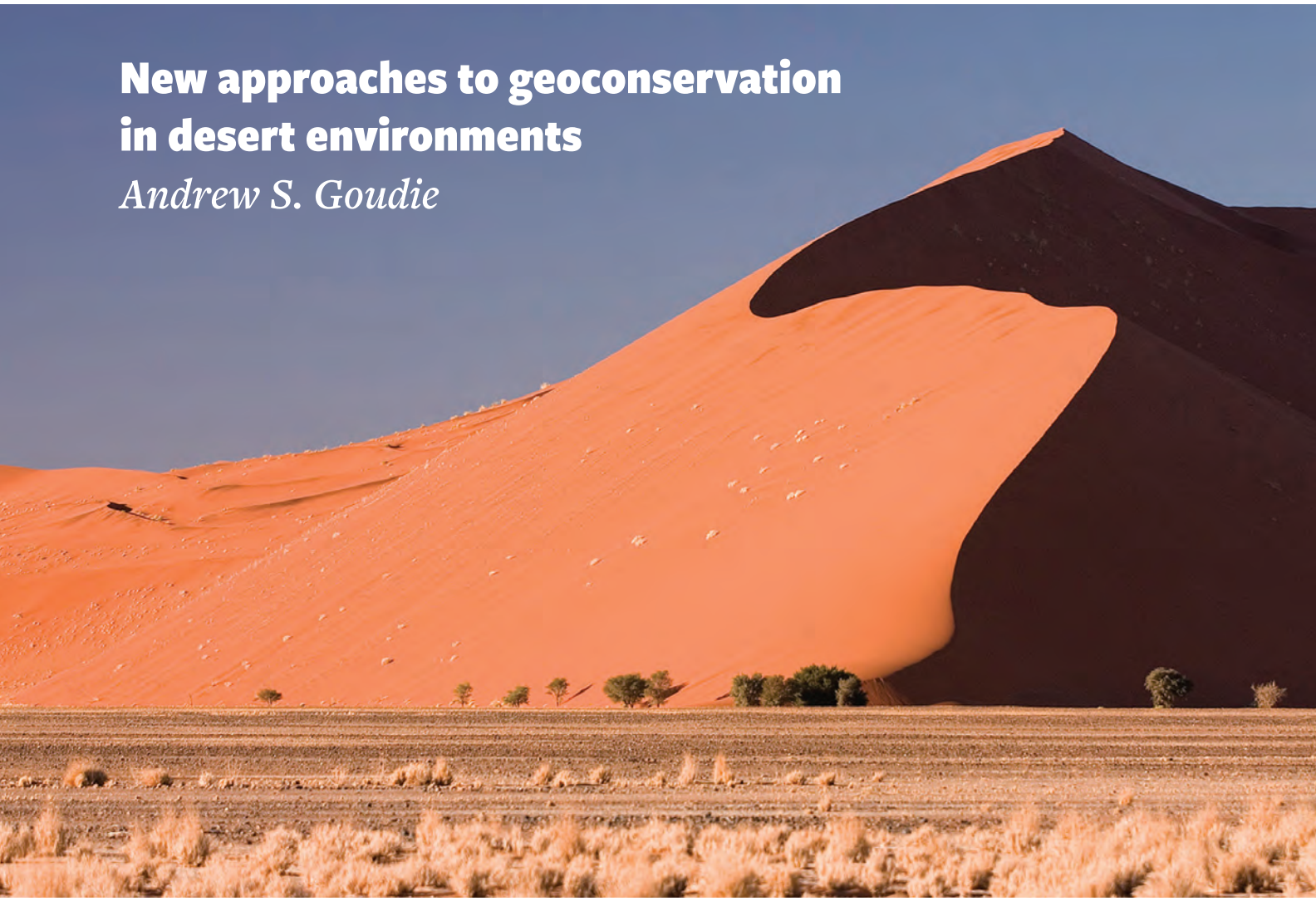
New approaches to geoconservation in desert environments

Andrew S. Goudie



ABSTRACT

Deserts are areas of great landform diversity and distinctiveness. In the past there was a shortage of desert World Heritage nominations. This situation persists, though shows some improvement. However, there are also desert landform complexes associated with mixed World Heritage sites and sites on various national World Heritage tentative lists. There are also two desert UNESCO Global Geoparks, both of which are in China. In recent years there has been the development of geotourism in arid regions and this has led to a greater interest in the economic value of geoconservation. However, there are various landscape threats that need consideration and management, including off-road driving, military activity, urbanization, river diversions, quarrying and mining, development associated with energy industries, and anthropogenic climate changes. In this paper, the concentration is on warm desert landscapes, and on conservation of geomorphological features, rather than, for instance, sites of particular stratigraphic or paleontological value.

INTRODUCTION

The world's deserts, which cover about a third of Earth's land surface and occur on all continents, including Antarctica, are areas that suffer from severe moisture shortages. One consequence of this is that there is a wide range of unusual and spectacular landforms, sculpted by wind, by occasional but strong rainfalls, and by ancient fluvial systems. As a result of

Sossus Vlei, Namib-Naukluft National Park and World Heritage Site, Namibia
LUCA GALUZZI

the aridity, the landforms and the processes that led to their formation remain clearly visible, uncovered for the most part by extensive vegetation.

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 inland Kalahari and Karoo dry zones. The South American drylands are confined to two strips, with the Atacama and Altiplano along the west coast and the Patagonian Desert along the southeast coast. The North American desert province occupies much of Mexico and the southwestern United States, including the Chihuahuan, Great Basin, Mojave, and Sonoran deserts. The fifth and final province is in Australia, which is the driest of the continents apart from Antarctica, though it has no areas of profound aridity.

The world's deserts are of considerable importance on a number of grounds. First of all, they cover (depending on the definition adopted) around one-third of the earth's land surface. Secondly, they are home to a large number of people. Currently at least 500 million people live in deserts and on desert margins. 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 climate and ecosystems all over the world.

WORLD HERITAGE SITES

The United Nations Educational, Scientific, and Cultural Organization (UNESCO) commissioned Goudie and Seely (2011) to undertake a review of World Heritage Sites in desert regions, as these were suspected to be under-represented. In particular, this was clear for the most distinctive landforms and land-forming processes of deserts: aeolian features, including dunes, yardangs (sharp-crested ridges carved by wind erosion from soft but coherent deposits), pans, dust sources and sabkhas (flat areas between a desert and an ocean, characterized by a crusty surface consisting of evaporite deposits). In addition, weathering forms and various types of crust, rind and varnish were also not well represented. The same is true of desert karst features, tufas (porous rocks composed of calcium carbonate and formed by precipitation from water), various Quaternary landforms (e.g., ancient river systems and pluvial lakes), and some highly important fluvial phenomena, including alluvial fans, pediments (broad, gently sloping expanses of rock debris extending outward from the foot of a mountain slope), and debris flows. The report also explored biodiversity issues and hotspots in deserts. Goudie and Seeley (2011) made suggestions for sites from the following areas that they considered were deserving of inclusion in the World Heritage List.

Western Desert, Egypt. This desert is characterized by classic barchans (moving crescent-shaped sand dunes) 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 imposing sandstone topography of the Gilf Kebir.

United Arab Emirates—Sabkha. The sabkha, consisting of marine salt flats on the western side of the Arabian Gulf, is the best developed and most studied example of this landscape type to be found anywhere on Earth (Figure 1). It extends along the coast over a distance in excess of 300km. It is also a highly important location for hydrocarbon extraction. Since Goudie and Seely wrote, the Abu Dhabi sabkha has been added to the UAE's tentative list.

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

Badain Jaran, China. This interior desert of China has been the subject of intense study in recent years by Chinese, Japanese, German, and UK scientists. In addition to being aesthetically magnificent, it

Figure 1. The Abu Dhabi Sabkha. The scale bar equals 10km. COURTESY © GOOGLE EARTH 2021

contains the world's tallest dunes (up to 450m). Within the dunes there are many intriguing inter-dunal lake basins. Since Goudie and Seely wrote, this site has been added to China's tentative list (in 2019).

Death Valley National Park, California/Nevada, USA. Death Valley National Park has the lowest point in the USA (Badwater Basin), and is bounded on either side by actively uplifting mountains. It is a classic 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 at the junction between the mountain fronts and the basin.

Namib-Naukluft National Park, Namibia. The ancient, coastal Namib Desert is a well-protected area with an extended period of detailed desert research based at Gobabeb Namib Research Institute. 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 displays the impact of sea-floor spreading since the Cretaceous, with the emplacement of many sub-volcanic complexes and the development of an upwarped passive margin escarpment. It also contains the full range of dune types, and excellent examples of the ways in which river courses can be blocked by dunes (as at Sossus Vlei). Since Goudie and Seely wrote, the Namib Sand Sea has been inscribed as a World Heritage Site (in 2013).

Lake Bonneville, Utah, USA. Lake Bonneville was a giant pluvial lake that occupied the basin in which the current Great Salt Lake lies. Made important by the classic work of the geologist G.K. Gilbert, Lake Bonneville possesses spectacular strandlines and ancient lake coast features (deltas, etc.). Ideas developed through research within the basin, which displays the interface between mountain glaciation and pluvial lake development, have been very important in understanding the evolution of ideas on climate change in mid-latitude locations and also on hydroisostasy (the earth's response to changes in surface ice and water loading during glacial cycles).

Lut Desert, Iran. This desert contains some of the largest and best developed yardangs (*kaluts*) found anywhere on Earth. These form parallel ridges and depressions over an area of 120x50km. Some of the ridges exceed 60m in height, and run parallel, with superbly developed aeolian streamlining, to the

formative *shamal* winds. Since Goudie and Seely wrote, Lut has been added to the World Heritage List (inscribed 2016).

Bodélé Depression, Chad. This depression on the south side of the Sahara 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). It is also believed to contain the fastest-moving barchans dunes on Earth.

Arches National Park, Utah, 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. In addition to the intrinsic value of the arches themselves, the area demonstrates the many forms of weathering features that develop in an arid climate, and the importance of groundwater sapping processes for stream development in desert regions.

Kimberley Limestone Ranges, Western Australia. This site, consisting of the Oscar and Napier Ranges, deserves to be designated on the basis of its karst features. It has become the type site for semi-arid karst, and displays many karren features (i.e., rocky surfaces on which there are a variety of small solution pits, grooves, and channels), 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 found there. The area has a number of national parks.

Hunza Valley, Pakistan. 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 unimaginable scale.

A number of desert sites have recently been inscribed, including the Okavango Delta in the Kalahari of northern Botswana (2014), Lakes of Ounianga in Chad (2012), Wadi Rum in Jordan (2011), and El Pinacate and Gran Desierto de Altar (2013) in Mexico.

Ten years on from the Goudie and Seely review, the International Union for Conservation of Nature (IUCN)—which is the advisory body on natural sites to the World Heritage Committee—needs to revisit this issue and assess where major gaps still occur.

MIXED SITES

Some existing World Heritage Sites, which have been included largely as cultural sites, also have geomorphological significance, and a case could be made for their designation as mixed properties. These include: the Aflaj Irrigation System of Oman (human-made landforms associated with irrigation); Al-Hijr Archaeological Site, Saudi Arabia (sandstone weathering); Ancient Thebes and its Necropolis, Egypt (accelerated weathering); Archaeological Ruins at Mohenjo-Daro, Pakistan (accelerated salt weathering); the Archaeological Site at Volubilis, Morocco (calcrete development); Champaner-Pavagadh Archaeological Park, India (fossil topographic dunes); Humberstone and Santa Laura Saltpeter Works, Chile (caliche mineral deposits); Incense Route Desert Cities in the Negev, Israel (desert runoff processes at Avdat); Rock art sites at Tadrart Acacus, Libya (rock rinds, desert varnish, sandstone weathering, and natural arches); St. Catherine area, Egypt (granite weathering); and Tsodilo Hills, Botswana (ancient linear dunes and pluvial lake deposits).

TENTATIVE LIST SITES

Some sites that are on the tentative lists of miscellaneous state parties to the World Heritage Convention have very considerable merit as exemplars of particular geomorphological processes or landforms. These include: the Band-E-Amir tufa lakes of Afghanistan; Algeria's Les oasis a foggaras et les ksours du Grand Erg Occidental, a group of oases; Argentina's Las Parinas, an arid area at a high altitude in the Puna, with many volcanic landforms and major salt flats; Australia's Great Sandy Desert, with excellent linear dunes; Botswana's Mkgadikgadi Pan Landscape and the Central Kalahari Game Reserve, which include one of the world's largest salt pans and the ancient river systems and paleo-lakes of the Kalahari; Chile's San Pedro de Atacama, which is an important example of a desert landscape in an area with complex block faulting and an enormous salt lake; China's Taklimakan

Desert–*Populus euphratica* forests, which includes a whole range of desert landforms, and is a major area for dust generation and wind erosion; China's Badain Jaran, with the world's tallest dunes; China's Dunhuang, with perfect examples of yardangs (Figure 2); India's Desert National Park, which includes a large area of the Thar (Rajasthan) Desert; Israel's Makhteshim Country, where there is a fine display of the relationship between rock structure and landforms; Kazakhstan's Steppes and Lakes of North Kazakhstan, an area with one of the largest known arrays of closed depressions and associated lakes; Mongolia's Great Gobi Desert, one of the best examples of a relatively high-altitude, cold desert (especially in winter); Namibia's Brandberg National Monument, Fish River Canyon, and Welwitschia Plains, which are sites that contain major inselbergs (isolated hills or mountains rising out of a plain), gorges, dunes and gravel plains; Qatar's Khor Al-Adaid Natural Reserve, an area that contains both dunes and sabkha; Sudan's Wadi Howar, which is a major former tributary of the Nile, and one of the most perfect examples of a river system that has ceased to flow through its length because of climate change; and Turkmenistan's Repetek Biosphere State Reserve, which contains a large portion of the southeast Karakum Desert.

GEOPARKS AND GEOMORPHOSITES

There is also the UNESCO Global Geoparks Network. As yet, there are only two desert sites, both of which were declared in 2015: the Alxa Desert Geopark of Inner Mongolia, China; and the Dunhuang Yardang National Geopark (Figure 2), which is also in China. It would be appropriate if more sites, from other parts of the world, could be included in the network.

Geomorphologists, partly because of initiatives associated with the International Association of Geomorphologists, have developed a considerable interest in geomorphosites (localities with landforms of special interest for society) and large numbers of studies have now emerged to identify such localities, particularly from Iran, China, Morocco, and Egypt. This is a necessary first step towards their conservation and management.

GEOTOURISM AND GEOHERITAGE

Desert areas with spectacular landforms can be major tourist attractions. For instance, in the USA each year Grand Canyon National Park attracts about 4.4 million recreational visitors, Joshua Tree National Park 1.4 million, and Badlands, Death Valley, and Arches National Parks around 1.0 million each. In

Figure 2. Sphinx-like yardangs in the Dunhuang Yardang Park, China. A.S. GOUDIE

many countries with desert terrain, the economic value of geotourism is becoming apparent and various new studies have been completed. The case has been made for the Lut Desert and salt lakes (*kavirs*) of Iran (Maghsoudi et al. 2019), the Western Desert of Egypt (Plyusnina et al. 2016), various parts of China (Wang et al. 2019), Namibia (Downing and Pforr 2021), Jordan (Wojtowicz and Wojtowicz 2016) and North Africa (Errami et al. 2015). A particularly comprehensive survey of 50 potential sites for geoconservation has been made for Oman (Searle 2014), including the Fahud anticline, which has already been damaged by the excavation of seismic lines (Figure 3).

Geoheritage trails have been proposed for some regions (e.g. Morocco; Errami et al., 2015).

THREATS TO GEOCONSERVATION

There are a number of threats to the conservation of geological and landform sites in deserts. These can be natural (as with sand encroachment at Siwa oasis in Egypt), but many are caused by human activities. Population growth in arid regions has tended to be greater than the world norm. Whereas the global population increased by 2.4 times between 1950 and 2000, that of dryland countries grew by 3.7 times on average. Within some individual countries, some dryland states grew even more than the national average. In the USA, for example, between 1990 and 2000 Nevada's population grew by 66% and that of Arizona by 40%.

Urbanization

Deserts contain many large cities, and the rate of urbanization increases apace (Figure 4). The average size of major dryland cities expanded 7.9 times between 1950 and 2000. In 2020, the metropolitan area of Cairo had a population of ca. 21 million; Karachi, 16 million; Los Angeles, 12.5 million; and Lima, 10.7 million. The footprint of such cities is enormous: they require water, fuel, building materials, food, space for construction, and room for recreation. All these needs have geomorphological impacts. Cities can encroach on sites of geological value, as is the case with some petrified forests on the fringes of Cairo in Egypt (AbdelMaksoud and El Metwaly 2020). There has also been a great loss of sabkhas and of mangrove swamps in the United Arab Emirates.

Off-road activities

Deserts have surfaces that are often unprotected by

Figure 3. The scars produced by a dense network of seismic lines at Fahud, Oman. The scale bar equals 1km. © GOOGLE EARTH 2021

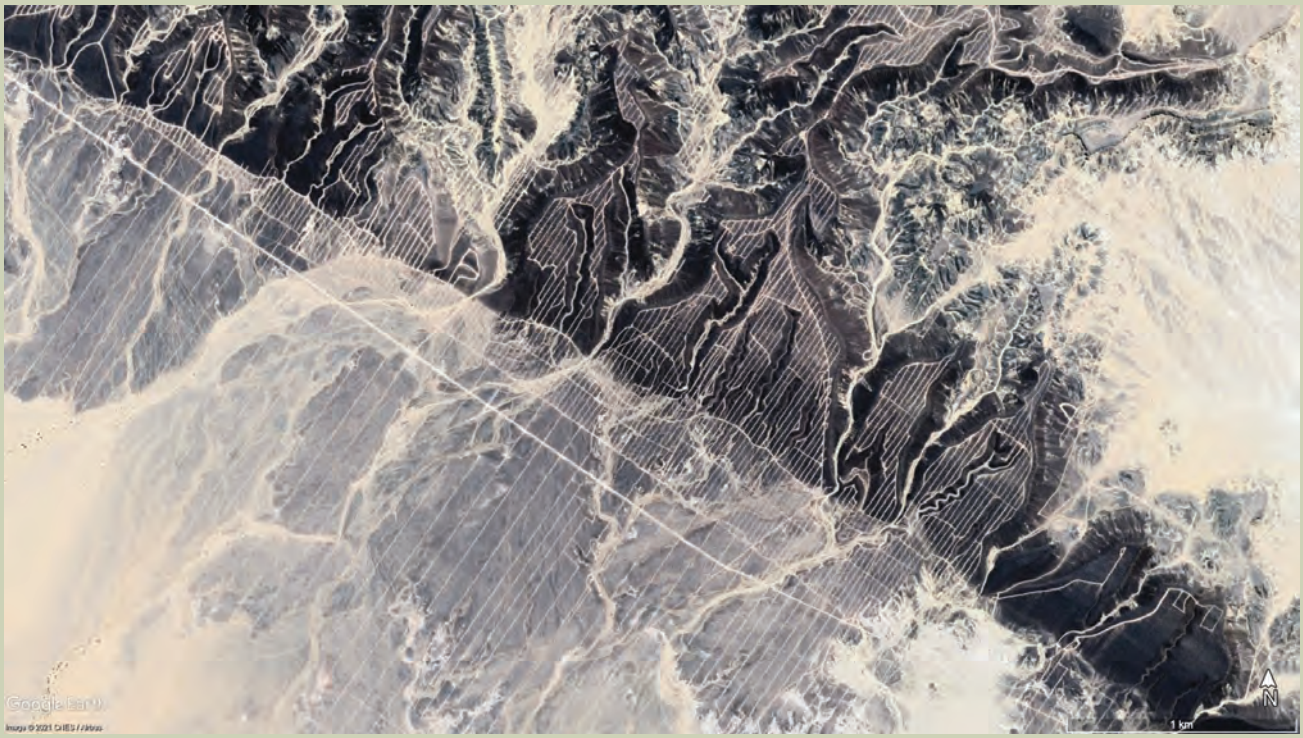


Figure 4. The growth of Dubai between 1984 (population 0.3 million) and 2020 (population 2.5 million). Note the development of offshore islands. The scale bar equals 10km. COURTESY © GOOGLE EARTH 2021

vegetation and which are highly susceptible to the passage of off-road vehicles (Figure 5), including those associated with burgeoning tourism and sport (e.g., the Dakar Rally). Surfaces become disturbed (making them prone to wind erosion), compacted, and denuded of their biological and rain-beat crust cover. The scars created can last for decades. The situation can be mitigated either by creating well-defined sacrificial areas, or by forbidding entry. Both these approaches have been employed successfully in the central Namib Desert near Swakopmund.

Military

It is an unfortunate fact that many wars have been

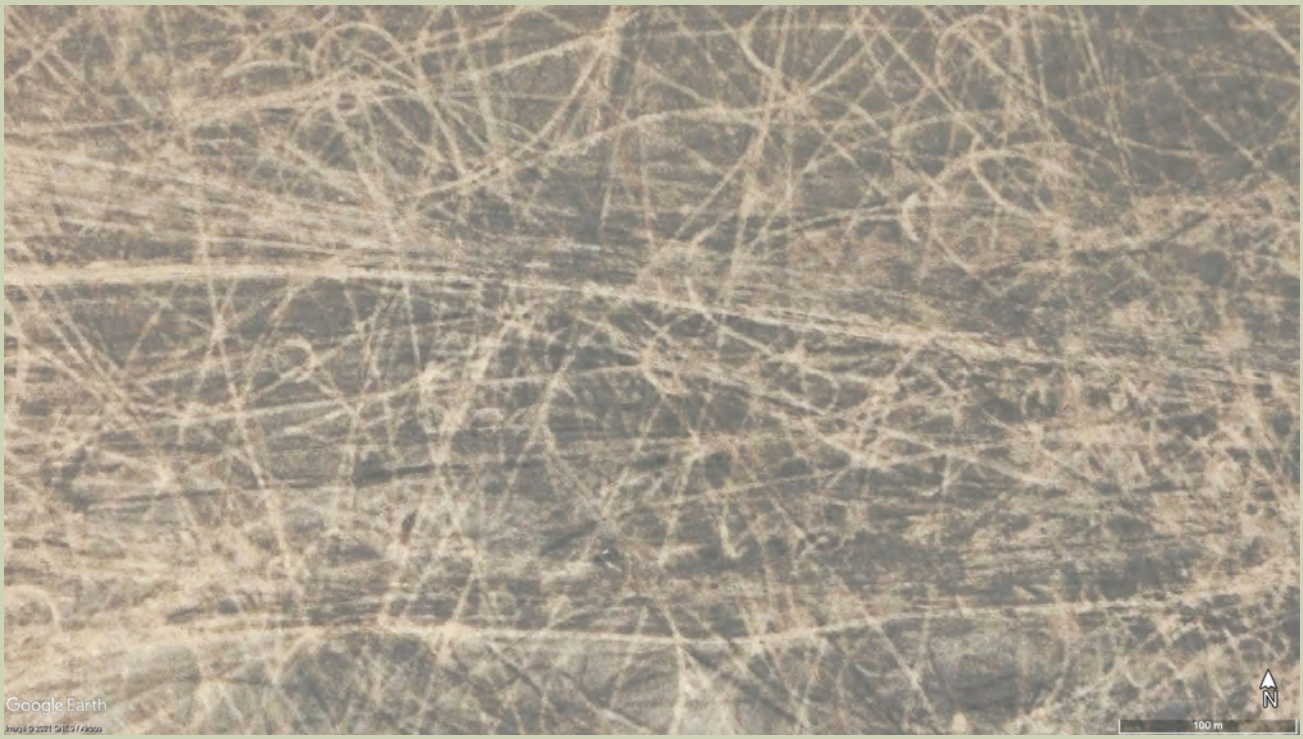


Figure 5. A disturbed desert (stone) pavement in the eastern Saudi Arabia, caused by off-road driving. Location ca. 26°35′S, 49°43′E. The scale bar equals 100m.

waged in arid areas over recent decades, including in Iraq, Libya, Somalia, Chad, Mali, Egypt, Syria, Kuwait, Afghanistan, Palestine, and Yemen. Among the consequences of military activity, either during war or during training exercises, are the destruction of ecosystems where the regeneration time of vegetation can be long, the generation of aeolian dust by armored vehicles and helicopters, the increase in fluvial sediment yields caused by the operation of tracked vehicles, and the destruction and scarring of stone pavements.

Quarrying and mining

One consequence of urban expansion is that desert areas have been subjected to great amounts of excavation for the aggregates used in the construction industry. Thus with the growth of Dubai, sand dunes have been mined and limestone hills flattened (Figure 6). Fine examples of caves and stalactites, along with archaeological materials occurring within them, have been destroyed. Licenses for quarrying should be preceded by surveys, so that valuable karstic sites are protected. Desert areas also have mineral resources, some of which are associated with specific arid zone phenomena. Examples include salt deposits, including the increasingly important lithium, nitrate (caliche), and calcrete-hosted uranium. There have been considerable worries about mining of the latter in the context of the Namib Sand Sea World Heritage Site.

River diversions and other hydrological modifications

To enable irrigation to occur, and to provide water for municipal supplies, many desert lake basins have been transformed by water abstraction and inter-basin water transfers. Notable examples of desiccation include the Aral Sea in Central Asia, Lake Poopó in Bolivia, Lake Urmia in Iran, and Owens Lake in California. The consequences of such desiccation include the generation of dust storms and the transport of toxic materials downwind, to the detriment of the health of local populations.

Energy industries

The search for oil has meant that seismic lines have been constructed in countries such as Oman. These scar the landscape and, because of the slow growth of vegetation, their effects are long lived (Figure 3). In addition, two forms of renewable power, solar and wind, both of which are particularly suitable for development in desert areas, can cause widespread

Figure 6. Sand mining of large linear dune systems in the United Arab Emirates. A.S. GOUDIE

disturbance. In coming decades, exploitation of renewable energy sources will almost certainly develop dramatically, and guidance needs to be developed to try and ensure that their footprint is made as small as possible.

Future climate changes

Desert areas will be particularly sensitive to future anthropogenic climatic change. Models indicate that most dry areas will become even drier, that dunes and dust storms may become more active, that river flows and drainage networks will be reduced, and that lakes may contract. Paleoclimatic work suggests that dune fields have been subject to repeated changes of state in response to Holocene and Late Pleistocene droughts. Similarly, closed basins, which are such a feature of desert landscapes, respond rapidly and profoundly to climatic changes, as we have seen with the desiccation of Lake Chad in the drought years of the late 20th century. River channels in arid regions have proved to be particularly sensitive to changes in precipitation and runoff, and have displayed rapid switches between incision and aggradation (e.g., the arroyo systems of the American Southwest). In addition, coastal environments, particularly sabkhas, which by their very nature are very low-lying, will be impacted by sea level changes. This needs to be appreciated because of the long-term implications for infrastructure development, and built into future planning zonation.

CONCLUSIONS

Desert regions have a great array of often spectacular landscapes that display the power of aeolian and other processes. There still remains a shortage of natural World Heritage Sites that relate specifically to deserts, but there are substantial numbers of mixed sites and tentative sites that contain good examples

of landform types and processes. Equally, there are only a modest number of desert UNESCO Global Geoparks. However, following on from the growth of domestic and international tourism, the value of spectacular landforms as a source of economic advantage is becoming ever more important. However, such landforms are subject to various threats, including off-road driving, military conflicts and training, urbanization, quarrying and mining, river diversions, developments associated with energy industries, and anthropogenic climate change.

Andrew S. Goudie
School of Geography and the Environment, University of Oxford
South Parks Road
Oxford, OX1 3QY United Kingdom
andrew.goudie@stx.ox.ac.uk

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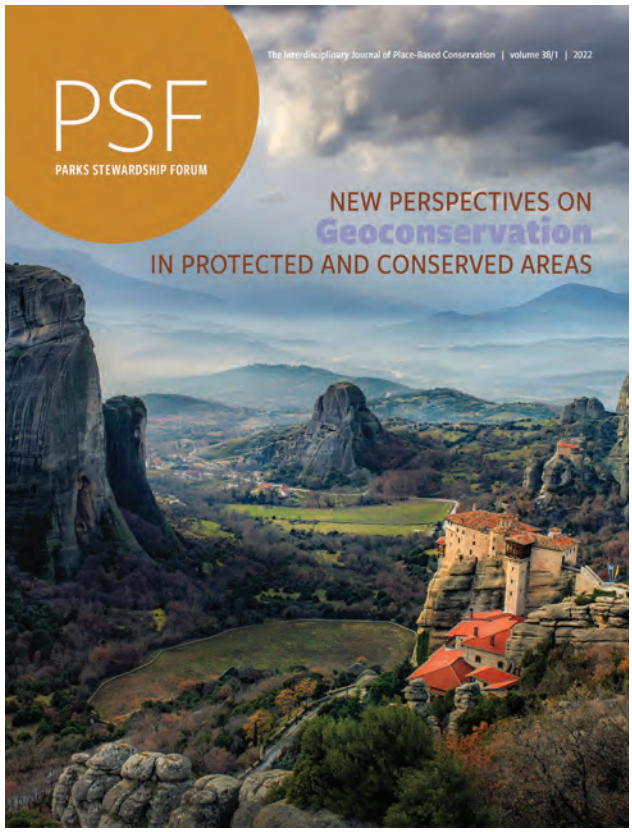

On the cover of this issue
The precipitous rock spires of Meteora World Heritage Site in Greece have a complex geological history. Over the centuries a number of Eastern Orthodox monasteries were built atop them, and today's World Heritage Site recognizes this cultural history as part of the overall geoheritage. | STATHIS FLOROS