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World Heritage Desert Landscapes

Potential Priorities for the Recognition of Desert Landscapes and Geomorphological Sites on the World Heritage List

IUCN World Heritage Programme

WCPA
WORLD COMMISSION ON PROTECTED AREAS

United Nations Educational, Scientific and Cultural Organization

World Heritage Convention

Published by: IUCN, Gland, Switzerland

Citation: Goudie, A. and Seely, M. (2011). *World Heritage Desert Landscapes: Potential Priorities for the Recognition of Desert Landscapes and Geomorphological Sites on the World Heritage List.* Gland, Switzerland: IUCN. 44pp.

Cover photo: Camel train in the desert of Tadrart Acacus, Algeria, inscribed on the World Heritage List for cultural criteria (Rock-Art Sites of Tadrart Acacus). 2007. © Catherine Gras

Layout by: Delwyn Dupuis

Produced by: IUCN World Heritage Programme

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Abstract

The world's deserts, which cover about a third of the land surface and occur in every continent including Antarctica, are areas with severe shortage of moisture. One consequence has been a wide range of unusual and spectacular landforms, sculpted by wind, occasional but strong rainfalls and ancient riverine systems. As a result of the aridity, the landforms and the processes that led to their formation remain clearly visible, uncovered by extensive vegetation. The fauna and flora of deserts often shows unusual, often extreme, adaptations to their arid habitats.

The purpose of this study is to advise State Parties to the World Heritage Committee on non-polar deserts as potential World Heritage Sites of Outstanding Universal Value with a focus on geomorphological aspects. It also discusses some of the issues relating to the integrity and management of these areas and the need to conserve them.

This study is produced as part of IUCN's role as advisory body to the UNESCO World Heritage Convention on natural heritage.

Acknowledgements

IUCN expresses its gratitude to the authors of the study, and to a number of reviewers who contributed comments on the draft study: Bastian Bomhard, Ronald Cooke, Bernhard Eitel, Exequiel Ezcurra, Nick Lancaster, Piotr Migon, Tony Parsons and Jim Thorsell. IUCN is also grateful to the International Association of Geomorphologists for their partnership in initiating this study, and in identifying reviewers. Within IUCN, Tim Badman, Tilman Jaeger and Tatjana Puschkarsky coordinated production and review at various stages of the production of the study.

About IUCN

IUCN, International Union for Conservation of Nature, helps the world find pragmatic solutions to our most pressing environment and development challenges. IUCN works on biodiversity, climate change, energy, human livelihoods and greening the world economy by supporting scientific research, managing field projects all over the world, and bringing governments, NGOs, the UN and companies together to develop policy, laws and best practice.

IUCN is the world's oldest and largest global environmental organization, with more than 1,000 government and NGO members and almost 11,000 volunteer experts in some 160 countries. IUCN's work is supported by over 1,000 staff in 60 offices and hundreds of partners in public, NGO and private sectors around the world. IUCN is the independent advisory body to the World Heritage Committee on natural heritage.

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1. INTRODUCTION

1.1 A GLOBAL REVIEW OF DESERT WORLD HERITAGE PROPERTIES: PRESENT SITUATION, FUTURE PROSPECTS AND MANAGEMENT REQUIREMENTS

The purpose of this thematic study is to advise State Parties to the World Heritage Convention on:

1. The scope of desert values already included on the World Heritage List.
2. The potential and priorities for further future recognition of desert landscapes and features on the World Heritage List in relation to the relevant World Heritage criteria.
3. The requirements for integrity and management that should apply to desert landscapes and features on the World Heritage List.

The geographical spread of this report is global, including, but not limited to, the territory of member states to UNESCO. The thematic scope of this study is on sites included, or with the potential to be included, on the World Heritage List in relation to their value as:

a) Landscapes that are formed by the primary action of desert processes and are of potential Outstanding Universal Value.
b) Desert features of outstanding and universal importance in relation to geosciences, including their accessibility and comprehension by civil society (*note*: IUCN considers this does not include sites with interests that are only of a specialised scientific importance).

This report concentrates on sites that are of particular value in terms of their geomorphology and landscapes. Issues relating to biodiversity may be important supporting values in these potential sites and in some cases may provide additional basis for possible World Heritage recognition. However, it should be noted that the present study does not seek to provide an analysis of sites that could be granted World Heritage Status on the grounds of their biodiversity values alone. This will be the subject of a subsequent study.

The World Heritage Committee considers natural heritage as having Outstanding Universal Value if the property meets one or more of the following criteria: (vii) to contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance; (viii) to be 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; (ix) to be outstanding examples representing significant ongoing ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals; (x) to contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of Outstanding Universal Value from the point of view of science or conservation. In this context, the study focuses primarily on sites with potential to meet criteria (vii) and (viii) of the World Heritage Convention.

The world’s deserts are of considerable importance on a number of grounds. First of all, they cover (depending on the definition adopted) up to one third of the Earth’s land surface. Secondly, they are home to a large number of people. Currently around 500 million people live in deserts and desert margins, totalling 8 per cent of the global population (UNEP 2006, *Global Deserts Outlook*). Thirdly, deserts harbour some rich ecosystems, though due to the extremely slow rate of biological activity in some arid areas, these ecosystems can take a long time to recover from damage. Deserts are also important in terms of economic activity: intensive irrigated agriculture, tourism, exploitation of hydrocarbon resources, etc. Fourthly, phenomena such as dust storms can have an impact on ecosystems all over the world.

1.2 CLASSIFICATION OF WORLD DESERTS

The world's deserts (**Figure 1**) occur in every continent including Antarctica and are areas where there is a severe shortage of moisture, predominantly because precipitation levels are low. In some deserts aridity is partly the result of high temperatures, which means that evaporation rates are high. In this review, we do not deal with polar deserts, even though they are very dry with the precipitation of the Arctic regions being as low as 100 mm *per annum* and at Vostok in Antarctica being less than 50 mm. Although some of these regions display the role of aeolian and other desert processes, they are for the most part dominated by the role of snow and ice.

Systems for defining aridity tend to be based on the water balance. This is the relationship that exists in a given area between the input of water in the form of precipitation (P), the loss arising from evaporation and transpiration by plants (evapotranspiration) (E_t), and any changes that may occur in storage (soil moisture, groundwater, etc.). By definition, in arid regions there is an overall deficit in water balance over a year and the size of that deficit determines the degree of aridity. The actual amount of evapotranspiration (AE_t) that occurs will vary according to whether there is any available water to evaporate, so climatologists have devised the concept of potential evapotranspiration (PE_t), which is a measure of the evapotranspiration that would take place from a standardised surface never short of water. The volume of PE_t will vary according to four climatic factors: radiation, humidity, temperature and wind. Thornthwaite (1948) developed a general aridity index (AI) based on PE_t (potential evapotranspiration):

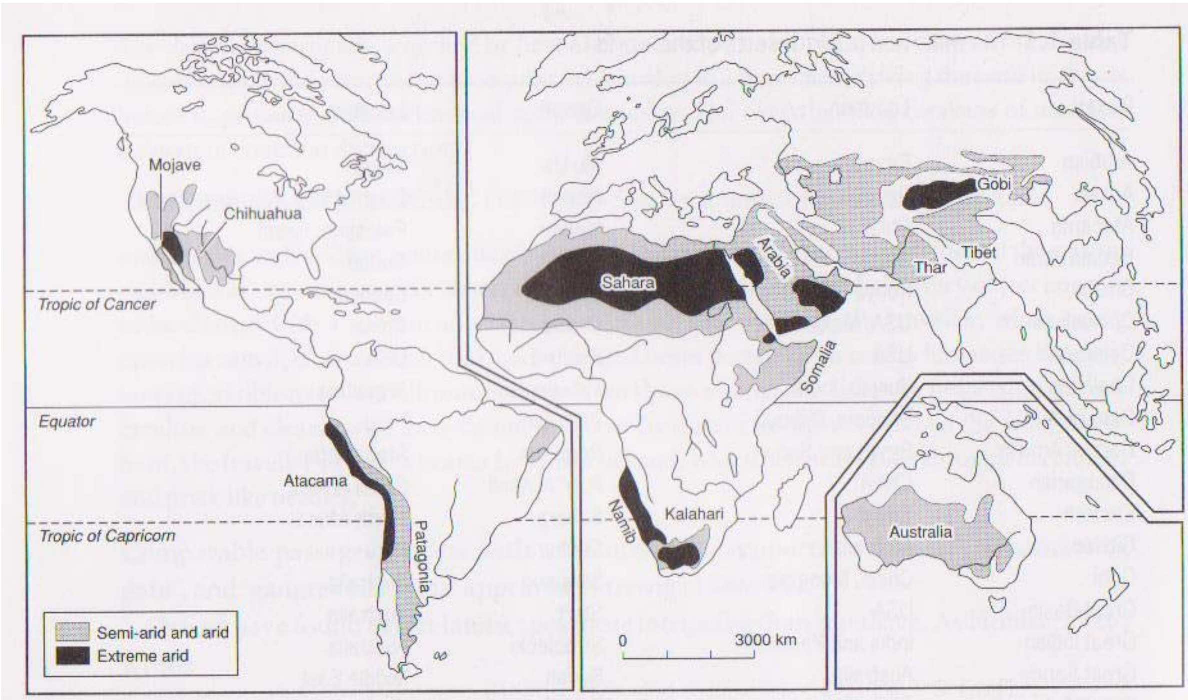
$AI = 100\ d/n$

The water deficiency d is calculated as the sum of the monthly differences between precipitation and potential evapotranspiration for those months where the normal precipitation is less than the normal evapotranspiration, and where n stands for the sum of monthly values of potential evaporation for the deficient months.

When $P = PE_t$ throughout the year, the index is 0.
When P = 0 throughout the year, the index is – 100.
When P greatly exceeds PE_t throughout the year, the index is + 100.

Under this system, areas with values below –40 are regarded as arid, those between –20 and –40 as semi-arid and those between 0 and –20 as sub-humid (Meigs 1953). The arid category can be further subdivided into arid and extreme arid, with extreme aridity being defined as the condition experienced in any locality in which at least 12 consecutive months without any rainfall have been recorded, and in which there is not a regular seasonal rhythm or rainfall. Deserts themselves tend to be seen as including the extreme (or hyper) arid, arid and semi-arid categories. All three categories are considered in this study.

Figure 1 Major non-polar deserts (from Goudie, 2002)



Extremely arid areas, which occur in the Atacama, Namib and the central and eastern Sahara, cover about 4 per cent of the earth's surface, arid areas about 15 per cent, and semi-arid areas about 14.6 per cent. Combined, these areas amount to almost exactly one-third of the Earth's land surface area.

There are various other aridity indices that have been developed. The United Nations Environment Programme has defined an index in their *World Atlas of Desertification* (UNEP 1992) where:

$AI = P/PE_t$

Under this classification hyper-arid areas have an aridity index less than 0.05 (c 7.5% of the global land area), arid areas have an aridity index between 0.05 and 0.20 (c 12.1% of the global land area), semi-arid areas have an aridity index between 0.20 and 0.50 (c 17.7% of the global land area) and dry sub-humid areas have an aridity index between 0.50 and 0.65 (c 9.9% of the global land area).

Some classifications are based on the length of the growing period. FAO regards arid areas as having a growing period of less than 75 days per year, semi-arid areas as having a growing period of less than 120 days per year, and dry sub-humid areas having a growing period of less than 180 days in the year.

In addition, deserts can be classified on the basis of their proximity to the oceans. Coastal deserts, such as the Namib of south western Africa or the Atacama of western South America, will have very different temperature regimes and humidity characteristics from the deserts of continental interiors. They tend to have relatively modest diurnal and seasonal temperature ranges and to be subject to frequent fogs.

The world's non-polar deserts occur in five great provinces separated by either oceans or equatorial forests. The largest of these by far includes the Sahara and a series of other deserts extending eastwards through Arabia to central Asia. The southern African province consists of the coastal Namib Desert and the Karoo and Kalahari inland dry zones. The South American dry zone is confined to two strips - the Atacama and Altiplano along the west coast and the Patagonian Desert along the south east coast.

The Atacama Desert near Putre, northern Chile, showing the snow covered peaks of the Andes Mountains. Photo: Andrew Goudie

The North American desert province occupies much of Mexico and the south-western United States, including the Mojave, Chihuahuan, Sonoran and Great Basin Deserts. The fifth and final province is in Australia, which is the driest of the continents apart from Antarctica.

Since, on the basis of climatic characteristics, one third of the Earth's land surface can be classified as desert, it is not surprising that there should be a great diversity of desert landscapes. Just as the temperate regions of the world comprise such features as mountains and plains, lakes, rivers and deltas, deserts have a corresponding diversity of topographic features.

Deserts may first be divided into those whose relief units are determined by geological factors and then subdivided into those which are distinctive owing to more specifically geomorphic factors. Thus, for example, while one can distinguish between shield deserts and mountain-and-basin deserts, on a more detailed scale these may be subdivided into sand deserts, stony deserts, clay plains and riverine deserts.

Mountain ranges and their associated basins make up between 40 and 50 per cent of the land surface of the Saharan, Arabian and south-western United States deserts. Though the overall relief is a product of tectonics, the landscape is modified by the desert climate, which is itself atypical since mountainous areas in deserts frequently receive more rainfall than the surrounding low-lying areas and may be cool enough to experience occasional frost. These mountains may act as the source areas for rivers.

The mountain-and-basin deserts are often undergoing present-day mountain building, and these tectonic processes create sharp fault junctions between mountains and plains. Alluvial fans are common at the point where sediment laden streams leave the mountain front and spread out over the plain or *bajada* zone. One of the finest examples of this type of desert is the fault-block topography of the arid lands of the south-western United States. In Death Valley, high mountains rising to over 3000 m are close neighbours of salt flats which lie below sea level. The high relative relief is one of the major controls of the types of geomorphological processes that operate.

The shield deserts which occur in India, Africa, Arabia and Australia have much less relief than the mountain-and-basin deserts, and this is rarely enough to lead to a moderation of aridity or to introduce forms which result from current frost action. They are also areas where tectonic activity has been less, so that ancient landforms have often survived extensively.

Within desert regions of these two major structural types there are some areas which are dominated by erosion, some by deposition, some by water action, some by wind action, some which are zones of salt accumulation and some which are zones of salt removal. The nature and location of the processes which operate are strongly influenced by the topographic situation. Thus Mabbutt (1969) (in Cooke et al. 1993) has described various major physiographic settings:

- *Desert uplands*, where geological controls of relief are important, bedrock is exposed, and relief is high. An existing World Heritage property in this setting is the Grand Canyon in the United States of America.
- *Desert piedmonts*, which are zones of transition separated from the uplands by a break of gradient but which nonetheless receive runoff and sediments from the uplands, and which have both depositional (e.g. alluvial fans) and erosional forms (e.g. pediments).
- *Stony deserts*, which consist of stony plains and structural plateaus, and may have a cover of stone pavement. An existing World Heritage property in this setting is Uluṟu-Kata Tjuṯa National Park in Australia.
- *Desert rivers and floodplains* (features of desert lowlands), which consist of the alluvial tracts and old terraces of major rivers. They are often characterised by anabranching channel

systems. Often they derive their flow from relatively humid upland areas and so may be subject to occasional severe floods.

- *Desert lake basins,* which are sumps to which the disorganised drainage progresses, and which are often salty. Existing World Heritage properties in this setting include Lake Turkana National Parks (notably Lake Rudolf) in Kenya and the Península Valdés of Argentina.
- *Sand deserts*, which tend to be beyond the limits of active fluvial activity but often derive their material by wind action removing erodible material from floodplains or lake basins, river deltas or coastal sand flats. They are characterised by dunes. An existing World Heritage property with these features is Aïr and Ténéré Natural Reserves, Niger, in the Sahara.

The tectonic settings of contemporary dryland areas have been discussed by Rendell (in Thomas 1997), who identified five types: cratons (shield and platform areas); active continental margins, associated with Cenozoic orogenic belts; older, Phanerozoic, orogenic belts; inter-orogenic basin and range and inter-cratonic rift zones; and passive continental margins. Examples of each of these types are given in **Table 1**.

The proportions of different deserts that are covered by dunes vary greatly. In the Sahara, Arabian Peninsula, Australia and Southern Africa, active sand seas cover between 15 and 30 per cent of the area classified as arid. By contrast, in the Americas, aeolian sand covers less than 1 per cent of the arid zone.

Another aspect of landscape diversity between different deserts is the extent to which drainage is to interior basins (i.e. endoreic) or directly to the sea. This may be an important control of such geomorphologically important phenomena as playa lake development and salinity. Endoreic systems are widespread in arid areas, but are by no means universal. Nonetheless, there is a striking contrast, for example, between the Kalahari, where there is little surface drainage and large closed depressions (e.g. Mkgadikgadi) and the coastal Namib, where rivers with mountain source areas flow directly into the Atlantic Ocean. It is a remarkable fact that all those parts of the world whose surfaces lie below sea-level are in desert areas.

Unfortunately, “the distribution and relative spatial importance of fundamental landform types has not yet been consistently or quantitatively described throughout the desert realm.” (Cooke et al. 1993) However, a flavour of diversity is presented in **Table 2** which shows the proportions of landform types in four desert areas where relevant data is available: the south-western United States of America, the Sahara, the Libyan Desert (mainly Egypt and Libya) and the Arabian Peninsula. The importance of fans and bajadas in the American southwest is striking as is the importance of bedrock fields (including hamadas) in the Sahara.

Table 1 Tectonic settings of arid zones

Contemporary tectonic setting	**Examples**	**Comments**
1. Cratons	Kalahari (Botswana) Great Karoo (South Africa) Simpson Desert (Australia) Rub Al Khali (Saudi Arabia)	Relative stability since the late Tertiary

Contemporary tectonic setting	Examples	Comments
2. Active continental margins and Cenozoic orogenic belts	Atacama (Peru and Chile) Sahara Sinai-Negev (Israel, Egypt and Palestine) Arabia-Zagros (Saudi Arabia and Iran) Thar (India) Taklimakan (China)	Compressional setting, thrust and transcurrent faulting
3. Older orogenic belts	Sahara Aravallis (India)	Some reactivation of existing fault zones
4. Inter-orogenic, inter-cratonic	Afar and Danakil (Ethiopia) Mojave Desert (USA) Great Basin (USA) Sonoran Desert (USA and Mexico) Chihuahua Desert (USA and Mexico) Monte Desert (Argentina)	Extensional tectonic setting, 'pull-apart' basins
5. Passive continental margins	Namib Desert (Namibia and South Africa) Patagonian Desert (Argentina and Chile)	

Note: The physical extent of the Sahara is such that it features in several of the categories listed above. *Source:* adapted from Rendell 1997, Table 2.1.

Table 2 Proportions of landform types in selected non-polar deserts

Landform type	South western USA	Sahara	Libyan Desert	Arabia
Desert mountains	38.1	43	39	47
Playas (base-level plains)	1.1	1	1	1
Desert flats	20.5	10	18	16
Bedrock fields (including hamadas)	0.7	10	6	1
Regions bordering through-flowing rivers	1.2	1	3	1
Dry washes	3.6	1	1	1
Fans and bajadas	31.4	1	1	4
Dunes	0.6	28	22	26
Badlands and subdued badlands	2.6	2	8	1
Volcanic cones and fields	0.2	3	1	2
Total	100.0	100	100	100

Source: Clements et al. (1957 in Cooke et al. (1993)). Figures are percentages of areas. *Note* that there is a lack of comparable data for some important desert regions, e.g. Central Asia.

2. OVERVIEW

2.1 DESERT LANDFORMS AND PROCESSES

Deserts possess a wide range of landforms and land forming processes, some of which are present in other biomes, but some of which are unique to or particularly well developed in dryland areas (**Table 3**).

Barchan sand dunes in the Kharga Oasis, Western Desert, Egypt. Photo: Andrew Goudie

Wind processes and landforms

Wind processes and landforms are very important in deserts. Dunes occur in a range of forms. Barchans are crescentic-shaped individual dunes, the horns of which point downwind. They occur in areas with limited sand supply and unidirectional winds. Barchanoid ridges are asymmetric waves, oriented transverse to the wind direction, which consist of coalesced barchans in rows.

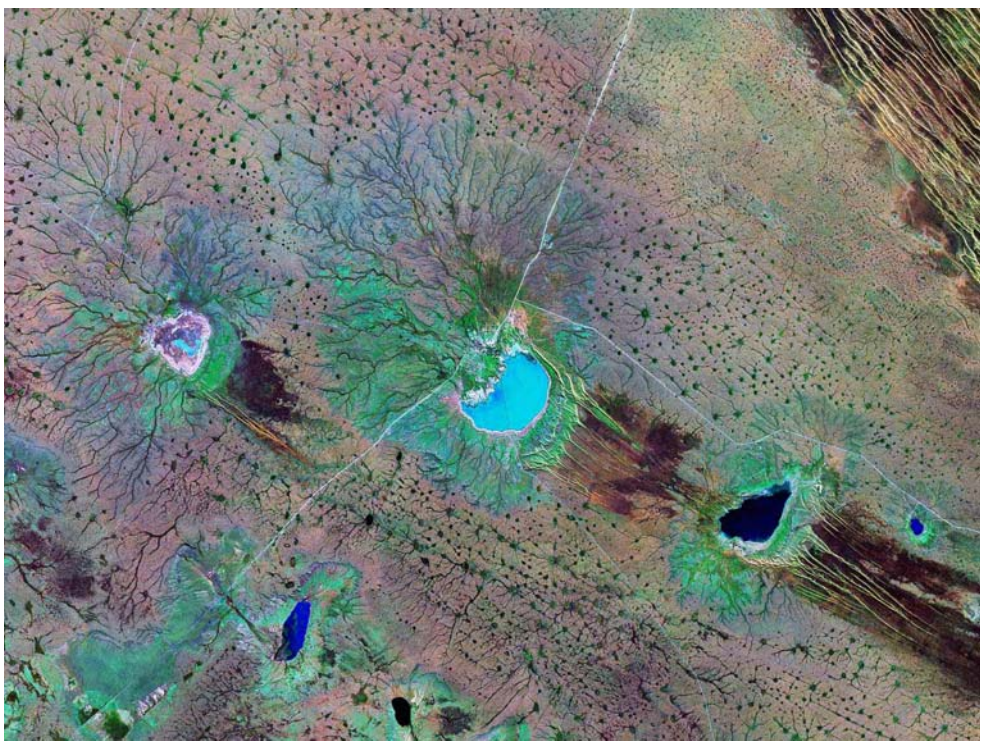
Table 3 Examples of desert landforms in existing natural and cultural World Heritage Sites

Landform	**Examples of presence in World Heritage Property**
Aeolian features	
Dunes	Willandra Lakes Region (Australia) (linears and lunettes) Aïr and Ténéré Natural Reserves (Niger)
Yardangs	
Pans	Willandra Lakes Region (Australia), Península Valdés (Argentina)
Dust storms and deflation surfaces	
Coastal sabkhas	Banc d'Arguin (Mauritania)
Weathering forms, processes and surface materials	
Sodium nitrate (caliche) crusts	Humberstone and Santa Laura Saltpeter Works (Chile) (cultural property)
Gypsum crusts (gypcrete)	
Calcium carbonate crusts (calcrete)	
Salts and salt weathering	
Cavernous weathering forms (tafoni and alveoles)	Rock-Art Sites of Tadrart Acacus (Libya), Tassili n'Ajjer (Algeria) (cultural property)
Desert varnishes and rinds	Twyfelfontein or /Ui-//aes (Namibia) (cultural property)
Desert karst and tufa deposition	Purnululu National Park (Australia) (sandstone only)
Fossil lakes and other pluvial evidence	
Relict weathering profiles	
Lake basins with palaeo shorelines, stromatolitic tufas etc.	Lake Turkana National Parks (Kenya)
Ancient river systems	
Fluvial and slope processes and forms	
Ephemeral stream channels (wadis)	Grand Canyon National Park (USA)
Badlands	Dinosaur Provincial Park (Canada), Ischigualasto/Talampaya Natural Parks (Argentina) (natural sites listed primarily for fossil values)
Pediments	
Sheetflood activity	
Inselbergs	Uluṟu-Kata Tjuṯa National Park (Australia)
Pediments	
Alluvial fans	
Debris flows	
Groundwater sapping	Grand Canyon National Park (USA)
Natural arches	Rock-Art Sites of Tadrart Acacus (Libya) (cultural property)

Complex sand dunes in the Alashan Desert, north western China. Photo: Andrew Goudie

Some transverse dunes also form normal to the dominant wind direction but lack barchanoid structures. Dome dunes form where dune height is inhibited by unobstructed strong winds. They lack a steep slip face. Linear dunes are parallel, straight dunes with slip faces on both sides and with their lengths many times greater than their widths. They often occur in areas with narrow bimodal winds. Blowouts result from the erosion of a pre-existing sand sheet, while parabolic dunes represent a type of blowout in which the middle part has moved forward with respect to the sides or arms. In areas of complex winds dunes may have a star-like form while in areas with winds from two opposing directions, reversing dunes may occur. In addition to these simple forms, more complex patterns combine various elements. Yardangs are wind erosion features with an aerodynamic shape, which may have relative relief of more than 100 m. They may run for tens of kilometres and have the same alignment as the prevailing, unidirectional winds. They are characteristic of hyper-arid areas. Pans, created by deflation of susceptible materials, are closed basins, which often have distinctive shapes and orientations with respect to winds. On their lee sides they may have accumulations of Aeolian material called lunettes. Tens of thousands of them occur in areas like the Llano Estacado of New Mexico or in Kazakhstan. Deflation of desert surfaces by the wind leads to dust storms, and these transport large amount of material away from desert source regions, thereby impacting on many components of the Earth System. They occur in hyper-arid areas, with strong winds and a ready source of deflatable material. In coastal areas, a combination of wind erosion, wind deposition, and marine action can produce extensive tidal salt flats called sabkhas.

A salt pan in Western Australia. Photo: Andrew Goudie



A landsat image of pans, both large and small, near Koes, Kalahari Desert, Namibia. Source: courtesy of NASA


A dust storm in West Africa. Photo: Andrew Goudie

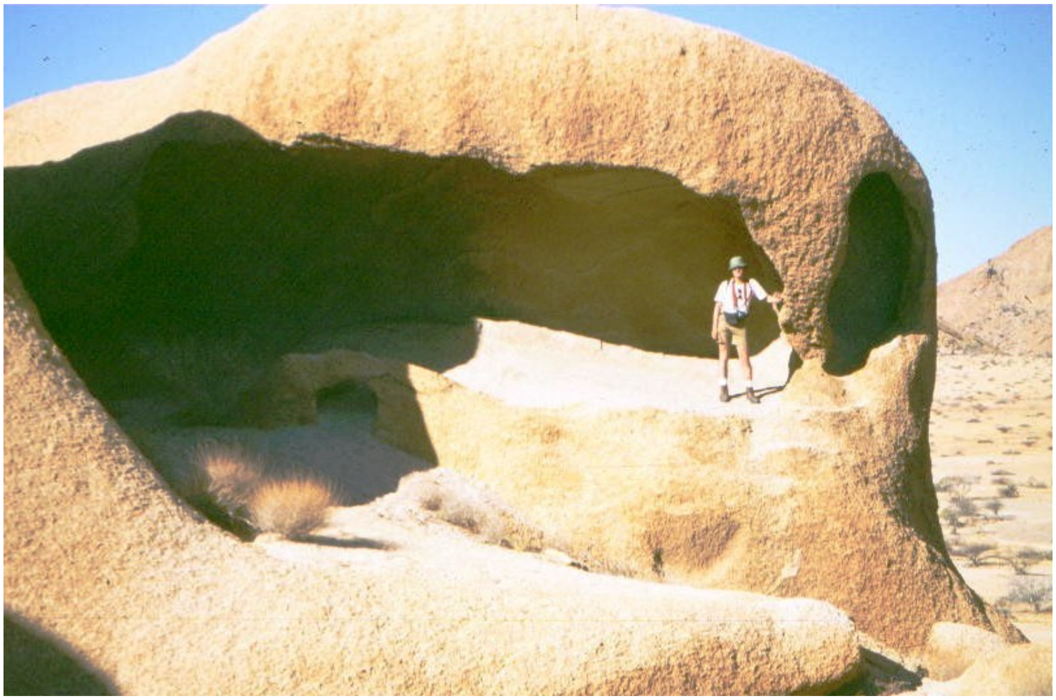
Weathering processes, forms and surface materials

Various types of highly characteristic surface materials are found in deserts. These include the accumulation of various types of crust (duricrust), including sodium nitrates (called caliche in South America), gypcretes (composed of calcium sulphate), and calcretes (composed of calcium carbonate).


Polygonal structures developed in gypsum crusts, near the Chotts of central Tunisia. Photo: Andrew Goudie

The build up of salts on desert surfaces can promote effective rock disintegration by salt weathering. Among the features thereby produced are cavernous forms, including tafonis and alveoles. Weathering, deflation, sheetflood action and vertical sorting processes produce armoured surfaces called desert or stone pavement. Desert surfaces are often covered in a dark patina of iron and manganese oxides, called desert varnish. In spite of the low rainfall, limestone solution does take place, producing small, shallow surface depressions called dayas. The deposition of calcium carbonate from solution means that freshwater carbonates, tufas or travertines, are also widespread in some desert areas.

A massive tufa accumulation in the Naukluft Mountains of Central Namibia.
Photo: Andrew Goudie



A large cavernous weathering feature developed in granite at Spitzkoppje, Namibia. Photo: Andrew Goudie

A tafoni developed in volcanic rock in the Atacama desert of northern Chile. Photo: Andrew Goudie.

Fossil lakes and other pluvial evidence

Many desert areas show the profound effects of more humid past conditions called pluvials. For example, areas that are currently very arid and salty may have previously held large freshwater lakes, more extensive drainage networks and ancient weathering profiles (as with the ferricretes and silcretes of central Australia). Conversely, there is evidence that in the late Pleistocene and other times parts of the tropics were drier than today so that deserts, including dune fields, were much more extensive. Relict dune fields cover much of the Kalahari and Sahel of Africa.

In spite of their current aridity, most deserts are greatly moulded by fluvial processes. Incision by desert streams (wadis) may be extensive, and in extreme cases leads to the formation of areas with exceptionally high drainage densities, called badlands. Surface runoff by sheetfloods creates extensive, gently sloping, rock cut surfaces called pediments or glacis, and these may abut steep, isolated hills called inselbergs. Rivers coming out from mountain fronts, especially in areas of active tectonism, may spread out to produce alluvial fans. The surfaces of alluvial fans may be created in part by debris flows. Groundwater may play a role in the formation of some desert stream networks and in the undercutting of slopes, contributing to the formation of natural arches.

A typical granite inselberg in the Spitzkoppe Range of central Namibia. Note the sharp break between the mountain mass and the gently sloping pediment at its foot.
Photo: Andrew Goudie

2.2 DESERT BIOTA AND CHARACTERISTICS

The desert biome comprises a variety of complex ecosystems with diverse and fragile groupings of sometimes bizarre plants, animals and fungi and little studied members of the Protista and Monera. The biomes may be influenced by their positions in coastal, inland or rain shadow deserts (Ezcurra 2006). Key characteristics of the biota are their adaptations to aridity, climate variability, scant summer and winter rainfall patterns and, most importantly, unpredictable rainfall pulses. Some elements of the desert biota escape from the desert environment while others tolerate it (Louw and Seely 1982). Some may find their homes only in the very limited, usually isolated wetland habitats of the drylands. The adaptations fostering tolerance may take the form of morphological, physiological or behavioural adaptations but most commonly some combination of the three.

A typical array of vegetation types with differing adaptations for coping in desert environments. (Clockwise: *Moringa ovalifolia*, *Aloe asperifolia*, *Parkinsonia africana, Trichocaulon clavatum*). Photos: Mary Seely

The most important factors that affect life in the desert biomes include radiation, heat and temperature, wind, water and nutrition. The radiant environment to which organisms in the desert environment are exposed is complex including, inter alia, direct solar radiation, diffuse radiation from clouds and the atmosphere, and considerable short wave radiation reflected from the soil's surface and other objects. The heat to which a desert organism is exposed comes not only from solar radiation but includes metabolic heat production, radiant heat transfer, conduction, convection and evaporative heat exchange, all of which are exacerbated in the desert environment. Wind and the role of limited water in the water balance of the organisms are also important influencing factors, together with nutritional stress. That plants and animals survive in the harsh and unpredictable conditions in desert environments at all requires an array of adaptations responding to the complex habitats in which they live.

Most plants and animals survive in the desert because they have adapted their life to avoid the most extreme of desert conditions. Tolerance of desert environments by organisms involves morphological, physiological and behavioural adaptations. Organisms may exploit favourable micro-climates within the desert ecosystem, no matter how unpredictable. Longer term escape and shorter term retreat describe the adaptations most commonly observed. Ephemerality and micro-climate exploitation are found in many desert plants. Diapause, as exemplified by temporary pond inhabitants, is usually facultatively, not seasonally, controlled in desert biomes. Prolonged dormancy, or aestivation, is important for ectothermic vertebrates. Birds and large mammals may undergo seasonal migration to take advantage of temporary resource availability. Short term escape, or retreat, usually refers to exploitation of available micro-habitats that are used daily in a myriad of ways by vertebrates and invertebrates alike.

Plant morphology, exemplified by cacti, contributes to tolerance of desert environments. Similarly, plant and arthropod cuticle, vertebrate integument and pelage and animal colouration present a variety of morphological adaptations. Water storage, ectopic fat storage and the shape and size of desert organisms are important adaptations for desert animals. Morphological adaptations are as varied as the desert biota, but all contribute, in one way or another, toward tolerance of desert environments and the diversity of life they support.

Physiological and behavioural adaptations are also wide-ranging. These include tolerance of tissue to high temperatures, tolerance to dehydration, tolerance to cold, adaptive heterothermy and behavioural thermoregulation. Additional adaptations consist of osmoregulation in arthropods, renal and extra-renal osmoregulation in desert vertebrates as well as other specialised respiration and transpiration in desert plants and animals. Imbibition of fog, dew and water vapour is a key adaptation where water is scarce as is the ability to adjust nutrition and metabolic rates. None of these adaptations, involving escape, retreat or tolerance, operate in isolation. It is the myriad combinations of morphological, physiological and behavioural adaptations that have evolved in diverse desert environments that contribute to the unexpectedly high and varied biodiversity and endemism of desert biomes.

An array of desert fauna with a variety of adaptations typically found in deserts. *(Clockwise: tenebrionid beetle – Onymacris bicolor; solifuge – Prosolpuga schultzei; chamaeleon – Chamaeleo namaquensis; nara cricket – Acanthoproctus diadematus).*
Photos: Mary Seely.

Combinations of adaptations of plants to desert environments result in a variety of expressions (Ezcurra 2006). Some desert succulents accumulate moisture in their fleshy stems and often have shallow root systems to capture minimal amounts of soil moisture after scanty rain. They mainly photosynthesise during the night to limit water loss. Columnar growth forms maximize exposure to light early and late in the day while avoiding excessive heat from the mid-day sun. Other plants have developed rosettes of succulent leaves that collect dew and fog. Yet another group of woody plants may drop their leaves during dry times and often have long taproots as well. Many desert plants have adopted an ephemeral life cycle, surviving as seeds, bulbs or dormant shrubs for long periods between unpredictable rains. The different attributes for survival contribute to the very varied flora of deserts.

Animal adaptations to life in deserts are as varied as those of plants and often act in concert. Mobile animals may move out of the desert completely during dry times while others may take refuge in burrows or simply beneath the sand. Side-winding behaviour has evolved in several deserts as a way to traverse warm surfaces. Animals with four legs may raise themselves above the hot ground and bipedalism allows rapid traverses at greater distances from the surface. Tails, ears, feathers or different coloured pelage may be deliberately used to warm or cool by different animals at different times of their daily cycle. The adaptations to maintain water balance range from ability to drink large quantities of water at one time to absorbing water through the skin or rectal pads as found in some insects. Taking up water from food, reducing water loss, tolerating dehydration, facultative hypothermia, and dormancy are all used individually or in combination as part of the diverse array of adaptations to maintain water balance.

Although abiotic factors greatly influence plants and animals in deserts, interactions between species may be equally important. Plants may serve as 'nurse plants' to germinating seedlings or provide shade or nesting shelters for animals. Conversely, birds or bats or rodents may serve as pollinators and a variety of animals disperse seeds. Protection of seeds from consumption has resulted in a variety of seed dispersal tactics that include seed capsules dispersing seeds decades after the plant itself has died. Biotic interactions are a fascinating, highly varied component of desert biodiversity.

Deserts tend to have relatively low biomass of plants and animals simply because of the arid environment although in some deserts the density and biomass of ants, termites, scorpions and isopods may be extraordinary. Nevertheless, most deserts have relatively high diversity with respect to reptiles and invertebrates and sometimes to succulent plants. Scorpions and camel spiders (solpugids) are more species-rich in deserts than in other habitats and along with spiders and acarines (mites and ticks) are particularly successful in deserts. Depending on the definition of the desert area, the degree of endemism of invertebrates, reptiles and some plants can be high. In most desert areas the invertebrates are not well known and their degree of endemicity may be higher than estimated. Protection of seemingly barren desert areas for their undiscovered endemic plants and animals could be expected to yield valuable results.


Living in sand has produced some of the more extreme adaptations in plants and animals. Photos: Mary Seely.

Left: Stipagrostis sabulicola: 20 m long roots extending just below or on the surface to collect fog and dew is fairly extreme to allow individual grass clumps to live at least half a century.

Right: A 'thermal dance' whereby the Meroles anchietae picks up first one foot and then the other to cool down while extending its foraging time on the surface.

3. PRIORITIES FOR DESERT WORLD HERITAGE SITES

This section reviews, largely in tabular form in Annex 1-4, previous IUCN reports on landscapes, features and previous decisions of the World Heritage Committee in relation to desert sites (data valid 2008). It provides context for the following section where sites of significant potential for recognition are suggested.

Sixteen World Heritage properties with earth science features of Outstanding Universal Value were listed by Dingwall et al. (2005). We identified eight desert World Heritage properties with earth science features of Outstanding Universal Value: Dinosaur Provincial Park (Canada), Grand Canyon National Park (USA), Ischigualasto/Talampaya Natural Parks (Argentina), Purnululu National Park (Australia), Tassili n'Ajjer (Algeria), Uluṟu-Kata Tjuṯa National Park (Australia), Wadi Al-Hitan (Egypt) and Willandra Lakes Region (Australia). The properties display a variety of geomorphological features ranging from fluvial features to sandstone and granite, mountains and plains. Despite being located in arid areas, the plant species richness amongst the properties ranges from 400 to 2,556 species. **Annex 1** lists these properties and their features (from Table 1, Dingwall et al. 2005).

A provisional assessment suggests that two properties can be identified as World Heritage properties with significant earth values, but which are inscribed on the World Heritage List for other reasons (Dingwall et al. 2005). Both properties, Aïr Ténéré (Niger) and Banc d'Arguin (Mauritania), are on the African continent and both were listed for their biodiversity values. Their geomorphological characteristics include plateaus, canyons, dunes and a volcanic massif as well as a coastal saline, mangrove swamp and salt marsh. **Annex 2** lists these properties and their features.

Three inscribed desert properties were not identified in the list of Dingwall et al. (2005). They lie in Africa (Lake Turkana, Kenya), Asia (Uvs Nuur Basin, Russia and Mongolia) and South America (Valdés Peninsula, Argentina) and their geomorphological features include: a rift valley lake, delta and active volcanoes, salt lakes and salt pans. **Annex 3** lists these properties and their features.

Five inscribed cultural properties with significant desert geomorphological values have been identified in South America, Asia and Africa: Humberstone and Santa Laura Saltpeter Works (Chile), Petra (Jordan), Rock-Art Sites of Tadrart Acacus (Libya), Tsodilo (Botswana) and Twyfelfontein (Namibia). Their geomorphological features include nitrate (caliche) deposits, weathering sandstone, rock domes and ancient dunes. **Annex 4** lists these inscribed cultural properties and their outstanding features.

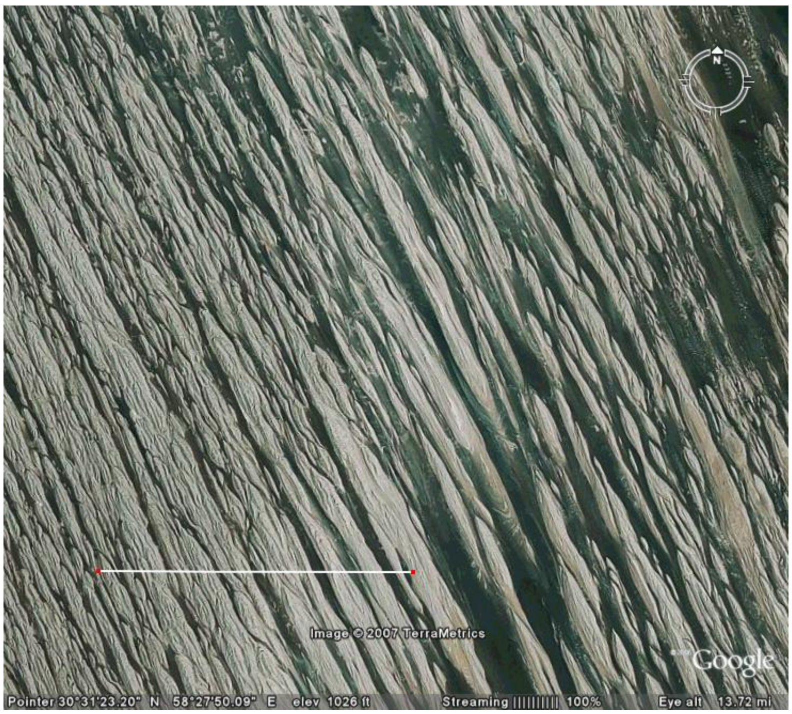
3.1 REVIEW OF TENTATIVE LISTS FROM STATE PARTIES

State Parties have filed Tentative Lists of potential World Heritage sites in their territories. Due to both changing information and lack of detail in some Tentative List entries, it is not possible to present a completely exhaustive review of all Tentative List sites relating to deserts that have been put forward by State Parties.

Seventeen desert landscape sites were identified which have been included by State Parties on their Tentative Lists. Two are suggested in the Tentative Lists as possible mixed properties, two as cultural properties and the remainder as natural properties. In terms of location, six are in Asia, eight in Africa and three in South America. The geomorphological characteristics cover a wide variety of forms. **Annex 5** lists these Tentative List sites. It should be noted that, due to the ever changing nature of notified Tentative Lists, this range of properties will vary over time, and is likely to have varied at least slightly since the above analysis was completed.

The Lut Desert in Iran, the Western Desert of Egypt, the Southern Namib Erg in Namibia, Chott el Jerid in Tunisia, the Thar Desert in India and Taklimakan Desert in China are identified by the authors as areas of *high potential* for listing. In the case of the Western Desert of Egypt and the Namib, the boundaries of the properties put forward on the Tentative List and the area that could have potential as considered in this present study are not necessarily identical and need further refinement.

1) The Lut Desert, Iran. This desert contains some of the largest and best developed yardangs found anywhere on Earth. These features, locally termed *kaluts*, form parallel ridges and depressions over an area of 120 x 50 km. Some of the ridges exceed 60 m in height, and run parallel, with superbly developed aeolian streamlining, parallel to the formative *shamal* winds. They are located near Bam (which is currently inscribed on the World Heritage List, and the List of World Heritage in Danger), and occur in association with some impressive barchan dunes (Gabriel 1938).



Enormous parallel yardangs (kaluts) in the Lut Desert of Iran. Source: Google Earth

2) Great Desert Landscapes / Western Desert, Egypt. The Western Desert in Egypt is significant as being the site of some of the most formative work that has even been undertaken in Aeolian geomorphology, most notably by Ball, Cornish, King, Beadnell and above all, Bagnold. It is characterised by classic barchans and linear dunes that have probably been the subject of more serious observation than any other dunes on Earth. However, it also has a full range of other desert features that reflects the area's profound aridity: spring mounds, tufa spreads, groundwater sapping features, closed depressions, yardangs, relict karst, the Selima Sand Sheet, and the sandstone topography of the Gilf Kebir (Embabi 2004).

Ralph Bagnold, pioneer of dune studies, recording sand movement in the Gilf kebir of the Western desert, Egypt in 1938. Photo: R.W.Peel

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The Dakhla Oasis, Western desert, Egypt, showing limestone cliffs (background) and deflated Holocene pluvial lake beds (middleground). Photo: Andrew Goudie

3) Southern Namib Erg / Namib Desert, Namibia. The ancient coastal Namib Desert of southern Africa has an extended period of detailed desert research based at the Gobabeb Training and Research Centre. The modern Sand Sea is underlain by a fossil desert of Tertiary age, represented by the lithified Tsondab Sandstone. In addition to this important example of desert evolutionary history, the Namib also exemplifies the impact of sea floor spreading since the Cretaceous, with the emplacement of many sub-volcanic complexes and the development of an upwarped marginal escarpment. It also contains the full range of dune types, excellent examples of the ways in which river courses can be blocked by dunes (as at Sossus Vlei), great spreads of calcretes and tufas, and many examples of granite weathering and inselberg and pediment formation (Lancaster 1989). This site is currently noted on the Tentative List in relation to both natural and cultural values.

Some of the world's largest dunes at Sossus Vlei in the Namib-Naukluft Park, Namibia. Photo: Andrew Goudie

4) Chott el Jerid / The Chotts, Tunisia. The closed basins of Tunisia, the subject of much classic French geomorphological research, consist of a series of large basins that were formerly more extensive in pluvial times. They are notable as being examples of saline basins, but they also have within them some of the best world examples of gypsum crusts and of gypsum dunes. They are bounded in part by extensive rock ramps, called glacis. The Chott Djerid is probably the most important of these features (Swezey 1997).

5) Thar Desert, India. The Thar is a relatively moist desert. It is characterised by suites of ancient dunes, including many that are cemented by calcium carbonate. It is unusual for displaying many dunes of parabolic form and for being traversed by many abandoned or shifting river courses. It is an example of a relatively low energy wind environment.

6) Taklimakan, China. The Taklimakan is one of the world's largest and highest deserts and is notable for its large arrays of dune forms, its large bounding alluvial fans, its pluvial lakes, and its ability to produce large numbers of dust storms.

A number of other Tentative Lists sites have very considerable merit as exemplars of *particular* geomorphological processes or landforms, and may have potential to demonstrate Outstanding Universal Value. Of particular note are the following:

1) Band-E-Amir, Afghanistan. These lakes, located in an arid portion of the country, have been the subject of detailed research by French and other scientists, and are of very considerable aesthetic appeal. They are a suite of tufa-dammed lakes which are of comparable importance to the Plitvice Lakes of Croatia. They may also warrant recognition on account of their karstic value.

2) Las Parinas, Argentina. This region belongs to the northern extreme of the Geological Province Cordillera Frontal and to the southern extreme of the Geological Province Puna, rising up to 6,400 meters, an arid area with mean annual rainfall less than 200 mm. The two highest volcanoes of the American Continent, Pissis and Ojos del Salado, are located within this area.

3) Les Lacs d'Ounianga. Chad. These lakes, which occur in the lee of topographic obstructions, are good examples of deflational basins, and also occur in an area of sand dunes, some of which may be relict features of former more arid conditions.

4) Gravures et peintures rupestres de l'Ennedi et du Tibesti, Chad. This is another classic mountain area of the central Sahara with excellent examples of many desert features. This site is currently noted on the Tentative List in relation to its cultural values.

5) San Pedro de Atacama, Chile. This site (mean annual rainfall less than 100 mm per annum) is located in the Atacama Desert in close proximity to the Andes and a major salt lake. It is an important example of a desert landscape in an area with complex block faulting. This site is currently noted on the Tentative List in relation to its cultural values.

6) Wadi Rum, Jordan. The Wadi Rum area of southern Jordan has many similarities to Petra and has a spectacular series of sandstone mountains and valleys with remarkable natural arches, the world's most spectacular networks of honeycomb weathering features, and very large landslide features caused by undercutting of slopes by groundwater sapping and salt weathering. This site is currently noted on the Tentative List in relation to both natural and cultural values.

7) El Pinacate et le Grand désert d'Altar, Mexico. This reserve lies in the north west of Mexico bordering the United States of America in the coastal plains of the Gulf of Mexico, forming part of the Sonoran desert. Its geological formations range from volcanic craters to basalt and granite mountain massifs.

8) Great Gobi Desert, Mongolia. The Gobi in Southwest Mongolia is a major desert and is one of the best examples of a relatively high altitude, cold desert (especially in winter). Although the Mongolian submission (by the Ministry of Enlightenment) dwells on the biological value of the site, it undoubtedly has a very large range of desert landforms, including gravel deserts.

9) Wadi Howar, Sudan. This is a major former tributary of the Nile, and is one of the best examples of a river system that has ceased to flow through its length because of climate change. It has been the subject of important palaeoclimatic research.

3.2 IDENTIFICATION OF PRIORITY SITES WITH POTENTIAL AS WORLD HERITAGE PROPERTIES

In this section we identify priority geomorphological sites which may have potential as World Heritage properties. These sites have been recommended by the authors based on their global assessment of the most significant known properties, and has been amended following comments made through review of the paper by a range of reviewers. Such a list cannot be exhaustive, but also indicates the types of superlative values that provide a strong basis for inclusion on the World Heritage List.

It is evident from what has been reported in **Chapter 2.1** and in **Annex 7** that there are large gaps in the coverage of desert landscapes and geomorphological features in existing World Heritage properties. In particular it is clear that the most distinctive landforms and landforming processes of deserts - aeolian features - are not reflected in the World Heritage List. This is the case for dunes, yardangs, pans, dust sources and coastal sabkhas, and this is also true for weathering forms and various types of crust, rind and varnish and for desert karst features, tufas, various Quaternary phenomena (e.g. ancient river systems and pluvial lakes) and some highly important fluvial phenomena, including alluvial fans, pediments and debris flow phenomena.

The following selection of 9 sites is considered by the authors, following considerable discussion and review of the available literature, to represent a selection of the most significant desert landscapes and geomorphological sites that are currently not included on the World Heritage List or on Tentative Lists by the State Parties. The selection with a focus on criterion (viii) is not exhaustive and has not attempted to analyse whether these suggested locations meet the necessary conditions of integrity with regard to their level of protection and management. The list does not follow any particular order. Nor are the suggestions precisely bounded areas, so there would be the need for any State Party referred to consider a range of factors before determining if a nomination is appropriate or likely to succeed, alongside, of course their own view of national priorities, and the views of stakeholders in these areas. The assessment is therefore on a purely technical basis regarding the global reputation of the area referred to. A strong case can be made that all these sites have superlative geomorphological value and include many types of desert geomorphological phenomena for which there are as yet no good examples in the World Heritage List. The list should be considered in the context of existing World Heritage Properties with earth science features of outstanding universal value (Annex 1), World Heritage Natural and Mixed Properties with significant earth science value (Annex 2) and various inscribed cultural sites with geomorphological potential (Annex 4). The following sites are listed in **Annex 6**.

Sabkha, United Arab Emirates. The sabkha, marine salt flats on the western side of the Arabian Gulf, are the best developed and most studied example of this landscape type to be found anywhere on Earth. It extends along the coastline of Abu Dhabi Emirate between Jabal Dhanna and Ras Ganada, a distance of 300 km. It is also a highly important model for hydrocarbon generation (Evans 1995).

Badain Jaran, China. This interior desert of China is a National Geopark and has been the subject of intense study in recent years, including by Chinese, Japanese, German and United Kingdom scientists. In addition to being aesthetically very impressive, it contains the world's tallest dunes (up to 450 m) in a great variety of forms, including star dunes. Within the dune, there are many intriguing inter-dunal lake basins. The area also possesses spectacular weathering features like tafonis and alveoles (Wu et al. 2006).

Arches National Park, USA. This area possesses a suite of sedimentary rocks of which various sandstones are the most important. The rocks have been eroded by fluvial and groundwater action to produce the largest collection of natural arches on Earth, and some of the largest and most aesthetically pleasing known specimens are found here. In addition to the intrinsic value of the arches themselves, the area is one that demonstrates the many forms of weathering features that develop in an arid climate, and the importance of groundwater sapping processes for river development in desert regions. This has some interest in that it can be used as a potential analogue of Martian features (Barnes 1987).

Colorado Plateau, USA. Bryce Canyon National Park, Canyonlands National Park, Capitol Reef National Park, Rainbow Bridge National Monument. These are truly world class sites that contain superb examples of a range of desert geomorphological phenomena.

The lowest point in the United States of America – Death Valley. Note the high bounding mountains, the alluvial fans and the salt flats.

Photo: Andrew Goudie

Death Valley, USA. Death Valley is the lowest point in the United States of America, and is bounded on either side by great actively uplifting mountains. It is an exceptional example of basin and range topography, of a salt lake and of pluvial lake expansion. It is also a classic area to study desert varnish of different ages. However, one of its most important landform types is the alluvial fan, which develops on the interface between the mountains and the basin (Hunt 1975).

Lake Bonneville, USA. Lake Bonneville is a giant pluvial lake which occupies the basin in which the current Great Salt Lake lies. Made important by the classic work of G.K. Gilbert, it possesses beautifully developed strandlines and ancient lake coast features. The basin displays the interface between mountain glaciation and pluvial lake development, and ideas developed here have been very important in understanding the evolution of ideas on climate change in mid latitude locations. The history of the basin included episodes of catastrophic flood pulses which have played a role in the development of neo-catastrophist thinking (Oviatt et al. 1992).

The fossil Pleistocene shorelines of Lake Bonneville, near Salt Lake City, Utah, USA. Photo: Andrew Goudie

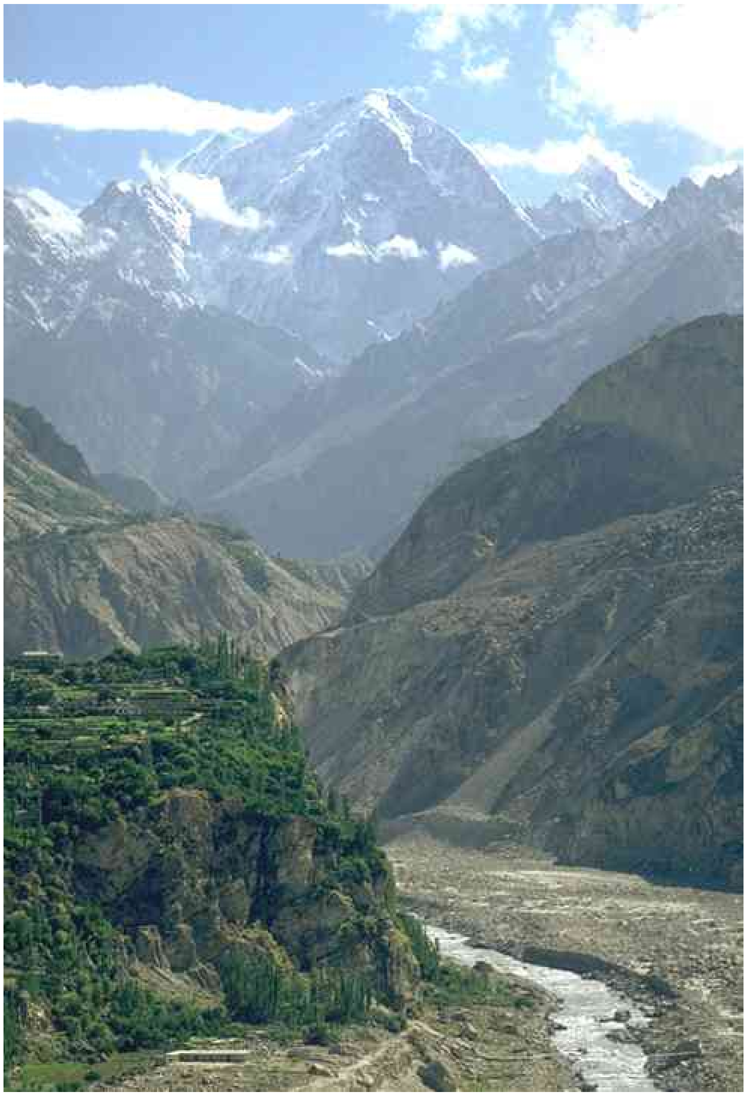
Bodélé Depression, Chad. This Saharan depression is very easily the largest dust source on Earth. It is therefore the best location to study the action of dust storms and to witness the effects of deflation on desiccated Holocene and Pleistocene lake sediments, including diatomites. Dust storms are extremely important for the environment, delivering nutrients to the oceans, to distant locations including the Caribbean and Amazonia, and having the potential to modify regional and global climate (Warren et al. 2007). The Bodélé is also believed to contain the fastest moving barchan dunes on Earth (Vermeesch and Drake 2008).

Satellite image of a dust storm over the Bodélé depression, Chad.
Source: MODIS, courtesy of NASA

The Kimberley Limestone Ranges, Australia. This site, consisting of the Oscar and Napier ranges, is of great importance because of its karst features. However, as a result of the classic work of Marjorie Sweeting and Joe Jennings, it has become the type site for *semi-arid karst*, and displays many karren features, tufas, gorges, box valleys, pediments, tunnel valleys, etc. It is also a superb demonstration of the importance of rock lithology on the development of landforms, for the exposed facies of the ancient Devonian reef are crucial in understanding the array of different slope forms that have formed (Goudie et al. 1990). Williams (2008) notes arid karst as a gap in relation to the representation of karst on the World Heritage List, and also notes Kimberley as an outstanding area.


Semi-arid limestone landscape with tufa mound and karren features, Napier Range, Kimberleys. Photo: Andrew Goudie

The Hunza Valley, Pakistan. In the Karakoram Mountains of Pakistan, the valley bottoms have an arid climate (less than 100 mm of rainfall). The degree of incision that has taken place is such that between the base of the Hunza River and Mount Rakaposhi, there is the first or second greatest relative relief on the Earth's land surface. One thus has a magnificent example of a mountain desert, with the interplay between active tectonics, present and past glaciation, river floods, massive debris flows, landslide damming of lakes, and scree formation on an exceptional scale (Miller 1984). This site is also of significant importance because of its mountain landscapes and tectonic significance. There are other parts of the Karakorams, in both Pakistan and China, which would be of comparable value in terms of their potential nomination to the World Heritage List, thus further comparative analysis would be needed to consider the potential for nomination within the region.


The Hunza Valley, Karakorams, northern Pakistan.
Photo: Andrew Goudie

Supplementary biodiversity information for priority sites with potential as World Heritage properties is summarized in **Annex 8.** This puts forward the authors' assessments primarily in terms of species richness for the sites proposed in this study.

4. INTEGRITY, PROTECTION AND MANAGEMENT

The present study provides guidance on desert landscapes that have potential to meet the criteria for inclusion on the World Heritage List in relation to criteria (vii) and (viii) in the views of the authors. It will be for the relevant State Parties to consider whether they wish to bring forward a nomination, but it should be noted in making this assessment that simply meeting natural criteria is not sufficient for a site to be inscribed on the World Heritage List. Paragraph 78 of the '*Operational Guidelines for the Implementation of the World Heritage Convention*'

(UNESCO 2008) requires that for a property to be deemed of Outstanding Universal Value it must meet the conditions of integrity and must have an adequate protection and management system to ensure its safeguarding. Integrity is defined in paragraph 88 as a measure of the wholeness and intactness of the natural heritage and its attributes. However, it is recognized (paragraph 90) in the Operational Guidelines that "no area is totally pristine, [...] and that human activities, including those of traditional societies and local communities, often occur in natural areas, and that these activities may be consistent with the Outstanding Universal Value of the area where they are ecologically sustainable."

In addition to the general requirements that apply to the integrity of protected areas, desert regions have a number of unusual characteristics that must be taken into account when their effective design and management is assessed. First, desert ecosystems, although they may have various built-in mechanisms to withstand extreme drought and temperatures, are often fragile, and may take a long time to recover from disturbance. Fragile biological crusts are very important in nutrient cycling, surface stabilization, in encouraging vascular plant growth and critical to the biodiversity values of deserts (Viles 2008). Removal of sparse vegetation cover may expose the surface to periodic erosion by wind or water, and damaged vegetation (including lichens and other biological crusts) may remain scarred for decades. There are, for example, areas of the Libyan Desert where the impacts of wheeled vehicles from the First World War are still visible. Belnap (2002) describes some of the impacts of off-road vehicles on biological crusts in the deserts of the United States of America. It is therefore very important that off-road driving and excessive trampling by humans and livestock be controlled.

In countries on the margins of deserts, desertification is a process of land degradation that is widespread, and various processes are increasing its severity, including the growth of cities which have a great demand for aggregates, wood and charcoal, the growth of recreation and tourism, the spread of four wheel drive vehicles, the exploitation of water resources for irrigation and water supply, the introduction and explosion of invasive species, the increasing occurrence and use of fire (Pellant et al. 2004), and the replacement of traditional, often nomadic subsistence societies, by cash crop economies based on established settlements.

Another particular management problem in deserts, because of the limited vegetation cover, is that garbage and litter are easily blown or washed across the surface and are not obscured from view. Material can be easily distributed across desert surfaces from badly managed landfill sites and other waste disposal areas. In windy areas, there is also a problem of redistribution of toxic materials by wind from mine tailings. Several deserts have a history of military and weapons testing grounds, including nuclear weapons with on-going major contamination, including the United States of America, Australia, China, India and the former Soviet Union. The present study is not intended to set out a full range of the management issues affecting arid areas, as these issues are well-explained in other literature, however in closing our analysis it is essential to note that the key features of deserts nominated to the World Heritage List should be identified, protected and appropriately managed in all cases, and that the particular threats that certain types of human use could pose to these features should be identified and addressed within the management system for any nominated property.

The impact of a four wheel drive vehicle and human footsteps on a stone (desert) pavement in the Western Desert of Egypt.
Photo: Andrew Goudie.

The growth of the construction industry in the United Arab Emirates has involved the wholesale mining of sand from dunes.
Photo: Andrew Goudie

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Annex 1: World Heritage properties with earth science features of Outstanding Universal Value (from Table 1, Dingwall, Weighell, Badman, 2005)

WHS Name	Country	Mean annual rainfall	Desert type	Desert Classi-fication	Geomorpholo-gical features	Reason for listing	Cultural significance	Research and facilities	Biodi-versity signifi-cance	Vegetation type	Vegeta-tion richness	Degree of endemism	Fauna - vertebrate	Faunal richness	Degree of endemism	Fauna - inver-tebrate	Faunal rich-ness	Degree of endemism
Dinosaur Provincial Park	Canada	406	Semi-arid	Grass-land	Badlands; fluvial erosion patterns	Fossil beds	Archaeolo-gical sites of native 'Plains Indian Culture'	Long-term palaeontological research; geomorphic process research in drainage basin	Fossil fauna deposits	Grassland; cottonwood riparian	Badlands provide habitat for number of ecologi-cally special-ised plant species	Cottonwood riparian most endangered in semi-arid regions; 10 species threatened or at limit of ranges	Many dinosaur remains	38 species of dinosaurs; 150 birds, 1 toad; critical winter range for native ungulates	7 birds locally threatened or at their biogeo-graphical limits	No com-ment	No com-ment	No comment
Grand Canyon National Park	USA	210-440	Semi-arid	Mountain desert	Canyon; groundwater action; long-term slope evolution	Deeply incised canyon	Prehistoric ruins attraction; outstanding private development in natural attraction	Major studies in geology, archaeology, fire management, sociology, ecological impacts and fauna and flora; resource study collection	Forest and game reserve originally	Five vegetation types; Desert cacti to spruce and pine	1500+ including represen-tatives of 5 of 7 life zones of North America	11 threatened species in park; 15 species recom-mended for listing as threatened	No comment	300+ birds; 76 mammals; 50 reptiles; 25 fish	1 mammal and 1 reptile endemic to park; 3 rare or threatened birds; 2 threatened fish species	No com-ment	No com-ment	No comment
Ischigualasto/ Talampaya Natural Parks	Argentina	<200	Semi-arid	Tempe-rate	Rivers and lakes; cliffs; badlands	Verte-brate fauna fossil site	Previously aborigines, Inca sites, rock art, no current inhabitants	Intensive research, recently by provincial universities where major displays exist; no facilities in the park	Fossil site, verte-brate fauna during Tertiary	Xeric shrubs and cactus, mesquite	172 species; 6 with special value; 100 fossil plants	No statistics	No comment	20 mammals, 36 birds, 20 reptiles and amphi-bians	No comment	No com-ment	No com-ment	No comment
Purnululu National Park	Australia	500-700	Sub-humid	Hot	Sandstone tower karst	Natural site, aboriginal title	Aboriginal Australians; restricted pastoralism	Various geographical, social, botanical research visits and publications	Vegeta-tion reflects transition location	Northern tropical savanna to inland arid desert	17 vegetation communi-ties; 653 species including 628 higher plants (597 native), 17 ferns, 8 lower plants	2 regionally endemic grevilleas; centre of endemism for spinifex	Missing of tropical and desert species	298 vertebrate species: 41 mammals, 149 birds, 81 reptiles, 12 amphi-bians, 15 fish	No comment	No com-ment	No com-ment	No comment
Tassili n'Ajjer	Algeria	25	Hyper-arid	Hot	Sandstone plateau, granite massif	Scenic and geologi-cal interest; prehis-toric cave art; floristic and faunal island of Sahelian life	15,000 neolithic rock engravings and cave paintings; from 12,000 BC; sparsely inhabited by nomadic Tuareg	Experimental centre at archaeological site of Timenzouzine; ongoing studies, natural resource inventories and conservation of rock art	Floristic and faunal island of Sahelian life in the middle of the desert; relict Medi-terranean cypress	Sheltered Medi-terranean and Sahelian flora; Sudanian riverine vegetation; endemic Saharan species	Species noted, no statistics	28 plants rare in Algeria	Medi-terranean and Saharan Palaearctic species; important for resting migratory birds	4 fish species; 23 larger mammals (5 endan-gered)	No comment	Diverse inver-tebrate fauna with relict Afro-tropical and Palae-arctic species	Large number of spiders and insects	No comment

WHS Name	Country	Mean annual rainfall	Desert type	Desert Classi-fication	Geomorpholo-gical features	Reason for listing	Cultural significance	Research and facilities	Biodi-versity signifi-cance	Vegetation type	Vegeta-tion richness	Degree of endemism	Fauna - vertebrate	Faunal richness	Degree of endemism	Fauna - inver-tebrate	Faunal rich-ness	Degree of endemism
Uluṟu-Kata Tjuṯa National Park	Australia	310	Semi-arid	Hot	Conglomerate mountains with sand plain	Abori-ginal heritage, land-scape, geology and arid desert eco-systems	Aboriginals; centre of local and religious significance; cave paintings	First expedition in 1894; many studies since 1930s: anthropology, climate, geology, hydrology, fauna and flora and major fauna survey in 1994 and 1995	No comment	Hardy perennial grass, acacia, low trees in soil pockets; foothills with grasses and shrubs; fans and outwash alluviums support complex of open grassland, low trees and shrubs; Plains support dense groves with perennial grass understory; sand dunes with grass, eucalypts and acacias.	No statistics	No statistics	No comment	22 native mammals; 150 bird species, 5 Australian reptile families repre-sented; aestivating amphi-bians	No comment	Poorly known	No com-ment	No comment
Wadi Al-Hitan (Whale Valley)	Egypt	10.1	Hyper-arid	Hot	Misc.	Fossil whales; Eocene fossil site; 25 genera of more than 14 families of vertebrat es	Abandoned in historical times, Faiyum depression, continuous habitation from Neolithic	Various research visits and publications; regulated scientific exploration and specimen collection	Eocene fossil site, esp. whales	Barren; few shrubs	No statistics	No statistics	Very sparse	19 reptiles, 36 breeding birds, few mammals	No com-ment	No com-ment	No com-ment	No comment
Willandra Lakes Region	Australia	290	Semi-arid	Hot	Pluvial lakes; dunes, lunettes	Dry lake basins	Human use sites for 30,000 years; currently 40 inhabitants	Considerable research; existing bibliography; benchmark study of changes in earth magnetism	Fossil remains of giant marsu-pials	Sparse scattered shrubs and woodlands interspersed with plains and dunes	No statistics	No statistics	No comment	20 mammal species recorded	No com-ment	No com-ment	No com-ment	No comment

Annex 2: World Heritage natural and mixed properties with significant earth science values, inscribed on the World Heritage List for other reasons (provisional assessment) (from Table 2 of Dingwall et al. 2005)

WHS Name	Country	Mean annual rainfall	Desert type	Desert Classification	Geomorphological features	Reason for listing	Cultural significance	Research and facilities	Biodiversity significance	Vegetation type	Vegetation richness	Degree of endemism	Fauna – vertebrate	Faunal richness	Degree of endemism	Fauna – invertebrate	Faunal richness	Degree of endemism	Misc
Aïr and Ténéré Natural Reserves	Niger	20-100	Hyper-arid	Hot	Plateaus, canyons, dunes; volcanic massif	Sanctuary for addax; other biodiversity	Tuareg; 30,000 years of settlement; rock engravings and petroglyphs, pre-islamic tombs	Interest since 1850, mainly project visits; small, poorly-equipped laboratory at Iférouane	Outstanding variety of landscapes, plant species and wild animals	Sahelian floristic enclave within the Sahara; well wooded oases; relict Sudanese and Mediterranean species above 1000m; Saharan species	350+ species	No Statistics	Diversity; 9 species on IUCN Red List for Niger; Aïr harbours threatened ungulates	40 mammal species, 165 birds, 18 reptiles, 1 amphibian	No comment	Not inventoried	No comment	No comment	
Banc d'Arguin National Park	Mauritania	34-40	Hyper-arid	Hot	Coastal saline; mangrove swamp; salt marsh	Wading birds; Ramsar Site	Traditional subsistence fishing; neolithic archaeological sites	Surveys and inventories since 1950s, field station at Cap Iouik with outstation at Oued Chibka	Marine fauna and flora, esp. migratory coastal birds	Sea grass in shallow water; halophytic on coastline, mudflats and islands; mangrove swamps; terrestrial vegetation is Saharan	No statistics	No Statistics	World's largest concentration of wintering shorebirds (2 million +); mammals, marine mammals; fish spawning and nursery ground; 5 marine turtles species, 2 breeding.	249 bird species; 15 nesting piscivores	No comment	High productivity of pelagic and benthic phytoplankton; crabs; cockles and gastropods	No comment	No comment	

Annex 3: Inscribed desert sites not identified on list of Dingwall et al. 2005

WHS Name	Country	Mean annual rainfall	Desert type	Desert Classification	Geomorphological features	Reason for listing	Cultural significance	Research and facilities	Biodiversity significance	Vegetation type	Vegetation richness	Degree of endemism	Fauna - vertebrate	Faunal richness	Degree of endemism	Fauna - invertebrate	Faunal richness	Degree of endemism
Lake Turkana National Parks	Kenya	<200	Hot	Semi-arid, hot	Rift valley lake, delta; active volcanoes	Koobi Fora hominid sites; migrant water fowl; crocodiles and hippos	Pastoralists and fishermen; 100+ archaeological sites	Extensive archaeological research	Outstanding laboratory for study of plant and animal communities; major breeding grounds for Nile crocodile and hippopotamus	Grassy savannas; sparse gallery woodlands	No statistics	No statistics	High diversity of particularly breeding and migrant birds; low carrying capacity of the area	350 aquiatic and migrant bird species; 47 fish; large mammals	7 species regionally threatened; 7 endemic fish	No comment	No comment	No comment
Uvs Nuur Basin	Russia and Mongolia	150-200	Cold	Cold steppe desert	Salt lakes	Salt lake has birds, snow leopard, agali sheep	Long history of nomadic herding	Diversity of biomes makes it a natural subject for biophysical and genetic research. Extensive research since 1984. Biosphere Reserve in 1997as study area for global change.	All major biomes of east central Asia; rare animals such as snow leopard and argali sheep	Cold desert, sand dunes, semi-desert, desert steppe, shrub steppe, wetlands, salty marshes, floodplain forest, deciduous and boreal forests, taiga, alpine meadows and tundra	552 species; 234 restricted to mountains; 52 relect species	19 endemic to Mongolia and Tuva, 5 endemic to Uvs Nuur	Diverse reflecting diversity of habitats	4 species of insectivora, 4 bats, 5 lagomorphs, 32 rodents, 18 carnivores, 9 artiodactyla, 5 lizards, 3 snakes; 368 bird species	22 locally rare mammals, 81 birds rare and endangered, 2 fish endemic to western Mongolia live in Uvs Nuur	No comment	No comment	16 of 20 rarely met species of beetle are endemic on dune deserts
Valdés Peninsula	Argentina	240	Semi-arid	Cool	Salt pans	Marine sanctuary incl. whales and seals	Sheep farming	Focused on marine colonial mammals and birds	Important for several species of coastal and marine birds, which form breeding colonies on it	Desert steppe	18 communities; 130 species from 41 families	38 species endemic to Argentina	Numerous marine birds and mammals breed here; abundant terrestrial mammals; 181 bird species (66 migratory)	No statistics	No statistics	No comment	No comment	No comment

Annex 4: Inscribed cultural sites with geomorphological potential

WHS Name	Country	Mean annual rainfall	Desert type	Desert Classification	Geomorphological features	Reason for listing	Cultural significance	Research and facilities	Biodiversity significance	Vegetation type
Humberstone and Santa Laura Saltpeter Works	Chile	0	Hyper-arid	Coastal	Nitrate (caliche)	Historical, abandoned mining complex from 19th century; over 200 former works	Abandoned saltpeter factory	No comment	No comment	Lichens
Petra	Jordan	150	Semi-arid	Warm	Weathering sandstone; gorges	Nabataean Caravan City	City, half built, half carved into rock	No comment	No comment	Sparse scrub
Rock-Art Sites of Tadrart Acacus	Libya	25	Hyper-arid	Hot	Sandstone weathering	Cave paintings	Thousands of rock paintings in very different styles	No comment	Changes in fauna and flora reflected in rock art	Barren
Tsodilo	Botswana	500	Sub-humid/ semi-arid	Hot interior savanna	Rock domes with ancient dunes	Over 4,500 rock paintings; 100,000 years chronological account of human activities and environmental change	San heritage	Museum with guides to rock paintings	Isolated inselberg enhancing biodiversity of area; changes of biota reflected in rock art	Savanna woodland
Twyfelfontein	Namibia	100	Hyper-arid	Warm	Sandstone rock domes with varnish and weathering rinds	Petroglyphs; largest concentration in Africa	San heritage last 2,000 years	Small museum	Reflects links between ritual and economic practices of hunter-gatherers	Arid savanna

Annex 5: Potential World Heritage properties with respect to desert landscapes recommended by State Parties on their Tentative Lists (as of February 2011)

State Party	Name of site	Category	Description
Afghanistan	Band-E-Amir	Natural	Lakes with special geological formations and structure; undisturbed historical and natural background
Argentina	Las Parinas	Natural	Volcanic morphology; rainfall <200mm; wetlands; long cultural history
Chad	Les Lacs d'Ounianga	Natural	Lake response to climatic variation
Chad	Gravures et peintures rupestres de l'Ennedi et du Tibesti	Cultural	Rock paintings and engravings
Chile	San Pedro de Atacama	Cultural	Rainfall <100 mm; Atacama people and culture
Egypt	Great Desert Landscapes	Natural	Qattara Depression, deepest point in Western Desert; The Great Sand Sea, underground fossil reservoir, silica glass; Wadi Sannur Cave (Eastern Desert)
Egypt	Desert Wadis	Natural	Wade Qena, Gemal and Allaqi (Eastern Desert)
Egypt	Southern and Smaller Oases, the Western Desert	Natural	Kharga Oasis, Dakhla Oasis, Kurkur and Dungul Oases, Moghra Oasis, Wadi El-Natroun Depression
Iran	Lut Desert (the vicinity of Shahdad)	Natural	Longest system of yardangs; tallest sand pyramid; hotest point; biggest nebkas in the world
Jordan	Wadi Rum	Mixed	Sudanian, Sand Dunes and Acacia-rocky Sudanian vegetation; mountains, wadis, sand dunes, springs; 50-100 mm rainfall
Mexico	Réserve de la Biosphère El Pinacate et le Grand désert d'Altar	Natural	Very arid, high temperatures, 560 species of plants; 41 mammals, 237 birds, 42 reptiles, 4 amphibians, 4 fish; in Sonoran desert near the Gulf of California
Mongolia	Great Gobi Desert	Natural	Southern Altai and Dzungarian Gobi; 410 plants, 49 mammals, 15 reptiles and amphibians and >150 bird species
Namibia	Southern Namib Erg	Mixed	Southern Namib Sand Sea in Western Namibia, from Sesriem to Saddle Hill along the coast to Sandwich Harbour, inland to the Kuiseb River Canyon
Sudan	Wadi Howar National Park	Natural	Volcanic and crater landscape of Meidob Hills, Jebel Rahib complex; palaeo lakes and large active barchan dune fields
Tunisia	Chott el Jerid	Natural	Gypsum, Salt Basins

Annex 6: Priority sites with potential as World Heritage properties (Goudie)

WHS Name	Country	Mean annual rainfall	Desert type	Desert Classification	Geomorphological features	Reason for listing	Cultural significance	Aesthetics	Research and facilities	Biodiversity significance	Vegetation type	Vegetation richness	Degree of endemism	Fauna – vertebrate	Faunal richness	Degree of endemism	Fauna – invertebrate	Faunal richness	Degree of endemism	Misc
Kimberley: Napier and Oscar Ranges	Australia	530	Semi-arid	Hot	Classic semi-arid karst	Semi-arid karst	Aboriginals, pastoralists	yes	Limited research, WA Museum in Perth	Hugh snail diversity				7 bat species			Diversity of snails			
Bodélé Depression	Chad	10			World's greatest dust source	Biggest dust source		no	Important research site											
Badain Jaran	China	50	Hyper-arid	Cool	Dunes and lakes	Highest dunes	Buddist and other relicts; city ruins; rock paintings	yes	Extensive research		Asian desert floristic area: forest grassland; desert / shrub grassland	- 72 families, - 322 genera, - 612 species		Temperate desert fauna	- 200 species - 27 national protected species - home town of camels					
Hunza Valley	Pakistan	145			Glaciated semi-arid valley	Desert mountains		yes	Long history of research											
Sabkha	UAE	80-100	Hyper-arid	Coastal, warm	Sabkha	Sabkha		yes	Classic studies since 1960's	Unicellular organisms, migrant birds	shrubs			410 birds, 125 breeding regularly						
Arches National Park	USA	250	Semi-arid	Warm	Sandstone arches	Arches		yes	National Park Centre			113 species of flowering plants			10 amphibians, 116 birds, 34 fish, 63 mammals, 28 reptiles					
Death Valley	USA	65			Fans	Fans		yes	Extensive research; National Park Centre	Blind fish		1,000+ described plants	12 only in park; 30 majority in park	Blind fish in hot water	440 animals (vertebrates and inverte brates)	4 pupfish; 1 pupfish, 3 mammals, 1 lizard (regionally endemic)			4 beetles, 15 snails	
Lake Bonneville	USA	390			Pluvial features	Pluvial lake		yes	Extensive research							fish not speciated since isolated				

Annex 7: **Desert landforms in relation to existing and proposed World Heritage properties**

	Aeolian features:					Weathering forms, processes and surface materials:								Fluvial and slope processes and forms:												Biodiversity:
Landforms	**Dunes**	**Yardangs**	**Pans**	**Dust storms and deflation surfaces**	**Coastal sabkhas**	**Sodium nitrate (caliche) crusts**	**Gypsum crusts (gypcrete)**	**Calcium carbonate crusts (calcrete)**	**Salts and salt weathering**	**Cavernous weathering forms (tafoni and alveoles)**	**Desert varnishes and rinds**	**Desert karst and tufa deposition**	**Stone (desert) pavements**	**Relict weathering profiles**	**Lake basins, palaeoshorel-ines, stromatolitic tufas etc.**	**Ancient river systems**	**Ephemeral stream channels (wadis)**	**Badlands**	**Inselbergs**	**Pediments**	**Sheetflood activity**	**Alluvial fans**	**Debris flows**	**Groundwater sapping**	**Natural arches**	
WHS Name																										
World Heritage properties with earth science features of Outstanding Universal Value (from Table 1 Dingwall, Weighell, Badman)																										
Dinosaur Provincial Park																	x	X			x		x			Fossil
Grand Canyon National Park											?	x					X			x	x			X	x	x
Ischigualasto/ Talampaya Natural Parks																	x	X			x		?			Fossil
Purnululu National Park										x	X	X		?			x		?		?			?		x
Tassili n'Ajjer	x	x		x					x	X	X		x	x	?		x		x	x	x			x	x	X
Uluṟu-Kata Tjuṯa National Park	x									X	x			x			x		X	?						x
Wadi Al-Hitan (Whale Valley)			x	x							x				?		?	?								Fossil
Willandra Lakes Region	X	x	X				?		?						X	X		?								Fossil
World Heritage natural and mixed properties with significant earth science values, inscribed on the World Heritage List for other reasons (provisional assessment) (Table 2 of Dingwall et al.)																										
Aïr and Ténéré Natural Reserves	X	x		X						?	x		x	x			x		x	x	x					X
Banc d'Arguin National Park	X			?	X																					X
Desert sites not on list of Dingwall et al. (Goudie)																										
Lake Turkana National Parks													x		X		x	x		?	?					X
Uvs Nuur Basin																										X
Valdés Peninsula			X																							X

Annex 7: **Desert landforms in relation to existing and proposed World Heritage properties**

	Aeolian features:					Weathering forms, processes and surface materials:								Fluvial and slope processes and forms:												Biodiversity:
Landforms	**Dunes**	**Yardangs**	**Pans**	**Dust storms and deflation surfaces**	**Coastal sabkhas**	**Sodium nitrate (caliche) crusts**	**Gypsum crusts (gypcrete)**	**Calcium carbonate crusts (calcrete)**	**Salts and salt weathering**	**Cavernous weathering forms (tafoni and alveoles)**	**Desert varnishes and rinds**	**Desert karst and tufa deposition**	**Stone (desert) pavements**	**Relict weathering profiles**	**Lake basins, palaeoshorel-ines, stromatolitic tufas etc.**	**Ancient river systems**	**Ephemeral stream channels (wadis)**	**Badlands**	**Inselbergs**	**Pediments**	**Sheetflood activity**	**Alluvial fans**	**Debris flows**	**Groundwater sapping**	**Natural arches**	
Cultural Sites with geomorphological potential (Goudie)																										
Humberstone and Santa Laura Saltpeter Works						X			X																	
Petra									X	X	X						X							X		
Rock-Art Sites of Tadrart Acacus	?	?		?					x	X	x		?				x		x					x	X	x
Tsodilo	x							?		?	x				x				X							x
Twyfelfontein											X								x	x	x					x
Priority sites with potential as World Heritage properties (Goudie), some included on Tentative Lists																										
Arches National Park										x	x									x	x			X	X	x
Badain Jaran	X		X							X	X				X											x
Bodélé Depression	x	X	x	X											X											x
Chott el Jerid	X		x	x	x		X	x	x						X					X						x
Death Valley	x			x			x		X	x	x		x		X		x	X			x	X	x			X
Hunza Valley									x	x	x											X	X			x
Kimberley: Napier and Oscar Ranges	x							x		x		X								X				x	x	x
Lake Bonneville	x			x			x								X											x
Lut Desert	X	X		X																						x
Southern Namib Erg	X	x	x	x	x		X	X	X	X	X	X	X			x	X	X	X	X	x				x	X
Sabkha	X				X				X																	X

Annex 8: Supplementary biodiversity information for priority sites with potential as World Heritage properties

UNEP, 2006. Global Deserts Outlook Appendix 1 & 2
Area and type of the desert ecoregions of the world (B-D); Species richness, human population, and human footprint of the desert ecoregions of the world (E-O)

WHS Name		Ecoregion Name	Description	Plant species richness	Vertebrate species richness	Endemic vertebrate species	Threatened vertebrate species	Human population density	Human footprint**
Arches National Park	Palearctic	Great Basin Shrub Steppe	Plain Desert	2556	489	0	7	2.8	12.8
Badain Jaran	Palearctic		Dune Desert						
Bodélé Depression	Palearctic	Sahara	Plain Desert	500	335	3	16	2	2.6
Chott el Jerid	Palearctic								
Death Valley	Nearctic	Mojave	Plain Desert	2490	498	3	12	17.7	15
Hunza Valley	Indo-Malay	Indus Valley Desert	Plain Desert	400	240	0	5	200.2	36
Kimberley: Napier and Oscar Ranges (National Park)	Australasia		Semi-arid Karst						
Lake Bonneville	Nearctic	Great Basin Shrub-Steppe	Plain Desert	2556	489	0	7	2.8	12.8
Lut Desert	Palearctic	South Iran Nubo-Sindian Desert and Semi-Desert	Plain Desert	900	483	5	24	20.7	26
Namib Desert	Afrotropical	Nama Karoo	Plain Desert	1100	481	6	18	1.8	11.1
	Afrotropical	Namib Desert	Coastal Desert	1000	301	7	8	1.2	4.8
	Afrotropical	Northern Namib	Coastal Desert	500	360	8	5	3.2	10.4
	Afrotropical	Succulent Karoo	Coastal Desert	4860	409	20	21	3.2	11.4
	Afrotropical	Succulent Karoo*	Winter rainfall	2439 endemics			2	4	
Western Desert, Bagnold Dunes	Palearctic	Sahara	Plain Desert	500	335	3	16	2	2.6

*Biodiversity Hotspots - Karoo - overview; Conservation International http://www.biodiversityhotspots.org/xp/hotspots/karoo/Pages/default.aspx 16/01/2008
**CIESIN Columbia University, IFPRI, the World Bank, and CIAT (2004). Global Rural-Urban Mapping Project (GRUMP) (http://sedac.ciesin.columbia.edu/gpw)

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