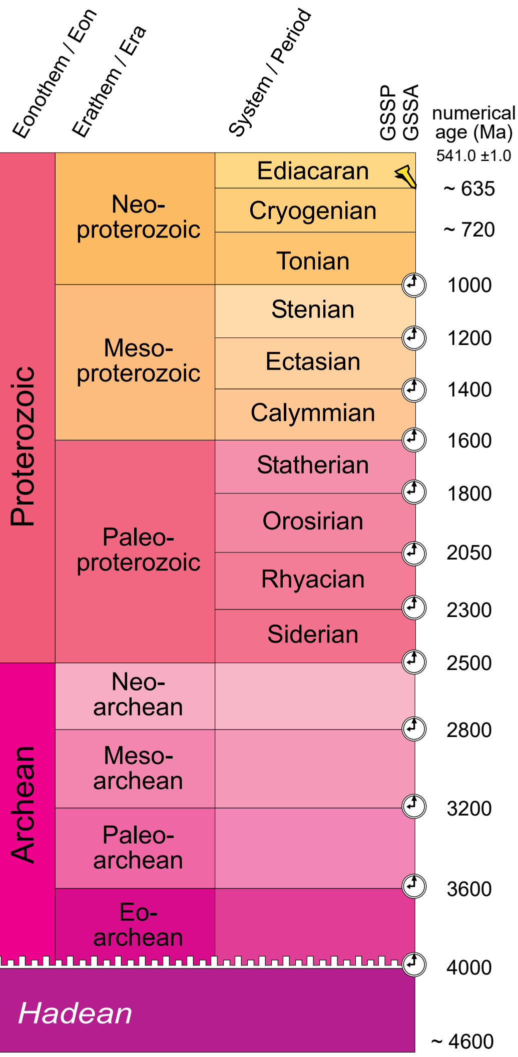
Doline: an enclosed depression of moderate dimensions (<1km wide or deep) that is the fundamental unit of relief in many *karst* t*errains* and serves a similar hydrological function to a catchment. The term 'sinkhole' is commonly used as a synonym for a doline.

Dynamic landforms: landforms constantly evolving or on the move, such as sand dunes in deserts and along sea coasts, or features such as sand and gravel bars in river beds, and unstable surface materials of soil and rocks on steep mountain slopes.

Earthquake: sudden violent shaking of the ground, typically causing great destruction, as a result of movements within the earth's crust or due to explosive volcanic processes.


INTERNATIONAL CHRONOSTRATIGRAPHIC CHART
IUGS
www.stratigraphy.org
International Commission on Stratigraphy
v 2020/03
Eonothem / Eon
Erathem / Era
System / Period
Series / Epoch
Stage / Age
GSSP
numerical age (Ma)
Phanerozoic
Cenozoic
Quaternary
Holocene
U/L
M
L/E
Meghalayan
Northgrippian
Greenlandian
present
0.0042
0.0082
0.0117
Pleistocene
Upper
0.129
Chibanian
0.774
Calabrian
1.80
Gelasian
2.58
Neogene
Pliocene
Piacenzian
3.600
Zanclean
5.333
Miocene
Messinian
7.246
Tortonian
11.63
Serravallian
13.82
Langhian
15.97
Burdigalian
20.44
Aquitanian
23.03
Paleogene
Oligocene
Chattian
27.82
Rupelian
33.9
Eocene
Priabonian
37.71
Bartonian
41.2
Lutetian
47.8
Ypresian
56.0
Paleocene
Thanetian
59.2
Selandian
61.6
Danian
66.0
Mesozoic
Cretaceous
Upper
Maastrichtian
72.1 ±0.2
Campanian
83.6 ±0.2
Santonian
86.3 ±0.5
Coniacian
89.8 ±0.3
Turonian
93.9
Cenomanian
100.5
Lower
Albian
~ 113.0
Aptian
~ 125.0
Barremian
~ 129.4
Hauterivian
~ 132.6
Valanginian
~ 139.8
Berriasian
~ 145.0
Phanerozoic
Mesozoic
Jurassic
~ 145.0
Upper
Tithonian
152.1 ±0.9
Kimmeridgian
157.3 ±1.0
Oxfordian
163.5 ±1.0
Middle
Callovian
166.1 ±1.2
Bathonian
168.3 ±1.3
Bajocian
170.3 ±1.4
Aalenian
174.1 ±1.0
Lower
Toarcian
182.7 ±0.7
Pliensbachian
190.8 ±1.0
Sinemurian
199.3 ±0.3
Hettangian
201.3 ±0.2
Triassic
Upper
Rhaetian
~ 208.5
Norian
~ 227
Carnian
~ 237
Middle
Ladinian
~ 242
Anisian
247.2
Lower
Olenekian
251.2
Induan
251.902 ±0.024
Paleozoic
Permian
Lopingian
Changhsingian
254.14 ±0.07
Wuchiapingian
259.1 ±0.5
Guadalupian
Capitanian
265.1 ±0.4
Wordian
268.8 ±0.5
Roadian
272.95 ±0.11
Cisuralian
Kungurian
283.5 ±0.6
Artinskian
290.1 ±0.26
Sakmarian
293.52 ±0.17
Asselian
298.9 ±0.15
Carboniferous
Pennsylvanian
Upper
Gzhelian
303.7 ±0.1
Kasimovian
307.0 ±0.1
Middle
Moscovian
315.2 ±0.2
Lower
Bashkirian
323.2 ±0.4
Mississippian
Upper
Serpukhovian
330.9 ±0.2
Middle
Visean
346.7 ±0.4
Lower
Tournaisian
358.9 ±0.4





Units of all ranks are in the process of being defined by Global Boundary Stratotype Section and Points (GSSP) for their lower boundaries, including those of the Archean and Proterozoic, long defined by Global Standard Stratigraphic Ages (GSSA). Italic fonts indicate informal units and placeholders for unnamed units. Versioned charts and detailed information on ratified GSSPs are available at the website http://www.stratigraphy.org. The URL to this chart is found below.

Numerical ages are subject to revision and do not define units in the Phanerozoic and the Ediacaran; only GSSPs do. For boundaries in the Phanerozoic without ratified GSSPs or without constrained numerical ages, an approximate numerical age (~) is provided.

Ratified Subseries/Subepochs are abbreviated as U/L (Upper/Late), M (Middle) and L/E (Lower/Early). Numerical ages for all systems except Quaternary, upper Paleogene, Cretaceous, Triassic, Permian and Precambrian are taken from 'A Geologic Time Scale 2012' by Gradstein et al. (2012), those for the Quaternary, upper Paleogene, Cretaceous, Triassic, Permian and Precambrian were provided by the relevant ICS subcommissions.

Colouring follows the Commission for the Geological Map of the World (www.ccgm.org)

Chart drafted by K.M. Cohen, D.A.T. Harper, P.L. Gibbard, J.-X. Fan

To cite: Cohen, K.M., Finney, S.C., Gibbard, P.L. & Fan, J.-X. (2013; updated) The ICS International Chronostratigraphic Chart. Episodes 36: 199-204.

URL: http://www.stratigraphy.org/ICSchart/ChronostratChart2020-03.pdf

Ecosystems: a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit. It is the sum total of all the abiotic and biotic processes going on, such as biogeochemical cycles and primary production.

• *Ecosystem functioning*: the collective life activities of plants, animals and microbes and the effects these activities – feeding, growing, moving, excreting waste, etc. – have on the physical and chemical conditions of the environment.

• *Ecosystem services*: the benefits people obtain from ecosystems. These include provisioning services, such as food and water production; regulating services, such as flood and disease control; cultural services, such as spiritual, recreational and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth (Millennium Ecosystem Assessment, 2005).). Ecosystem services are provided by both geodiversity and biodiversity.

• *Ecosystem structure*: the biophysical architecture of an ecosystem; the composition and arrangement of all the living and non-living physical matter at a location.

Ediacaran period: see *Geological timescales.*

Environmental Impact Assessment (EIA): an analytical process undertaken prior to decisions being taken on development projects, in an effort to avoid unforeseen adverse consequences. The process involves identifying, predicting, evaluating and mitigating the natural, social and other relevant environmental effects of development proposals.

Epithermal activity: shallow-depth activity that is low in temperature and pressure, resulting in formation of mineral veins and ore deposits.

Erosion: wearing away of the land surface by natural forces, such as water, ice or wind.

Evaporite rocks: See *Rocks.*

Exposure: a site or place where rock or softer sediments are visible at the surface. Also known as *Outcrop.*

Exposure sites: geological features that are spatially extensive below ground level actively renewed by erosion or, so that if one site or exposure is lost, another could potentially be excavated nearby. They include exposures in active and disused quarries, coastal and river cliffs, road and rail cuttings, and natural rock outcrops.

Extinction: in a geological context, an event in the distant past when substantial numbers of existing species disappeared due to natural causes.

Extremophiles: species that can withstand extreme conditions, such as darkness in caves or very high temperatures associated with volcanic activity.

Finite sites: features of limited extent that will be depleted and damaged if any of the resource is removed or lost. Examples include geological sites with fossil-bearing rocks of limited extent or a mineral vein deposit.

Fluvial processes: natural terrestrial processes based on water movement, usually in rivers.

Fossil: an organic trace or remain of former living matter buried by natural processes and subsequently permanently preserved in rocks.

Fumaroles: a hot spring in a volcanic area emitting very hot water, steam and noxious gases.

Geoconservation: the conservation and management of geoheritage.

Geodiversity: the variety of rocks, minerals, fossils, landforms, sediments and soils, together with the natural processes that form and alter them. It includes past and present geological and geomorphological features and processes that record the history of the Earth and the evolution of life forms as represented in the geological record, including fossils of plants and animals and their habitats.

Geodiversity Action Plan: a plan that defines clear long-term aims and objectives, and sets out measurable short-term targets and actions, to conserve and enhance the geodiversity and geoheritage of a particular area. It also identifies staffing and financial resources necessary to achieve them. These plans can also assist the integration of geodiversity and geoheritage into the conservation management of different categories of protected area.

Geoheritage: those elements, features and processes of geodiversity, either singly or in combination, that are considered to have significant value for intrinsic, scientific, educational, cultural, spiritual, aesthetic, ecological or ecosystem reasons and therefore deserve conservation. Geoheritage constitutes a legacy from the past to be maintained in the present and passed on for the benefit of future generations. Geoheritage records the cumulative story of the Earth preserved in its rocks and landforms, as in the pages of a book. It is represented in special places (see *geosite*) and objects (geological specimens *in situ* and *ex situ* in museum collections) that are fundamental to our appreciation of the history of the Earth and the evolution of life.

Geology: the study of the Earth as a whole, its origin, structure, composition and history, and the nature of the processes that gave rise to its past and present states.

Geological timescale: a system of chronological dating of geological strata (*stratigraphy*). It is used by Earth scientists to describe the timing and relationships of events in the history of the Earth, measured in millions and multiples of millions of years.

Geomorphology: the study of the landforms and processes on and immediately below the surface of the Earth.

Geopark: a generic term ascribed by a nation or region to an area with outstanding geological heritage aimed at both conservation and promoting its use in a sustainable way. Most Geoparks are not protected areas but they may contain protected areas. See also *UNESCO Global Geopark.*

Geoscience: the study of the Earth's evolution and the current status of its abiotic aspects. The term comprises *geology*, *geomorphology,* geophysics, hydrology and physical geography.

Geosite: any site that has a single or a variety of geological or geomorphological features or processes worthy of protection on account of its scientific value. This is short-hand for terms such as 'geological sites' or 'geomorphological sites'.

Geomonitoring (or Site condition monitoring): monitoring of particular features and processes to ascertain the state of health of the component interests at a geosite or for a whole system.

Geosensitivity: See *Sensitivity.*

Geotourism: sustainable tourism based on the geological and geomorphological features and processes of an area. These range in scale from a specific site, such as a tourist cave, through to extensive areas with spectacular scenery.

Geyser: the ejection of superheated water and steam from underground sources in active or recently active volcanic regions.

Glaciation: a period of cold climate resulting in widespread expansion of ice sheets and mountain glaciers. Ice ages include intensely cold episodes (glacials) and alternate with warmer periods (interglacials) when there is a reduction of ice cover.

Glacier: snow compressed to form a solid of ice that moves with gravity. It takes various forms. *Ice caps and ice sheets* are extensive sheets of ice covering large areas such as Antarctica and Greenland, and can occur on a smaller scale as in Iceland and Svalbard. *Valley glaciers* fill pre-existing valleys and often enlarge them by steepening the sides, as in the Andes and the European Alps for example.

Gneiss: a metamorphic rock whose formation is caused by intense heat and pressure on pre-existing rocks.

Granite: a coarse grained igneous rock formed below the Earth's surface after the slow cooling of magma, forming minerals of which quartz and feldspar are dominants.

Groundwater: water stored in and flowing through rocks and sediments below the ground surface supplied by water infiltrating from the surface or through concentrated sources such as a sinking stream. During periods with no rainfall, surface waters are fed by groundwater.

GSSP (Global Boundary Stratotype Section and Point): a standard unit used in the identification of type sections and reference points to define the boundaries of the stages in the geological timescale according to internationally agreed standards. The International Commission on Stratigraphy, a commission of the International Union of Geological Sciences (IUGS), is working to reach international agreement on the definition of global standard units. The site where a GSSP is identified and approved is marked by a symbolic Golden Spike.

'Hard' engineering: the use of heavy engineering methods and techniques that ignore in part or whole the natural processes operating on a site or area and therefore create an unnatural situation. (Cf. *'soft' engineering*.)

Hydrological changes: changes in the speed and power of water flows in channels and over the ground surface causing changes in the distribution of unconsolidated materials downstream.

Hydrothermal phenomena: those occurring where geothermal activity reaches the ground surface in the form of superheated water and steam. They interact with volcanic materials to form features such as hot springs, *geysers*, mud pools and *fumaroles*.

Igneous rocks (or Magmatic rocks): see *Rocks.*

Infiltration: the process by which water enters and moves downwards through the soil.

Integrity sites: geomorphological sites that include both static (inactive) features, such as Pleistocene glacial landforms, and active features, such as those formed by river, coastal, karst and contemporary glacial processes.

Karst: suites of landforms, commonly including sinking streams, blind and dry valleys, closed depressions (termed *dolines* and larger flat-floored poljes), caves, formed largely as a product of *dissolution* acting on rocks that have a high solubility in natural waters.

Lahar: mudflow or debris flow composed of a slurry of *pyroclastic* material, rocky debris and water caused by a volcanic eruption . The material flows down from a volcano, typically along a river valley.

Lampenflora: algae, mosses and vascular plants that grow in artificial light in tourist caves.

Landforms: surface or underground features formed by a particular natural process, such as a glacial moraine or a sand dune or a cave.

Landscape scale: a wide-area conservation approach over a whole landscape, as opposed to that at the site level.

Lava: molten material flowing over the ground and into water from a volcano or vent in the Earth's surface. It solidifies on cooling into different shapes, such as described by the Hawai'ian terms aa (a blocky shape) and pahoehoe (a ropy shape).

Limestone: a *sedimentary rock* composed mainly of calcite and/or dolomite formed by the precipitation of non-organic material and accumulation of organic material in marine or, less frequently, freshwater environments. Tufa and travertine are examples of freshwater limestones.

Local Geodiversity Action Plans (LGAPs): plans that set out a framework, guiding principles and priorities to ensure conservation of geoheritage and the networks of geosites at a regional or local scale.

Magma chamber: a cauldron of molten rock below the Earth's surface containing materials that may reach the surface as molten materials, solids, or gases.

Managed realignment: a technique, usually applied to soft coasts of sands and other unconsolidated material, where the sea is allowed to penetrate further inshore through the removal of human-made structures, such as walls or embankments, and enabling the formation of saltmarshes that absorb wave energy. It is used to reinstate the coast to a more natural regime.

Metamorphic rocks: see *Rocks.*

Minerals: Inorganic substance with a characteristic chemical composition and an ordered arrangement of atoms, ions or molecules which occur by natural geological processes.

Mineralogy: the study of minerals – their origin, form and constituents.

Moraines: landforms at or near the margins of glaciers and ice sheets comprising unconsolidated sediments of all sizes, from clays to boulders. Terminal moraines occur at the front of a glacier, and lateral moraines at the sides.

Moveable geoheritage: fossils, minerals, and rocks with exceptional value moved to an *ex situ* location, for instance in museum collections, to improve their protection.

Nature-based Solutions: actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.

OECM (Other Effective Area-Based Conservation Measures): a geographically defined area other than a protected area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the *in situ* conservation of biodiversity with associated ecosystem functions and services and, where applicable, cultural, spiritual, socio-economic and other locally relevant values are also conserved.

Oolite: *limestone* formed of ooliths; spherical particles grown by accretion around a nucleus in deep water.

Outcrop: a place where rock is exposed at the surface and not covered with soil, vegetation or built structures.

Overland flow: the dispersed flow of water over the ground surface before it is concentrated in a channel

Palaeontology: the study of fossils of plants and animals providing knowledge about the origin and evolution of life on Earth and about ancient environments.

Parent material: source rock or sediment from which overlying material, especially soils, are derived.

Periglacial: describes the climate, natural processes and landforms in cold, non-glacial environments in mountain or polar regions. The main process is repeated freezing and thawing of the ground, resulting in the formation of ice-wedge polygons and patterned ground (sorted circles and stripes), the slow downslope movement of rock debris and the collapse of rock faces.

Permafrost: ground that is permanently frozen, occurring principally in the polar regions and on high mountains.

Permian: see *Geological timescale.*

Petrology: the study of all aspects of rocks, including mineral constituents, textures, structure and origins.

Plate tectonics: unifying theory combining continental drift, sea-floor spreading, seismic and volcanic activity, and crustal structures. The Earth's blocks of rocks on land and under the sea are formed into eight major and several minor internally rigid plates that are in motion relative to each other. The term also refers to the study of their relative movements over time in the formation of continents and oceans. The margins of the individual plates take various forms; the most important for terrestrial geoconservation are where the plates are colliding or where they are moving apart. Examples of the former are the margins between the Pacific and North American plates, the Pacific and the South American plates, the African and Eurasian plates, and the Indian and Eurasian plates, all of which have played a fundamental role in the evolution of major mountain systems and volcanic activity. In other places, the plates are separating; examples are best manifested on land in Iceland and under the sea along the Mid-Atlantic Ridge.

Pleistocene: see *Geological timescale.*

Pre-Cambrian: see *Geological timescale.*

Protected area: a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.

Pyroclasts: material blown into the atmosphere by volcanic activity, such as pumice, and ash, and eventually coming to rest on the Earth's surface.

Quartz: a silica mineral in *igneous, metamorphic* and *sedimentary rocks*. It is one of the most commonly occurring minerals on Earth and also the major constituent of sand in deserts and along coasts.

Quaternary: see *Geological timescale.*

Radon: a naturally occurring radioactive gas that **is** inert, colourless and odourless produced by the decay of thorium and uranium minerals in certain rocks.

Rift valley: an elongated trough bounded on both sides by faults, their movement causing the land surface to be lowered compared with the surrounding land. An example in the East African Rift Valley.

Robust: the ability of a geoheritage feature or process to withstand damage arising from natural causes or human intervention.

Rocks: solid matter in mineral or organic form, forming part of the Earth's crust. It is subdivided by its origins into three main types: *sedimentary, igneous,* and *metamorphic*.

Sedimentary rocks are formed from pre-existing material by soft materials (*sediments*) being deposited by water, ice or wind into rivers, lakes and oceans or onto the ground surface, and subsequently transformed to form more solid material. *Carbonate* rocks, such as *limestone*, dolostone, and the *evaporite* rocks, such as gypsum, anhydrite and salt, are particular types of sedimentary rocks found in karst areas. *Limestones*, sandstones and mudstones are common examples of sedimentary rocks.

Igneous or *Magmatic rocks* result from the slow solidification of magma below the Earth's surface and are called *intrusive* rocks (i.e. *granite*). These rocks can also be formed on the surface due to lava cooling associated with volcanic activity and are called *extrusive* rocks (i.e. basalt).

Metamorphic rocks are rocks previously formed by sedimentary or igneous processes that have been changed into different minerals and structure as a result of heat and/or pressure often associated with the movement of tectonic plates or in contact with magma. For example, marble is metamorphosed limestone.

Sediment: soft unconsolidated material, which range across a variety of sizes, from the finest clays and silts, through coarser sands and pebbles, to the coarsest boulders.

Sedimentary rocks: see *Rocks.*

Sensitivity: a measure of the susceptibility or robustness or fragility of a particular feature or a process to damage irrespective of whether it is natural or human induced, and the degree to which it is affected or will respond.

Seismic activity: earth movements noted on the ground resulting from tectonic and volcanic activities in the Earth's crust.

Significance: a comparative expression based on either specialness or rarity or of the best example of a feature or process.

Siliceous: substance where the principal component is silica (SiO_2).

Silurian: see *Geological timescale*.

Site Condition Monitoring: see *Geomonitoring.*

'Soft' engineering: the use of natural approaches, such as beach nourishment or dune regeneration, avoiding the construction of fixed structures (e.g. rock armouring), as opposed to *Hard engineering*.

Soft rock: a *rock* that is relatively easily eroded and weathered by water, ice or wind. Some sandstones are a good example.

Soil: material composed of mineral particles and organic remains that overlies the bedrock and supports growth of rooted plants.

Speleology: the scientific study of caves and their formation and processes.

Speleothems: a general term for all mineral deposits formed in caves. Most are formed of calcite and the precipitation process is the reverse of the *limestone dissolution* process. Common forms include dripstones (e.g. stalactites and stalagmites) and flowstones.

Strategic Environmental Assessment (SEA): a systematic decision-support process, aiming to ensure that environmental issues are considered effectively in policy, plan and programme making.

Stratigraphy: a branch of geology concerned with the form, arrangement, geographic distribution, chronologic succession and correlation of rock strata with sedimentary origin.

Terrane: an area of land where the rocks and structures are of a similar age and type and with a similar early geological history.

Tor: a free-standing rock tower formed *in situ* by weathering of the surrounding weaker rock and its removal downslope.

Tsunami: a series of large, fast-moving waves on the sea surface caused by earthquakes associated with movement at the margins of tectonic plates.

UNESCO Global Geopark: a territory recognised by UNESCO where sites and landscapes of international geological significance are managed within a holistic concept of protection, education and sustainable development. Geoparks are not considered protected areas, but rather as tools for engaging communities and business interests.

U-shaped valley: a glaciated valley with steep sides and a flattish floor formed by glacial erosion.

Unconformity: a discontinuity in the rocks indicating that a time lapse (which could involve many millions of years) between the lower and upper layers has occurred.

Value: the geoheritage value of a site or specimen has a number of components. *Intrinsic value* means important in itself independently of human appreciation. *Scientific value* relates to the value for research and education. *Aesthetic, cultural and spiritual values* refer to human connections, interactions and appreciation of geoheritage. *Ecological value* relates to supporting biodiversity and ecosystem functioning. The diversity of substrates, landform mosaics and soil formation, together with processes such as water flow regimes, sediment supply, erosion and deposition, provide the foundations for habitats and species and ecosystem functioning. *Environmental goods and ecosystem services* values relate to the direct and indirect benefits that people receive from the natural environment and properly functioning ecosystems.

Volcano: a constructional feature formed by material reaching the Earth's surface or on the sea bed through a naturally occurring vent or fracture at the Earth's surface supplied from deep inside the Earth. Materials erupting through the fractures or vents are either molten - *lava* (sometimes with entrained crystals), solid - *pyroclasts*, and gaseous - water vapour, acidic gases. Eruption styles range from slow and effusive to sudden and explosive. Large volcanoes are often called central volcanoes because of their size in a system or super volcanoes because of the eruptive power with pyroclastic material spread widely around the world through atmospheric circulation. Volcanoes are often, but not always, associated with the movements at the margin of tectonic plates. The chemical composition of the erupted material is highly variable and ranges from acidic to alkaline.

Vulnerability: a measure of the likelihood of damage to a geo feature or process from natural or human-induced causes. It is typically determined by considering by sensitivity to change and adaptive capacity to change.

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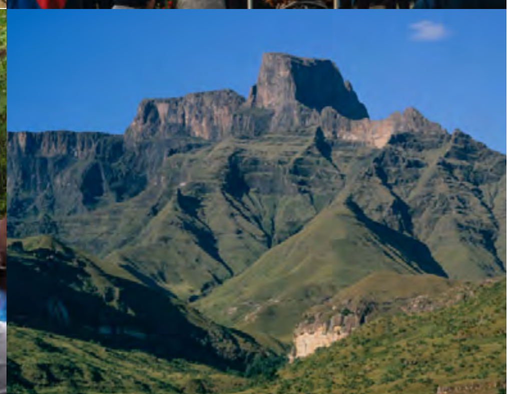

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