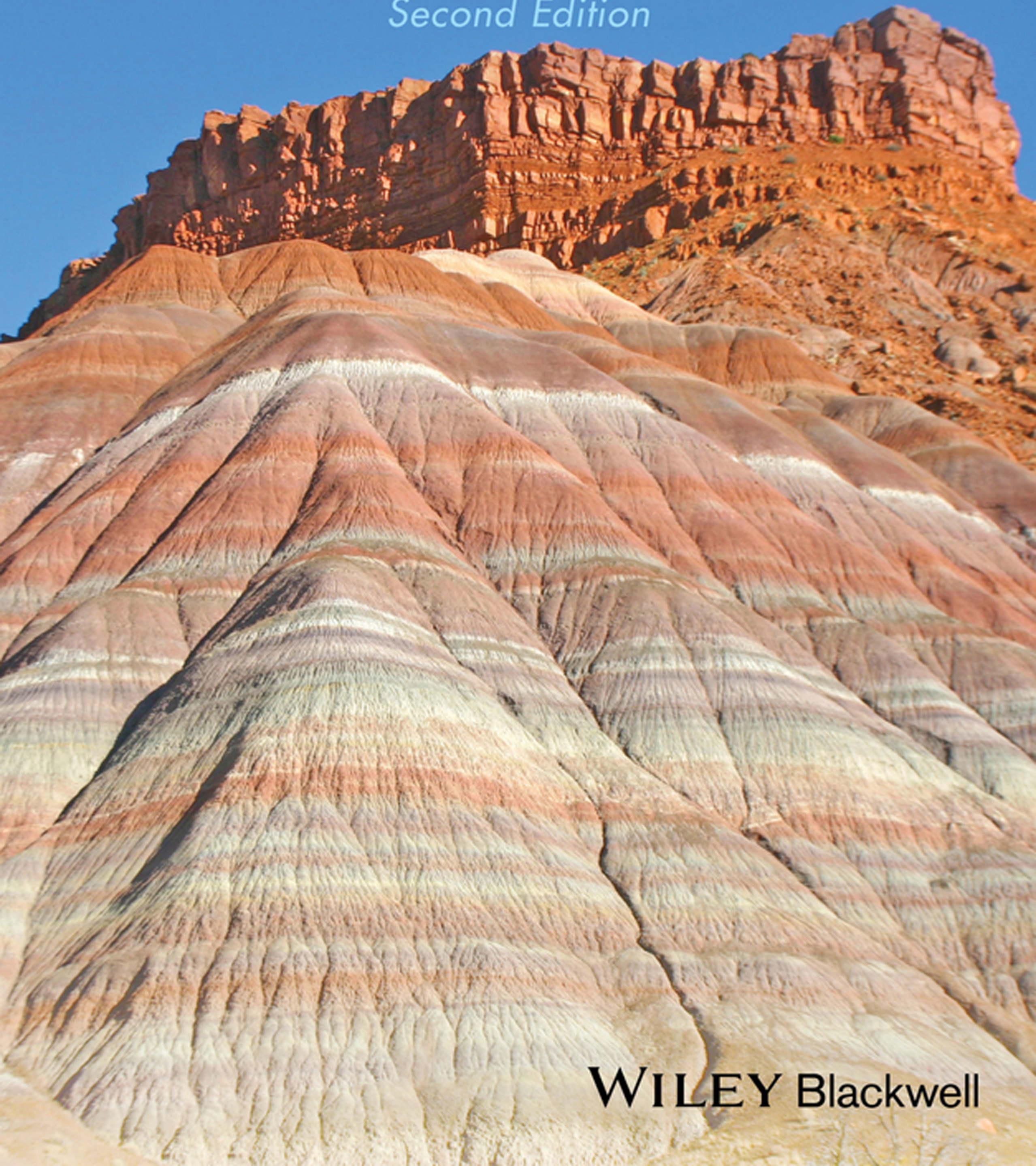
MURRAY GRAY

GEODIVERSITY

Valuing and Conserving Abiotic Nature

Second Edition



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Preface to Second Edition

It is almost 10 years since I completed the first edition of this book. This second edition has been extensively revised given the progress that has been made in the subjects of geodiversity and geoconservation over this time. For example, I have created separate chapters for 'World Heritage Sites' and 'Global Geoparks', given the increased interest and success of these site networks. Several of the other chapters have been split to make the subject matter more digestible. Chapter 4 on *Valuing Geodiversity* has been restructured to reflect the 'ecosystem services' approach. Chapter 6 has a new section on the need for conservation of the Global Stratotype Section & Points (GSSP) network. Most of the other chapters have been updated, and I have given greater attention to topical issues such as climate change and marine conservation. And overall, I have tried to make a clearer case for geodiversity being a fundamental basis for geoconservation, geotourism, geoparks, etc.

Since writing the first edition, I have been invited to give presentations in many countries including the Netherlands (twice), Norway, USA (twice), Canada, Portugal, Romania, Poland, Austria, Malaysia, Hong Kong and throughout the UK. I have also attended further conferences in Norway and Portugal as well as in Italy, Croatia, France and Greece. This has given me the opportunity to broaden my experience of geoconservation in these and other countries and this is reflected in new text or illustrations in almost every chapter. In particular, Chapter 13 is a new summary that draws upon this experience of geodiversity and geoconservation methods. I am very grateful for these invitations and opportunities and for the kind comments that colleagues have made about the first edition. I have developed my own ideas on geodiversity significantly over the last few years and incorporated these in this new edition. Inevitably these additions have had to be accompanied by some pruning of material, particularly in reducing the section on geoconservation of geomaterials.

I am very grateful to the many scientists with whom I have had discussions on issues in the book over many years. I am also grateful to Fiona Seymour and Lucy Sayer at Wiley Blackwell for their patience and encouragement when the preparation of this edition overran significantly. Jasmine Chang (Production Editor, Wiley, Singapore) and Sangeetha Parthasarathy (Laserwords, Pvt Ltd, India) skillfully managed the production of the book, assisted by Mitch Fitton (copyeditor) and Gill Whitley (permissions). Ed Oliver, Cartographer in

the School of Geography at Queen Mary, University of London kindly drew all the diagrams, and I am grateful to the many publishers and individuals who gave permission to reproduce figures and photographs in this book. As usual I thank Pauline for putting up with other things not being done while I completed this edition. Given my advancing years, I can assure readers that there will not be a third edition. So this is about my final contribution to our subject. I hope you find it interesting and useful and that younger generations can continue to advance a subject that deserves to be much better known and understood.

Murray Gray
Norfolk, January 2013

Preface to First Edition

I began writing this book on 11 September 2001 and completed it as the Iraq War drew to an end in April 2003. The nineteen months spent writing the book were dominated by the 'war on terror' and during that time much was written about globalisation, religious conflicts and cultural diversity. While Fukuyama (2001) sees these events as only blips in the trend towards modernity, Sacks (2002) believes that we should not just be tolerant of difference but should celebrate it. 'Only when we realise the danger of wishing that everyone should be the same—the same faith on the one hand, the same McWorld on the other—will we prevent the clash of civilizations. . . .' (Sacks, 2002, p. 209).

This book is about the value of difference, diversity and distinctiveness in the natural world. A few weeks after 9/11, when Osama bin Laden appeared on television to denounce the aerial bombing of Afghanistan, I predicted that specialists in that country's geology would be able to identify his whereabouts from the bedrock lithology and colour shown in the background. And sure enough, it was not long (*The Times*, 19 October 2001) before newspapers were reporting that Dr John Ford Shroder of the University of Nebraska had identified the rocks as being from the Pliocene Shaigalu or Eocene Siahan Shale Formations of the Katawaz Basin in south-east Afghanistan. This allowed search activities to be focused in these areas. This is a very unusual, but perfectly clear example of one of the applications of the principles of geological diversity. If Afghanistan had been composed of a single rock type, bin Laden's general whereabouts would have been much more difficult to locate.

On the first anniversary of 9/11, I was attending a conference on the geological foundations of landscape in Dublin Castle, Ireland. And as I stood for the minute's silence I was reminded too of Ireland's tragic past and present, but also of the way in which geology and landscape transcend administrative boundaries and can bring people together to value their heritage, conserve its integrity and overcome political barriers and national bureaucracies. In this case, the Royal Irish Academy and Geological Surveys of both the Republic of Ireland and Northern Ireland worked together to organise the conference and field trips.

The mountains and tectonics of Afghanistan, the deserts and rivers of Iraq and the bogs and coastline of Ireland, illustrate landscape geodiversity very clearly, but there is also diversity in their economic geology resources. The oil wealth of Iraq is well known and is attributed by some as the underlining reason for the war.

But Afghanistan also has a huge geological wealth, as yet largely unexploited. This includes an estimated 300 million barrels of oil, about 100 million tonnes of coal and large reserves of copper, gold, iron, chromite and industrial minerals (Stephenson and Penn, 2003). We also know about the Afghan gemstones—the lapis lazuli, ruby and spinel of Badkhshan, the emeralds in the Panjshir valley, the rubies and sapphires of Jegdalek and Gandamak and the pegmatites of Nuriston (Bowersox and Chamberlin, 1995). I hope that the people of Afghanistan will be able to realise the future projected for them by Bowersox and Chamberlin (1995, p. xv) when they said that 'At present, the Afghan gemstone wealth is undetermined, mostly undiscovered, and certainly unexploited. We believe the potential of the country is so great as to promise an acceptable standard of living for every man, woman and child. ....'

This book is aimed at several types of reader. First, I hope it will be of interest to those closely involved in geoconservation whether in universities, nature conservation agencies, geological surveys or other organisations around the world. The book is intended to highlight best practice and I hope there are ideas in it that specialists can use. I apologise if I have omitted brilliant initiatives in geoconservation in one country or another and hope that I will be told about these (j.m.gray@qmul.ac.uk) for a possible second edition. Secondly, the book is intended to stimulate discussion and thought on geoconservation by those whose primary concern has been wildlife conservation. It is therefore at least partly written with biologists and other non-geologists in mind. Thirdly, I hope it will stimulate further university courses in geodiversity and geoconservation and will become an established university textbook for second and third year undergraduates or postgraduate courses.

The book would not have been written without my three decades of experience working in the geosciences and public life, during which time I have benefited from the ideas of countless people. I was born and educated in Edinburgh and must thank my late parents for the educational opportunities they gave me. At the University of Edinburgh I studied both geography and geology and gained greatly from that education. There can be few better places to study the geosciences and conservation than Edinburgh and Scotland given their diverse geology and geomorphology, their association with founders of the subject like James Hutton, John Playfair and Charles Lyell, and the innovative conservation efforts that have been nurtured there from the famous nineteenth century American conservationist, John Muir, who was born in Dunbar, only 30 km east of Edinburgh, to the modern-day geoconservation work of Scottish Natural Heritage.

In public life, I have been a member of South Norfolk District Council and Chairman of its Planning Committee for many years and have served on regional planning panels and Environment Agency committees for the East of England. I am grateful to these organisations for the invaluable opportunities they have given me to understand how geoconservation can be promoted through local and regional government.

The book was largely written during sabbatical leave from my teaching duties at Queen Mary, University of London in 2001–2002 and I wish to thank the College authorities and my Head of Department, Professor Roger Lee, for their generous support and encouragement for this project. My geography colleagues not only covered my teaching, but also made many valuable suggestions for improving the book. Ed Oliver, cartographer in the Geography Department at Queen Mary, skilfully drew all the diagrams for this book to an unfairly short timescale.

During the sabbatical year I benefited from discussions with many people including John Gordon (Scottish Natural Heritage), Stewart Campbell (Countryside Council for Wales), Colin Prosser (English Nature), and by e-mail with Kevin Kiernan, Mike Pemberton and Chris Sharples in Tasmania, Archie Landals and David Welch in Canada and Vince Santucci in the United States. I spent May 2002 in the Canadian and American Rockies learning about geoconservation in those two countries and benefited from discussions with Dave Dalman (Banff National Park), Archie Landals (Alberta government), Dan Fagre (USGS, Glacier National Park), Arvid Aase (Fossil Butte National Monument), Hank Heasler and Lee Whittlesey (Yellowstone National Park), Bill Dolan (Waterton Lakes National Park) and numerous others. Other people, too numerous to mention have helped by providing detailed information or supplying diagrams or photographs and I am grateful to all of them.

The following people kindly read and commented on drafts of all or part of the book—Matthew Bennett, Cynthia Burek, Lars Erikstad, John Gordon, Archie Landals, Andrew McMillan, Mike Pemberton, Colin Prosser, Vince Santucci and Chris Sharples—and I am extremely grateful to all of them for their encouragement and valuable suggestions. This is a better book as a result of their comments. Cynthia Burek kindly allowed me to participate in the workshops aimed at creating a Local Geodiversity Action Plan (LGAP) in Cheshire.

I am grateful to many copyright holders for permission to reproduce figures. The sources are acknowledged in the figure captions, and where I received no reply I have assumed that there is no objection to inclusion of the material in this book.

I must thank John Wiley & Sons for their faith in this project and particularly to Sally Wilkinson and Keily Larkins for their efficient handling of the book material. Finally, my thanks to Pauline for putting up with my obsession with the geosciences in general and this book in particular over a long period of time.

Murray Gray
Norfolk, April 2003

Part I

What is Geodiversity?

1
Defining Geodiversity

If the Lord Almighty had consulted me before embarking upon creation, I should have recommended something simpler.
Alfonso X, King of Castile and Leon (1252–1284), quoted in Mackay (1991)

1.1 A diverse world

Let us begin by imagining the very simplest of planets (see Figure 1.1). A planet composed of a single monomineralic rock such as a pure quartzite. A planet that is a perfect sphere with no topography and where there is no such thing as plate tectonics. Although it has weather, this is very similar everywhere with solid cloud cover, light rain and no winds, so that there is little variation in surface processes or weathering. Consequently the soil is also very uniform. The absence of gradients and surface processes means that there is little erosion, transportation or deposition of sediments. This planet has seen few changes in its 4.6 thousand million year history and there is, in any case, no sedimentary record of these changes. To say the least, this is not a diverse or dynamic planet.

It has to be admitted that our imagined planet has certain attractions. In fact, Alfonso X was a forerunner of many Medieval and Renaissance writers who deplored the rough and disorderly shape of the Earth and 'infestation by mountains which prevented it from being the perfect sphere that God must surely have intended to create' (Midgley, 2001, p.7). Furthermore, there are no natural hazards such as earthquakes or avalanches to cause death and destruction. Civil engineering is very simple given the predictability of the ground conditions. Walking is easy with no gradients to negotiate or rivers to cross. But think of the disadvantages. In a planet made entirely of quartz there are no metals and therefore no metallic products. And in any case, since there is no coal, oil or natural gas, and no geothermal, wave, tidal or wind power, the energy to produce any goods or electricity is lacking. Everywhere looks the same so getting lost is easy and there is no sense of place. Employment and entertainment are limited, given the absence of materials and lack of environmental diversity. The quartzite

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Figure 1.1 'Knowledge', the sculpture by Wendy Taylor in Library Square at Queen Mary, University of London, United Kingdom. The steel ball at the centre represents the Earth. Fortunately the real Earth is not like this (see text).

is too hard and massive to quarry in the absence of mechanical equipment or explosives, so the buildings are primitive, being constructed from soil and the simple vegetation types that exist on our planet. For in the absence of physical diversity and habitat variation, little biological evolution of advanced plants and animals has been able to take place. This means that we humans would probably not exist on this planet, but if we did we would certainly find this to be a very primitive and boring place.

Thankfully our world is not like this. It is highly diverse in almost all senses—physical, biological and cultural—and although this produces problems for society and even conflicts and war, would we really want a less diverse and interesting home? The diversity of the physical world is huge and humans have put this diversity to good use even if we often fail to fully appreciate this fact. Diversity also brings with it flexibility of technologies and a greater ability to adapt to change.

Although our medieval ancestors hated the physical chaos of the Earth, our modern aesthetic appreciation of planetary diversity is probably deeply buried in our evolutionary psyche so that we often value it more than uniformity. The broad diversity of places, materials, living things, experiences and peoples not only makes the world a more useful and interesting place, but probably also stimulates creativity and progress in a wide range of ways. Diversity therefore brings a range of values, and it is the thesis of this book that things of value ought to be conserved if they are threatened. And, as we shall see, there are many threats to planetary diversity induced by human actions both directly and indirectly.

The term 'conservation' is used in preference to 'preservation' in this book since the latter implies protection of the *status quo*, whereas nature conservation must allow natural processes to operate and natural change to occur. Unfortunately, human action has often accelerated or tried to stop natural processes, and has thus destroyed much that is valuable in the natural environment. While change through human action is inevitable, we should at least understand the consequences of our actions and hopefully minimise the impacts and losses. Conservation is therefore about the management of change.

In the Preface to the first edition of this book I referred to a growing respect for diversity and a realisation that there is value in difference. Since then, the 'diversity' agenda has taken hold and there has been a blossoming appreciation for the value of local environmental, social and cultural distinctiveness and diversity. This book represents an undervalued aspect of this trend and aims to raise the profile of 'geodiversity'.

1.2 Biodiversity

Nowhere has the trend towards the value of diversity been more evident than in the field of biology. In recent decades the growing concern about species decline and extinction, loss of habitats and landscape change led to a realisation of the multi-functioning nature of the biosphere. For example it acts as a source of fibre, food and medicines, it sustains concentrations of atmospheric gases, it buffers environmental change and it contains millions of species of plants and animals, most of which have unknown value and ecosystem function and deserve respect in their own right. Yet of the 1.5–1.8 million known species, it is estimated that up to a third could be extinct in the next 30 years (Grant, 1995).

Concern for species and habitat loss led to some important international environmental agreements and legislation including the Ramsar Convention on wetland conservation (1971), Convention on International Trade in Endangered Species (CITES) (1973) and the Bonn Convention on Conservation of Migratory Species (1979). More recently the European Union has played an active role in biological conservation, for example through the Habitats Directive and Birds Directive.

An International Convention on Biological Diversity was first proposed in 1974 and during the 1980s the phrase 'biological diversity' started to be shortened to biodiversity. An important meeting of the US National Forum on Biodiversity took place in Washington DC in 1986 under the auspices of the American National Academy of Sciences and Smithsonian Institution. The conference papers (Wilson, 1988) mark an important milestone in the history of nature conservation and caused the issue to be taken seriously by politicians both inside and beyond America.

International recognition of the need for biosphere conservation led to the UN Convention on Biodiversity agreed at the Rio Earth summit in 1992, ratified in 1994 and signed by over 160 countries. The agreement was far reaching and the main features are listed in Table 1.1. Since then great attention has been given at international, national, regional and local levels to protecting and enhancing the biological diversity of the planet. These are usually classified into genetic diversity (conserving the gene pool), species diversity (reducing species loss) and ecosystem diversity (maintaining and enhancing habitats and their biological systems). And biodiversity is not just about numbers of species or ecosystems but about the countless interconnections between them. A wealth of strategies and action plans are being implemented to carry forward the aims of the UN Convention. Every signatory country must prepare a national plan for conserving and sustaining biodiversity, has a responsibility for safeguarding key ecosystems and is responsible for monitoring genetic stock. International designations include Ramsar sites (under the Ramsar Convention) Special Protection Areas (under the European Union Birds Directive) and Special Areas for Conservation (under the European Union Habitats Directive). The International Union for Nature Conservation (IUCN) has helped over 75 countries to prepare and implement national conservation and biodiversity strategies. Jerie, Houshold and Peters (2001, p. 329) have referred to this as 'the torrent of effort being put into the management of biodiversity'. Even some ecologists have spoken of the obsession with loss of species and habitats rather than focusing on the more important issue of functional significance of species in a variety of ecosystems (Dolman, 2000).

In the UK, *Biodiversity: the UK Action Plan* (HMSO, 1994), *Working with the Grain of Nature*, a biodiversity strategy for England (DEFRA, 2002a), *Conserving Biodiversity—the UK approach* (DEFRA, 2007) and *Biodiversity 2020* (DEFRA, 2011a) have been supplemented by many regional and local

Table 1.1 Main features of the Convention on Biological Diversity (after Mather and Chapman, 1995).

- Development of national plans, strategies or programmes for the conservation and sustainable use of biodiversity.
- Inventory and monitoring of biodiversity and of the processes that impact on it.
- Development and strengthening of the current mechanism for conservation of biodiversity both within and outside protected areas, and the development of new mechanisms.
- Restoration of degraded ecosystems and endangered species.
- Preservation and maintenance of indigenous and local systems of biological resource management and equitable sharing of benefits with local communities.
- Assessment of impacts on biodiversity of proposed projects, programmes and policies.
- Recognition of the sovereign right of states over their natural resources.
- Sharing in a fair and equitable way the results of research and development and the benefits arising from commercial and other utilisation of genetic resources.
- Regulation of the release of genetically modified organisms.

initiatives including Local Biodiversity Action Plans (LBAPs), Species Recovery Programmes (SRPs) and Habitat Action Plans (HAPs). These are being implemented by the national conservation bodies (Natural England, Scottish Natural Heritage, Natural Resources Wales, Northern Ireland Environment Agency) in collaboration with local authorities and a wide range of wildlife and conservation organisations (e.g. County Wildlife Trusts, Royal Society for the Protection of Birds, Campaign to Protect Rural England). By 2009 there were 1150 priority species and 65 priority habitats in the UK. In addition, Section 40 of the Natural Environment and Rural Communities Act (2006) requires all public bodies in England and Wales to have regard to biodiversity when carrying out their functions, and is now referred to as the 'biodiversity duty'.

About 100 books have appeared with 'biodiversity' in the title (from Wilson, 1988 to Waterton, Ellis and Wynne, 2012). Wilson (1997, p. 1) refers to 'biodiversity' as 'one of the most commonly used expressions in the biological sciences and has become a household word'. 'Biodiversity science' and 'biodiversity studies' have been born and the origin and maintenance of biodiversity 'pose some of the most fundamental problems of the biological sciences' (Wilson, 1997, p. 2). The Rio+20 conference in 2012 confirmed the importance of biodiversity and the threats to it.

1.3 Geodiversity

Geological and geomorphological conservation (geoconservation) have a long history. In 1668 the Baumannshöle cave in Germany was the subject of a nature conservation decree by Duke Rudolf August (Erikstad, 2008). In the first 20 years of the nineteenth century the quarrying of stone from Salisbury Crags in Edinburgh, Scotland, was having such a serious impact on the city landscape that legal action was taken in 1819 to prevent further deterioration (McMillan, Gillanders and Fairhurst, 1999; Thomas and Warren, 2008). An erratic boulder in Neuchâtel, Switzerland was protected in 1838 (Reynard, 2012). The first geological nature reserve in the world was established at Drachenfels/Siebengebirge in Germany in 1836 and other German hills were protected at Totenstein (1844) and Teufelsmauer (1852). Yosemite was protected by the State of California, United States, in 1864 and Yellowstone was established as the world's first National Park in 1872 largely for its scenic beauty and geological wonders (see Box 6.1). Also in the 1870s, Fritz Muhlberg campaigned to protect giant erratic boulders in Switzerland that were being exploited as kerbstones (Jackli, 1979), and in Scotland the 'Boulder Committee' was established, under the direction of David Milne Home, to identify all remarkable erratics and to recommend measures for their conservation (Milne Home, 1872a, 1872b; Gordon, 1994). Some of the first specific geological sites to be protected were also in Scotland where City Councils acted to enclose Agassiz Rock striations in Edinburgh (1880) and the Fossil Grove Carboniferous lycopod stumps in Glasgow (1887). Other initiatives have followed and many countries now have areas and sites protected at least partially for their geological or landscape interest. But despite many international conferences and books in the past 20 years (e.g. G. Martini, 1994; O'Halloran *et al*., 1994; Stevens *et al*., 1994; Wilson, 1994; Barrentino, Vallejo and Gallego, 1999; Gordon and Leys, 2001a; Gray, 2004; Burek and Prosser, 2008; Brocx, 2008; Wimbledon and Smith-Meyer, 2012), in most countries geoconservation is weakly developed and lags severely behind biological conservation.

Geologists and geomorphologists started to use the term 'geodiversity' in the 1990s to describe the variety within abiotic nature. The major attention being given to biodiversity and wildlife conservation was simply reinforcing the longstanding imbalance within nature conservation policy and practice between the biotic and abiotic elements of nature. Although geological and geomorphological conservation had been practised for over 100 years, these were usually the 'Cinderella' of nature conservation (Gray, 1997a). Many international nature conservation organisations, although using the general term 'nature conservation' appeared to see this as synonymous with 'wildlife conservation' and focused most or all of their attention on the latter. Milton (2002, p. 115) summarised the situation well in stating that 'Diversity in nature is usually taken to mean diversity of living nature ...'. Pemberton (2001a) believed that nature conservation agencies and governments across Australia, and overseas, 'tend to emphasize the need for the conservation of biodiversity whilst virtually ignoring the geological foundation on which this is built and has evolved'. He attributed this to the lack of training of earth scientists in geoconservation theory, policy and practice. He made the interesting observation that 'The majority of earth scientists are trained and employed in the extractive industries. To be involved in conservation could be seen to be contrary to the goals of the profession. ...' and he compares this with the biological sciences where conservation is a major graduate employer. 'This has generally meant that geoconservation has remained something of an oddity, divorced from mainstream nature conservation, and so it has generally had low priority within land management agencies' (Pemberton, 2001a). Although geoconservation has not yet been accorded great prominence in Australian nature conservation, Kiernan (1996, p.6) believed that 'few professional land managers would, having been made aware that a particular landform was, say, the only example in Australia of its type, seriously argue against the validity of safeguarding it, just as they would wish to safeguard the continued existence of a biological species.'

A similar situation has existed in the United Kingdom, where although geoconservation policy and practice have long been actively pursued and developed by several groups and organisations, this has not always been recognised by the wider nature conservation community or public. Therefore, some geologists and geomorphologists saw 'geodiversity' not only as a very useful new way of thinking about the abiotic world, but also as a means of promoting geoconservation and putting it on a par with wildlife conservation (Prosser, 2002a). An example of using 'nature' and 'wildlife' synonymously came in Sir John Lawton's report (2010) *Making Space for Nature* which was subtitled *A review of England's wildlife sites and ecological network*. Sadly and amazingly, it was followed by a government White Paper on the natural environment *The Natural Choice: Securing the Value of Nature* (DEFRA, 2011b), that manages, in its 76 pages, to discuss nature in England and Wales without once referring to geology, geomorphology or geodiversity!

In the United States, most nature conservation effort has been directed through the national parks system, and although several units of the system have been established for their geological or geomorphological interest (see Section 9.2.1), this is not always recognised. For example, Sellars' (1997) eloquent history of nature conservation in the US National Parks is almost entirely dominated by wildlife issues, reflecting the major concerns of the parks system over the past 140 years.

It is difficult to trace the first usage of the term 'geodiversity', and indeed it is likely that several earth scientists coined the term independently, as a natural twin to the term 'biodiversity'. Once the Convention on Biodiversity popularised the word and concept of 'biodiversity' in 1992, it became difficult to avoid noting that there is an abiotic equivalent. The early history of geodiversity was reviewed by Gray (2008a) who noted that the first use of the principle of geological diversity and its relevance to geoconservation pre-dates the Convention on Biodiversity. Kevin Kiernan, working for the Tasmanian Forestry Commission in the 1980s was using the terms 'landform diversity' and 'geomorphic diversity' and drawing parallels with biological concepts by using terms such as 'landform species' and 'landform communities' (K. Kiernan, pers. comm.). In one seminar paper in 1991, he pointed out that 'The diversity among landforms is just as valid a target as the diversity of life when developing nature conservation programs. . . . ' (Kiernan, 1991), a remark that was certainly prophetic. The term 'geodiversity' appears to have been first used by F.W. Wiedenbein in a German publication in April 1993 (see Wiedenbein, 1993, 1994), closely followed by Sharples in Tasmania in October of the same year (Sharples, 1993). Subsequently it became widely adopted in studies of geological and geomorphological conservation in Tasmania in particular (Kiernan, 1994, 1996, 1997a; Dixon, 1995, 1996a, 1996b). Sharples (1993) used it to cover 'the diversity of earth features and systems. He also stresses (Sharples, 2002a) the importance of distinguishing the terms 'geodiversity', 'geoconservation' and 'geoheritage'. He defines them as follows:

- 'geodiversity' is the *quality* we are trying to conserve,
- 'geoconservation' is the *endeavour* of trying to conserve it, and
- 'geoheritage' comprises *concrete examples* of it that may be specifically identified as having conservation significance.

The most important landmark for geoconservation in Australia was adoption of the Australian Natural Heritage Charter in 1996 and subsequently updated in 2002 (Australian Heritage Commission, 1996, 2002), which has the term and substance of geodiversity interwoven throughout its Articles (see Section 12.6). As a result, geodiversity is now a widely used and understood term in Australian nature conservation. However, Joyce (1997, p. 39) is critical of the term 'geodiversity' since it '. . . may be attempting to draw too strong a parallel between sites, landscape features and processes in biology and geology'. This issue is discussed in Section 14.1.

In 1995, Ibáñez, De-Alba and Boixadera (1995a), Ibáñez *et al.* (1995b) and McBratney (1995) started to use the word 'pedodiversity' to describe the diversity of soils as an abiotic component of global geodiversity (Ibáñez *et al.*, 1998).

In the United Kingdom, Gray (1997a, p. 323) suggested that 'perhaps one day we will see ... a Geodiversity Action Plan for the UK to rank alongside its biological counterpart' and this was launched in September 2011, partly to give a national frameworks for the many Local Geodiversity Action Plans (LGAPs) now published in the country (see Section 12.5). Stanley (2004, p. 48) argued that 'biodiversity is merely part of Geodiversity' and proposed a wide definition (see Table 1.2). Prosser (2002a, 2002b), in useful discussions of terminology, accepted the validity of the term 'geodiversity' and it has now become widely used throughout the United Kingdom.

The Nordic Council of Ministers introduced the term 'geodiversity' into nature conservation in their countries in 1996. Johannson (2000) published an excellent

Table 1.2 Some definitions of geodiversity.

Authors	Definition	Comments
Dixon (1996), Eberhard (1997), Sharples (2002a), Australian Heritage Commission (2002)	'the range or diversity of geological (bedrock), geomorphological (landform) and soil features, assemblages, systems and processes'	A thematic definition
Semeniuk (1997), Brocx (2008)	'the natural variety of geological, geomorphological, pedological, hydrological features of a given area, from the purely static features at one extreme, to the assemblage of products, and at the other, their formative processes'	An area-based definition. Note also the inclusion of hydrological features
Johannson *et al.* (2000)	'the complex variation of bedrock, unconsolidated deposits, landforms and processes that form landscapes . . . Geodiversity can be described as the diversity of geological and geomorphological phenomena in a defined area'	Note the emphasis on landscapes and defined area.
Nieto (2001)	'the number and variety of structures (sedimentary, tectonics, etc.), geological materials (Minerals, rocks, fossils and soils) that make up the terrain of a region, in which organic activity takes place, including anthropic'	Another area-based definition. Note also the inclusion of the relevance to biodiversity and human activity.
Stanley (2001)	'the link between people, landscapes and culture; it is the variety of geological environments, phenomena and processes that make those landscapes, rocks, minerals, fossils and soils which provide the framework for life on Earth'	A thematic definition strongly linked to human activity and biodiversity. Note also reference to landscapes.

Table 1.2 (*continued*)

Authors	Definition	Comments
Kozlowski (2004)	'the natural variety of the Earth's surface, referring to geological and geomorphological aspects, soils and surface waters, as well as to other systems created as a result of both natural (endogenic and exogenic) processes and human activity'	Note the inclusion of surface hydrology and the link with human activity.
Gray (2004)	'the natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (land form, physical processes) and soil features. It includes their assemblages, relationships, properties, interpretations and systems'	A thematic definition. Note reference to interpretations.
Spanish 'Natural Heritage and Biodiversity' National Law (2007)	'the variety of geological features, including rocks, minerals, fossils, soils, landforms, landscapes, geological formations and units, that are the product and record of the Earth's evolution'	A thematic definition. Note reference to landscapes and Earth history.
Serrano and Ruiz-Flano (2007)	'the variability of abiotic nature, including lithological, tectonic, geomorphological, soil, hydrological, topographical elements and physical processes on the land surface and in the seas and oceans, together with systems generated by natural, endogenous and exogenous, and human processes which cover the diversity of particles, elements and places'	A thematic definition, but note the inclusion of hydrology, seas and oceans and scale factors.
Burek and Prosser (2008)	'the variety of rocks, minerals, fossils, landforms, sediments and soils, together with the natural processes which form and alter them'	A thematic definition.

book on the geodiversity of the Nordic countries, and an English summary was produced in 2003 (Nordic Council of Ministers, 2003). Erikstad and Stabbetorp (2001) used the term in relation to natural areas and environmental impact assessment, and it appears now to be in common usage in the Scandinavian countries. A few authors in Europe (e.g. Panizza, 2009) have begun using the term 'geomorphodiversity' (geomorphological diversity) but this seems an unnecessary addition to the already overly complex geoconservation terminology.

Apart from the publication of a special issue of the *George Wright Society Forum* in 2005 (Santucci, 2005) and an article in *Geoscience Canada* in 2008

(Gray, 2008b), there is little evidence that the term has been adopted in North America.

Table 1.2 shows some of the main definitions of geodiversity that have been developed over the past 15 years, including one by the author that has been widely quoted. The table has a commentary on these definitions that suggests that a modified definition would be appropriate to incorporate hydrological features and landscapes in particular. Consequently, I propose the following new definition:

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

1.4 Aims and structure of the book

It is the thesis of this book that 'geodiversity' is a valid and appropriate way in which to look at planet Earth. The specific aims of this book are:

- to raise awareness of the geodiversity of the planet and the value of this diversity;
- to point out the threats to this diversity;
- to examine the ways that this diversity can be conserved, managed and restored;
- to outline the need for a more holistic and integrated approach to nature conservation and land management.

I hope the book will stimulate interest in these topics not just amongst geologists, geomorphologists and soil scientists, many of whom are at least aware of the issues, but also amongst the wider academic and non-academic community—biologists, nature conservationists, landscape architects, planners and politicians—for the world in general has not paid sufficient attention to these issues.

The book is divided into five parts comprising 15 chapters. These follow a natural sequence. The current Chapter 1 begins Part I, which tries to explain what geodiversity is. Chapters 2 and 3 attempt the extremely difficult task of describing the geodiversity of the planet. The aim of these chapters is not to catalogue every variation in rocks, minerals, sediments, processes, landforms, soils, fossils, and so on, but rather to outline the main principles and causes of diversity in the abiotic world. Chapter 2 looks at the early history of the Earth and evolution of global geodiversity. The focus of the book is on the terrestrial systems and the solid Earth (which I shall refer to as the 'geosphere'), rather than conservation or environmental management of all planetary abiotic systems. Consequently I shall say little about conservation of atmosphere and oceans. Chapter 3 examines the local scale. As stated above, biodiversity is often classified into genetic, species and ecosystem diversity, a classification that is based primarily on scale. Such a system is not as appropriate for geodiversity although we can certainly recognise scale differences in the abiotic world. For example, landforms combine to form landscapes which combine to make continents or tectonic plates. Nonetheless, the obvious way to classify abiotic nature is by using a well-tried tripartite subdivision of *material, form* and *process*. The main diversity in earth materials is in lithospheric materials—rocks, minerals, sediments and soils. Form comprises landforms and physical landscapes while numerous processes act on the materials to produce landforms. Anyone who already has a good understanding of the planet's geodiversity can probably skip this chapter.

Part II summarises the values of, and threats to, geodiversity. Chapter 4 discusses the value of the planet's geodiversity in terms of what are called 'abiotic ecosystem services' or 'geosystem services'. A summary diagram at the end of the chapter recognises over 25 types of abiotic value. Chapter 5 outlines the main threats to this valuable geodiversity including mineral extraction, river engineering, fossil collecting, urban expansion, coastal defence, waste disposal, agricultural practices and afforestation. The impact of these activities will be greater on some physical materials and systems than on others, and the issue of sensitivity and vulnerability to human modification emerges from this chapter as very important factors.

The subsequent chapters then follow logically from the previous two using the simple conservation equation:

$$\text{Value} + \text{Threat} = \text{Conservation need.}$$

Part III comprises four chapters describing the 'site-based approach' to geoconservation. Chapter 6 covers the general aspects of international geoconservation, including the important network of Global Stratotype Section and Point (GSSP) sites, while Chapters 7 and 8 describe World Heritage Sites and Global Geoparks respectively. These chapters along with Chapter 9 on National Geoconservation networks and strategies follow traditional methods of conservation, namely by designating protected areas and using legislation and other approaches to conserve and manage them.

Part IV looks at a range of other approaches and new initiatives to extend geoconservation beyond protected areas to the sustainable management of the 'wider landscape', Chapter 10 focusing on the landscape conservation, Chapter 11 on land-use planning and Chapter 12 on policy making.

Finally, in Part V I have attempted to bring ideas together. Chapter 13 tries to draw together some of the main elements of the previous seven Chapters to describe some of the aims and methods of geoconservation and the role of geodiversity as an important basis for geoconservation, geotourism, geoparks, etc. Chapter 14 revisits some important issues for geodiversity in relation to biodiversity and discusses a basic paradox for geodiversity. On the one hand the subject needs to establish itself as a distinctive, independent and essential field of nature conservation, but on the other there is a growing need and trend towards an integrated approach to nature conservation incorporating geological and biological systems and indeed to integrated land management in general. Finally Chapter 15 draws some conclusions and tries to establish a revised vision for the year 2025.

This structure of valuing geodiversity, understanding the threats and conserving and managing the resource and indeed the whole impetus for writing the book follows a logical pattern reflected in the following quote from African conservationist, Baba Dioum (in Rodes and Odell, 1997):

> For in the end we will conserve only what we love.
> We will love only what we understand.
> And we will understand only what we are taught.

I hope this book stimulates a much greater interest in the values of geodiversity and the need to conserve them.

2 Geodiversity: the Global Scale

The wondrous world that we are so familiar with has been shaped by fundamental forces operating on scales that we humans can barely grasp,

Iain Stewart and John Lynch (2007)

The geodiversity of the Earth is hardly less remarkable than its biodiversity. Any attempt to fully describe this geodiversity would fill several books, and so the challenge in the next two chapters is to summarise it in a few thousand words concentrating on the factors producing the diversity rather than an encyclopaedic catalogue of the whole range of minerals, rocks, sediments, fossils, soils, landforms, processes, etc. on the planet. There are several books that describe the geology, geomorphology and pedology of the Earth in more detail, many of them in lavish colour. Readers are referred to those by Summerfield (1991), Grotzinger and Jordan (2010), Holden (2012) and particularly to the superbly illustrated book by Marshak (2012).

Geodiversity applies at various scales from the global scale of continents and oceans to elemental scale of atoms and ions. This is no different to the scale issue in biodiversity where bioscientists have to deal with habitat variations on a global scale, but also with genetic diversity and biotechnology at the microbiological scale. This chapter deals with the global scale—the early history of the Earth and plate tectonics—since they are the keys to understanding much of the planetary geodiversity at many scales.

2.1 Origin the Earth

To understand the current geodiversity of the planet we need to understand how the planet originated and how it has evolved through its 4 600 000 000 year (4.6 Ga) history. Astrophysicists believe that the Earth and other planets of our

Geodiversity: Valuing and Conserving Abiotic Nature, Second Edition. Murray Gray.

solar system developed from a residual disk of gas and dust, called a planetary nebula, left over from the formation of the Sun, perhaps 15 Ga. All 92 naturally occurring elements were already in existence at this time, having been formed by nuclear fusion at very high temperatures from an original mix of hydrogen and helium, the two lightest elements.

There then followed a long series of collisions and combinations in which gaseous atoms coalesced to form molecules, molecules combined to form dust, and dust accreted to become small pieces of rock called planetesimals (Marshak, 2012). Over millions of years further collisions resulted in larger and larger rock lumps that in turn attracted smaller pieces, often as meteorites. Thus 'the Earth was conceived and grew violently, a chaos of impact and fragmentation and annealing. All was instability' (Fortey, 1997, p. 31). Eventually, a series of protoplanets revolving (in the same direction and, with the exception of Pluto, in the same plane) around the Sun evolved into the planetary system we see today, with smaller lumps (asteroids and meteoroids) still hurtling around space and occasionally colliding with the planets. The Earth's Moon is believed to have been formed when a particularly large collision at 4.5 Ga blasted debris into orbit that subsequently coalesced (Canup and Asphaug, 2001). It is still pockmarked by impact craters, whereas the Earth's have been largely eradicated by subsequent geological evolution (see later). The near spherical shape of the planets is produced by gravitational pull aided by geothermal heat as a result of planetesimal collision and radioactive decay of elements.

The Earth's basic composition was established at this early stage with iron (35%), oxygen (30%), silicon (15%) and magnesium (13%) forming most of the Earth's matter (Table 2.1). The solar wind is believed to have blown most of the light elements (hydrogen, helium, etc.) into the outer parts of

Table 2.1 Composition (by weight) of the whole Earth and of the crust. Note that differentiation has created a light crust depleted in iron and rich in oxygen, silicon, aluminium, calcium, potassium and sodium (after Press and Siever, 2000).

Element	Whole Earth	Crust
Iron	35	6
Oxygen	30	46
Silicon	15	28
Magnesium	13	4
Nickel	2.4	< 1
Sulphur	1.9	< 1
Aluminium	1.1	8
Calcium	1.1	2.4
Potassium	< 1	2.3
Sodium	< 1	2.1
Other	< 1	< 1