International Journal of Heritage and Sustainable Development
Vol. 1, No. 1, June 2011, pp. 60-71

Care and Management of Ancient Stone Monuments during Environmental Change

Myra J. Giesen *International Centre for Cultural and Heritage Studies, Newcastle University, UK* myra.giesen@ncl.ac.uk

Aron D. Mazel *International Centre for Cultural and Heritage Studies, Newcastle University, UK*

David W. Graham *School of Civil Engineering & Geosciences, Newcastle University, UK*

Patricia A. Warke *School of Geography, Archaeology and Palaeoecology, Queen's University, UK*

Ancient stone monuments (ASMs), such as standing stones and rock art panels, are powerful and iconic expressions of Britain's rich prehistoric past that have major economic and tourism value. However, ASMs are under pressure due to increasing anthropogenic exposure and changing climatic conditions, which accelerate their rates of disrepair. Although scientific data exists on the integrity of stone monuments, most applies to "built" systems; therefore, additional work specific to ASMs in the countryside is needed to develop better-informed safeguarding strategies. Here, we use Neolithic and Bronze Age rock art panels across Northern England as a case study for delineating ASM management actions required to enhance monument preservation. The state of the rock art is described first, including factors that led to current conditions. Rock art management approaches then are described within the context of future environments, which models suggest to be more dynamic and locally variable. Finally, a Condition Assessment and Risk Evaluation (CARE) scheme is proposed to help prioritise interventions; an example of which is provided based on stone deterioration at Petra in Jordon. We conclude that more focused scientific and behavioural data, specific to deterioration mechanisms, are required for an ASM CARE scheme to be successful.

Keywords: management ancient stone monuments, climate change, resilience, management, condition assessment

Introduction

Ancient stone monuments (ASMs), including standing stones and carved rock art panels, exemplify Britain's rich prehistory and provide a visual link to our ancestors. These non-renewable heritage resources have great cultural, aesthetic, and tourism value, frequently acquiring Scheduled Ancient Monument and even World Heritage status. Often, these monuments provide an important testimony to a time without written records and are irreplaceable. Despite their perceived immutability, ASMs are under mounting pressure due to increasing population densities associated with urban expansion, pollution, and agricultural activity as well as climate change. As a result, ASMs are growing in disrepair and ultimately may vanish from the countryside.

In spite of their apparent vulnerability, strategies for specifically addressing the management of ASMs are limited. This is partly due to their perceived longevity, but also because most scientific information on stone integrity and resistance to change is biased towards built environments (Prikryl and

Smith, 2007; Fort et al., 2006; Smith and Warke, 1996), which do not always apply to ASMs in the countryside. As an example, the nature of the stone used in ASMs often differs from built structures. Unlike stones used in built structures, ASM stone usually is not "worked" having been carved in situ with such monuments typically located in rural landscapes where they are subject to differing ecological and physical pressures compared with built systems in urban settings. As such, significant gaps exist in our understanding of the key factors that influence ASM state, especially given increasing human intrusion in the countryside and forecasted dynamic changes in our climate over the next century.

As background, research into physical, chemical, and, to a lesser degree, biological weathering (bioweathering) of rock carvings has been performed since the 1970s (Bakkevig, 2004). However, only recently have more extended scientific studies on rock deterioration been performed to better inform ASM management (e.g., St. Clair and Seaward, 2004; Macedo et al., 2009). Although this current study does not provide new data on deterioration mechanisms, its aim is to highlight key issues pertinent to ASM preservation with a particular focus on management approaches that might be implemented now to future-proof ASMs during periods of environmental and climatic change. Within this context, the objective is to consider four issues related to ASM preservation. First, we will examine and clarify differences between the terms "resilience" and "resistance to change" within the context of ASM management. Second, pressures and threats to ASMs will be summarised, including how such pressures might alter under different climatic conditions. Third, ancient rock art panels across the countryside in Northern England will be used as a case study for discussing management questions related to environmental change. These panels were selected partially because they rarely have been studied in a holistic manner, but also to demonstrate differences in ASM integrity relative to the integrity of stone built monuments. Finally, management implications will be discussed for enhancing the resilience of ASM sites, including the development of formalised condition assessment schemes for ASMs to help prioritise sites for managerial and other interventions. The ultimate goal is to stimulate the development of formalised frameworks for heritage management that both consider present and future climatic conditions and could be translated to other similar scenarios.

Resilience Versus Resistant to Change

"Resilience" is a term applied in many disciplines, ranging from engineering to anthropology, but its meaning often differs. In fact, the term frequently is misused, which confuses its implications, especially in the management of complex systems. The term describes a system's ability to remain functionally consistent over time under stress and also its ability to readily recover to its original state after disturbance. Therefore, we define resilience to mean the "quality or state of being flexible" at the system level. With this in mind, ASMs innately are not resilient. Although in comparison to other materials, stone is typically highly resistant to change, it is not literally resilient because when stone deteriorates it does not return to its original state. ASM deterioration is non-reversible and permanent. Therefore, the first key in management is to maintain the current state of the ASM for as long as possible, which means creating and/or retaining resilient environments around the ASM such that changes in the ASM condition state are minimised. As such, management should focus on creating environments surrounding ASM that are intrinsically stable in themselves, which will in turn maximize the ASM's tendency to "remain stable" by keeping local conditions as consistent as possible (e.g. moisture conditions, drainage, exposure to air, animals etc.).

As an aside, ASMs are by definition "old", sometimes up to 6000 years old, and their presence in current landscapes argues that a high level of resistance to change must exist. However, we also must consider that the ASMs that remain may be the remnants of a much larger collection, much of which already has been lost during the past centuries with today's 'survivors' representing a self-selecting group of more resistant stone types. While past resistance to change is related partially to wise selection of stone by the original creators of the monuments, population densities, agricultural intensity, and pollution were much lower in the past, and temperature and precipitation patterns have been relatively consistent for the last 10,000 years (Bond et al., 1997). However, growing evidence suggests that environmental conditions that facilitated past long-term resistance to change may not continue into the future. Therefore, contemporary ASM management must consider increasing populations, greater exposure to pollution, and other broad threats, such as gradual or sudden changes in our climate (Broecker, 2010).

Pressures and Threats

To consider how ASMs might be affected by future conditions and, in turn, help define appropriate management solutions for preservation, it is first important to establish the types of threats that might affect their longevity. It is not completely clear which of the current and/or future threats are of greatest importance. Although, it is reasonably certain that most threats will differ over space and time, some will be predictable and others not, while still others are unknown at this time. This variability makes developing management strategies difficult and suggests that the best general approach for ASM preservation is to 1) better understand the "science" behind the deterioration; 2) develop methods for prioritising sites for protection and immediate action; and 3) refine monitoring approaches for defining ASM "state" to flag where deterioration of consequence might be occurring. To start, we will summarise various pressures and threats that are "known", somewhat predictable, and often controllable. After that, we will present specific data on rock art in North East England. Then we will discuss less controllable factors, such as sudden climate change. As will become apparent, many factors that affect monument integrity are hard to define and quantity. Therefore, creating resilient environments around ASMs, regardless of future conditions, is of greatest importance to management.

Known Processes

The processes responsible for stone decay must be understood to successfully prevent, treat, and/or manage ASMs; failure to do this can lead to inappropriate strategies that can amplify original problems or trigger new deterioration scenarios. Many processes affecting ASM decay are similar to or the same as those influencing built stone structures (BSSs), yet key differences also exist. Mutually significant decay processes between built and non-built monuments include physical breakdown (e.g. flaking, granular disintegration, cracking); chemical breakdown (e.g. staining, pitting, and scalloping/fluting); alternation and deposition (e.g. recrystallisation and crusts); biological weathering (e.g. lichen, ephilithic algae, endolithic algae, and vegetation growth); and direct human impacts (e.g. repair, cleaning, quarrying, and graffiti) (modified listing from Smith, 2010:126-135). However, processes unique to ASMs include "other" human impacts (e.g. turf removal); agricultural intrusion (e.g. ploughing, field clearance, controlled burnings and plantings, and increased nitrates levels from fertilizers); animal activity (e.g. persistent trampling or rubbing the rock surfaces and contact with their waste); and linked ecosystem impacts (i.e. altered grazing patterns, vegetation change, and altered ASM exposure (Greeves, 2009)). On a synoptic level, the two key differences between ASMs and BSSs stem from where they are found (i.e. rural settings for ASMs, urban settings for most BSSs) and rock sources used for the monuments (i.e. ASMs are often natural outcrops, while BSSs typically are quarried).

The net product of these factors is that different pressures are imposed on ASMs in comparison to BSSs; specifically, impacts on ASMs often are more "ecological" where direct cause and effect relationships are less predictable. The classic example of how ASMs differ from BSSs is in the preservation of Callanish on the Isle of Lewis (Bohncke, 1988; Dark, 2006). Callanish is one of the iconic standing stone structures in Britain and is quite well preserved. However, this preservation is largely a consequence of changing climatic conditions not long after Callanish was abandoned. For reasons that only partially are understood, precipitation, drainage, and vegetation patterns altered in the region resulting in accelerated rates of peat accumulation and burial of the stones (Bohncke, 1988). This burial protected the stones from both human impact and also weathering, which has resulted in their preserved state today. This story is very pertinent here because it shows how cascading factors in an ecosystem can dramatically alter preservation state of ASM at a given site. However, it also shows why climate change matters (positively in this case) and considering such change in management strategies must be important relative to long-term monument preservation.

Threats to Rock Art in Northern England

Until recently, scant attention had been paid to the threats facing British ASMs (beyond major sites like Stonehenge and Callanish), especially open-air rock carvings (RAPP 2000). In order to begin rectifying this situation, Barnett and Diaz-Andreu (2005) canvassed 13 rock art recorders and researchers in 2003 and 2004 about their perceptions regarding the factors influencing the decay of British rock art. Although based largely on anecdotal evidence, this survey, which addressed physical/chemical, biological, and human factors, provided the first synthesis of the factors influencing the deterioration of British rock art.

Between 2002 and 2004, at roughly the same time that Barnett and Diaz-Andreu (2005) were undertaking their survey, Mazel, with the support of Stan Beckensall, the doyen of British rock art studies, undertook a comprehensive project (Beckensall Archive Project) to record the rock art of Northumberland in Northern England. Based on the extensive archive developed by Beckensall over a ca. 40 year period, the primary aims of the Beckensall Archive Project was to create a user-friendly website, supported by a database, to provide the basis for future research, educational outreach, and the wider public access and understanding of rock art (Mazel 2005, 2007; Mazel and Ayestaran, 2010). In addition, the project aimed to improve our understanding of the vulnerability of, and threats to, the carvings by natural and anthropogenic processes and to develop an appreciation of future management and conservation requirements. This aspect of the Beckensall Archive Project was achieved through the completion of on-site panel report forms, which included the collection of information relating to conservation and management issues. In fact, human and animal interaction with rock art was recorded at 575 of the 720 panels recorded in the countryside during the project (Table 1).

Conservation and management information also was recorded during the Northumberland and Durham Rock Art Pilot Project ((NADRAP) Oswald et al., 2006; Sharpe et al., 2008) between 2004 and 2008, but this information has yet to be collated. It is worth noting, however, that several volunteer recording teams collected the NADRAP information, while the Newcastle University Beckensall Archive Project material was collected by a single recorder (Mazel) and is therefore likely to represent a more consistent dataset. However, when the NADRAP data are collated it will be useful to compare these two datasets.

Table 1. Past destruction and current threats to Northumberland rock art based on the recording of 575 panels recorded between 2002-2004.

Nature of past destructive factor or current threats	N	%	
Quarrying	93	16.2	
Livestock scratches	60	10.4	
Plough damage	16	2.8	
Turf removal	16	2.8	
Plantation	11	1.9	
Driven on	8	1.4	
Burning	6	1.0	
Graffiti (ancient)	4	0.7	
Relocation of rocks during farming activities	2	0.3	
Candles	2	0.3	
Chalking	1	0.2	
Graffiti (modern)	1	0.2	

Table 1 presents the destructive factors and threats to Northumberland rock art that were identified during the Beckensall Archive Project. These issues can be grouped into three categories 1) past destructive factors; 2) recent interference by visitors; and 3) modern agricultural practices. In terms of past practices, it would appear that quarrying (Figure 1) has been most detrimental to the rock carvings in that one in six panels (i.e. 16%) display evidence of this activity. However, this is likely to underestimate quarrying activity because some (possibly many) rock art panels may have been removed completely. For example, the presence of carvings in stone walls, and the bases of bridges and houses (see Figure 2) provide evidence of such quarrying and the use of carved rocks. Quarrying, however, is no longer considered to represent a threat to the conservation of rock art.

Figure 1. Evidence of quarrying on a rock panel at Lordenshaw.

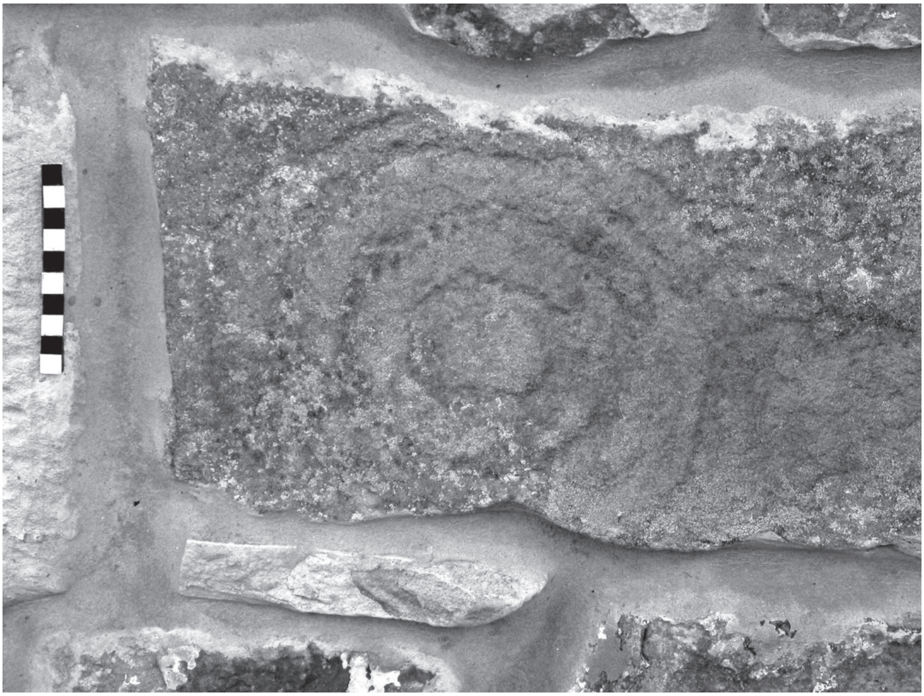


Figure 2. Evidence of a rock art panel being utilized in the construction of a house. Note: scale is in centimetres.

Considering the impact of farming practices in rural Northern England, about 80% of the panels were considered "threatened" by cows and sheep walking on them, although only 10% showed actual evidence of damage in the form of scratching (Table 1). It is likely that most, if not all, of the plough damage relates to past practices, although one instance was noticed where recent ploughing had gouged within 40 cms of a carved panel. Panels being driven on by other vehicles (1%), burnt accidentally or through controlled burns (1%), and/or covered with plantation litter (2%) represent other threats to the rock art, although more work is needed to understand fully the extent of such factors.

While about 10% of the panels showed evidence of human visitation (e.g. modern cairns, paths, litter), turf removal was noted at only 3% of the panels. Furthermore, contemporary graffiti and wilful human damage was not apparent as a major factor influencing the state of rock art in Northern England. A distinction was drawn between ancient and modern graffiti and, while the number of observations were low (four and one, respectively), it is noteworthy that the majority of the graffiti was believed to predate the twentieth century. Interference with rock art panels by candles placed on the rocks and chalking was not deemed a major threat to rock carvings in the database.

Many of the destructive factors and threats recorded by Mazel (Table 1) are consistent with those reported by Barnett and Diaz-Andreu's (2005), although the apparent low human impact on the rock carvings recorded by Mazel differed somewhat from perceptions of the Barnett and Diaz-Andreu respondents. In addition to the threats listed in Table 1, Barnett and Diaz-Andreu's survey respondents also noted a range of chemical and biological agents that they believed threatened rock art, although no direct proof of impact was shown.

While the ongoing threats to the rock art noted above can (and should) be mitigated through the implementation of effective management strategies, it is becoming increasingly appreciated that management strategies need to consider a wider range of pressures using a systems approach. The Barnett and Diaz-Andreu's (2005) respondents were on the right track when they made the link between the increasing prevalence of lichens and changes in the local environmental conditions (Macedo et al., 2009). Although, the simple presence of lichens does not necessarily constitute a problem as lichens can fulfil either a bioprotective or a biodestructive role (St. Clair and Seaward, 2004). Nevertheless, this observation highlights the potential for more subtle impacts that climate change or pollution might have on the long-term future of rock art (and ASMs in general).

Climate Change and its Manifestation

Many inaccuracies and misunderstandings exist about climate change, especially its spatial and temporal effects. For the purpose this discussion, the assumption is that climate change is occurring and it must be considered in terms of ASM preservation. Therefore, it is critical that we consider the range of past, current, and future expressions of change that might affect sites such as rock art panels in Northern England. Prior to discussing implications, a few key points must be clarified about climate change. First, "climate change" does not necessarily mean "warming." Climate modelling shows that different locations around the world will be affected differently by changes in atmospheric conditions. Figure 3 shows three scenarios of possible change in surface temperature by the end of the 21st century (Solomon et al., 2007) and Figure 4 shows equivalent predicted precipitation patterns over the same timeframe (Meehl et al., 2007). As the two figures show, temperatures are expected to increase in some places, especially Polar Regions, whereas other locations, such as the temporal margins, will become much drier.

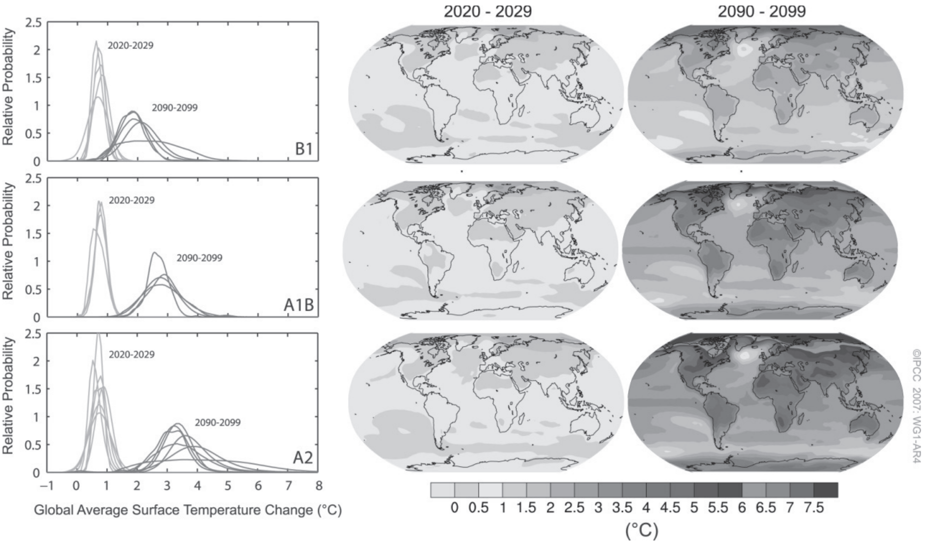


Figure 3. Projected changes in global surface temperatures through the end of the 21st century, including variability in predictions based on different model assumptions (Reproduced with permission from Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Figure TS.28. Cambridge University Press).

Therefore, climate models show that change will occur everywhere, but it will be manifested quite differently at the local level. For example, in Northern England where the rock art panels exist, most climate models predict more intense and locally dynamic precipitation events, especially in the winter, but only slightly warmer air temperatures; whereas, farther south in England, conditions are predicted to be drier year round and generally warmer, particularly in the summer. From a management perspective, these predictions are useful because they imply greater differences will exist between wet and dry seasons in the future, and conditionally higher and more variable rates of local runoff, which suggest on-site drainage conditions must be considered carefully. However, the resolution of the above predictions is not exact and, in fact, the line between "North" and "South" is approximate. As such, we contend that one must plan for different futures and embed as much resilience as possible into local ASM sites.

Although spatial variation of change is significant (and somewhat obvious), two points related to climate change are potentially more important for future-proofing ASMs. First, all climate predictions become much less reliable the farther into the future they are made. As an example, A2 scenario in Figure 3 (a scenario that assumes current human behaviour does not significantly alter) shows that predicted temperature changes among models vary by only 0.5oC in 2029, but predictions for the same locations differ by ~5oC in 2099, which implies greater uncertainty exists in forecasted conditions farther into the future. These broad predictions partially result from the fact that each climate model assumes different levels and types of uncertainty in their structures, which become differentially amplified or suppressed over time based on the type of uncertainty and the model. Variations also result from the fact that each model assumes slightly different initial conditions and weighs the drivers of climate change differently, including human behaviour. Although this imprecision is worrying, the key for ASM management is that we need to be innately cautious in management decisions, especially until modellers have a better grasp of trends and the true human responses to climate change have been established.

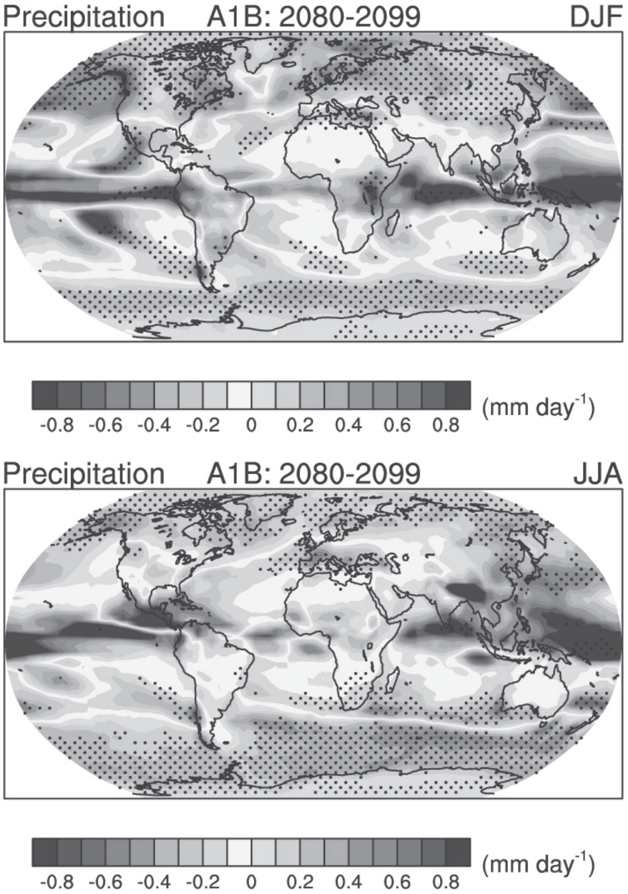


Figure 4. Projected relative changes in global winter (DJF; December, January and February) and summer (JJA; June, July and August) precipitation patterns by the end of the 21st century based on IPCC panel predictions (Modified and reproduced with permission from Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Figure 10.9. Cambridge University Press).

The final point related to climate change and ASM protection is of a more fundamental nature, stemming from the behaviour of complex systems as energy levels increase. Figure 5 shows a sample of how a complex system responds to increasing energy (e.g. a generally warming atmosphere), and is characterised by sudden changes in system state as energy is increased. The figure shows that complex systems, such as our atmosphere, do not behave in a linear manner, especially as energy levels become higher. Specifically, as energy increases (exemplified by warming, more intense precipitation etc.), complex systems innately bifurcate; i.e. they jump between broadly differing states and, as such, sudden or dramatic change becomes innate (Broecker, 2010).

The practical consequence of this natural phenomenon is that climate-driven changes of conditions surrounding ASMs probably will not be gradual or linear; consequently, management approaches must be designed with consideration of sudden change in mind. Unfortunately, predicting sudden change exactly in complex systems is impossible; therefore, we feel it is essential that any "climate change" management of ASMs be underpinned by improved, more sensitive methods for monitoring of ASM state relative to mechanisms of deterioration of greatest concern. Given sudden changes will not be readily predicable a priori (consider the difficulty of predicting earthquakes, another manifest response of complex systems); research is needed on sensor and other technologies for stone, which can be calibrated to changes in stable state. The results of these studies can inform managers of interventions to enhance the resilience of the local environment around the ASM. Therefore, the goal of management in this respect is to buffer ASM environments, so that catastrophic changes in state are less likely to take place, and, if such change does occur it can be mitigated and managed more effectively.

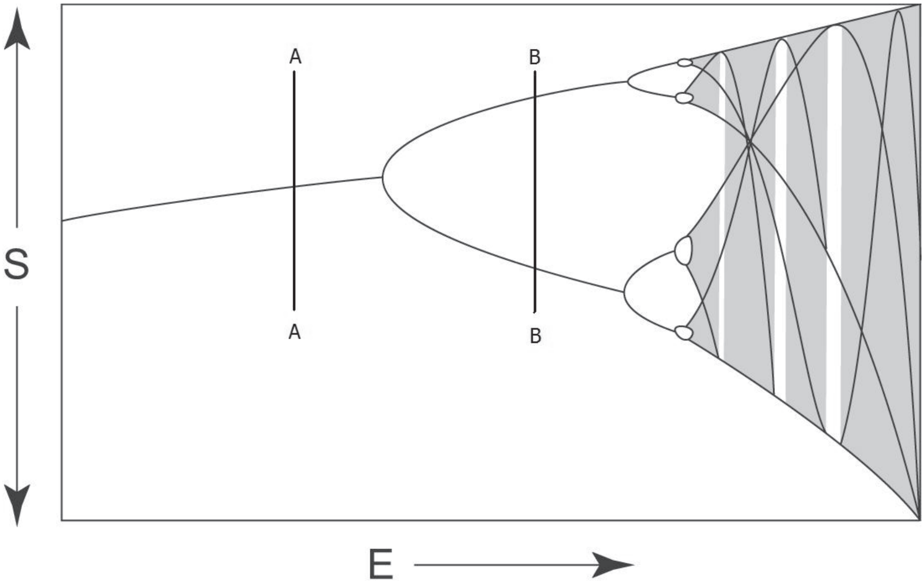


Figure 5. Effects of increasing energy level (E) on the number of possible stable states (S) in a complex system (e.g. our atmosphere). At low energy levels, changes in state are usually gradual, but as energy levels increase, systems can have multiple stable states (i.e., one stable state exists at energy level A, whereas two stable states exist at energy level B) and, as such, are more prone to sudden change between states (i.e. bifurcation). Heritage management must have contingencies against the impact of sudden change on resource stature, which should include consideration of the fact that the exact nature and timing of change is impossible to predict.

Management Approaches for the Future

It will be evident from the data and insights presented above that the future-proofing of ASMs is not straightforward. Managers need to grapple with a wide array of issues facing heritage sites including

1. identification of which sites/panels should be preserved,
2. where sites are in the landscape,
3. what is the best way to preserve each site,
4. who should pay for preservation, and
5. the nature and extent of public access to sites.

It is not surprising then that, as with all heritage resources, clear and far-sighted management planning is a vital first step in the care of ASMs.

As background, an identified ASM usually is added to an inventory or register where baseline data are recorded about its state; e.g. location, age, size, function, type, and level of significance. These initial appraisals can vary considerably and often lack standardised condition information. Further, ASMs usually are not checked regularly (or at all, in some instances) until they become part of a dedicated research (or monitoring) project, whereupon, heightened interest may raise their profile enough to be incorporated into a management plan. Fortunately, the NADRAP and the Beckensall Archive Project have provided a valuable baseline for rock art panels in Northern England, however, the issue of prioritizing sites for attention and intervention remains as there simply are not enough resources to manage all sites and panels everywhere. Therefore, condition assessment and risk evaluation must underpin sound management. Managers not only need to know the current condition of the ASMs in their care, but they also must have a basic understanding of the mechanisms that contribute to deterioration in order to evaluate current and future risk. To achieve this, a simple to use, relatively rapid, and formalised scheme is needed to help managers proactively identify those ASMs in most need of remedial intervention. Furthermore, a formalised assessment scheme would allow managers of different sites to compare data and evaluate outcomes based on a common approach and terminology.

Such a staged system approach to condition assessment first was developed by medical clinicians as a tool for the assessment and treatment planning for cancer patients (Hermanek and Sobin, 1987). Their model was based on many decades of research into the extent of cancer spread and predicted extent and success of treatment. Although deceptively simple, the model is very well grounded and scientifically robust, and provides an internationally recognised triage system for cancer. This "staging system" approach goes beyond basic description by incorporating a risk assessment based on evaluation of current condition and identification of actual and potential risk factors. This, in turn, enables an assessment of "prognosis" or long-term outcome if no intervention is undertaken and gives an indication of the extent of intervention required. In fact, this terminology is not arbitrary because the medical model provided inspiration for development of such a staging system for use on historic buildings (Warke et al., 2003; Warke, 2010).

Although this system primarily was developed for built structures, it has since undergone successful modification for application to archaeological stonework closer to ASMs where intervention and limited financial resources exist, but where the majority of archaeological structures are of similar age, similar archaeological significance, and exhibit similar levels of deterioration. This new system was trialled successfully at Petra in Jordan and a typical field recording data sheet for the Palace Tomb at Petra is provided as demonstration of a viable condition assessment scheme (Figures 6 and 7, respectively). In practice, parallel assessments are performed among similar types of sites and management priority is placed on the sites that display and represent greatest need based on quantitative comparisons using standard guidance criteria within a stage assessment grid, such as Figure 8. At Petra, this approach led to the Palace Tomb being prioritised as being in urgent need of intervention primarily because of the unstable nature of blockwork and a high risk factor in terms of potential injury to site visitors as well as catastrophic loss of the archaeological record.

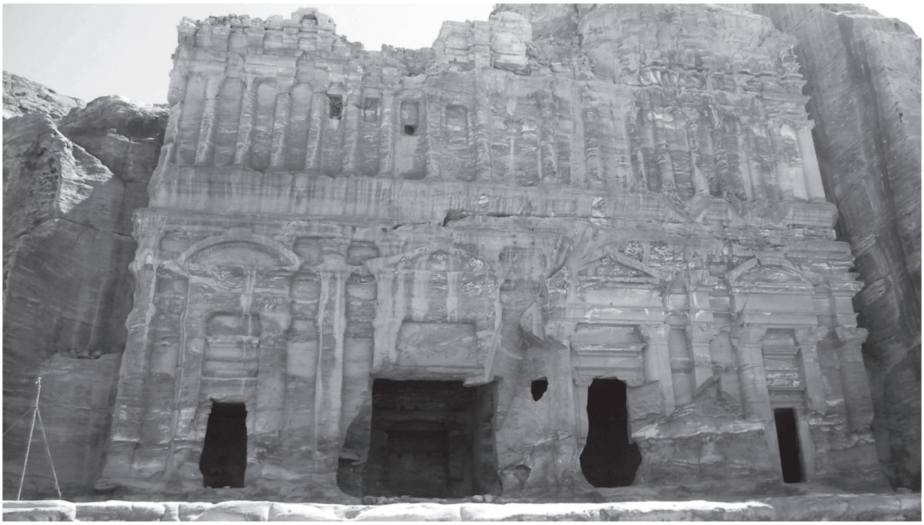
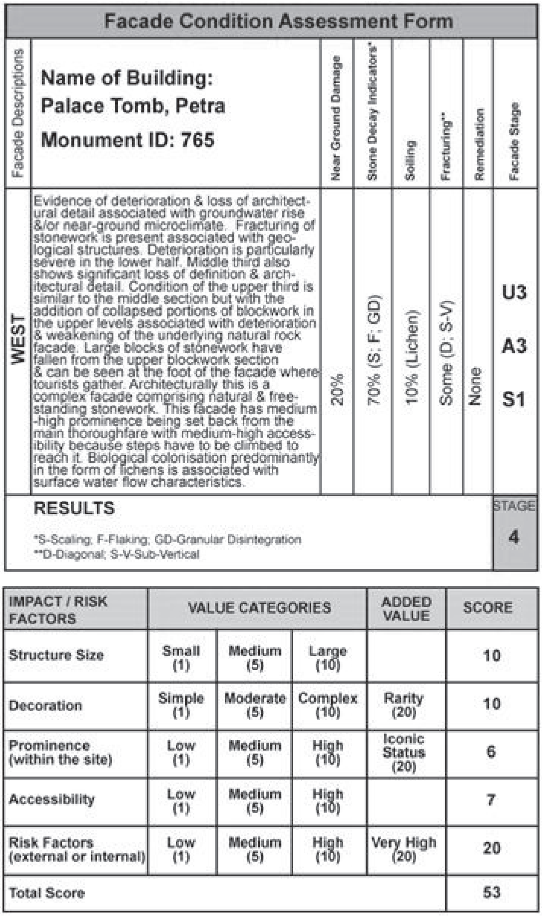


Figure 6. Petra in Jordan where a CARE scheme pertinent to ASM has been used successfully. The West-facing façade of the Palace Tomb is shown here. Note: the loose block work on the upper section of the façade and also the fallen blocky debris on the ground near the main entrance to the tomb.



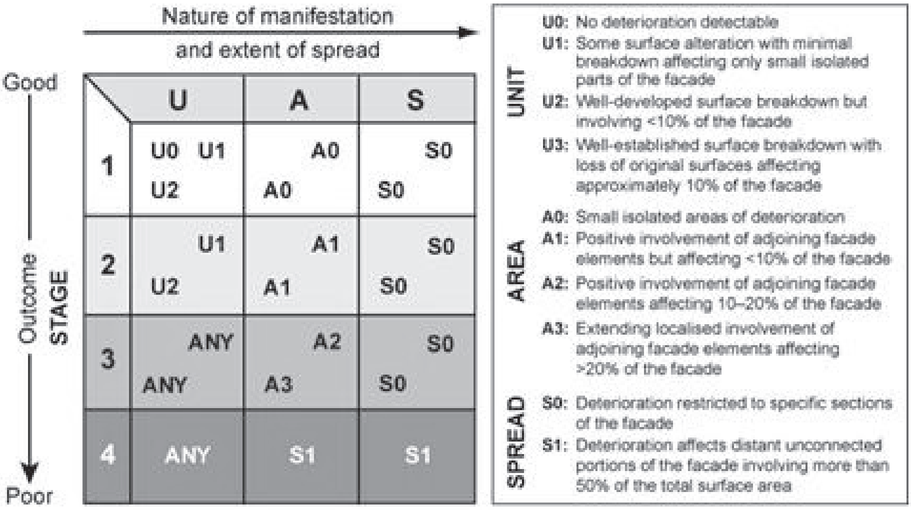
Facade Condition Assessment Form

Facade Descriptions	Name of Building: Palace Tomb, Petra Monument ID: 765	Near Ground Damage	Stone Decay Indicators*	Soiling	Fracturing**	Remediation	Facade Stage
WEST	Evidence of deterioration & loss of architectural detail associated with groundwater rise &/or near-ground microclimate. Fracturing of stonework is present associated with geological structures. Deterioration is particularly severe in the lower half. Middle third also shows significant loss of definition & architectural detail. Condition of the upper third is similar to the middle section but with the addition of collapsed portions of blockwork in the upper levels associated with deterioration & weakening of the underlying natural rock facade. Large blocks of stonework have fallen from the upper blockwork section & can be seen at the foot of the facade where tourists gather. Architecturally this is a complex facade comprising natural & free-standing stonework. This facade has medium-high prominence being set back from the main thoroughfare with medium-high accessibility because steps have to be climbed to reach it. Biological colonisation predominantly in the form of lichens is associated with surface water flow characteristics.	20%	70% (S; F; GD)	10% (Lichen)	Some (D; S-V)	None	U3 A3 S1
	RESULTS *S-Scaling; F-Flaking; GD-Granular Disintegration **D-Diagonal; S-V-Sub-Vertical						STAGE 4

IMPACT / RISK FACTORS	VALUE CATEGORIES			ADDED VALUE	SCORE
Structure Size	Small (1)	Medium (5)	Large (10)		10
Decoration	Simple (1)	Moderate (5)	Complex (10)	Rarity (20)	10
Prominence (within the site)	Low (1)	Medium (5)	High (10)	Iconic Status (20)	6
Accessibility	Low (1)	Medium (5)	High (10)		7
Risk Factors (external or internal)	Low (1)	Medium (5)	High (10)	Very High (20)	20
Total Score					53

Figure 7. Façade condition assessment form for the Palace Tomb in Petra, Southern Jordan.

The significance to ASMs of the assessment scheme for Petra does not lie in the specific issues encountered at Petra, but in the broad value of using a formalised assessment scheme as a management tool, which enables prioritisation of individual monuments in greatest need of urgent intervention based on a standard guide. Therefore, we suggest that such a model be developed for ASM management to allow rapid easy-to-use formalised Condition Assessment and Risk Evaluation (CARE). Currently, we do not have adequate details on destructive mechanisms affecting ASMs. In developing such an ASM CARE scheme, topics requiring further investigation include 1) the proximity of the ASM to current human and agricultural activity; 2) the regional location of the ASM relative to changing forecasted climatic conditions; 3) altered spatial demographics of human movement due to climate change; and 4) the influence of ground vegetation on ASM exposure conditions. In the case of rock art panels, the key now is to gain more scientific and other information on what dictates rates of deterioration, and also on management approaches that enhance site resilience, both factors are critical for developing the most suitable CARE criteria. In fact, such work is underway and soon will be completed for the protection of rock art in Northern England, but it is our intention to apply it to similar sites and ASMs around the world.



	U	A	S
1	U0 U1 U2	A0 A0	S0 S0
2	U1 U2	A1 A1	S0 S0
3	ANY ANY	A2 A3	S0 S0
4	ANY	S1	S1

U0: No deterioration detectable
U1: Some surface alteration with minimal breakdown affecting only small isolated parts of the facade
U2: Well-developed surface breakdown but involving <10% of the facade
U3: Well-established surface breakdown with loss of original surfaces affecting approximately 10% of the facade
A0: Small isolated areas of deterioration
A1: Positive involvement of adjoining facade elements but affecting <10% of the facade
A2: Positive involvement of adjoining facade elements affecting 10–20% of the facade
A3: Extending localised involvement of adjoining facade elements affecting >20% of the facade
S0: Deterioration restricted to specific sections of the facade
S1: Deterioration affects distant unconnected portions of the facade involving more than 50% of the total surface area

Figure 8. General guidance criteria for assignment of Stage Assessment for monuments (adapted from Warke et al., 2003).

Conclusions

The future of ASMs is not guaranteed because our environment is changing. Therefore, it is incumbent upon us to understand factors that have most contributed to the preservation of ASMs in the present-day landscape, and then develop sustainable management approaches to enhance long-term site resilience in the face of changing environmental conditions. We are part way there with regard to rock panels in North East England, but the second half of question has still to be resolved. The mechanistic basis of ASM decay is largely a scientific question, including better understanding the possible impacts of changing climatic conditions. However, heritage management expertise, especially in developing a sound and workable CARE system to help priories decisions in an ever-diminishing funding environment.

References

Bakkevig, S. (2004) Rock art preservation: Improved and ecology-based methods can give weathered sites prolonged life, Norwegian Archaeological Review 37, 65-81.

Barnett, T. and Diaz-Andreu, M. (2005) Knowledge capture and transfer in rock art studies: results of a questionnaire on rock art decay in Britain, Conservation and Management of Archaeological Sites, 7, 35-48.

Bohncke, S.J.P. (1988) Vegetation and habitation of the Callanish area, Isle of Lewis, Scotland, in H.H. Birks, H.J.B. Birks, P.E. Kaland, and D. Moe (eds.): The cultural landscape - Past, present and future, Cambridge University Press, pp. 445-466.

Bond, G., Showers, W., Cheseby, M., Lotti, R., Almasi, P., deMenocal, P., Priore, P., Cullen, H., Hajdas, I. and Bonani, G. (1997) A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates, Science, 278, 1257-1266.

Broecker, W. (2010) The great ocean conveyer: Discovering the trigger for abrupt climate change, Princeton University Press, Princeton NJ.

Dark, P. (2006) Climate deterioration and land-use change in the first millennium BC: Perspectives from the British palynological record, Journal of Archaeological Science, 33, 1381-1395.

Fort, R., Alvarez de Buergo, M., Gomez-Heras, M., and Vazquez-Calvo, C. (eds.) (2006) Heritage, Weathering and Conservation, Taylor and Francis, London.

Greeves, T. (2009) Dartmoor's vanishing archaeology, British Archaeology, 108, 32-35.

Hermanek, P. and Sobin, L.H. (1987) TNM Classification of Malignant Tumours, Springer-Verlag, Berlin.

Macedo, M.F., Miller, A.Z., Dionisio, A., and Saiz-Jimenez, C. (2009) Biodiversity of cyanobacteria and green algae on monuments in the Mediterranean Basin: an overview. Microbiology, 155, 3476-3490.

Mazel, A.D. (2005) Virtual access to the Beckensall Northumberland rock art archive, International Newsletter on Rock Art, 42, 24-27.

Mazel, A.D. (2007) On the fells and beyond: exploring aspects of Northumberland rock art, in A. Mazel, G. Nash, and C. Waddington (eds.): Art as Metaphor: The Prehistoric Rock art of Britain, Archaeopress, Oxford, pp. 231-256.

Mazel, A.D. and Ayestaran, H. (2010) Visiting Northumberland rock art virtually: the Beckensall archive analysed, in T.F. Barnett and K.E. Sharpe (eds.): Carving a future for British rock art: new approaches to research, management and presentation, Oxbow Books, Oxford, pp.

Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A. Knutti, R., Murphy, J.M. Noda, A., Raper, S.C.B., Watterson I.G., Weaver, A.J., and Zhao, Z.-C. (2007) 2007: Global Climate Projections, in S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, pp. 747-845.

Oswald, A., Bryan, P., and Barnett, T. (2006) The Rock Art Recording Pilot Project in Northumberland and County Durham, English Heritage Research News, 2, 24-27.

Prikryl R. and Smith B.J. (eds.) (2007) Building Stone Decay: from Diagnosis to Conservation. Geological Society Special Publication, The Geological Society, London.

RAPP (2000) Rock Art Pilot Project: Main Report, Bournemouth University School of Conservation Sciences and University College London Institute of Archaeology for English Heritage, Bournemouth and London.

Sharpe, K., Barnett, T., and Rushton, S. (2008) The Prehistoric Rock Art of England: Recording, managing and enjoying our carved heritage, English Heritage and Northumberland County Council, Newcastle upon Tyne.

Smith, B.J. (2010) Diagnosing Decay: The Nature of Stone Weathering, in J. Curran, P.A. Warke, D. Stelfox, B.J. Smith, and J. Savage (eds.): Stone by Stone: A Guide to Building Stone in the Northern Ireland Environment, Appletree Press, Belfast, pp. 102-133.

Smith, B.J. and Warke, P.A. (eds.) (1996) Processes of urban stone decay, Donhead Publishing, London.

Solomon, S., Qin, D., Manning, M., Alley, R.B., Berntsen, T., Bindoff, N.L., Chen, Z., Chidthai-song, A., Gregory, J.M., Hegerl, G.C. Heimann, M., Hewitson, B., Hoskins, B.J., Joos, F., Jouzel,J, Kattsov, V. Lohmann, U., Matsuno, T., Molina, M., Nicholls, N., Overpeck, J., Raga, G. Ramaswamy, V., Ren, J., Rusticucci, M., Somerville, R., Stocker, T.F. Whetton, P., Wood R.A., and Wratt D. (2007) 2007: Technical Summary, in S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, pp. 19-91.

St. Clair, L.L. and Seaward, M.R.D. (eds.) (2004) Biodeterioration of Stone Surfaces. Kluwer Academic Press, Dordrecht.

Warke, P.A. (2010) Mapping Stone Decay, in J. Curran, P.A. Warke, D. Stelfox, B.J. Smith, and J. Savage (eds.): Stone by Stone: A Guide to Building Stone in the Northern Ireland Environment, Appletree Press, Belfast, pp. 134-161.

Warke, P.A., Curran, J.M., Turkington, A.V., and Smith, B.J. (2003) Condition assessment for building stone conservation: a staging system approach, Building and Environment, 38, 1113–1123.

Acknowledgements

We thank the UK AHRC/EPSRC Science and Heritage Programme for funding a Research Cluster on ASM management. We specifically thank Research Cluster members who contributed to discussions on long-term care of ASMs, including Chris Burgess, Abdul Chaudhry, Chris Fowler, Chris Hayward, Ian Head, Jacqui Huntley, Chris Jones, Haida Liang, David Manning, Geoff Parkin, Sara Rushton, Mark Seaward, Kate Wilson, Rob Young, and Elizabetta Zanardini. Additional financial support came from ECOSERV, an EU Marie Curie Excellence Grant (MEXT 023469).