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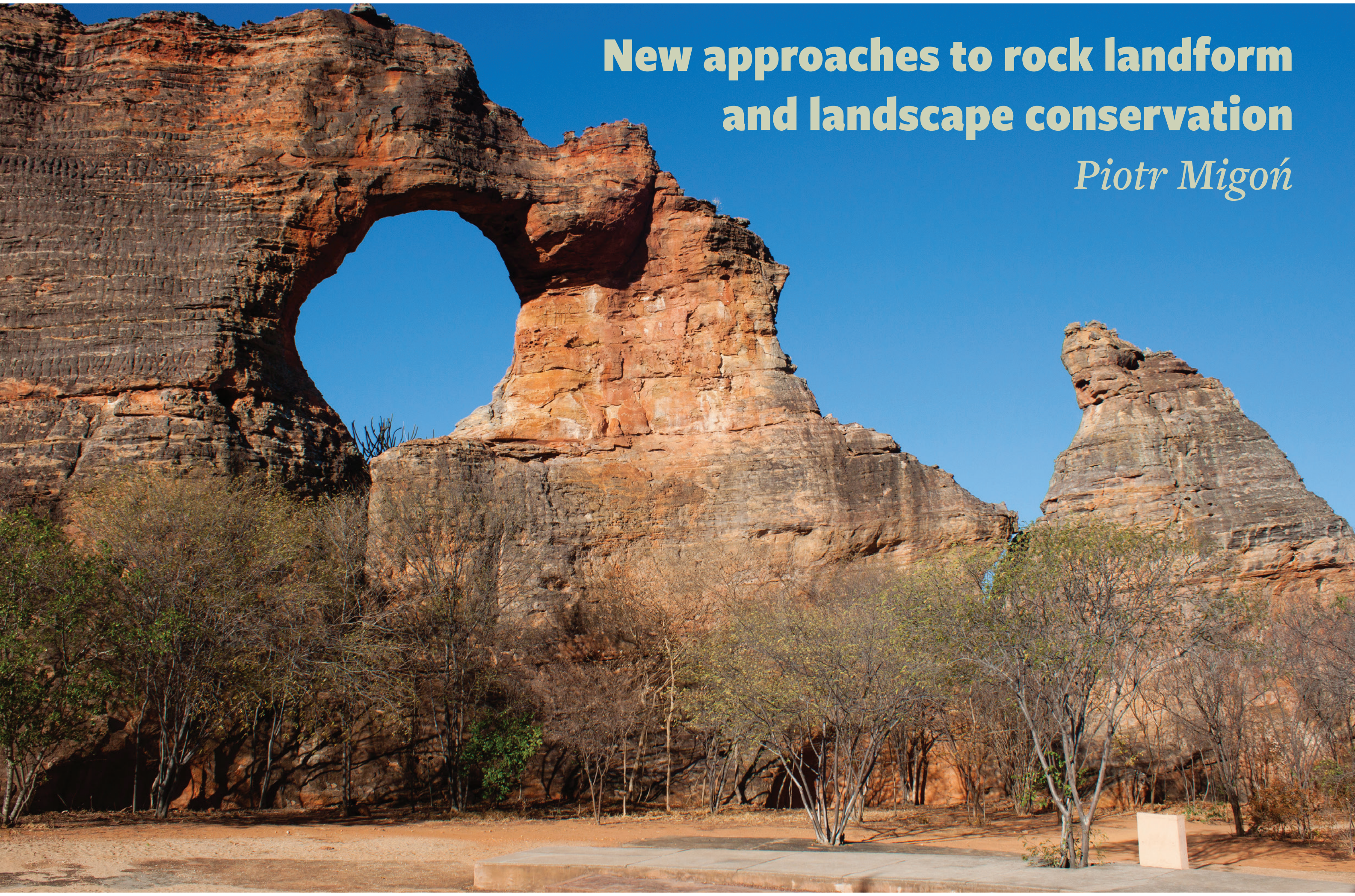

New approaches to rock landform and landscape conservation

Piotr Migoń

ABSTRACT

Rock landforms are natural outcrops of solid bedrock, exposed at the earth surface due to higher resistance to weathering and erosion. They are important carriers of information about past and more recent geological and geomorphological processes, underpin biodiversity and cultural values, and may have considerable aesthetic significance. Many are popular tourist destinations. They are subject to different threats, including physical damage through quarrying and vandalism, may suffer from excessive rock climbing, or their values are compromised by uncontrolled vegetation growth. Their interpretation is often poor or non-existent. Conservation measures and solutions are mainly site-specific and typically require coordination with biological conservation, including prioritization of conservation efforts focused on localities of special scientific significance.

INTRODUCTION

In the contemporary natural world that evolves under increasing pressure from humans, conservation and protection are primarily focused on its most fragile, sensitive and non-renewable elements, both biotic and abiotic. The perspective of rapid and irreversible change, especially if this may lead to extinction or disappearance, prompted conservation efforts and educational campaigns. Increasing appreciation of geoheritage and geodiversity, coupled with the growing awareness of their value and significance, resulted in various conceptual advances and new practical solutions aimed at their conservation and preservation (Gray 2013). However, there are certain elements of geodiversity that seem to be at

Pedra Furada, Serra da Capivara National Park and World Heritage Site, Brazil ARTUR WARCHAVCHIK the margins of current conservation trends. Among them are topographic elements built of exposed solid rock, such as granite, basalt, or sandstone, collectively called *rock landforms.* Being built of rock commonly perceived as hard, durable, and impervious to change, especially in the short-term, human life-time perspective, they may be thought of as not in need of any specific conservation practices. Such a stance is far from true though. In fact, different values associated with rock landforms are at risk, as not all rocks are equally hard and resilient. Some are astonishingly soft, and their imposing stature may be deceptive. This article aims to briefly explain rock landforms and their associated values, outline major threats and challenges, and suggest some good practices that should govern their conservation.

ROCK LANDFORMS AND LANDSCAPES

Except in specific settings and circumstances, such as high mountains, seaside cliffs, or quarries, solid rock is rarely exposed at the earth surface. It is typically concealed by a layer of *in situ* weathering products, known as *regolith* (which may also include sediment coming from elsewhere), which in its uppermost part supports soil. Nevertheless, the regolith mantle is not everywhere continuous, and solid bedrock may protrude through, forming natural outcrops of different sizes and shapes (Figure 1). These may be inconspicuous, low, shield-like elevations and platforms, but they may also be impressive hills or mountains hundreds of meters high, weirdly shaped smaller elements resembling ruined buildings, or rock cliffs along valley sides, within the slopes of mountains, and along the shores of water bodies (Gerrard 1986). Some are described in geomorphological vocabulary under specific names. Thus, bedrock hills rising sharply from an otherwise flat, regolith-supported surface are known as *inselbergs* (literally "island hills"—the term is derived from German), whereas smaller outcrops,

Figure 1. Diversity of rock landforms: A—solitary hill (inselberg) built of very resistant volcanic rock (Agathla Peak, Arizona, USA), B—granite tor (Karkonosze Mountains, Poland), C—rock city (El Torcal, Spain), D—granite boulder with weathering pit as an example of surface weathering microform (Jizerské hory, Czechia). PIOTR MIGOŃ

up to 15–20m high and a few tens of meters long, are *tors* (the word derived from the Welsh *twr*—a pile of boulders). Other terms in use to account for the variety of rock landforms are *pedestal rocks, hoodoo rocks,* and *rock pinnacles.* They may show diverse micro-topography themselves, with distinctive minor landforms such as circular or elongated weathering pits, cavernous hollows in vertical rock walls known as *tafoni* and honeycombs, and networks of rills on both steep and gently sloping surfaces. Singular rock landforms may combine into larger assemblages. The term *ruiniform relief* is used to describe large groups of bedrock outcrops, which collectively may resemble ruined towns, whereas associations of tall rock cliffs and towers, separated by deep, but passable clefts, are referred to as *rock cities* (Migoń et al. 2017). They look most impressive in scarcely vegetated terrains, but forested areas of Central Europe also hide remarkable examples. One also has to mention *blockfields*—extensive areas covered by loose angular boulders, typical for uplands and some mountain tops.

Thus, rock landforms differ in size, but more important are differences in origin and age, as these directly bear on the scientific significance of these rock features. Most bedrock landforms are products of non-uniform weathering and consequent removal of loose debris liberated by weathering (Twidale and Vidal Romaní 2005; Migoń 2006; Young et al. 2009). The reasons for unequal weathering, in turn, usually reside in the rock itself, which is rarely homogeneous in composition and structure. Typically, parts with a higher density of natural discontinuities are less resistant and disintegrate faster. The more massive compartments remain and gradually rise as the surrounding terrain is lowered. Various conceptual models have been developed to explain how this process of non-uniform weathering proceeds in detail, and it is now certain that rock landforms can have more than one origin. Some exposed bedrock features result from one or more of the following causes: mass movements, river or marine undercutting, aeolian abrasion, glacial stripping, and re-shaping of pre-existing surfaces. Likewise, rock landforms vary in age and require different lengths of time for their formation. Some of the largest inselbergs in ancient shields may have begun to form in the Mesozoic era and certainly needed millions of years to acquire their contemporary shape. Tors in European oldlands, such as Dartmoor in southwestern England, were traditionally considered as inherited pre-Quaternary landforms, although more recent research showed that their growth and decay are continuous and ongoing processes. Many rock landforms, such as crags, mid-slope cliffs, and extensive blockfields, originated in the cold-climate environments of the Pleistocene (Migoń 2006).

Not all rock types support rock landforms. The very weak ones, such as shales or schists, rarely do this. But other ones are well known for their association with remarkable scenery. These mainly include granites (Twidale and Vidal Romaní 2005; Migoń 2006) and sandstones (Adamovič et al. 2006; Young et al. 2009; Migoń et al. 2017). Granites build some of the most spectacular inselbergs in the world and the most classic tors, often shaped as ruined castles or towers. Domes are another distinctive shape of granite rock landforms. In other localities, huge monolithic boulders, some in excess of 15m, or widespread block fields occur. The biggest tafoni caverns and the largest weathering pits are also reported from granite areas. Sandstones, in turn, are shaped into long cliff lines punctuated by deep clefts, or give rise to widespread ruinform relief, including rock cities and rock labyrinths. If a massive sandstone layer overlies weaker strata beneath, characteristic residual tabular hills (mesas, buttes) form, for which the Colorado Plateau in the American Southwest is a classic locality. Minor differences in lithology or bedding account for the origin of pedestal rocks, whose shapes resemble giant mushrooms and which are often referred to as such in local toponymy.

SIGNIFICANCE AND VALUE OF ROCK LANDFORMS

As with most other geodiversity components, rock landforms have multiple values, which justify conservation and protection (Gray 2013). Although in many cases it is probably aesthetic values that are the most appealing to the general public, conservation is primarily guided by the scientific values and these have to be introduced first. In brief, the scientific significance of bedrock landforms is twofold. First, being natural rock outcrops, they are excellent, easily accessible windows into the distant geological past, into the times when a given rock originated (Figure 2). Thus, for example, granite tors and inselbergs expose, often over distances of tens or hundreds of meters, the rock with all its textural variability and magmatic facies change, veins and enclaves of different composition, and primary and secondary joints. Sandstone cliffs and rock cities allow sedimentary structures, lateral and vertical

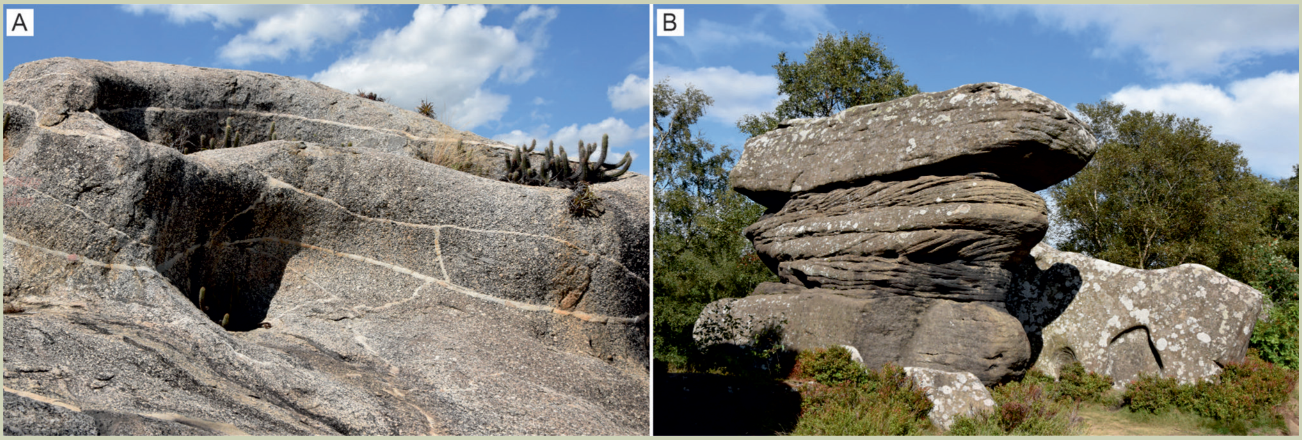

Figure 2. Bedrock outcrops as carriers of information about magmatic and sedimentary processes: A—aplite veins in coarse-grained granite, magmatic foliation structures in the lower left corner (Quixadá, Brazil), B—stacked sandstone beds with different sedimentary structures (Brimham Rocks, England). PIOTR MIGOŃ

changes, and post-sedimentary deformations to be traced. Consequently, sedimentary histories may be reconstructed. In contrast to quarry faces, rock landforms are typically 3-D objects, enhancing the suitability for the interpretation of rock origin. Second, bedrock landforms inform us how the earth surface has evolved and which changes are occurring at present. Morphology, relationships to cover deposits in the surroundings, and the geomorphological context are the vital sources of information for the recognition of processes and timescales involved in deciphering the origin of these features. For instance, in Central and Western Europe the spatial association of tors with angular blockfields suggests a periglacial origin and a Pleistocene inheritance, whereas the occurrence of clay-rich regolith around tors is more compatible with a much longer history and an origin in pre-Quaternary times. Superimposed weathering features, such as large tafoni or pits, are indicative of general surface stability, hence of rather low rates of change and general longevity of the residual landforms. In formerly glaciated lands, differences in the shape of tors helped to constrain the efficacy of glacial erosion and were input data for paleoglaciological mapping and modeling (Migoń 2006).

The presence of rock landforms may underpin biodiversity values, as these landforms are like isolated islands within a different type of terrain, characterized by site-specific bedrock, soils, water availability, and, in the case of rock cities and labyrinths, microclimate. Tropical and arid inselbergs have been shown to be local biodiversity hot spots, with different plant communities occupying different ecological niches, from exposed hilltops to shaded, damp ravines and temporary waterholes in weathering pits (Porembski and Barthlott 2000; Figure 3). In Central Europe microclimatic conditions in deep clefts of sandstone rock cities account for the altitude reversal of vegetation belts and the occurrence of Pleistocene relics, whereas exposed tops of tabular hills support thermophilous species, well adapted to water deficit.

The value of rock landforms is not limited to the natural world. Many are of considerable cultural significance, both tangible and intangible (Gordon 2018). The former includes associated historical heritage, ranging from grand fortresses and castles erected in the top part of bedrock hills through various religious structures such as chapels, shrines, calvaries, and singular symbolic structures, to less conspicuous but nonetheless important archaeological remains such as stone circles, ramparts, and tombs (Figure 4). Often these historical monuments are perfectly blended with the natural scenery, forming local cultural landscapes of high aesthetic value. Distinctive rock landforms become immortalized in local legends and folk tales, reflecting not only the inability of untrained people to explain their origin and presence, but also deep spiritual connection of local people with these sites, which are inseparable components of local identity. Some serve as regional landmarks, easily identified even from afar, and are inspirations for distinctive crafts.

The aesthetic value of rock landforms is difficult to evaluate objectively, but it can be inferred from the

Figure 3 (above). Inselberg massifs, especially in arid and semi-arid areas, are typically characterized by higher biodiversity than their surroundings (Pedra da Boca, Brazil). PIOTR MIGOŃ

Figure 4 (below). Ruins of the medieval Trosky castle in northern Czechia occupy a twin basaltic neck, adding cultural dimension to the impressive natural outcrop. PIOTR MIGOŃ sustained interest in these features for tourism and recreation purposes. People have long been attracted by bizarre shapes of tors and hoodoos, marveled at impressive rock inselbergs, and ready to explore rock labyrinths. Viewing points towards rock formations are popular sightseeing and photography stops, whereas the formations themselves may also play the role of excellent lookouts of high interpretation value.

Last but not least, rock landforms may also have economic value, since they attract visitors ready to pay to see them. This particularly applies to larger assemblages of bedrock features (rock labyrinths, rock cities) that have been developed for tourism. Entrance fees have been imposed, the proceeds from which sometimes are later spent to sustain conservation activities and improve living standards of local populations. The status of some localities is raised by various global, national, and regional protected area designations, including as UNESCO World Heritage Sites and UNESCO Global Geoparks, national parks, and nature reserves. Examples of World Heritage Sites include several Chinese granite mountains (Huangshan, Sanqingshan), Uluru and Kata Tjuta sandstone inselbergs in Australia, Serra da Capivara in Brazil, or Meteora in Greece (Figure 5). Rock landforms are also used by climbers, presenting challenging routes across seemingly inaccessible rock faces.

THREATS AND CHALLENGES

Despite apparent durability, rock landforms are not impervious to change, and their values can be compromised. The catalogue of threats to their integrity and the challenges that conservation faces is quite varied (Table 1). First and foremost, physical damage to the site may occur. The most devastating of all is stone quarrying, which may lead to the complete disappearance of an outcrop. For example, in the 19th century several granite tors and huge boulders in several Central European lands fell victim to quarrying, including Waldviertel in Austria and Lausitz and Erzgebirge in Germany. In the Stołowe Mountains tableland in southwestern Poland, large residual sandstone boulders, which constituted a unique legacy of hillslope processes and plateau degradation, were ubiquitously used as a convenient source of building material. Less evident alterations were associated with trail engineering, aimed at increasing accessibility of rock

Figure 5. The granite massif of Sanqingshan (China) has been a UNESCO World Heritage Site since 2007. PIOTR MIGOŃ

Threats	Counteraction and remedies
Quarrying	Long-term management plan Legal designation of protected areas
Physical alterations/shape modifications	Long-term management plan Legal designation of protected areas
Vandalism/rock surface defacing	Monitoring at key localities Blocked access to vulnerable localities Educational panels
Rock climbing	Designation of exclusion zones Closure of climbing routes
Uncontrolled vegetation growth	Periodic clearing
Natural disintegration processes	Engineering using least-invasive solutions, but only if visitors' safety may be compromised and no alternative access is available
Negligence/lack of interpretation	Development of interpretation tools

Table 1. Threats to rock landforms and possible conservation measures.

formations for tourism and recreation. On the other hand, however, rock-hewn stairs, fissures widened to accommodate paths, artificially leveled rock platforms, and other modifications are the testament of early developments in tourism, typically from the 19th century, and have acquired some historical value. The same can be said about plaques commemorating famous people or memorable events, erected or carved in visible spots, and larger-scale bas-reliefs, typical of sandstone areas of Central Europe. A recent threat, reported from various parts of the world, is rock outcrop defacing using paint. In soft rock, such as sandstone, defacing may also take the form of chiseling out letters or symbols, which are almost impossible to remove afterwards. Incidentally, vandalism has had more serious effects. Minor hoodoo rocks rising above a very small base may be forcibly toppled and various rocking stones no longer move after they are displaced too much by unaware visitors.

An important, but often overlooked, issue is the disappearance of rock formations from sight due to uncontrolled vegetation growth after a previous period of much better visibility, for example in largely deforested, former agricultural landscapes. Whereas this is not a problem in drylands or areas above the tree line, it may be quite serious elsewhere, where trees and shrubs can easily colonize rock outcrops and their immediate surroundings. Although the rock landform itself is not damaged in this way, it may lose its other values, especially its suitability as a site for geo-educational activities based on scientific significance. This is because the landform is no longer visible and cannot be easily explored; even direct access may become very difficult. Furthermore, an overgrown rock is hardly a recognized landmark any longer and loses its attractiveness for tourists, whereas at the same time poor visibility from a distance may prompt visitors to leave marked trails and explore on their own, which may be both against the rules and not entirely safe. It seems that a good solution of how to simultaneously sustain the values of rock formations and support biodiversity is yet to be found.

Rock landforms may seem entirely stable naturally, but this is far from truth. They are continuously subject to natural processes of weathering and mass movements. Whereas the former are usually slow and incremental, the latter may be sudden and involve larger rock fragments that fall down, topple, or slide. In jointed soft rock, production and downslope displacement of debris may occur almost without interruption. From the nature conservation point of view, these are natural processes illustrating how nature works and do not require human intervention. However, the situation is different at tourist sites, where they may compromise the safety of visitors such that workable solutions have to be found.

Human exploration of rock outcrops, including rock climbing, may have negative effects too. Whereas very hard rocks such as granites or quartzites are hardly prone to damage, sandstones are a different matter. Even if massive in terms of joint density, their intact strength can be surprisingly low and they may easily crumble if too much force is applied to the rock surface. Moreover, sandstones disintegrate into sand, which is very erodible if lacking a protective grassy mat. Water erosion of sand-covered slopes below sandstone rock formations may thus be a serious problem.

The final group of challenges addressed here is of a very different nature: interpretation to the public. Rock outcrops tell fascinating geological and geomorphological stories and have huge potential to engage visitors and to raise their awareness of geoheritage, if these stories are appropriately conveyed. This is not an easy task though, as it requires from the visitors simultaneous understanding of basic concepts and terms in petrology, tectonics, geomorphology, climate change, and Quaternary history, if the interpretation is not to be naïve and oversimplistic. Consequently, interpretation facilities (panels, website resources) have to be adequately designed in terms of wording and graphics to be understandable to the public, but also placed in spots where they will work most effectively. Good visibility of an outcrop subject to interpretation is among the key prerequisites.

ROCK LANDFORM CONSERVATION—TOWARD GOOD PRACTICE

Considering all threats and challenges, themselves of very different sorts, a catalogue of conservation measures and good practices will be complex (Table 1). Moreover, it is unrealistic to expect that universal solutions can be offered. Challenges vary between vegetated humid lands and dry, cold, or deforested areas, as the exposure of rock formations is different. Different recommendations will be more pertinent to areas where rock landforms are rare, in contrast to terrains where they are abundant. Cultural contexts and underpinnings are very different too, including realization of the fact that some rock formations are valued primarily for their cultural or spiritual significance rather than for their scientific content.

Nevertheless, it seems that a proper inventory and evaluation should always be a starting point, with due attention to all values possibly associated with rock landforms treated as geosites. The literature offers a variety of geosite assessment procedures that can be used (Brilha 2018), and an expert decision on which one applies best in a particular region should be made prior to further field and desk work. The inventory should result in prioritization of conservation efforts, as it may be simply impossible to invest in all sites of interest if there are many. At this stage, it is worth reflecting on the fact that the most valuable sites from a scientific viewpoint are not necessarily the largest ones. For example, peculiar weathering relief or a particularly instructive sedimentary structure may determine the value of a rock outcrop, rather than its shape or size. At this stage, collaboration with a biologist is recommended, so that suggested conservation priorities for abiotic and biotic components are not in conflict.

After prioritization is agreed, principal on-site conservation measures will include reasonable vegetation clearance (if applicable) so that the outcrop is adequately exposed and serves as a good viewing point; design of access routes that includes trail engineering, marking, and signposting; as well as provision of basic interpretative facilities. The latter should explain clearly the values of a particular locality and indicate the conduct of visitor behavior. This is important, since in contrast to more specialist geosites of mineralogical or paleontological interest, rock formations tend to be visited mostly by casual tourists whose awareness of geoheritage and its fragility may be low. In some locations, more sophisticated engineering may be necessary if an outcrop is to be made accessible yet presents considerable technical difficulties and may be considered unsafe. Possible solutions include iron or wooden ladders, railings, and barriers. All these provisions need to be regularly monitored and maintained, as they may deteriorate naturally or become damaged and unsafe. While designing access routes, evaluation of rock slope stability should be undertaken. Piles of loose debris at the foot of a rock wall is an indicator that close access may not be entirely safe.

If applicable, the rules of rock climbing need to be agreed upon and observed. In soft sandstones there are special rules aimed at minimizing the negative impact on the rocks, whereas some routes may require temporary closures to allow for natural regeneration, or even permanent ones if such impacts may result in lasting damage to both the rock and the plant communities growing upon it.

CONCLUSIONS

Natural rock formations present specific challenges for geoconservation. On the one hand, they are among the most visited geoheritage sites because of their often eye-catching shapes and dimensions, as well as associated non-scientific values. Thus, there may be particular pressure to increase their availability to the public. On the other hand, they seem impervious to change, following the common perception of a rock as something hard, stable, and resistant. Nevertheless, a fundamental distinction between hard solid rock, such as granite, and soft solid rock, such as sandstone, has to be made. Both are known to support great scenery, but sandstone landforms are much more fragile and prone to damage. Consequently, specific conservation measures will be different. In fact, general conservation rules for rock formations are very simple and include inventory and evaluation, mitigation of physical damage resulting from human pressure, provision of adequate access and interpretative facilities, and—if applicable—maintenance of visibility. Otherwise, site-specific solutions will apply, adjusted to the local geological, geomorphological, and cultural context.

It is beyond doubt that rock landforms have multiple values, perhaps more than any other geosites. In particular, their association with cultural values is enormous and diverse. Therefore, they are not only the focus of geoconservation interest, but other stakeholders may have an important role to play. To develop successful cooperation is challenging, but it also offers an excellent opportunity to show that geoheritage really matters and underpins many other spheres of life.

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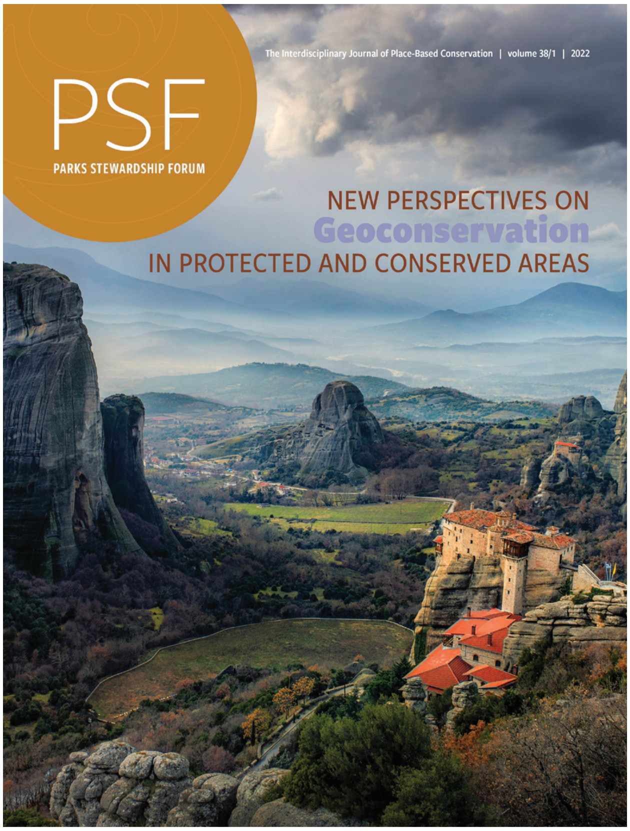

On the cover of this issue

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