CHAPTER 18

GEOCONSERVATION IN PROTECTED AREAS

Principal authors:
Roger Crofts and John E. Gordon

Supporting author:
Vincent L. Santucci

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PRINCIPAL AUTHORS

ROGER CROFTS is an International Union for Conservation of Nature (IUCN) World Commission on Protected Areas (WCPA) Emeritus, was Founding CEO of Scottish Natural Heritage (1992–2002), WCPA Regional Vice-chair for Europe (2000–08), and is Chair of the Royal Scottish Geographical Society.

JOHN E. GORDON is a Deputy Chair of the WCPA Geoheritage Specialist Group, and an honorary professor in the School of Geography & Geosciences, University of St. Andrews, Scotland, United Kingdom.

SUPPORTING AUTHOR

VINCENT SANTUCCI is Senior Geologist and Palaeontologist with the US National Park Service, USA.

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TITLE PAGE PHOTO

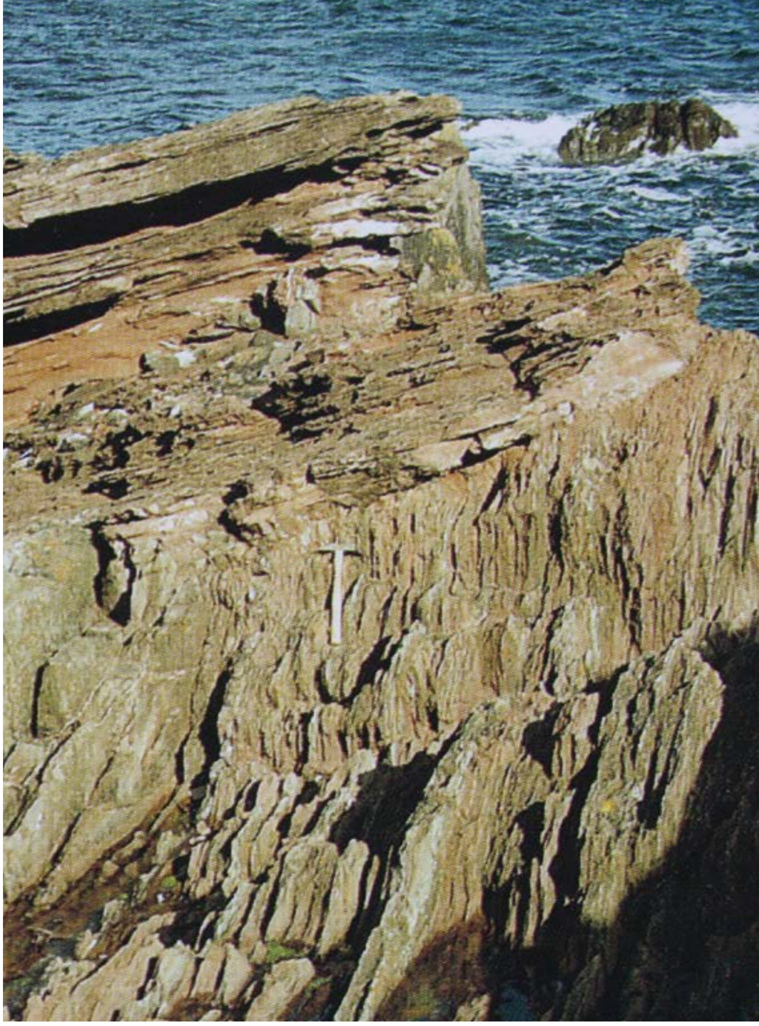
Old Faithful geyser and geothermal area, one of the outstanding geoheritage sites of the world, Yellowstone National Park and World Heritage property, USA
Source: Graeme L. Worboys

Introduction

The Earth is a dynamic planet with a remarkable geodiversity. The continental masses and oceans on the surface of the Earth have changed continuously over much of geological time. Oceans have opened and closed, and continents have fragmented and collided, accompanied by plutonic igneous activity, volcanism and large-scale crustal deformation. Earth's abiotic processes have operated both continuously and episodically over vastly different time scales, from hundreds of millions of years to minutes, and over different spatial scales, from whole continental plates to the microscopic. Mountain ranges have formed and been eroded, and the rock debris deposited and recycled. As the continents have changed and migrated across the surface of the globe and through different climatic zones, rocks have formed in many different environments. The history of life on Earth is also archived in the fossil record contained in these rocks. Long-term global climate change has influenced surface processes, leading to periodic 'icehouse' and 'hothouse' conditions. All of these processes and events have left a legacy in the rock record and have created the diversity of landscapes and landforms evident across the globe. Our geoheritage is the story of the Earth; a narrative through time preserved in its rocks, landforms, fossils, minerals and soils that provides a strong case for geoconservation.

The Earth's geodiversity contributes fundamentally to most of the ecosystem services recognised in the Millennium Ecosystem Assessment (MEA 2005). It provides the foundation for plants, animals and humans, and is a vital link between people, nature, landscapes and cultural heritage. It contributes to sustainable development and benefits public health through providing assets for outdoor recreation and enjoyment of the natural world. Knowledge and understanding of how the Earth works are also essential to informing management of the land, rivers and the coast at a time of great uncertainty about the effects of climate change and sea-level rise. It is vital, therefore, that geodiversity and geoheritage are fully integrated into the management of protected areas and accorded a level of importance equivalent to biodiversity as part of an ecosystem approach that recognises the value and integrity of both abiotic and biotic processes in nature conservation.

This reasoning has been accepted by the International Union for Conservation of Nature (IUCN) with the passing of Resolutions 4.040 at Barcelona (IUCN 2008) and 5.048 at Jeju, Korea (IUCN 2012), which both clearly state that geodiversity is part of nature and geoheritage is part of natural heritage.



Siccar Point, a Site of Special Scientific Interest, Scotland, United Kingdom, which conserves the historical site where James Hutton, the founder of modern geology, observed a huge gap of time in the rocks (an unconformity)
Source: Lorne Gill/Scottish Natural Heritage

A number of important definitions have been developed in recent years as the practice of geoconservation has evolved. The following definitions capture the key elements. For definitions in Spanish of all the key terms, see Carcavilla et al. (2012).

Geodiversity

Geodiversity is 'the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes) and soil and hydrological features. It includes their assemblages, structures, systems and contributions to landscapes' (Gray 2013:12).

'Geodiversity is the variety of rocks, minerals, fossils, landforms, sediments and soils, together with the natural processes which form and alter them' (Dudley 2008:66).

Geodiversity is a relatively recent term; its first use in English was in Tasmania, Australia (Sharples 1993; Gray 2008). Despite some initial resistance and concerns about the validity of implied parallels with biodiversity, the term is now widely accepted (Gray 2013). Geodiversity is the abiotic equivalent of biodiversity and therefore is a

The Tay Estuary, Scotland, United Kingdom, a Site of Special Scientific Interest and a Ramsar site. The river supplies sediment that maintains reed beds that in turn support important biodiversity interest and illustrates the links between geodiversity and biodiversity.
Source: Roger Crofts

Kvarken World Heritage Site, west Finland, where new land is emerging from the sea as a result of rebound (glacio-isostatic uplift) following the melting of the Scandinavian ice sheet, the weight of which had depressed the land surface
Source: UNESCO

natural complement to biodiversity rather than a separate and unassociated subject. It covers past and present Earth processes, embraces static features that have a range of ages and reflect the variety of processes during the Earth's history, and includes modern processes that significantly influence biodiversity. The relationship between geodiversity and geoheritage is discussed by Durán et al. (1998), Nieto (2001) and Carcavilla et al. (2008).

Geoheritage

Geoheritage comprises those elements of the Earth's geodiversity that are considered to have significant scientific, educational, cultural or aesthetic value (Díaz-Martínez 2011; GSA 2012). They include special places and objects (specimens *in situ* and in museums) that have a key role in our understanding of the abiotic and biotic evolution of the Earth (ProGEO 2011). A site or area of high geoheritage significance can comprise a single feature of value, and does not need to have a diversity of features present.

Geoconservation

Geoconservation has been defined as 'the conservation of geodiversity for its intrinsic, ecological and (geo)heritage values' (Sharples 2002:6).

A broader definition is 'action taken with the intent of conserving and enhancing geological, geomorphological and soil features and processes, sites and specimens, including associated promotional and awareness raising activities, and the recording and rescue of data or specimens from features and sites threatened with loss or damage' (Prosser 2013:568).

In some traditions, geology and geomorphology are considered to be separate but linked subjects; in others, geomorphology is part of geology. Regardless of which approach is followed, it is important to emphasise that both geology and geomorphology are explicitly included within geodiversity, geoheritage and geoconservation as defined above, and that the term 'geosites' can embrace both geological and geomorphological features. Sometimes 'geological diversity', 'geological heritage' and 'geological conservation' are used to include both geological and geomorphological interests. Thus, to avoid confusion, we strongly recommend use of geodiversity, geoheritage and geoconservation as defined above—that is, embracing both geological and geomorphological features.

This chapter provides protected area managers and staff with practical information and generic guidance on the role of geoconservation in protected areas. Emphasis is placed on both the importance of protecting geoheritage in its own right and the value of understanding the formative influence of geodiversity on flora and fauna at site, habitat, landscape, ecosystem and biome scales.

The chapter is in two sections. The first sets out the case for geoconservation in protected areas; and the second provides advice on the guiding principles of site assessment and conservation. Detailed guidance will be prepared as an IUCN World Commission on Protected Areas (WCPA) 'Best Practice Guideline on Geoheritage Site Conservation and Management'.

The need for geoconservation in protected areas

Geoheritage values

Many protected area managers and staff, and their advisers, will be familiar with the fundamental importance of biodiversity conservation. As this subject is the basis of the Convention on Biological Diversity (CBD) 1992, and has an associated program of work on protected areas, biodiversity conservation is seen by many as the *raison d'être* of protected areas and their management. The underlying rocks, sediments and soils, their evolution and the recent and current Earth processes to which they are subject are, however, also vital. Why?

Gray (2004) summarised the key values of geoconservation as: intrinsic, cultural, aesthetic, economic, functional, and for research and education. Generally, the emphasis has been on the value of geoheritage for scientific research and education, but there is now much greater awareness of the wider significance of geoconservation, especially in an ecosystems context (Gray 2013).

Many protected areas are designated because of their geoheritage values, including one of the world's first national parks: Yellowstone, USA. Some are global or regional type sites for critical stages in the history of the Earth and the marker horizons in rocks representing the boundaries between different geological periods. Others are examples of past geological processes representing major events in the evolution of the continents and oceans, such as the collision between the Indian and Eurasian tectonic plates to create the Himalaya and the Tibetan Plateau. Yet others are designated for their research significance, such as the inverted rock sequences resulting from tectonic plate collisions and the thrusting of older strata above younger strata, displayed, for example, in the Moine Thrust Zone in Scotland. Many are significant because their fossils exhibit key stages in the evolution of life on Earth, such as the Burgess Shale in Yoho and Kootenay National Parks, British Columbia, Canada. Others are significant for the type of minerals found there, reflecting complex geochemical evolution. And some are significant for their current geological processes such as tectonic plate separation in Iceland, or the development of glacial landforms on the Antarctic Peninsula.

Furthermore, many protected areas are designated because their geological and geomorphological features are visually and scenically dominant in the landscape, and quite often have an iconic significance in the cultural history of the area and the nation. The Golden Mountains of Altai in the Russian Federation, Bogd Khan Mountain in Mongolia and Triglav National Park in Slovenia are examples. Many components of geodiversity also have direct cultural significance, such as caves that preserve the paintings and inscriptions or other sacred values from earlier periods of human occupation.

Rock art at Royal Natal National Park, KwaZulu-Natal, South Africa, illustrating cultural associations with natural caves

Source: Roger Crofts

Geoheritage in protected areas can exist at a number of scales, from small individual features, such as wind-sculpted stones (ventifacts) in desert environments and rocks (erratics) transported long distances by glaciers, to whole mountain chains and large river basins. All scales are important, and geoconservation needs to take into account features and processes across the whole continuum, from site to landscape scale. But areas need not exhibit high geodiversity to qualify for protected area status. For example, a thick sequence of deep-water limestones may represent an important part of basin history and exhibit the evolution of life. The apparent low geodiversity in the rocks may hide a rich biodiversity that is not so evident to the naked eye, but is crucial as a type section or reference locality for a particular evolutionary phase or change.

Table 18.1 Principal human-induced threats to geoheritage in protected areas

Threats and pressures	Examples of impacts on geoheritage in protected areas
Urbanisation, construction (including commercial and industrial developments inland and on the coast), infrastructure, onshore wind farms and related activities	Destruction of landforms and exposures of sediments and rocks Fragmentation of site integrity and loss of relationships between features Disruption of geomorphological processes Changes to soil and water regimes; destruction of soils and soil structure
Mining and mineral extraction (including extraction from opencast mines, pits, quarries, dunes and beaches, riverbeds, 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, forestry)	Landform damage through ploughing, ground levelling and drainage Loss of landform and outcrop visibility and access to exposures Stabilisation of dynamic landforms (for example, sand dunes) Soil erosion Changes to soil chemistry and soil water regimes Soil compaction, 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 landforms and sediments Disruption of geomorphological processes Seabed and sub-seabed surface scour/penetration
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 (reactivation or stabilisation) Loss of key features, such as ice caps and glaciers, glacial lakes and outflows
Sea-level rise (anthropogenic causes)	Loss of visibility and access to coastal exposures and outcrops through submergence Loss of exposures through enhanced erosion Changes in coastal exposures and landforms Loss of all or substantial parts of protected areas New features developed from, for example, storm surges
Restoration of pits and quarries (including landfill)	Loss of exposures and natural landforms
Stabilisation of rock faces (for example, 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 record

Sources: Adapted from Gordon and Barron (2011); Brooks (2013); Gray (2013)

Threats to geoheritage

Often the argument is made that geoheritage does not need conservation in protected areas because it is unchanging and no evident threats from human activities can undermine the state or value of the features of interest. This is not correct. Many conservation disputes have centred on threats to geodiversity—for example, the dispute in Tasmania about hydro-electricity development at Lake Pedder (Houshold and Sharples 2008). In fact, the pressures and threats facing geoheritage are many and varied (Table 18.1), and may arise through economic drivers for development and changes in agriculture and forestry policy that affect land-use decisions. Those

River Clyde Meanders Site of Special Scientific Interest, Scotland, United Kingdom. Allowing rivers to flood naturally maintains floodplain processes and helps to mitigate flood impacts downstream.
Source: Patricia and Angus Macdonald/Scottish Natural Heritage

Vadehavet National Park, Jutland, Denmark. Vehicular access onto sand dunes can cause instability and loss of geoheritage interest
Source: Roger Crofts

features and forms that are static and apparently robust can easily be damaged or destroyed by urban, industrial, commercial and infrastructure developments, extractive industries, coastal defences, changes in land use, careless scientific activity, collectors of rocks, minerals and fossils, and visitor pressures. Significant damage and losses of key sites have occurred in the past and are ongoing (Gray 2013). Many features are relict or inactive, and therefore non-renewable, and once damaged or destroyed cannot be replaced. Other features are highly dynamic and maintaining the interest and the contribution they provide to conservation as a whole is vital—for example, the supply of sediment to maintain mudflats and saltmarshes for wintering bird populations. The need for protected areas for geoheritage and their effective management in the face of these human-induced threats cannot be overemphasised.

Features of geoheritage interest in protected areas typically occur as natural and human-made exposures, landforms and active geomorphological process systems. Some are therefore created and maintained by natural processes; others, by human activities such as quarrying. Prosser et al. (2006) consider the potential threats to different types of protected area. The principal impacts are physical damage, destruction or removal of the interest, loss of visibility or access to exposures through burial by landfill or concealment by vegetation, damage to site integrity through fragmentation of the interest and loss of relationships between features, and disruption of natural processes or the natural state. For example, exposures in disused quarries can be lost through landfill, prime glacial landforms can be destroyed by quarrying for sand and gravel, and key exposures can be sealed and natural processes disrupted by coastal protection measures and riverbank protection and flood defences. Mineral extraction can have positive and negative impacts. Quarries and gravel pits are a significant geological resource, particularly in areas where natural exposures are poor or scarce. Quarrying may reveal new sections of value, and many important sites are in former quarries where the geological interest would not otherwise have been exposed. Quarrying can, however, also pose a direct threat to particular landforms—for example, limestone quarrying may destroy parts of cave systems and limestone pavements. While there will tend to be a presumption against any new quarrying in protected areas that would damage intact landforms, in other cases the potential value of new sections—for example, in revealing the three-dimensional sedimentary architecture of an esker system—may need to be balanced against further loss of the landform integrity. In such cases, careful judgment has to be made to ensure the reasons for exposure are entirely compatible with the particular conservation objectives of the features. A range of agricultural activities may impact on geological sites and landforms. Landforms can be damaged by deep ploughing and land levelling, concealed beneath commercial afforestation and damaged by extraction haul roads. Soils are under pressure from land-use practices and contamination, intensification of agriculture, afforestation, waste disposal, acid deposition and urban expansion.

Conventional approaches to coastal and river protection from erosion and flooding typically involve large-scale ‘hard’ engineering, which seals key exposures behind

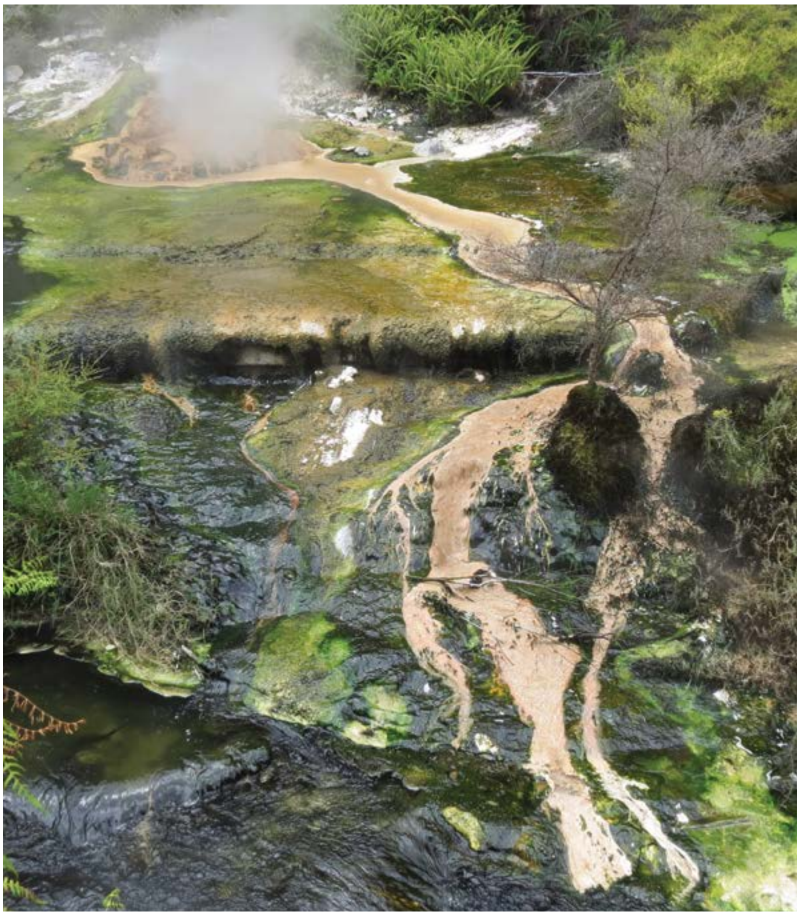
Aberdeen, Scotland, United Kingdom: examples of groynes and concrete seawalls that interrupt natural processes and cause problems down-drift

Source: Roger Crofts

concrete seawalls, rock armour or gabions. Natural processes of sediment supply and movement are disrupted, usually displacing the problem elsewhere. Hence, wider off-site impacts may also occur—for example, erosion down-drift of coastal defences. Other threats may arise from the effects of climate change and sea-level rise, and particularly the human responses (for example, in the form of 'hard' flood protection and coastal defences), especially on dynamic systems. These present particular management challenges that will require collaboration among governments, planners, decision-makers and local communities to ensure sustainable management of geodiversity as part of wider, long-term adaptation strategies to enable protection of ecosystem services (Prosser et al. 2010).

Pressures and threats in the marine environment include bottom fishing, aggregate extraction, oil and gas installations, renewable energy installations, cables and pipelines, navigational dredging, waste disposal and military activity. They have the potential to impact upon both geomorphological and geological features on the seabed (DEFRA 2010; Brooks 2013). Given the dynamic nature of the marine environment, all of these activities may have wider impacts through the interruption of existing sediment transport pathways and by altering sedimentation patterns and hydrodynamic processes.

Climate change has recently been recognised as an emerging issue for geoconservation (Prosser et al. 2010; Sharples 2011). It is likely that active geomorphological, hydrological and soil systems, in particular, will undergo major changes in response to climate change. These may include erosion or depositional burial of some older elements of geoheritage. While it will be possible to prevent loss of some specific geoheritage sites, at the broader landscape scale it is unlikely to be possible to prevent widespread process changes, and indeed the scale of intervention required to do so would compromise many other natural values. The most appropriate (and cost-effective) action at the landscape scale may be to allow active abiotic processes to adapt naturally to changed climate conditions.



Thermophilic plants represent biotic dependency on the hot chemical cocktail of Waimangu Volcanic Valley, Rotorua, New Zealand

Source: Roger Crofts

Links to biodiversity, ecosystem functions and services

Geoconservation in protected areas delivers many important contributions to biotic nature and to society. It supports landscape and biodiversity conservation, economic development, climate change adaptation, and sustainable management of land and water, historical and cultural heritage, and people's health and wellbeing (for example, Johansson 2000; Brilha 2002; Stace and Larwood 2006; Gordon et al. 2012; Gray et al. 2013). Perhaps most significantly, geodiversity underpins or delivers most of the ecosystem services identified in the Millennium Ecosystem Assessment (MEA 2005). It is a key component of supporting services, and contributes significantly to provisioning, regulating and cultural services (Figure 18.1). Without the contribution of geodiversity, many of the ecosystem services essential to supporting life on Earth would simply not exist or would require vastly more expensive technological alternatives—for example, provision of fresh water, regulation of water and air quality, and soil formation and nutrient cycling for food production. Geodiversity also provides additional, indispensable goods and services (for example, minerals, aggregates and fossil fuels) that are non-renewable capital assets, as well as substantial 'knowledge' benefits (for example, records of past climate changes, understanding of how Earth systems operate and ecosystem service trends).

At its simplest, geodiversity provides the foundation for life on Earth and for the diversity of species, habitats, ecosystems and landscapes. Most species depend on the abiotic 'stage' on which they exist (Anderson and Ferree 2010), not only rare or specialised ones (for example, those associated with limestone pavements or metallogenic soils), and there is a close connection between flora and fauna, the soil and the underlying rocks, and the topography and water and other nutrients on which they depend for growth and survival (for example, Semeniuk et al. 2011). Now that we concentrate much more on the continuing ecological health of ecosystems and their

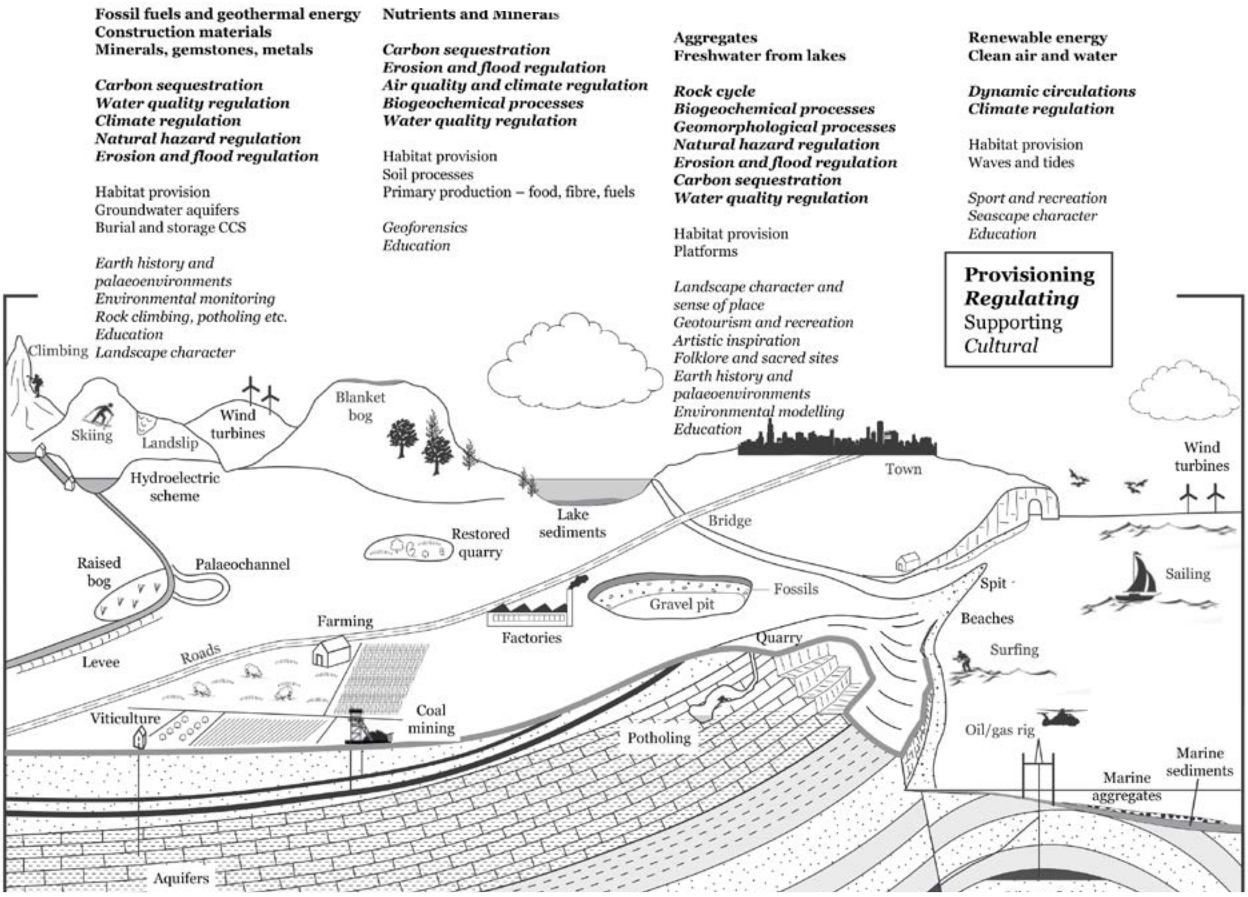
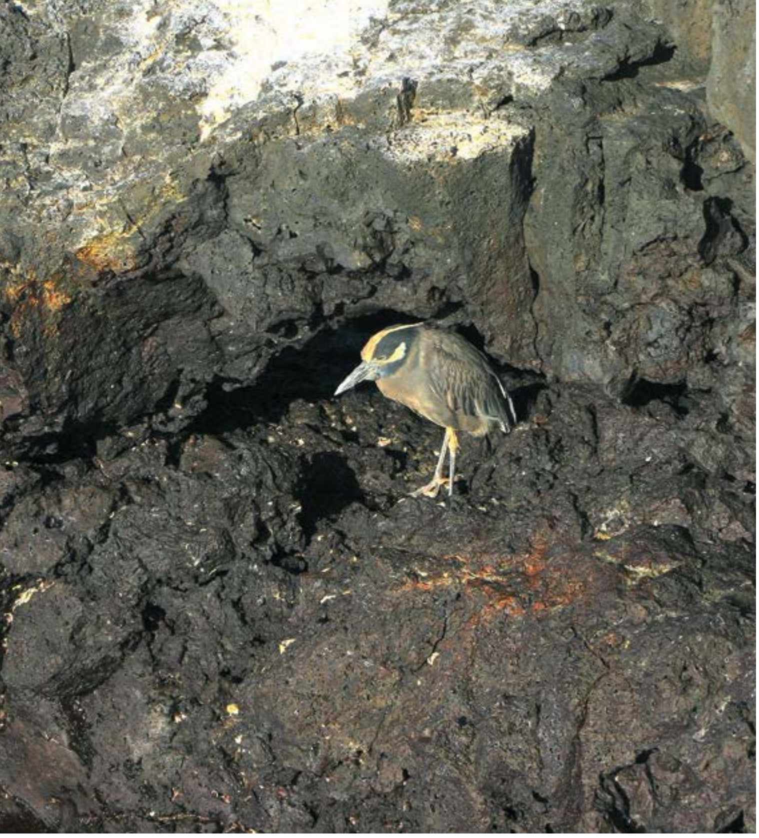


Figure 18.1 Schematic illustration of the goods and services derived from geodiversity: the grey layer above the bedrock represents soil

Source: Reprinted from Gray et al. (2013), reproduced with permission from Elsevier



San Cristóbal, Galápagos National Park, Ecuador, where eroded ledges between lava layers provide perfect roosting places for the yellow-crowned night heron (*Nyticorax violaceus*)
Source: Roger Crofts

Alvar Öland World Heritage Site, Sweden, where limestone-dependent flora is found on the limestone pavement
Source: Roger Crofts

component parts, it is vital to understand the linkages between the Earth's natural abiotic processes and the contribution they make to biodiversity conservation.

The nature of and variations within forest ecosystems are determined as much by bedrock and soil types, climatic exposure and landform topography—which determine local variations in water availability and nutrient flows—as by the diversity of their flora and fauna. Coastal protected areas reflect the interplay of bedrock and sediment types with fluvial and marine processes in their evolution and current status, even though the protection might be for migratory birds or littoral flora. High-latitude and high-altitude protected areas, important for megafauna and Arctic/alpine flora, are characterised by freezing and thawing of the ground and the seasonal supply of nutrients. Indeed, the list of relationships between major biomes and their past and current Earth processes is endless and, therefore, fundamental to the identification, designation and management of many protected areas. Put simply, without an understanding of the Earth processes that have led to their formation and of the Earth processes they are currently experiencing, management of the biological aspects of protected areas will not be as effective as it should be (Santucci 2005). This is emphasised by the current interest in the 'conserving the stage' approach in which flora and fauna are viewed as the actors and geodiversity as the stage on which they thrive. In this 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 to which plants and animals can relocate may be crucial to their survival (Anderson and Ferree 2010).

Protection of sites that reveal palaeo-environmental records is critical. Analysis of changes in fossils, pollen and fungal spores, for example, and the changing factors that affect biodiversity (for example, climate change, volcanism, erosion and sedimentation) in protected areas can provide increased understanding of the dynamics of biodiversity. While the past is unlikely to provide exact analogues for restoration ecology, palaeo-environmental records have an important part to play in supporting conservation biology through enabling understanding of ecological and evolutionary processes, ecosystem dynamics and past ranges of natural variability (Gillson and Marchant 2014). In addition, the long-term perspectives provided by palaeo-environmental records should improve awareness of trends in ecosystem services and help to validate conservation management decisions and prioritise limited resources for management intervention.

Restoration ecology is an important element in the management of protected areas where, for example, they have suffered degradation and loss of functionality. In developing plans for restoration, due account should be

taken of the contribution of natural abiotic processes to ensure that restoration is likely to be successful and that geodiversity is not adversely affected.

Consequently, geoconservation is crucial for sustaining living species and habitats, to maintain both the abiotic setting or 'stage' and the natural processes (for example, floods, erosion and deposition) necessary for habitat diversity and ecological functions. There is a strong case for more integrated approaches to the management of protected areas that would benefit both biodiversity and geoconservation (Hopkins et al. 2007; IUCN 2012; Matthews 2014).

Relevance of the IUCN definition for geoconservation in protected areas

The revised IUCN definition of a protected area refers to abiotic nature for the first time by substituting the narrower term 'biodiversity' with the broader term 'nature': '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 2008:8).

The use of the word 'nature' is quite deliberate for a number of reasons. It allows specific recognition of the abiotic elements in protected areas that were excluded in the previous definition referring only to biodiversity. It recognises that many protected areas exist to conserve abiotic nature in some form or other. It also recognises that abiotic nature is important for its own sake, as it is an intrinsic element of any definition of nature.

In the elaboration of the guidelines, 'nature' is explained as always referring 'to biodiversity, at genetic, species and ecosystem level, and often also refers to geodiversity, landform and broader natural values' (Dudley 2008:Table 1, p. 9).

The use of the term 'nature' is further elaborated in IUCN Resolution 5.048 (IUCN 2012:66), 'to ensure that, when reference is made in the *IUCN Programme 2013–2016* to nature in general, preference be given to inclusive terms such as "nature", "natural diversity" or "natural heritage", so that geodiversity and geoheritage are not excluded'.

The example given in the 2008 guidelines is the Rum National Nature Reserve in Scotland, established to protect unique geological features, specifically separation and layering of magma chamber rocks during Palaeogene igneous activity; it is also of European regional significance for its bird species.

Cotopaxi National Park, Ecuador, where chronologies of volcanic activity have been constructed from successive volcanic ash (tephra) layers

Source: Roger Crofts

A systematic approach to identifying geoconservation interests

A clear, logical and objectively based methodological framework is essential for the identification of features and sites of geoheritage interest (Sharples 2002; ProGEO 2011). This applies at all levels, from international assessments to local inventories. Without such an approach there will be no means of judging whether all aspects of geoheritage are included, the extent to which the areas selected are representative, rare or unique, and how the system can be extended as knowledge increases and new geoheritage interest is recognised.

In the following text, we provide examples of methodologies that may be applied at a range of scales, from international assessments to local inventories of geoheritage interests that could be developed and applied by individual protected area managers.

Nations and organisations embarking on the development of protected areas for geoheritage are advised to seriously consider using the systems and classifications already in existence as they represent careful attention to all of

Box 18.1 Site categories in the Geological Conservation Review in Great Britain

1. Sites of international importance: interval or boundary stratotypes; type localities for biozones based on fossils and time zones based on particular rock strata; key localities for particular rock types, minerals or fossils, and landforms; historically important sites where significant discoveries were made or knowledge was significantly increased, or where features and phenomena were first discovered and described.
2. Sites that are scientifically important because they contain exceptional features that are exceedingly rare in their formation or their existence.
3. Sites that are nationally important because they are representative of a geoheritage feature, event or process that is fundamental to Britain's Earth history.

the issues. Clearly, modifications and additions to suit national circumstances should be made, but within a tried and tested international system.

One systematic approach that is relevant, in the generality, to other countries is the Geological Conservation Review (GCR) in Great Britain (England, Scotland and Wales), developed and applied over the past three decades (Ellis 2011). Three distinct, but complementary, categories of site are incorporated in this geoscience-based system (Box 18.1).

Sites were assessed under seven broad groupings: stratigraphy, palaeontology, Quaternary geology, geomorphology, igneous petrology, structural and metamorphic geology, and mineralogy. For practical purposes, these groupings were, in turn, subdivided into thematic subject 'blocks' according to stratigraphical age, type of formation, geographical area or different geological and geomorphological processes. Obviously, other countries and regions might choose different groupings according to their specific geology and geomorphology. Also, depending on the purpose of the inventory, the criteria may in addition to scientific value include aesthetic, cultural, educational, historical, economic and ecological values, as well as potential use and vulnerability (see below).

It is proposed that seven key elements provide the basis for a comprehensive geoheritage protected area system for any region or country (Table 18.2).

Table 18.2 Key elements of a geoheritage protected area system

Key elements	Geosites demonstrating:
Key stages in Earth history	Interval or boundary stratotypes, type localities for biozones based on fossils and type localities for time zones based on particular rock strata
Major structural features	Tectonic events/episodes associated with plate movements. Examples include features associated with plate collisions resulting, for example, in formation of mountain chains, accompanied by thrusting, folding and compression of strata. Other examples associated with the convergence of plates include the formation of island arcs, central volcanoes and extensive lava flows
Formation of minerals	Rare and representative mineral deposits and types of mineral locations
Evolution of life	Fossils and fossil assemblages representing stages in the evolution of life and gradations and interruptions in life sequences in the fossil record reflecting evolutionary trends and catastrophic events, such as meteorite strikes and eruptions of supervolcanoes
Modern Earth processes	Features representative of active processes particularly associated with tectonic plates, such as different types of volcanoes and other eruptive forms, and those associated with the interface between land and sea around coasts and estuaries, river systems, and glacial and periglacial environments
Representative surface and subsurface features	Features representative of particular periods of Earth's history, or particular rock formations or Earth processes, or that are unusual or distinctive—for example, cave systems, earth pillars, domed and other upstanding rock formations
Records of past environmental conditions	Past environmental conditions, such as glacial, periglacial and interglacial phases of the Quaternary period, and including landforms, sediments and rock sequences from all periods of Earth's history

To ensure the protection of geoheritage, conservation management is required through dedicated networks of protected sites, as one of a number of possible strategies. As far as possible, geoconservation should be integrated into the conservation management of all categories of protected area. In doing so, there is a need to make the

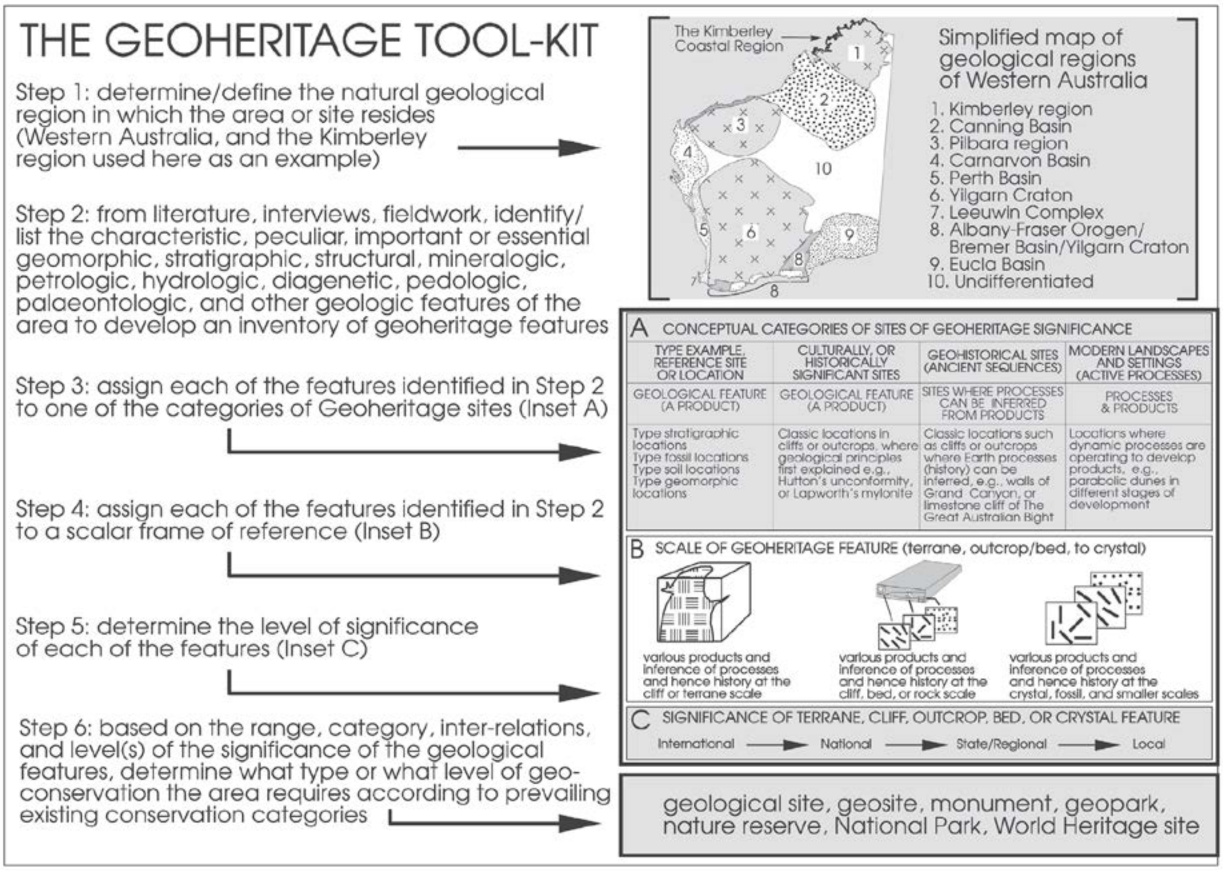


Figure 18.2 Steps in the use of the Geoheritage Toolkit to identify and assess sites of geoheritage significance

Source: Brocx and Semeniuk (2011). Illustration reproduced by permission of the authors and the Royal Society of Western Australia.

links between geodiversity and biodiversity much more explicit in conservation planning and the selection of protected areas and, as for biodiversity, to optimise the synergy with ecosystem services in conservation planning.

Geoheritage protected area toolkit

Many different protected area assessment systems are in operation at international, national and local levels. At all levels, a fundamental requirement is for a geoheritage inventory and a full understanding of key sites that need to be protected (Sharples 2002; ProGEO 2011). The Geoheritage Toolkit, developed in Western Australia to identify and assess protected areas of geoheritage significance for science and education, illustrates the main steps (Figure 18.2) (Brocx and Semeniuk 2011). The Geoheritage Toolkit is a category-based method in which distinct regions are first identified, then an inventory of key geological and geomorphological features is produced at all scales (from mountain-scale to micro-scale), the features are allocated to a category of geoheritage, and their significance is assessed using the semi-quantitative evaluation of Brocx and Semeniuk (2007).

Geoconservation and protected area designations

There are many types of geoheritage protected area systems—some international, some national and some local. The main types are described.

International

World Heritage

The World Heritage Convention recognises geoheritage values both directly, through inscription of properties on the UN Educational, Scientific and Cultural Organisation (UNESCO) World Heritage List under Criterion (viii) either on its own or in combination with other natural or cultural criteria, and indirectly, through recognising the supportive role of geoheritage values in underpinning biological, cultural and landscape diversity (Dingwall et al. 2005). To be included on the World

Heritage List, sites must be of *outstanding universal value* and meet at least one of 10 selection criteria. Of the 981 sites inscribed by 2013 on the World Heritage List, 759 are cultural, 193 are natural and 29 are mixed sites. Around 80 sites are inscribed primarily because of their geoheritage interest under Criterion (viii) as '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'. Some sites may also qualify under Criterion (vii): 'to contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance.' Dingwall et al. (2005) proposed 13 geological and geomorphological themes as a basis for assessing properties for World Heritage potential.

Geoparks

Geoparks are areas with outstanding geoheritage established primarily to promote geotourism and to support local economic development. They are not protected areas *per se*, but they may wholly, or in part, be covered by protected areas. They are not systematically identified and classified as a comprehensive global network; many are based on community-led, voluntary initiatives and others on top-down designation. Nevertheless, the Global Network of National Geoparks or Global Geoparks Network (GGN), assisted by UNESCO (Figure 18.3), provides an international framework to conserve and enhance the value of the Earth's heritage, its landscapes and geological formations, and the creation of geoparks will probably *de facto* provide a level of landscape-scale coordination of conservation, sustainable use and complementary social and economic development, though not always in the strict definitions of IUCN categories. In 2014 the network comprised 111 national geoparks worldwide (UNESCO 2014a).

Figure 18.3 Logo of the UNESCO-assisted Global Geoparks Network

Source: UNESCO

Geoparks combine conservation of geoheritage with encouragement of its enjoyment, understanding and education and support for sustainable socioeconomic and cultural development through geotourism (McKeever et al. 2010). The GGN operates in close synergy with the World Heritage Convention, the Man and the Biosphere (MAB) World Network of Biosphere Reserves, and with national and international non-governmental organisations (NGOs) and geoheritage conservation programs. Sites within the GGN are required to meet criteria relating to size and setting; management and local involvement; economic development; education; and protection and conservation (UNESCO 2010). Geoparks are not necessarily specifically protected areas, and are subject to four-yearly reviews of their performance and management. Should a geopark fail to meet the criteria and the issues raised are not addressed within two further years, it is removed from the GGN list.

Dingwall et al. (2005) recommended that the GGN should be seen as a complementary approach to World Heritage listing; however, it should be recognised that the GGN is not primarily a listing of important sites; they are sites selected for tourism and promotion purposes. There remains a need for an international listing of important geosites alongside World Heritage sites and geoparks since each has a different role to play in international geoconservation.

Internationally important geosites

As a contribution to the global geosites inventory program (Wimbledon et al. 2000), some countries, such as Spain (García-Cortés et al. 2001, 2009) and Portugal (Brilha et al. 2005), completed inventories of internationally important sites. Geosites identified under this program are incorporated into national protected area systems to ensure their proper management. Originally adopted by the International Union of Geological Sciences, and later abandoned due to financial problems, the global geosites program is currently under development in many other European countries (Wimbledon and Smith-Meyer 2012) and its principles remain valid for the identification and global comparison of geological frameworks and geoheritage sites of international relevance.

A major gap in the international network of protected sites for geoheritage is the network of more than 100 Global Stratotype Sections and Points (GSSPs) established by the International Commission on Stratigraphy, a commission of the International Union of Geological Sciences (Gray 2011). This network comprises all the key sites for the stage, system and series boundaries of the geological column, which form the fundamental building blocks of stratigraphy.

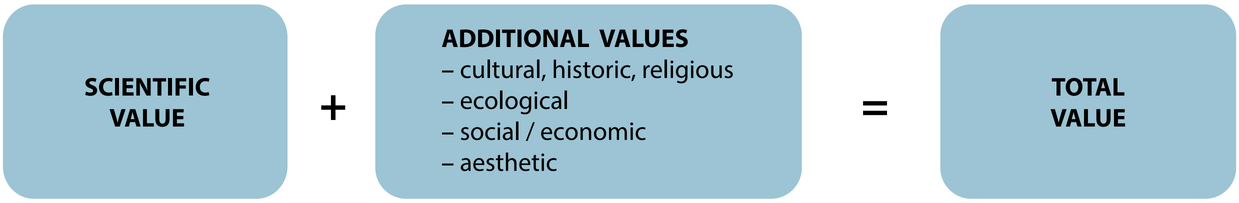


Figure 18.4 Core and additional values of geoheritage

Source: Adapted from Reynard (2009b)

National

Many countries have adopted site assessment systems for geological and geomorphological features using a range of criteria (Wimbledon and Smith-Meyer 2012). The majority are based on criteria that include scientific value, representativeness, rarity, diversity of features and integrity (Lima et al. 2010), and comparative assessment and published information provided by experts on the area, working to a defined geological framework (Erikstad et al. 2008; ProGEO 2011). Assessments are usually based on an expert judgment approach, but in some cases numerical parametric approaches have been adopted or proposed (for example, Lima et al. 2010; Bruschi et al. 2011). The latter are probably more useful where a wider range of criteria is being applied (for example, educational and tourism use, vulnerability) and different weightings can be allocated to different criteria. Where the focus is specifically on the scientific value, parametric scoring approaches risk losing sight of the fundamental scientific reasoning. Hence, it is vital that full scientific justification is provided, as in the case of the Geological Conservation Review (GCR) in Great Britain.

The GCR, and the analogous Earth Science Conservation Review in Northern Ireland (National Museums Northern Ireland 2003), are good examples of a systematic national assessment (see above). The underlying rationale is that sites are selected solely for their scientific interest through a process of expert review, and must make a special contribution to the understanding and appreciation of Britain's geoheritage. More than 3000 sites have been selected and most are designated as Sites of Special Scientific Interest (SSSIs) and have statutory protection. In Scotland, this type of approach has been extended to the marine environment to identify key areas for geodiversity on the seabed from the coast out to the edge of the continental shelf (Brooks et al. 2013). Given resource constraints and the difficulties in managing and monitoring submarine areas, a pragmatic approach may be to prioritise action on the basis of the sensitivity and vulnerability of the geoheritage interests and to align marine geoconservation with biodiversity conservation as far as possible through an integrated approach (Gordon et al. 2013). For example, in Norway, the application of 'nature areas' mapping in the marine environment is intended to provide a basis for integrated conservation, reflecting the close links between marine geodiversity and biodiversity (Dolan et al. 2009; Thorsnes et al. 2009).

Outside Europe, systematic national site assessments have generally not been completed and this is seen as a major gap. In Australia, however, a great deal of work has been undertaken throughout the continent, with the Geological Society of Australia playing a leading role alongside State bodies (Sharples 2002; Brocx 2008; Joyce 2010; Worboys 2013). The *Tasmanian Geoconservation Database (TGD)* (DPIPWE 2014) provides a good existing model. The TGD is an extensive inventory of sites of geoconservation significance and was initially compiled from a range of previously *ad hoc* inventories. Over the past 15 years it has been actively managed by a specialist reference group appointed by the relevant government agency (Department of Primary Industries, Parks, Water and Environment: DPIPWE) and, as a result, is gradually developing into a more systematically organised and comprehensive geoheritage inventory. Despite having no statutory power, it has become a key tool in land management in Tasmania (DPIPWE 2014).

In addition to scientific value, other approaches have recognised the aesthetic, cultural/historical, economic and ecological values of protected areas for geoconservation (Kiernan 1996; Panizza 2001; Coratza and Panizza 2009; Reynard 2009a). Reynard (2009b) proposed geological value as the core value and the others as additional values (Figure 18.4).

Some approaches have also applied quantitative methods to site assessment incorporating both scientific and wider values—for example, in Switzerland (Reynard et al. 2007), Spain (Bruschi et al. 2011; Pellitero et al. 2011), Portugal (Pereira et al. 2007) and Greece (Fassoulas et al. 2011). Rovere et al. (2011) extended this approach to assess geoheritage in two underwater areas off the coasts of Greece and Italy. Some approaches have focused on subsets of geosites. For example, the International Association of Geomorphologists has addressed the assessment and conservation of geomorphological sites (Reynard et al. 2009).

The value of soil has tended to be overlooked in geoconservation assessments, although it is addressed in ecosystem service assessments (for example, Haygarth and Ritz 2009; Dobbie et al. 2011). For soils in Scotland, however, Towers et al. (2005) developed a methodology for a soil conservation index based on assessing soil rarity, representativeness and diversity using soil pedological characteristics.

Local

There are many different approaches to local geoconservation around the world. In Great Britain, for example, networks of sites of regional or local importance have been identified. These are variously known as Local Sites or Local Geological Sites (England), Local Geodiversity Sites (Scotland) and Regionally Important Geodiversity Sites (Wales) (DEFRA 2006; Scottish Natural Heritage 2006). They have discretionary protection guidance on dealing with development applications and their value lies in the fact they can be designated for a much broader range of criteria than SSSIs, including educational, aesthetic and historical significance (Burek 2012). Other countries, too, have identified regional networks of geosites, such as Spain (see, for example, Fuertes-Gutiérrez and Fernández-Martínez 2010). For local planning purposes, including management of large protected areas such as national parks, recognition of geoheritage values will be important even if they do not appear on national lists or meet normal criteria as stand-alone protected areas (Erikstad 2012).

Principles of geoconservation

This section sets out general principles for geoconservation in protected areas.

The role of IUCN management categories and geoconservation

Geoconservation in protected areas applies to all of the IUCN protected area management categories and it specifically applies to Category III. The 2008 guidelines (Dudley 2008) set out the situation in both cases and are quoted below.

Relevance of all categories

The IUCN protected area management categories (Chapter 2) have a wide application to the management of geoheritage. This reflects the linkage between abiotic and biotic conservation, as well as cultural values. As a result, geoconservation can apply to the management of protected areas assigned to any one of the six management categories as well as to those assigned to Category III. Examples are given in Table 18.3. Geoheritage values can also apply to all of the other categories. The 2008 guidelines provide the examples given in Table 18.4.

IUCN Category III protected areas

Traditionally, Category III has been regarded as the only one for conservation of specific geoheritage features and processes. This is not entirely the case, as will be discussed below. The detailed definition of this category is:

> Category III protected areas are set aside to protect a specific natural monument, which can be a landform, seamount, submarine cavern, geological feature such as a cave or even a living feature, such as an ancient grove. They are generally quite small protected areas and often have high visitor value. (Dudley 2008:17)

As defined in the guidelines, the primary objective of Category III is 'to protect specific outstanding natural features and their associated biodiversity and habitats' (Dudley 2008:17). Other objectives can also apply, such as:

- to provide biodiversity protection in landscapes or seascapes that have otherwise undergone major changes
- to protect specific natural sites with spiritual and/or cultural values where these also have biodiversity values
- to conserve traditional spiritual and cultural values of the site (Dudley 2008:17).

A Category III protected area could include some of the following elements.

1. Natural geological and geomorphological features: such as waterfalls, cliffs, craters, caves, fossil beds, sand dunes, rock formations, stratotypes and stratigraphic sections; valleys and marine features such as seamounts or coral formations.
2. Culturally influenced natural features: such as cave dwellings and ancient human tracks.
3. Natural-cultural sites: such as the many forms of sacred natural sites (sacred groves, springs, waterfalls, mountains, sea coves, and so on) of importance to one or more faith groups.
4. Cultural sites with associated ecology: where protection of a cultural site also protects significant and important biodiversity, such as archaeological and historical sites that are inextricably linked to a natural area.

Table 18.3 Examples of geoheritage protected areas in the IUCN management categories

Category	National examples and reason	World Heritage property examples
Ia. Strict Nature Reserve	Greenland Ice Cap, Greenland: ice cap and nunataks Geysir Valley, Kronotsky Zapovednik, Russia: volcanic features	Macquarie Island Nature Reserve, Australia: Earth mantle rocks Surtsey, Iceland: biotic and abiotic processes on new island formed in 1963–67
Ib. Wilderness Area	Maspalomas Dunes Special Nature Reserve, Spain: saltmarshes within Pleistocene dunes Noatak Wilderness, Alaska, USA: river basin	Putorana Plateau, Russia: basalt plateau
II. National Park	Grand Canyon National Park, USA: stratigraphic record and arid land erosion	Dolomit Bellunesi National Park, Italy: karst, glaciokarst and reefs
III. Natural Monument or Feature	Jenolan Karst Conservation Reserve, Australia: karst system Bosques Petrificados, Argentina: petrified forest	Boodjamulla (Lawn Hill) National Park, Australia: terrestrial vertebrate fossils Dinosaur National Park, Canada: dinosaur fossils
IV. Habitat/ Species Management Area	Montserrat Mountain Partial Natural Reserve, Spain: sedimentary rocks, caves and mountain erosion forms Lord Howe Island Marine Park, Australia: volcanic seamount	Galápagos National Park, Ecuador: modern geological processes
V. Protected Landscape/ Seascape	Cairngorms National Park, UK: Earth history and modern geomorphological processes Cabo be Gata-Níjar Natural Park, Spain: volcanic and Quaternary history Lyngsalpan landscape protected area, Norway: alpine mountains with glaciers, moraines, geodiversity protection	Škocjan Caves Regional Reserve, Slovenia: sinkholes, caves and underground rivers
VI. Protected Area with Sustainable Use of Natural Resources	Nublo Rural Park, Spain: volcanology, geomorphology Sečovlje Salina Nature Park, Slovenia: salt extraction	Great Barrier Reef Marine Park, Australia: coral reef system evolution

Sources: Lockwood et al. (2006); Dudley (2008); UNESCO (2014b); for Spanish examples, E. Díaz-Martínez, Personal communication; for Norwegian examples, L. Erikstad, Personal communication

Table 18.4 Geoheritage and the appropriate IUCN management category

Aspect of geoheritage	Suitable IUCN category
Protection is aimed primarily at an individual feature of interest (natural monument such as a waterfall or cave) or a site of national or international value for understanding the Earth's history (for example, a stratotype)	Primarily Category III
An assemblage of landforms (for example, glaciated valley system, cordillera) and/or processes, or geological features	Primarily Categories Ia, Ib, II and V
The features have potential for interpretation and stimulating geotourism	Primarily Categories II and III
The geoheritage interest is itself a foundation for habitats and species (for example, calcium-loving plants or species adapted to dynamic sand dunes)	Primarily Categories Ia, Ib, II, IV, V and VI
Geoheritage has important links with cultural landscapes (for example, caves used as dwellings or landforms adapted to terraced agriculture)	Primarily Category V, and also Categories II and III
Geoheritage is the basis for sustainable management (activities associated with natural processes, such as volcano tourism, or use of floodplains as traditional rice-growing areas)	Primarily compatible with Categories V and VI
Protection that includes geological features that have particular spiritual or faith-based values for a proportion of stakeholders	Primarily Categories Ia and III

Table 18.5 Category III protected areas compared with other categories

Categories Ia and Ib	Category III is not confined to natural and pristine landscapes but could be established in areas that are otherwise cultural or fragmented landscapes. Visitation and recreation are often encouraged and research and monitoring limited to the understanding and maintenance of a particular natural feature
Category II	The emphasis of Category III management is not on protection of the whole ecosystem, but of particular natural features; otherwise Category III is similar to Category II and managed in much the same way but at a rather smaller scale in both size and complexity of management
Category IV	The emphasis of Category III management is not on protection of the key species or habitats, but on protection of particular natural features and processes
Category V	Category III is not confined to cultural landscapes, and management practices will probably focus more on stricter protection of the particular feature and processes than in the case of Category V
Category VI	Category III is not aimed at sustainable resource use

Source: Dudley (2008)

Biodiversity components of Category III protected areas are of two main types:

1. biodiversity that is dependent on the conditions of the natural feature—such as coastal wetlands dependent on tidal inundation, the spray zone of a waterfall, the ecological conditions in caves, plant species confined to cliffs, or the grasslands confined to low limestone plains or alvars
2. biodiversity that is surviving because the presence of cultural or spiritual values at the site has maintained a natural or semi-natural habitat in what is otherwise a modified ecosystem—such as some sacred natural sites or historical sites that have associated natural areas. In these cases, the key criteria for inclusion as a protected area will be: 1) the value of the site as a contribution to broad-scale conservation; and 2) prioritisation of biodiversity conservation within management plans.

Category III has been suggested as providing a natural management approach for many sacred natural sites, such as sacred groves. Although sacred natural sites are found in all categories and can benefit from a wide range of management approaches, they may be particularly suited to management as natural monuments.

Category III is really intended to protect the unusual rather than to provide logical components in a broad-scale approach to conservation, so their role in landscape or ecoregional strategies may sometimes be opportunistic rather than planned. In other cases—for example, cave systems—such sites may play a key ecological role identified within wider conservation plans. Important natural monuments can sometimes provide an *incentive* for protection and an opportunity for environmental/cultural education even in areas where other forms of protection are resisted due to population or development pressure, such as important sacred or cultural sites. In these cases, Category III can preserve samples of natural habitat in otherwise cultural or fragmented landscapes.

Category III is distinctive from the other categories as management is usually focused on protecting and maintaining particular natural features and the processes that ensure their continuation (Table 18.5).

The fact that an area contains an important natural monument does not mean it will inevitably be managed as a Category III area—for instance, the Grand Canyon in Arizona is managed as Category II, despite being one of the most famous natural monuments in the world, because it is also a large and diverse area with associated recreational activities, making it better suited to a Category II model. Category III is most suitable where the protection of the feature is the sole or dominant objective.

Establishing new geoheritage protected areas

Within the systematic frameworks for identifying protected areas for geoconservation (see above), opportunities will arise for new sites to be designated. These will result from a number of circumstances, such as new knowledge and understanding of features and processes, new exposures arising from natural erosion or from quarrying, new site surveys in areas previously overlooked, and the formation of new territory with associated mineral deposits on land and below sea-level as a result of tectonic and volcanic activity. In judging whether to add new protected areas, the fit within the existing systematic framework should be considered and any adjustments made to the site network to take into account the new knowledge or interpretations.

Surtsey World Heritage Property, Iceland: a new island formed between 1963 and 1967 at the geological plate separation zone along the Mid-Atlantic Ridge

Source: Roger Crofts

Guidance from geoconservation strategic frameworks

A hierarchy of guidance for geoconservation can be a valuable part of the toolkit for protected area management. The cascade from a national geodiversity framework, through regional and local geodiversity action plans to geoconservation protected area management plans, allows the management of the protected area to be placed in a wider context, and linkages to be established that will reinforce management and place responsibilities on other parties to act in supportive ways. Specific applications must match local conditions, legislation and management systems.

At a national level, a geodiversity framework can be particularly helpful in developing a strategic approach to geoconservation, setting out high-level objectives that can be used to measure and report on progress, help enlist partners and coordinate activities, and promote geoconservation (for example, Gordon and Barron 2011). Geoconservation strategies and action plans are currently being developed in many European countries (Wimbledon and Smith-Meyer 2012). Examples of national frameworks include the UK Geodiversity Action Plan (UKGAP) and Scotland's Geodiversity Charter (Box 18.2).

At a local or regional level, local geodiversity action plans (LGAPs) are needed to evaluate potential uses of protected areas, to target and prioritise resources, and to target appropriate management and interpretation of protected areas (English Nature 2004; Burek and Potter 2006). There are now many examples of LGAPs in the United Kingdom (for example, Lawrence et al. 2007). In some cases, they are integrated with local biodiversity action plans. In Italy, the proactive management of the geological heritage in the Piemonte (PROGEO-Piemonte) program aims to develop action planning for geoheritage management with the participation of local partners and to meet the needs of local communities in respect of tourism, sustainable development and geohazard awareness (Ferrero et al. 2012). Such plans can also provide a model for developing the protection of geoheritage and its integration into the conservation management of different categories of protected area.

The fundamental building block for local action plans is an inventory or audit of geodiversity sites and resources within an area, as developed, for example, in the United Kingdom (for example, Lawrence et al. 2004) and Tasmania (for example, DPIPWE 2014).

Guiding principles for geoconservation in protected areas

Development of more integrated approaches to the management of natural systems depends, in part, on the effective application of geoconservation principles. These are of general application and also relevant specifically to protected area management (Box 18.3). These principles are easier to list than to implement in practice, as there will inevitably be resistance to accepting change and adapting to new approaches. It will take time and patience to bring all interests onside and think creatively. Key protected area personnel will need expertise in negotiation and resolving conflict.

Many of these principles are now being applied in protected area management. This is exemplified in shoreline management plans and integrated river catchment management. It is also recognised in comprehensive, ecosystem-based planning frameworks developed, for example, in the Oak Ridges Moraine Conservation Plan, Ontario (Ontario Ministry of Municipal Affairs and Housing 2012). The ecosystem approach, in particular, has been adopted as a primary framework for action under the CBD and provides a means for closer integration of geodiversity and biodiversity on a wider scale.

Box 18.2 Strategic frameworks for geoconservation: UK experience

The UK Geodiversity Action Plan (UKGAP 2014) provides a strategic framework for geodiversity action across the United Kingdom, linking national, regional and local activities. Agreed by organisations, groups and individuals currently involved in geodiversity activities, it provides a mechanism for encouraging partnership, influencing decision-makers, policymakers and funding bodies, and promoting good practice. The UKGAP comprises six themes:

1. furthering the understanding of geodiversity
2. influencing policy, legislation and development design
3. information gathering and management
4. conserving and managing geodiversity
5. inspiring people to value and care for geodiversity
6. sustaining resources (people and financial) for geodiversity.

Each theme has a set of objectives and targets (areas of work that contribute to delivering the objectives).

The Scottish Geodiversity Forum promotes Scotland's geodiversity and seeks to widen the profile of geodiversity and to influence national and local policies in education, community involvement and health, the development of tourism and the wider economy. Members include local geoconservation groups, geoparks, industry, education and academic sectors, related government and NGOs and interested individuals. Scotland's Geodiversity Charter, produced by the forum, sets out a strategic approach to geoconservation focused on an ecosystem approach, including a vision that Scotland's geodiversity is recognised as an integral and vital part of the environment, economy, heritage and future sustainable development, to be safeguarded and managed appropriately for present and future generations (Scottish Geodiversity Forum 2013). The signatories (currently 51) commit to contributing to the activities of the forum and delivering the objectives of the charter through four main areas of activity:

1. raising awareness of the importance of geodiversity and its wider links with landscape, culture and sense of place, and encouraging a sense of pride through education (at all levels, including schools, universities and lifelong learning), promotion, outreach and public interpretation
2. integration of geodiversity in relevant policies to ensure sustainable management of the natural heritage, land and water at landscape and ecosystem scales
3. conservation and enhancement of geoheritage and its special character, within existing designated sites and areas, by further designation of nationally and locally important sites, and in the wider rural, urban and marine environments
4. research to improve understanding of the role of geodiversity in providing benefits to ecosystems and people, and to address key knowledge gaps such as the functional links between geodiversity and biodiversity in terrestrial, freshwater and marine environments.

Site planning guidance

Some sites will not be designated and managed purely for geoconservation. Geoconservation interests will be included in sites managed for various aspects of biodiversity conservation or for ecosystem services or for cultural reasons, in accordance with the IUCN definition. In all cases, whatever the balance of significance between the different reasons for designation of a protected area, a comprehensive approach to managing all of the valued interests will be required.

It is essential in all of these situations for the geoconservation component to be included in all of the site documentation and site management specification, as well as in the work plans and activities of all staff. This material should be an intrinsic part of the protected area management plan described in Chapter 13. The site documentation material for geoconservation, to form part of the protected area management plan, should include:

- the reasons for conserving the geoheritage interest (for example, scientific, educational), including the type of interest and the level or scale of relevance (local, regional, national and international)
- specification of the particular elements (for example, materials, structures, landforms), systems and processes to be conserved, including their classification (for example, stratigraphy, tectonics, geomorphology, palaeontology, mineralogy, hydrogeology, petrology) and precise locations within the site (established through mapping and photography)
- specification of the degree of fragility, risks of damage and potential threats and other causes of loss of interest to the features and processes
- links to other aspects of nature and culture being protected

Box 18.3 Guiding principles for geoconservation in protected areas

1. The inevitability of natural change should be recognised: no system or element of a system is static forever, and change will occur particularly as a result of global climate change. The traditional approach of maintaining the current state to preserve features should be reconsidered in cases where preservation is not the management objective (see also Chapter 10 for more explanation).
2. Changes resulting from global climate change, irrespective of the extent attributed to natural or anthropogenic factors, will inevitably challenge management objectives. Careful consideration will be needed where, for example, the features are lost and/or processes are lessened or intensified, and so change the basis for protection. It may mean that the protection status can no longer be justified.
3. Natural systems and processes should be managed to maintain natural rates and magnitudes of change and to maintain their capacity to evolve through the action of natural processes.
4. Natural systems and processes should be managed in a spatially integrated manner—for example, to achieve complementary objectives, such as geodiversity, biodiversity and landscape diversity conservation.
5. Any management and intervention should work with, rather than against, natural processes: mimicking nature and natural processes is more effective than trying to impose human solutions that seek to control or halt natural processes.
6. Natural systems should be managed within the limits of their capacity to absorb change: some systems will be more able than others to absorb change and others will be very fragile with a low threshold for change.
7. The sensitivity of natural systems should be recognised, including the potential for irreversible changes if limiting thresholds are crossed. It is rarely the case that abiotic systems are robust and can absorb any change imposed upon them. If certain types or levels of change are made, the conservation effort will be negated as the original features and processes will have been irreversibly changed.
8. Conservation management of active systems should be based on a sound understanding of the underlying physical processes—for example, the implementation of coastal cells in the preparation of shoreline management plans; the integration of river, soil and slope processes in catchment management plans; monitoring active processes.
9. Engineering solutions that are based on ‘hard’ structures, such as concrete, should be avoided as they can wreck the features and processes of the protected area. Instead, ‘soft’ approaches to management should be adopted using natural materials that mimic nature as far as possible—for example, removal of mangroves that serve as a natural form of protection of the coastal edge and are protected for their biological interest and replacing them with solid structures such as concrete walls should be avoided.

Note: These principles have been further developed in Crofts and Gordon (2014).

- potential conflicts with the management of the non-abiotic interests, especially biotic and cultural interests, and how these can be resolved
- the management requirements to maintain or enhance the interests, depending on the reasons for the designation, and the need to minimise conflict with other reasons for designation
- management arrangements within the area, including boundary definition, core and buffer zones, and assignment to the appropriate IUCN management categories and governance types
- a protocol for monitoring and reviewing the state of conservation of the geoheritage interest.

Wimbledon et al. (2004) provide an exemplary case study of the application of such a methodology to geosite management in Wales.

The use of core and buffer zones

The identification of core and surrounding buffer zones should be an important element of the management arrangements for geoconservation. The two concepts are closely linked and the buffer is a necessary complement to the core zone, as without it, it will be much more difficult to protect the features in, and the integrity of, the core zone. The UNESCO Man and the Biosphere Reserve approach provides a practical basis for identifying the two zones. For biosphere reserves, they are defined as follows.

- *Core area(s):* Securely protected sites for conserving biological diversity, monitoring minimally disturbed ecosystems, and undertaking non-destructive research and other low-impact uses (such as education). In addition to its conservation function, the core area contributes to a range of ecosystem services, which, in terms of the development functions, can be

calculated in economic terms (for example, carbon sequestration, soil stabilisation, supply of clean water and air, and so on). Employment opportunities can also complement conservation goals (for example, environmental education, research, environmental rehabilitation and conservation measures, recreation and ecotourism).

- *Buffer zone:* Usually surrounds or adjoins the core areas, and is used for cooperative activities compatible with sound ecological practices, including environmental education, recreation, ecotourism, and applied and basic research. In addition to the buffering function related to the core areas, buffer zones can have their own intrinsic, 'stand-alone' functions for maintaining anthropogenic, biological and cultural diversity. They can also have an important connectivity function in a larger spatial context as they connect biodiversity components within core areas with those in transition areas (UNESCO 2014c).

Although this is written from the standpoint of conserving biological diversity, for our purposes, the phrase 'abiotic or geoconservation' can be substituted or added.

A single core surrounded by a buffer zone will not always be the correct approach. 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 in those situations.

In practical terms, 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 geoheritage sites that combine many features and where maintaining the effective functioning of Earth processes is critical.

Approach for Category III sites

If the feature(s) being protected is relatively static, inactive or relict, the core area can usually be drawn quite tightly around its areal extent. The definition of the boundary will depend on the need to control external activities that will have a detrimental effect on the site, such as excessive visitor numbers, geological investigations for research or education requiring removal of large samples, or vegetative growth that would obscure the interest. In addition, activities that damage the key interests being protected should be prohibited in the core area and similarly restrictions imposed in the buffer area, with statements made in the management plan and at the site itself to indicate the restrictions and the reasons they are in place. A larger boundary may also be required where sites need to be excavated periodically to maintain clear exposures, or to allow space for exposures to retreat where they are eroding naturally (for example, at the coast).

Approach for larger-scale geoheritage protected areas

Many geoheritage protected areas will be substantial in area and a different approach will be needed to ensure protection of the key features and the processes operating there. A comparable way of looking at this aspect is to think of the requirements to protect a biodiversity site designated as a nesting and roosting area for birds. Without also protecting the areas of food supply through some suitable measures, such as through buffer zones or extending the core area, the nesting and roosting site will become redundant if the birds have no ready supply of food.

Similarly, for geoheritage protected areas the buffer should be defined as the area needing conservation management to protect the features and forms, and the systems and processes that are the reason for the protection. For example, a gravel-bed river system on a modern sandur or outwash plain will only retain its dynamic interest if the fluctuating water supply from the glacier or ice cap is maintained. Therefore the sandur should be designated as the core protected area and the water sources should be protected (for example, from dams and abstraction for hydro-electricity) through designation in the buffer zone. Similarly, cave systems are susceptible to land-use activities in their wider hydrogeological catchment areas that affect water and sediment discharge into the cave passages and so require appropriate buffer zones. Buffer zones may also be required for dynamic process features—for example, in river and coastal environments—to ensure the natural processes can continue to operate across their full range of natural variability (for example, the migration of a meander belt across a floodplain).

Managing geoconservation in protected areas

Conservation requires the development of clear management objectives and periodic monitoring. In the United Kingdom, generic conservation management

Table 18.6 Classification of geosite types for conservation management in the United Kingdom

Category	Type of site
Exposure or extensive	Active quarries and pits
	Disused quarries and pits
	Coastal cliffs and foreshore
	River and stream sections
	Inland outcrops
	Exposures in underground mines and tunnels
	Extensive buried interest
	Road, rail and canal cuttings
Integrity	Active process geomorphological
	Static geomorphological
	Caves
	Karst
Finite	Finite mineral, fossil or other geological
	Mine dumps
	Finite underground mines and tunnels
	Finite buried interest

Source: Prosser et al. (2006)

principles have been developed for different categories of geoconservation protected area, with an important distinction between 'exposure', 'integrity' and 'finite' sites (Table 18.6). These are explained below, as they may be equally applicable in other parts of the world. Examples of the application of this system in England can be found in Natural England (2014).

Exposure sites

Protected areas with exposures 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 and foreshore exposures, road and rail cuttings, and natural rock outcrops inland. 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 may not be crucial. Exposure sites are not usually damaged by quarrying or erosion, but the exposures can be obscured by landfill and dumping of rubbish. Loss of exposures can, however, 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 (for example, 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 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, they cannot be reinstated or replaced since they are unique or the processes that created 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 resiting 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.

The principal conservation management objective for active geomorphological 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 (for example, between rivers and their floodplains). A consequence is that the landforms produced by them may change over time and some may be transitory. For example, gravel bars in a riverbed may be destroyed in a large flood but may reform as the discharge and sediment transport readjust to 'normal' flow conditions. They may also reform in different locations. Active process sites are also susceptible to changes outside the conservation site boundary—for example, through upstream changes that affect river discharge and sediment inputs. This is more likely to occur on sites with river, coastal, cave or slope (mass movement) processes and their associated features. Some active geomorphological 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 type sites, occurrences of Quaternary interglacial deposits and fossil-bearing horizons. 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 (for example, Bridgland 2013). Finite sites require close control over the removal or loss of material and 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. Depending on the type and level of the main use of a site (for example, public interpretation or research), it may not be practical or necessary to maintain an exposure. In such cases, access should be maintained for excavation as and when required (for example, for scientific research).

In general, there must be a presumption against development in protected areas that would damage the area and undermine the reasons for its protection. Where a development would result in significant damage to a geoheritage protected area that 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 supporting the need for the development. In this case, 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.

Risk management

Robustness and sensitivity

As noted above, geosites and features show varying degrees of sensitivity to different types of human activity. Some features may be relatively robust (the degree to which they can withstand disturbance) and therefore require relatively little management intervention. Others, however, are highly sensitive (susceptible to damage or degradation from human activities). Most, however, with the exception of some small-scale active process features (for example, periglacial patterned ground or gravel bars in a river), have limited resilience (the ability to reform if damaged or destroyed). These are important considerations in prioritising the management of sites and features in protected areas. Building on earlier studies, Kirkbride and Gordon (2010) compiled a sensitivity assessment of relict landform and active geomorphological process sites to a range of human activities in the central part of the Cairngorms National Park in Scotland. The evaluation of relict landform sensitivity is relatively straightforward, based on a simple assessment of the likely scale of impact and loss of interest. For active geomorphological systems, however, 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).

Risk assessments

There will be a variety of natural processes operating beyond the protected area that affect it and the features, forms and processes that are the basis of its designation. Determining the likely impact and the options for responding is, therefore, an important component of management. Risk assessments and prioritisation of management action will need to be undertaken of the likelihood and potential effects, especially of:

- plate tectonic activity, such as earthquakes and other seismic activity, volcanic eruptions and lava flows, tsunamis, landslides and mudflows
- global climate change, including extreme events especially in mountain areas, along rivers and at the coast, changes in precipitation regimes, increases in unpredictability of the weather, sea-level rise, melting glaciers and glacial lake outbursts, and melting of permafrost.

It is important to be realistic as in either set of circumstances some features will be more vulnerable and will be lost or damaged and others radically changed. Careful judgment will be required, however, to ensure the management response does not have a more damaging effect than the natural phenomenon. Systematic assessment of the impacts on geoheritage, as undertaken for the Tasmanian Wilderness World Heritage Area (Sharples 2011), would allow risk-based prioritisation for action. In the case of hard-rock features, it is questionable whether any effective management intervention would be beneficial or indeed practical. In line with the principle of making space for natural processes, the preferred response for geomorphological systems will be to allow natural processes to evolve undisturbed and to manage the consequences of change (for example, adapt site boundaries) rather than attempt to 'fix and control'. Where other interests are threatened, soft forms of intervention that have a minimal impact on the protected area features should be the preferred option (for examples of river and coastal management, respectively, see The RRC 2013; Scottish Natural Heritage 2000). Where this is not possible, the most realistic response will be to record or archive samples *ex situ*. 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 be the implementation of appropriate actions, including exclusion or rerouting of visitor access and management of visitor expectations.

Managing specific threats to geoheritage in protected areas

Inevitably, there will be interactions and potential conflicts between geoconservation in protected areas and biodiversity and cultural conservation, as well as conflicts with other activities, particularly those seeking to exploit natural resources for human use, legitimately or otherwise (see Table 18.1). Some of the main threats are dealt with in turn and build on the general guidance provided above.

Mineral exploitation

Interaction with mining and mineral extraction at the surface and below the surface has been a longstanding issue. Dialogues between the IUCN WCPA and industry, represented by the International Council on Mining and Minerals (ICMM), have resulted in a protocol by the industry (ICMM 2003) and the IUCN's position statement for World Heritage sites (IUCN 2013).

There is a still a view held particularly by some mining interests and shared by some members of the WCPA that mining is prohibited in IUCN Categories I–IV protected areas, but can be allowed in Categories V and VI protected areas. This position has created problems in many Category V landscape protected areas in Europe. For example, approval exists for goldmining in the Loch Lomond and The Trossachs National Park in Scotland and stone quarrying in the Peak District National Park in England. In contrast, a joint resolution by indigenous peoples and the IUCN Commission on Environmental, Economic and Social Policy states that mining should not be allowed in protected areas, World Heritage sites, indigenous territories and sacred natural sites (see Chapter 5). This is an unfortunate unresolved matter that requires urgent attention within the IUCN as a whole. In the meantime, a cautious approach is recommended to ensure that any ongoing mining activities do not result in loss of or damage to the geoheritage interest. For new mining proposals, it is essential that an appropriate risk assessment is undertaken before any decisions are made. In all cases, local communities, whose lives and livelihoods might be affected, should be fully consulted before any decisions are made.

It should be recognised that not all extractive activity has a negative impact on the geoheritage interest, as new exposures provide the opportunity for investigation and bring new understanding of Earth evolution both at the site and of more general application. Care must be taken, however, that new exposures or valuable specimens are not lost in the commercial imperative to remove as much material as possible as soon as possible. If extraction is consented for the site, therefore, legally binding agreements should be made between the managing authorities and the resource owners, including the placing of financial bonds for restoration of the site or for maintaining certain exposures for research and teaching as part of the restoration plan. Decisions will also need to be taken about how much of the resource it is permitted to extract. Often, it will be valuable from a geodiversity perspective to leave some of the resource in the ground to allow for future investigations and for teaching and demonstration.

When applications are made for mining beneath protected areas, such as for coalmining or oil and gas extraction, including fracking, detailed assessments need to be undertaken of the potential effects on the geoheritage interests—the features and forms at the site and most especially the processes operating there.

Loch Lomond and The Trossachs National Park, Scotland, United Kingdom (an IUCN Category V protected area), where spoil from the Cononish goldmine creates water and visual quality problems but provides specimens for examination
Source: Roger Crofts

Legal mining under protected areas remains a vexed issue. The removal of a non-renewable resource is not sustainable, can cause the surface to collapse and can have wider impacts. If approval is given, it should be accompanied with regulations, including robust legal agreements with compliance monitoring and enforcement of the agreements.

Artisanal and small-scale mining can have profound effects on protected areas and care needs to be taken in assessing potential effects and defining solutions. A methodology has been devised and tested in Africa and provides a toolkit of six elements focusing on assessing the extent of the problem, and working with relevant stakeholders to identify solutions and alternative approaches (ASM-PACE 2013).

Once extraction is complete or in long-disused quarries, there is often a demand to use them as sites to deposit waste materials from industrial, residential or other sources. This will especially be the case where there are few other locations locally where waste material can be disposed. It is essential that the local, national and international importance of the exposures and their value for teaching and research purposes are assessed before decisions are reached.

Development and development planning

Development of infrastructure of all types—transport, commercial buildings, houses, and so on—will have an impact on geoheritage conservation in protected areas. The most sensitive will be in existing protected areas or adjacent to them, where the effects will transfer across the protected area boundary. Key issues to be addressed before any decisions are made about actual development or before development proposals are written into plans are to consider the potential loss of features and the loss of natural processes that secure their conservation.

Large commercial, industrial and residential developments will affect the natural processes and could lead to permanent loss of protected areas. Attempts should be made to retain these areas within developments and ensure an adequate buffer zone is designated to safeguard their integrity.

Culverting and canalisation of water courses and flood prevention works along riverbanks are, for example, too damaging to be allowed where the natural processes of water flow and the features and forms created are the reason for protection. Similarly, these works will also hide key protected exposures in riversides, and should not be permitted unless there are exposures of equal value to be preserved nearby.

Coastal protection

Exposure of sections along the coast can reveal new sources of information about the evolution of life on Earth and about the processes that have operated in the past. Attempts to stop coastal erosion by construction of barriers will automatically conceal these interests and the rationale for the protected area status will be lost.

Many natural coastal systems are large in scale and highly dynamic and their perpetual protection is justified. Attempts to remove materials, especially sands, gravels and pebbles, for use in construction, and the placement of barriers made of wood or stone on the beach to halt the natural flow of sediments will inevitably undermine the rationale for protection and should be avoided.

Rising sea-levels and increased storminess in some parts of the world raise demand for greater protection of developed coastlines by the construction of hard engineering structures such as seawalls. These will irreplaceably damage adjacent protected area interest. Attempts should be made to use new solutions, such as allowing the coastline to retreat naturally inland and at the same time to relocate activities from the coastal edge to sites further inland so they are likely to be less affected. Where that is not an option, an alternative may be to utilise 'green infrastructure' (for example, through stabilisation of existing barrier islands by planting natural vegetation) or to develop artificial bars at or near the shoreline. These are challenging issues, as protection against potential loss of property is likely to be regarded

Managed realignment of the coast between artificial rock headlands at Montrose has helped to maintain sediment supply to the adjacent St Cyrus and Kinnaber Links Site of Special Scientific Interest and St Cyrus National Nature Reserve, Scotland, United Kingdom

Source: Roger Crofts

as of greater importance than loss of protected sites. In a landmark legal case in England, however, on an eroding coast where property was threatened, the fundamental principles of site designation and geoconservation, including allowing natural processes to take their course, were upheld by the courts (Prosser 2011).

Biodiversity conservation

Interactions between geoheritage and biodiversity conservation can be both positive and negative. The positive elements have been described earlier in this chapter. The negative elements need to be recognised and solutions found by protected area managers. 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 processes that maintain them. Taking a one-dimensional approach, favouring either geoheritage or biodiversity conservation is unlikely to result in a resolution benefiting conservation as a whole. Questions that will need to be addressed include the following.

- What is the basis of the conflict between the biotic and abiotic interests in and around the protected area?
- Is the conflict capable of resolution without undermining both interests or is it more fundamental?
- If the latter, is one of the interests more important than the other in the long term to national and international nature conservation and needs to be safeguarded and the other sacrificed?

There will also be practical questions to be addressed, such as the following.

- Is vegetation growth damaging or obscuring the geoheritage interest and would its removal or restraint damage the biodiversity interest? Alternatively, should the geoheritage interest be taken off-site or allowed to be obscured provided that if re-examination in the light of new knowledge is justified it can be periodically re-exposed?
- Are current Earth processes—for example, glacier melt or river erosion—which are important for maintaining the geoheritage interest, having a damaging effect on the biodiversity interest? If so, can manipulation of the processes to have minimal effect on their natural pattern be undertaken to achieve biodiversity conservation benefits?

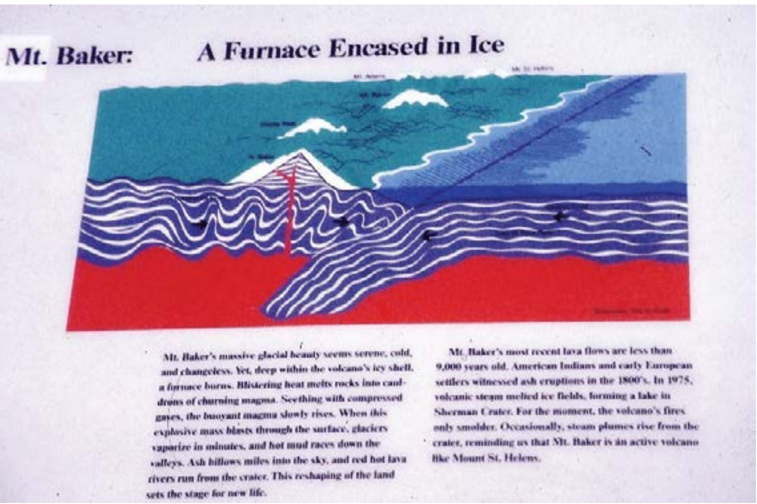
Sometimes it will not be possible to achieve a solution at the protected area level, and the wider context of the habitat, ecosystem or biome will need to be taken into consideration in determining the relative merits of conserving one element in one place and the other in another place within the biogeographical unit.

Finally, it is important to discourage attempts to maximise habitat/species diversity by landscape modifications that result in the creation of incongruous landforms/landscapes—for example, 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 (Gray 2013).

Box 18.4 National Fossil Day, USA

In 2010, National Fossil Day was established in the United States as an educational partnership to promote the scientific and educational values of fossils. Nearly 300 partners, including museums, professional science and teacher organisations, amateur palaeontology groups, fossil sites, universities, libraries and other categories, are distributed in all 50 States and provide fossil-related educational outreach and activities to children and families at the local level. National Fossil Day has become a nationwide celebration in the United States, which is hosted in the second week of October during Earth Science Week.

Source: National Park Service (2014a)



Mount Baker, North Cascades National Park, Washington State, USA: easily understandable sign interpreting the geological evolution of the landscape

Source: Roger Crofts

Geoheritage education and interpretation

Alongside site protection and management, raising wider awareness and involvement through education and interpretation is a key part of geoconservation. The purpose should be to inform and entertain as well as to educate, as recognised in the far-sighted aspiration of James Hutton (1785) that study of the Earth 'may afford the human mind both information and entertainment'. Education spans a broad spectrum, from learning through formal didactic education and informally by experience provided through interpretation. It also spans a broad spectrum of audiences from those simply wishing to 'be there' to those actively seeking education as a primary focus. Much of the conventional geoheritage interpretation is aimed at a broad sector in the middle. Effective geoconservation will ultimately depend on better public awareness, understanding and support.

Interpretation of geodiversity and geology-based tourism (geotourism) are not new, as demonstrated by the longstanding appeal of and cultural interest in show caves, glaciers, sacred mountains and other natural 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. Traditional geological interpretation, however, has been based on a didactic approach providing information rather than interpretation, with geologists using explanatory boards and leaflets. The problem has been that these are not aimed at the needs of the visitor as they are too detailed and use far too technical language, so the general user cannot understand them. Unfortunately, there are too many examples of this approach. Lessons could be learnt from the approaches taken by indigenous peoples and traditional local communities who have lived with and interpreted landscapes or landscape elements (or seascapes) in many different ways. They have integrated them into their daily lives, often according them spiritual, cultural and other significance, and often using them for crucial livelihood and ecological functions (for example, Cruikshank 2005).

Recent developments have been a more experiential approach in geo-interpretation, embracing the cultural dimension of geodiversity and resulting in more effective communication, through partnerships (Box 18.4) and the production of more appropriate materials, presented in stimulating ways using a range of media and based on the best interpretative practices and sound educational principles (for example, Tilden 1977; Ham 1992, 2007; Veverka 1994; Brown 2004; Scottish Natural Heritage 2011). Protected area managers can learn from these best-practice developments in interpreting and promoting geoheritage in a sustainable way. Innovative approaches include more integrated interpretation, linking, for example, geology, landscape, cultural heritage and industrial archaeology. The UNESCO-supported geoparks initiative has emerged as an important driver for innovation in geo-interpretation, with an agenda to engage with a wide and varied audience through promoting geotourism and related activities (Box 18.5).

Old Faithful visitor precinct, Yellowstone National Park, USA: compatible visitor facilities alongside maintenance of geothermal hot springs

Source: Roger Crofts

Box 18.5 Geoparks and geotourism

The geoparks rationale is to promote the conservation of geoheritage, as well as sustainable economic and social development, through understanding and experience linking geology, natural heritage and cultural heritage. Most geoparks emphasise the links between geological evolution of the landscape, biodiversity and people's lifestyles and cultural traditions, protecting and utilising geological assets through sustainable tourism development and linked with education, lifelong learning, guiding and wider environmental protection initiatives—for example, Jeju in Korea, the Oki Islands and San'in Kaigan Geoparks in Japan, and Stone Forest (Shilin) and Sanqingshan Geoparks in China. Many have developed innovative interpretation linking these different themes through the common thread of geology. For example, Katla Geopark in southern Iceland has developed innovative interpretation integrating the area's geological and cultural histories based on trails and on-site panels, digital tools and novel exhibits and installations designed to stimulate people's interest rather than simply present information, along with creative engagement with local schools (Katla Geopark 2014), while North Cascades National Park in Washington State, USA, has informative interpretation plaques on trails on subduction zones and evocative signs including John Muir's poetic prose (National Park Service 2014b). Exploring geoheritage in this way can enable protected area managers to

1. help local people and visitors to (re)discover a sense of wonder about geoheritage and its links with cultural roots and sense of place
2. provide opportunities for creative ways for people to engage with, and appreciate, geoheritage through different cultural experiences
3. promote a more holistic understanding of the natural world.

For further information and case studies on geotourism, see Dowling and Newsome (2010) and Newsome and Dowling (2010).

Monitoring and evaluation

Measuring and monitoring the condition of geoheritage protected areas are essential to establish their condition and state, and how these are changing. The US National Park Service has established guidelines for monitoring geological and palaeontological resources (Santucci and Koch 2003; Santucci et al. 2009). Similarly, the Geological Survey of Spain is currently developing an indicator system to assess and follow-up on the state of conservation of geoheritage (García-Cortés et al. 2012).

In Great Britain, protocols for monitoring SSSIs—the basic domestic protected area system for abiotic and biotic interests—are in place (Ellis 2004). The geomorphological component is based in part on the work of Werritty et al. (1998), who provided a conceptual and methodological framework for monitoring geomorphological features and systems. The key attributes measured and the targets based on the classification in Table 18.6 are:

1. protected area attributes to be monitored
    - 'visibility': factors to be monitored will be lack of concealment from vegetation/soil/talus build-ups/engineering constructions

- quality of appearance or lack of disturbance to the internal structure of features: the physical condition of rock, sediment, landform, spoil heap (for example, lack of disruption of sediments in a landform that are not yet visible); lack of fragmentation of exposure, no physical damage to important parts of rock faces, sediment stacks and landforms; quality and visibility are intimately linked attributes
- extent of features: for example, the quantity of geological material such as the volume of important spoil material in a mine dump, or area of rock face in an exposure site where it is advantageous to have a greater amount of rock exposure to study
- process dynamics: freedom of geomorphological processes to evolve naturally and unimpeded.

2. key indicators of favourable conservation condition
    - landform elements remain unconcealed
    - physical composition, morphology and internal structure of the key landforms and sediments remain intact and undisturbed by anthropogenic interventions
    - extent of key geomorphological features is not diminished through physical damage or fragmentation
    - natural geomorphological processes are unimpeded: the levels of activity of the geomorphological processes and their spatial domain retain the capacity to operate across their full range of natural variability
    - geological exposure remains unconcealed, intact and unmodified by anthropogenic intervention
    - extent of key geological features has not diminished: both vertical and lateral extent of features constant or increasing (Ellis 2004).

A broadly similar approach has been developed by the Tasmanian Government, which has identified three broad categories of geoconservation indicators

- data coverage indicators give the status of knowledge of geodiversity, which governs our ability to ensure the successful conservation of it
- site integrity indicators apply to sites of particular geoconservation significance, where the degree of physical integrity (or degradation) of the sites and features has been identified (for example, in the *Tasmanian Geoconservation Database*)
- 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 significance, and the integrity of ecosystem processes generally. Process integrity indicators will provide a measure of the sustainability of natural landform and soil processes (RPDC 2013).

Geoconservation expertise requirements and opportunities in protected area management

The variety of geoheritage protected areas and the amount and variety of knowledge required to identify and manage them effectively mean there is a great need for specialist geoconservation expertise. Geological and geomorphological scientific knowledge is essential if the protected areas are to be robustly identified and placed within wider Earth heritage systems and if the networks of areas are to be kept up to date with new knowledge and new interpretations. The safety of workers and visitors is of paramount concern in geoconservation protected areas, so expertise in risk assessments and management prescriptions is essential. Predicting and coping with the effects of floods, tsunamis, earthquakes, volcanic eruptions and active geothermal sites, slope failures, cliff instability, and glacial and permafrost melt are all examples of the need for technical knowledge. There should be scope for employing local experts to undertake specialist jobs as well as ensuring that local and traditional knowledge is pursued to best effect.

Management of specific types of geoheritage protected areas, such as sites with moveable heritage (fossils, minerals) or with active processes (coastal areas, rivers, and so on), is needed to ensure the key values are maintained, and that external actions and changes do not deleteriously affect the key features and processes. The ability to communicate the importance of the features and processes of protected areas in a manner the public can understand and be inspired by is also an important requirement of specialist staff.

Protected area management teams should progressively incorporate Earth science expertise with the aim of achieving an integrated approach to nature conservation. Bringing together geological, biological and cultural heritage specialists in teams will help to ensure full comprehension and conservation of natural resources (Díaz-Martínez and Díez-Herrero 2011).

A spectacular massed Jurassic *Ammonite* fossil deposit (often referred to as an *Ammonite* graveyard) is exposed on an erosion-resistant shoreline pavement near Lyme Regis, Jurassic Coast, Dorset and East Devon World Heritage Property, England. This is a Site of Special Scientific Interest. The circular fossil *Ammonites* may be seen, as can their location across the platform as identified by multiple circular pools of water that pinpoint the selectively eroded fossils.

Source: Graeme L. Worboys

Conclusion

The Earth's geodiversity is an essential consideration in protected area management, particularly in the context of managing for nature, both abiotic and biotic. Geoheritage is constituted by those elements of geodiversity that have significant scientific, educational, cultural or aesthetic values. Such special geoheritage may be systematically categorised according to key stages in Earth's history; structural features; formation of minerals; evolution of life; Earth process; surface and subsurface features and records of past environmental condition (Table 18.2). Key examples of geoheritage phenomena need to be protected, such as in geoparks, as IUCN Category III protected areas, or within other IUCN protected area categories. Once established, active responses by protected area managers are needed to address threats such as mineral exploitation and infrastructure development. Responses incorporate planning and on-ground works, while guiding principles of management (Box 18.3) establish a framework for such action. As with other natural phenomena, monitoring condition, and trends in condition, form an integral part of active management.

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