The Crumbling Wonder

Evaluating Environmental Threats to the Archaeological Sandstone Monuments of Petra (Jordan)

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1. Introduction

A marvellous ancient site, located in the southern part of Jordan between the spectacular desert mountain-ridges which are the result of the diverging Great African Rift Valley (see appendix I, p.75). This ancient site is an archaeological wonderland which was rediscovered in August 1812 by the Swiss explorer Johan Ludwig Burckhardt (Bala’awi 2011, 1-2; Harding 1938, 36). The film industry as well contributed to its current fame and was especially made famous by the Hollywood action-movie *Indiana Jones; the Last Crusade*. This site is, in fact, one massive city carved out of sandstone which covers a vast area, even beyond the defined archaeological park’s borders, and goes by the name of “Petra” which is Greek for “stone”. This breath-taking location on earth is filled with ancient mysteries and loads of archaeology. Most of its splendour remains unseen today and has yet to be discovered, located and uncovered.

![Fig. 1](source: www.businessdestinations.com)

**Fig. 1:** A spectacular view of a part of the Petra Archaeological Park, located between the Sharah mountains. To the left, you can see a part of the famous ‘Street of the Facades’ of Petra (source: www.businessdestinations.com).

Petra is located in Jordan between the *Sherah*-mountains, an extensive mountain-ridge East of the Wadi Araba desert, which one will encounter approximately 265 kilometres South-West of Amman, the capital city, and is located in the region known as Ma’an (Heinrichs 2008, 643; Joukowsky 2001,1).
1.1 Petra’s Archaeology and Problem

Even though Petra has already undergone several extensive archaeological researches and countless excavations and currently is still subjected to various excavation projects, much of Petra’s secrets remain covered until present-day. Therefore, Petra holds a significant potential for future archaeological discoveries.

The North Carolina State University, for example, is currently conducting its “North Ridge Program” in Petra, directed by Dr. Tom Parker, which is mainly focused on researching the non-elite life during the Roman imperial presence and control in Petra which, at that time, was incorporated in the Roman province of Arabia (Peters 1977, 265; www.petranationaltrust.org).

The city of Petra was carved by the ancient Nabataeans between approximately 150 B.C. and 100 A.D. during which the majority of the monumental rock-cut tombs and caves were created. The city not only hosts thousands of caves, monumental tombs and facades additionally, it hosts an immense water system once created by the Nabataeans. Beside it is home to Roman (soldier) tombs, a Roman amphitheatre, high places of sacrifice and much more. The city belonged and was controlled by the Nabataeans until its full annexation into the Roman empire in 106 A.D. from which many influences are still observable today (Joukowsky 2001, 1-3; Peters 1977, 265).

In 1985, UNESCO listed the extensive area of Petra on the World Heritage List and in 2007 UNESCO elected Petra to have its place on the list of the New Seven Wonders of the World. Especially this new title of Petra gave an economic boost to the tourism-sector of this region and subsequently that of Jordan. Previously, Petra received around 200,000 visitors per year whereas nowadays Petra welcomes approximately 1,000,000 visitors annually (Paradise 2013, 176). This increased flow of tourists has significant impact on the culture and lifestyle of the local people; the Bedouins, or the “Bdul” (fig. 2, p. 7), who are the local people from the Petra region and who have adjusted to the harsh environment inside Petra and the surrounding deserts (Abu al-Haija 2011, 93-100; Bille 2012, 107-123; Heinrichs 2008,643).

Beside the impacts on the local and traditional Bedouin lifestyle resulting from contact with tourists who derive from various cultures, the increased physical and chemical weathering of the local soft sandstone is another negative side-effect of increased
tourism. Most of the tourist businesses, ranging from the tourist facilities to donkey- or camel-rides, within the Petra Archaeological Park are all, in some way, affecting the local natural environment.

![Fig. 2: A traditional local Bedouin family preparing bread, or “gobus”, in an ancient Nabataean cave in which they have decided to retain (aspects of) their Bedouin lifestyle. Picture taken by John Stanmeyer (source: http://scontent-a.cdninstagram.com/).](image)

Of great importance is the continuous protection of the, already, highly fragile sandstone monuments which are found in and around Petra while safeguarding the safety of the tourists, animals and local people. Safety can be maintained by predicting and preventing the degradation and eventual collapse of monuments and the occurrence of natural rock-falls. As well the destructive flash floods that may occur in times of weather changes, which mainly arise shortly prior to and during the winter, deserve attention.

Most of the rock-cut monuments in the entire Petra region have suffered from degradation to various extents, from minor to major destruction as a result of the weathering effects on its sandstone. As well, natural hazards, such as flash-floods after heavy rainfall, storms and earthquakes have contributed to great extents to the severe damage attested on various monuments, ancient Nabataean caves and tombs.
Due to the increasing instability of the fragile monuments, as result of physical and natural weathering and anthropogenic factors, the preservation and protection of these should become one of ever-increasing national and global concern as so far only three of the approximately 2000 monuments in Petra have enjoyed conservation works (Bala’awi 2011, 5; Heinrichs 2008, 644).

Fig. 3: A dried up Wadi, just outside Petra’s archaeological park, carved through time by the force of water and still filled with natural debris caused by a major and destructive flash-flood that occurred during the early winter of 2014, along bringing much stone debris, from hand-sized cobbles up to large (broken off) boulders that were once part of the surrounding mountains (source: personal picture collection, 01-10-2014).

1.2 Research Questions
The aim of this research is to shed light on the archaeological monuments which are subjected to the effects of various and continuous weathering activities as result of environmental and anthropogenic factors. These weathering processes will continue to occur within and around the Petra Archaeological Park (PAP), therefore a review on affected monument is ought important due to the perishable nature of the sandstone monuments. Additionally, there will be aimed to suggest methods and regulations which might be applied in order to prevent further damage to these ancient monuments which all yield valuable information about Petra’s past.
By means of assessing information throughout this research, I hope to be able to answer the following research question: What are the present and future risks to Petra’s Nabataean monuments as result of weather extremities and naturally occurring hazards. Additionally; what are possible options to prevent further damage?

In order to conduct this research, specific archaeological monuments were selected. The selection is based on the degree of severity of their degradation which reflects the fragile nature of the sandstone monuments in Petra (see Appendix II, p. 77). There will be an intention to underline the consequences of continuous weathering on the sandstone monuments. The following table represents the archaeological monuments, along with their current condition, that were carefully selected for this thesis.

<table>
<thead>
<tr>
<th>Location</th>
<th>Name</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mu’Eissra Area</td>
<td>Tomb No. 609</td>
<td>Collapsed</td>
</tr>
<tr>
<td>Ad-Deir (Monastery)</td>
<td>Urn</td>
<td>Heavily Eroded</td>
</tr>
<tr>
<td>El-Khubta Mountain</td>
<td>Corinthian Tomb</td>
<td>Heavily Eroded</td>
</tr>
</tbody>
</table>

Table 1: The selected archaeological monuments (left column), their given name or number (middle column) and their condition (right column). Note: the above information refers to the selected archaeological monuments during the time of selection, from 10-2014 / 02-2015, in Petra’s Archaeological Park (PAP).

Beside the main archaeological features, such as the monumental tombs, there will also be a section targeting natural features and hazards inside the Petra Archaeological Park that could pose a threat to the safety of the park’s inhabitants, visitors and archaeology. Examples of past rock-falls and flash-floods will be given in order to highlight their destructive powers and the possible dangers they could attest of. On the next page, a list is presented which consists of the chosen natural features in the Petra Archaeological Park which could be viewed as potential hazards and will be further discussed in chapter 2.
<table>
<thead>
<tr>
<th>Location</th>
<th>Type</th>
<th>Presence</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Al-Khazneh (Treasury)</td>
<td>Stuck boulder; possible threat</td>
<td>Year-round</td>
</tr>
<tr>
<td>The Al-Habis Mountain</td>
<td>Freestanding boulder; possible threat</td>
<td>Year-round</td>
</tr>
<tr>
<td>Petra Archaeological Park stretching from various valleys (wadi’s) to the ‘spring waters’</td>
<td>Flash floods</td>
<td>Seasonally; mainly winter</td>
</tr>
</tbody>
</table>

**Table 2:** A list representing the natural features inside Petra’s Archaeological Park that were carefully selected and which could be or eventually form a natural hazard or threat towards the park’s overall safety and its archaeological monuments.

The main reason for this specific focus is to shed light on the fragile nature of Petra’s sandstone monuments which are in dire need of protection and, to create an increased awareness about the perishable nature of the archaeology in and around Petra which is highly susceptible to the effects of physical and chemical weathering.

**1.3 Thesis Structure**

Beneficial to understanding the weathering and degradation of the archaeological monuments, the weather of Petra and her surroundings will be analysed as first. This analysis will incorporate the weather conditions attested between the summer and winter which, not rarely, goes along with periods of rainfall which can range from light to severe. Following the review of the natural hazards, naturally occurring and possibly hazardous features inside Petra’s Archaeological Park will be brought forward which examines the previously chosen natural features (table 2, p. 10).

Subsequently, past destruction and present monumental degradation will be reviewed on the basis of the formerly selected archaeological monuments inside the Petra Archaeological Park (table 1, p. 9). In addition to the review of the affected archaeological monuments in the park, there will be a focus on the types of weathering which could have caused and remain to cause the breakdown of the Nabataean rock-cut monumental artworks which are all composed of the fragile sandstone.

Ultimately, there will be a brief review on the possible methods which could be applied or are applied in order to prevent further damage to Petra’s monuments and to
safeguard the locals’ and tourists’ safety. Following the brief review on possible conservation and protection methods, light will be shed on the variety of stakeholders involved in terms of the application of regulations, protection and conservation in Petra’s Archaeological Park. As result of the collected and reviewed information, a conclusion will be given in the final chapter which aims to offer a summarized answer on the research question of this thesis.
2. Petra in its Environment

The mountainous area in which Petra is located, is in fact a natural frontier and could have once offered protection against external enemies during the time of the Nabataeans and during the period when Petra became part of the Roman empire within the province of Arabia (Peters 1977, 265). However, these mountains do not offer protection against the climatic forces in this area which can fluctuate highly between the summer- and winter-season.

2.1 Big Shifts

During the shift from the dry and hot summer- to wet and cooler winter-seasons, Petra and the surrounding areas are often subjected to decreases in temperature and a rise in heavy rain- and even snowfall (Bala’awi 2011, 4). The Bedouin locals of and in Petra, known as the Al-Bedul, often try to prepare for winter-times by safeguarding their donkeys, chickens and/or their herds of goats in the surrounding ancient Nabataean caves meanwhile trying to maintain their own safety regarding the possibility of flash-floods after sudden heavy rainfalls and the possible threat of a collapse of an already weakened sandstone monument or the movement of natural nearby features such as loose boulders.

Yearly, Petra’s archaeological park and its surrounding areas receive a fair share of the effects of seasonal changes which include rainy days along with some of the unfortunate resulting damage to various parts of the surrounding mountains and archaeological monuments as well, the famous ancient Nabataean caves of which several are still being used by local Bedouin families (Bala’awi 2011, 4).

2.2 Natural Hazards

The winter of early 2014 became known, according to Petra’s local Bedouin community, as a harsh winter and it was different due to the fact that it led to relatively more destruction in Petra, resulting from flash-floods and surface run-off water, compared to the previous winter. Whereas each winter is responsible for at least some damage to the archaeology of and inside the park, the winter of early 2014 was relatively extreme and resulted in heavy rain- and snowstorms that gave way to downslope movement, such as
rock-falls, which inflicted damage to objects in its path. An additional side-effect of this type of weather extremity, is the surface run-off water which became the main feeder for a massive flash-flood which evolved into a destructive debris-flow (fig. 4, below and fig. 3, p. 8) which ended up in Wadi Assiyagh where all the debris-filled water collected (Nichols 2009, 93-95). The debris-flow damaged parts of the ancient stairs leading up to the Monastery (Ad-Deir) monument and brought the Petra Archaeological Park to a temporary closure in order to protect its visitors. This debris-flow was not merely capable of damaging most in its path, the flow simultaneously collected all unconsolidated surface material in its path which, in some cases, included archaeological objects such as basalt grinders (fig. 5, p. 15).

![Image of debris flow](image.png)

**Fig. 4:** silent contestants of a massive and destructive flash-flood that rushed through the valley inside Petra towards the lowest point of Wadi Assiyagh (the 'Spring Water') where all of the material collected and ended up as deposit material (source: personal photo-collection, 13-10-2014).

These snow- and rainfalls, that occur regularly amidst the shift from summer- to winter-season and during the winter itself, are most likely one of the main factors triggering the destruction of the Nabataean sandstone caves and monumental architecture and is a main contributor to the occurrence of rock-falls from surrounding mountains (for an example, see Appendix III, p. 79).
Due to the absence of vegetation on most of the surfaces found within Petra, especially on the flat and usually steep surfaces of monuments, water derived from rain- or (melted) snowfall runs down in a relatively fast rate and is therefore able to ignite significant movements in the form of landslides and debris-filled flash-floods in the archaeological park which could pose major threats to the relatively soft sandstone monuments, natural features and caves in the present and future. As well these natural hazards pose threats to the tourist’s safety, a major example is that of a massive flash-flood in the Siq which occurred in 1963 killing more than 20 French tourists (Comer 2012, 55-57; Lingis 2002, 54-55; www.petranationaltrust.org).

Sandstone is a type of rock and is classified as a ‘soft stone’ which obtains the main characteristic of a high porosity and, therefore, relatively soft. This characteristic is a main contributor to the fragile nature of the sandstone monuments and caves in and around Petra (Nichols 2009, 90-94). This attested fragility of Petra’s sandstone is a positive aspect when it comes to monumental building activities in combination with the required specialized crafting tools and skills which the Nabataeans applied however, it has a negative outcome in terms of the monument’s long-term stability and preservation (Turkington 2005, 229).
Small-scale alterations on sandstone surfaces can present itself in the form of small and big cave-like holes, pits and dips and are known as ‘tafoni’ (Dorn et al. 2013, 65; Huinink 2004, 1225). Larger-scale and rather drastic effects are often both the result of chemical and physical weathering and are often presented in the form of natural sandstone cliffs with a honeycombed surface (tafoni) and sandstone columns and immense arches (fig. 6, p. 16 and fig. 7, p. 17). The destructive phase is the final phase during which the internal structure has reached its breaking point, past its threshold, following continuous subjection to the effects of physical and chemical weathering which eventually results in the breaking down or solution of the relatively soft sandstone.

The moment a sandstone formation reaches its breaking point, it often triggers a collapse of smaller pieces of unconsolidated sandstone rocks and, in some cases, even complete fissures might manifest themselves within the internal structure of a sandstone monument, cave or the mountain’s surface causing it to reach an unstable state. The instability caused by weathering result in an increased susceptibility to future physical and chemical weathering and earthquakes (Turkington 2005, 229-232).

![Figure 6: A natural sandstone bridge in the desert of Wadi Rum (Jordan), formed as result of continuous subjection to physical and chemical weathering. Tafoni characteristics are seen which are the main result of chemical weathering](http://velvetescape.com/wp-content/uploads/2012/03/IMG_2267.jpg).

The effects of a collapse, or rock-fall, of loose fragments derived from the sandstone mountains in the Petra Archaeological Park might be devastating and dangerous to the park’s environment, archaeology and the safety towards locals and visitors. Moreover, rock-falls and flash-floods can cause touristic pathways to be blocked which may
temporarily stop the continuous flow of tourists in the archaeological park which has a negative impact on the tourist-business for the local Bedouins of Petra who live of the money they earn by offering donkey- or camel-rides, guiding tourists and by selling souvenirs, food and drinks. In fact, such an event occurred a few years ago when a tomb’s façade completely collapsed close to the, usually crowded, staircase leading to the renown High Place of Sacrifice and occurred in the vicinity of tourists. Thankfully, no one was injured however, such an incident indicates the continuous presence of the risk of collapsing monuments and natural features (petranationaltrust.org).

![Figure 7: A natural arch above the beginning of the staircase leading to the Monastery, formed by a large sandstone rock which, in the past, collapsed between the two mountain-walls (source: own photo-collection, 12-10-2014).](image)

In the past the breakdown of natural features and archaeological monuments inside Petra occurred, of course, as well however, in the present there is a safety to be retained in the park as well the growing consciousness of protecting Jordan’s archaeological heritage. Such example of past destruction of one of Petra’s natural
features is attested by the natural arch above the Monastery’s staircase which occurred a considerable time ago (fig. 7, p. 17).

Both the weathering activities along with the natural hazards, which all occur in the region in which the Petra Archaeological Park is situated, are responsible for the degradation and alteration of the natural occurring sandstone formations and archaeological monuments by means of physical and chemical processes. The rocks are broken down in smaller components due to continuous exposure to physical and chemical weathering into unconsolidated surface material, also known as regolith (Nichols 2009, 90-91). Regolith is susceptible to transportation and downslope movements under gravity and as result of significant surface run-off water and flash-floods during the winter season when there is an increased occurrence of rain- and snowfalls (Nichols 2009, 44). Flash-floods are known to be able to cause shallow landslides on elevated surfaces and will converge in the lower parts of Petra’s valleys (for a recent example; Appendix IV, p. 81). Various streams eventually collect in Wadi Asssiyagh, also known as the ‘spring waters’, inside Petra where it can develop into a destructive debris flow. These debris flows can form a major threat to the visitor’s safety and is able to damage archaeological remains and monuments in its path. Additionally, the transportation of archaeological surface material, such as basalt grinders, is made able by means of heavier flash-floods (Wiegand et al. 2013, 5-6).

Another great aspect of the climate in Jordan which surely should be taken into account, is its impact throughout time. Due to continuous temperature changes which occur throughout the year in Jordan, implying the winter and summer and day and night, Petra’s sandstone monuments Petra are continuously subjected to the weathering effects of these fluctuating temperatures, mainly during the shift from summer to winter. The continuing shifts between significantly decreasing and increasing temperatures can cause physical weathering in the form of freeze-thaw actions in the winter and an increased salt-formation during warmer days in which water, derived from rainfalls and contained in fractures of the rocks, evaporates resulting in the formation of salt crystals (Nichols 2009, 90). Not only the temperature-differences causes physical and chemical weathering, additionally the changes in climatic
circumstances between the summer- and winter-season are contributing factors to weathering processes in Petra. During the summers, the entirety of Petra’s environment and, already weakened, archaeological monuments are subjected to continuous and intense sunlight along with temperatures averaging between 30 and 45 degrees Celsius. Whereas in the wintertime, all of the monuments are facing temperatures around the freezing point however, winter here is regarded as mild and rainy (Paradise 2013, 177).

In the early summer, the difference between the temperatures during the day and night is significant. Besides, in the winter temperatures can reach below freezing point in the night which could cause the water present in the rocks to freeze and expand which forces existing fissures to widen (fig. 8, below).

As well, temperature fluctuations will cause minerals within the internal structure of the rock to expand and retract at different rates which will cause internal instability and shattering of the (surface of the) rock (Nichols 2009, 89-91). These type of physical weathering processes are the result of the significant differences in the weather between the summer, winter, day and night and are also known as ‘thermal shock’.

These various physical weathering processes will, eventually, result in the break-down of rocks which can have drastic effects on its surrounding area.

Figure 8: An example of frost-shattering; the result of continuous freeze-and-thaw actions upon the rock which causes internal weakening and eventually results into destabilization resulting in damage. Freeze-thaw action is a physical weathering process in which water, present in the rock, will freeze and expand forcing the cracks to widen and causing the rock to break. (source: Nichols 2009, p. 91).

Due to the natural hazards and previous physical weathering processes which occurred throughout time, a large number of ancient Nabataean rock-cut monuments in and
around Petra have suffered damages to various extents. Petra suffered at least three known earthquakes in the past during and after Nabataean presence, these earthquakes occurred in 363 A.D., 551 A.D. and 747 A.D. (Guzzo 2002, 47-127; Taylor 2001, 104-111). One can imagine that even one extreme winter, with heavy rain- or snowfall and temperatures close or below the freezing-point, can result into major damages to the already highly fragile and weathered monuments, let alone another earthquake (Heinrichs 2008, 643-644; Nichols 2009, 89-94).

2.3 On the Edge
Beside the dangers of the heavier flash-floods, loose and large boulders should also be taken into account in terms of possible hazardous features inside the archaeological park of Petra, especially in the possible event of an earthquake (Paolini et al. 2012, 16). Two natural features of considerable size, composed of sandstone, have been appointed in order to be used as an example in the light of the park’s safety.

2.3.1 The Al-Habis Boulder
One of natural features, which could form a possible threat under changing physical conditions, is located on top, at the edge, of the Jabal, or ‘mountain’, Al-Habis and is visible from a considerable distance (fig. 9, p. 21).

Petra and its surrounding areas have faced several devastating earthquakes in the past 2000 years of which the collapsed columns, tremendous rock-fractures, some broken monuments and dislocated natural features are silent contestants. A number of the earthquakes were recorded in history and now allows us to be aware of the exact years in which Petra has been subjected to this natural phenomenon that is known to have occurred in this region. Petra has so far underwent a notably devastating earthquake in 31 BC, 114 AD, 363 AD, 551 AD and 747 AD. These earthquakes were of various devastating seismic strengths on the Richter’s scale (Rababeh et al. 2014, 63-64; Peterman 1994, 98-103; Guzzo 2002, 127). The occurrence of earthquakes in this region is due to Petra’s location right above the Wadi Arab Fault which leads from the Dead Sea to the Gulf of Aqaba, the North-East / South-West orientated Al Matahan Fault and the North-East / South-West orientated Abu Ullayqa Fault. As well Petra is located in a crescent-shaped valley which is an extensive part of the Great African Rift resulting from
past tectonic activities and is consisting mainly of the Umm Ishrin sandstone formation (Bala’awi 2011, 19; Paradise 1995, 207-208; Paradise 1999 354; Rababeh et al. 2014, 63-64).

Figure 9: Jabal Al-Habis located on a satellite image of a part of Petra’s Archaeological Park and, below; the selected natural feature which is a freestanding sandstone boulder of considerable size which could pose a threat to the park’s safety and the surrounding archaeological monuments (source; upper picture: www.google.com/maps; lower picture: www.tripod.net, red circle applied afterwards).

Given the fact that Petra is situated on top of a tectonically active location indicates that this region is still prone to the occurrence of earthquakes that are of varying magnitudes. Based on the latter, we can conclude that the risk of considerable natural destruction, resulting from moving tectonic plates, is still present and could trigger the dislocation of natural features such as the selected freestanding sandstone boulder on top of the Al-Habis mountain which is located in Petra’s archaeological park and adjacent to the famous monument known as the Qasr al-Bint. Adding to the location of this boulder, it is as closely located to the Basin restaurant which is a famous resting place for the visiting tourists. If an earthquake of significant magnitude, 6 or higher on
the scale of Richter, strikes the Petra region once again, it might result in further destruction, deformation and displacement of the park’s archaeological and natural features. As a result, the park’s authority might apply a temporary closure in regard of its overall safety. In the image on the next page, the red arrows illustrate the directions in which the boulder could fall or slide down during another powerful earthquake and possibly result in the damage of various aspects, albeit archaeological or natural, that are located in its direction during the fall (see fig. 10, below).

Figure 10: the sandstone boulder, encircled in red, and the possible directions into which it could fall down during an heavy earthquake (source: tripod.com, circle and arrows applied afterwards).

2.3.2 Al-Khazneh’s Hidden Danger

Beside the naturally present boulders in the archaeological park, there are several noteworthy and colossal fragments which were once part of Petra’s sandstone mountains and afterwards subjected to disintegration and continuing degradation as result of physical and chemical weathering. A number of these massive sandstone fragments are presently found fastened between large fissures in the mountain or monuments or between two separate sandstone formations. An example chosen in this aspect, are rather large sandstone fragments which are stuck between a fissure located to the upper-right of the famous Treasury, or Al-Khazneh (fig. 11, p. 23). The large fragments are currently consolidated between the two sandstone mountain walls on both sides which form the fissure directly adjacent to the Treasury which is the main
attraction inside the Petra Archaeological Park. Various features, such as the given examples, and sandstone monuments in the park require direct attention from local and global agencies in the form of an analysis, research and the resulting protection methods in order to prevent a possible steep release of debris, when the sandstone’s threshold is reached, that could result in significant damage to the most well-known monument of Petra as well threaten the safety of tourists that often take photographs in the front of this monument (Paradise 2013, 176; Warke et al. 2006, 727).

Figure 11: Within the red lines; the fastened sandstone fragments which used to be part of the sandstone mountain however, due to weathering split off, dislocated and currently forms a possible threat to the Treasury (Al-Khazneh) and the tourists’ safety (source: personal picture-collection, 01-11-2014).

Factors contributing to a possible release and subsequent hazardous rock-fall of these sandstone fragments are not merely those related to an earthquake. Surface run-off water, wetting-and-drying processes, thermal expansion and contraction, salt formation
and the freezing-and-thawing mechanisms working on the fragment and adjacent sandstone mountain walls could result in a decrease of the fissure’s tension. When the grip of the surrounding rocks reduces, the possibility of a downward movement of the stuck sandstone fragments, under the pure mechanism of gravity, arises (Dorn 2013, 61; Nichols 2009, 44-45). In addition to the sandstone fragments currently fixed in the large fissure to the right of the Treasury, there is an example from a past significant rockfall which can be seen as a scree, which is an accumulation of mainly coarse debris, at the base of the mountain wall located at the right side of the open area in which the Treasury is situated (see fig. 12, below). The debris accumulation is stable since it does not surpass its maximum angle which, in that case, would cause further downward movement of the sandstone blocks. This is the pure result of the mechanisms of gravity throughout the passage of time and various chemical and physical weathering processes to which the fallen debris were subjected and, in fact, are still subjected to (Nichols 2009, 44; Volkwein 2011, 2618-2621).

Figure 12: Within the highlighted area is the scree formed by the rock-fall which occurred at some moment in the past under gravity as result of physical- and chemical weathering processes (source: personal picture-collection, 01-11-2014).
3. Monumental Destruction in Petra

The breath-taking environment and archaeology that is present throughout the Petra’s Archaeological Park is extensive however, it is as well affected by various external forces. Since its very existence, the sandstone formations, and thus the Nabataean archaeological monuments, are subjected to the various effects of weathering albeit it chemical or physical. Beside the weathering processes, there are as well the effects of anthropogenic activities such as the increased flow of tourists since Petra’s nomination as becoming one of the UNESCO’s world wonders, building activities in the park of which the Basin Restaurant is an example (fig. 13, below), insufficient maintenance and neglect (Heinrichs 2008, 643; Paolini et al. 2012, 16; Paradise 1999, 353-354).

The fragility of Petra’s natural and archaeological environment is attested by the collapse of Nabataean sandstone-hewn monuments and surrounding natural features. In this chapter, the soft nature of the archaeological monuments in Petra will be reviewed by means of the selected monuments (table 1, p. 9) which as well encompasses an example from the recent past. Additionally, there will be shed light on various types of weathering in order to grasp the processes leading to the decay of Petra’s beautiful archaeology which has affected more than 80% of the sandstone facades in the park to a severe extent. For this reason and for future reasons, such as the protection of the park’s archaeology, Petra been listed on the World Monument Fund’s list of ‘100 Most Endangered Sites’ since 1995 (Bala’awi 2011, 19).

Figure 13: Situated between the trees is the Crowne Plaza’s Basin Restaurant which is a famous resting place for the visitors. It is an example of one of the anthropogenic activities inside Petra’s park however, not directly affecting archaeological structures (source; petranationaltrust.org).
3.1 Assessing Past Destuctions

Past examples of monumental destruction should allow the individual to realize the disastrous effects of continued weathering patterns on the archaeological monuments along with the consequential results of insufficient maintenance. The most recent example to be brought forward in this case, is the Nabataean tomb no. 609 of which its façade completely collapsed in 2011 and became known as the Mu’Eissra collapse (see fig. 14, below). The façade fell down on top of a camel which resulted in its death, luckily no local Bedouins or tourists were affected by this event (petranationaltrust.org).

Figure 14: The collapsed façade of Tomb no. 609 in the Mu’Eissra area inside Petra which occurred in 2011, killing one camel (source: personal picture-collection, 01-04-2015).

Upon observing past destructions, there is a difference to be discovered in recent collapsed monuments and in ones that occurred a relatively longer time ago.

In the case of Tomb no. 609, the new surface exposed after the façade collapsed is in fact a rejuvenated surface and obtains its original light colour which, in this sense, is indicative of a relatively recent monumental collapse. In comparison to this, another example of a collapsed façade in the Wadi Farasa area (fig. 15, p. 27) illustrates how an older sandstone surface looks like a lengthier time after it was exposed following a
collapse of the once attached façade. The differences are explained by the effects of physical and chemical weathering in which the surface is subjected to crust-formation which changes the roughness and appearance of the original sandstone surface (Heinrichs 2008, 655; Turkington 2005, 238-240).

Figure 15: the collapsed façade in Wadi Farasa which occurred a significant time ago since the surface has already a quite developed crust-formation as result of post-collapse weathering processes and does not attest of a rejuvenated surface, such as that of Tomb no. 609, any longer (source: personal picture-collection, 02-04-2015).

3.2 Weathering Types
Weathering is a process responsible for the decay of bedrock and the removal and transportation of the resulting unconsolidated debris which are known as regolith (Nichols 2009, 91-92).

Sandstone is known to be of rather fragile nature when it comes to various processes concerned with weathering and erosion resulting from environmental and anthropogenic factors. The sandstone monuments and natural features in Petra are thus susceptible to any circumstances, such as extreme weather and human activities, in the archaeological park that lead to further degradation (Bala’awi 2011, 3; Heinrichs 2008, 643-644). In order to fully grasp the amount of weathering processes modifying and afflicting damage on the archaeological Nabataean monuments, there will be an
overview, below, of the several types of weathering processes that are operational in
and around Petra and which are the main contributors to the monumental degradation.
The main weathering factors contributing to the sandstone decay in Petra are physical,
biological and anthropogenic in origin leading to various weathering forms which are
categorized under; ‘loss of stone material’, ‘deposits’, ‘detachment of stone material’
and the occurrence of fissures and joints which can be attested on and at most of the
archaeological monuments in Petra (Heinrichs 2008, 643-659). Therefore, the focus in
terms of weathering lies on these elements and, as previously mentioned, will be
reviewed hereafter.

3.2.1 Physical Weathering in Petra
Several processes are grouped together under one collective name which is known as
physical weathering however, each of these processes are different in terms of
operation. In the case of the breakdown of rock without altering its chemical
composition, we speak of physical weathering to which various processes belong.
Water, wind, salt crystallization, anthropogenic activities and thermal shock, resulting
from significant changes in temperatures which triggers an expansion of minerals during
high temperatures and contraction at low temperatures, are the main physical
weathering processes subjecting Petra’s archaeological monuments and features to
further decay (Paolini et al. 2012, 12-14). Furthermore, there are the impacts of
biological and chemical weathering (Bala’awi 2011, 19-23; Nichols 2009, 90-91).

Water, in Petra’s Archaeological Park (PAP), deriving from rainfall does not occur often
however, when it does it not rarely results in flash-floods leading to erosion in various
degrees. This makes water an active agent contributing to the destabilizing environment
towards the archaeological monuments and features in Petra’s archaeological park. This
environmental force could have been one of the main factors for the Nabataeans to
design and construct ceramic pipes within their hydrological system in order to reduce
and deflect parts of this natural flow of water in order protect themselves and their
monumental artworks. Currently, the water is able to inflict considerable damage to the
archaeology of Petra when it develops from rainwater into flash-floods. Beside flash-
floods and rainwater, surface water as well causes indirect damage by entering the
cracks, as result of past earthquakes and ongoing physical weathering, of porous sandstone rocks where water will eventually evaporate which leads to the formation of salt crystals which grow and expand (fig. 16, below) and ultimately widen the existing fissures. Salt-crystallization is commonly known as the most destructive factor in the case of sandstone formations and other porous rocks, albeit a natural feature or monumental architecture, in the sense of subjection to extensive physical stress acting from within (Alshawabkeh 2010, 125-126; Bala’awi 2011, 19-20; Doehne 2002, 51; Dorn 2013, 61; Nichols 2009, 90; Sancho 2003, 54-56).

Beside the impacts and resulting damage of water and salt-crystallization, wind is another main contributor to the degradation inflicted to the Nabataean archaeology throughout Petra. Wind is known for its abrasive powers in which wind-borne sand particles will form a natural sandpaper abrading the sandstone surfaces of the monuments and other natural and archaeological features causing overall surface-recession in Petra’s park. In addition to its abrading actions on surfaces, the fluctuating speeds of the wind in Petra also enhances the process of the formation and distribution of salt crystallization which develop in pre-existing fractures in the sandstone rocks (Alshawabkeh 2010, 126; Bala’awi 2011, 20-21; Nichols 2009, 90; Heinrichs 2008, 658-660).

**Figure 16:** the above diagram indicates the cycle of growth of a salt-crystal. This process is known as crystallization. After influx of water (indicated above as H2O), as result of rainfall, any present salt molecules will remain present during evaporation when temperatures in the rock increase. Repeating cycles cause further development of the crystal and its size will eventually subject both sides of the pores to mechanical pressure outwards (source: www.tue.net).
3.2.2 A Word on Roots

Often the least factor one would think about, which eventually does result in major damage, are; plants. In fact, it are the roots of the plants which find their way in pre-existing holes and small fractures in the soft sandstone rock. On a short-term basis, not much of an effect can be noted except for the beauty of the plant itself however, on a long-term basis, these seemingly innocent plants could lead to the opening of significant fissures and an increase in large-scale fractures resulting in a decreased internal stability of the soft rocks. When the internal physical structure of the sandstone is being increasingly destabilized, it eventually gives way to a collapse of the sandstone monument and/or natural feature in the form of, if not total, major losses of stone (Alshawabkeh 2010, 130; Bala’awi 2011, 22; Turkington 2013, 68)

3.2.3 Anthropogenic Factors

Since the nomination of Petra, in 2007, to be added to UNESCO’s New Seven Wonders of the World List, the overall tourist flow increased significantly and rose far above the park’s carrying capacity (Bille 2012, 111-112; Comer 2012, 55-57). In order to cope with the requirements to assure a comfortable and safe stay for the visitors, numerous facilities were erected in the park. Some restaurants, legislated souvenir-shops, built-in toilets, a museum and a first-aid post are now located in the archaeological park and are the results of the needs and wishes from tourists which have increased in numbers after the park’s new status (fig. 13, p. 25).

Beside the construction of buildings to facilitate the tourist-flow within Petra, the local Bedouin community is offering a wide range of services to the park’s visitors which are ranging from donkey and camel-rides to guided tours and spending nights in one of the ancient Nabataean caves. The caves, hewn and carved out of the sandstone mountains, are still in use, despite efforts of UNESCO in 1985 which were aimed to relocate the Bedouin community to the government-planned village of Umm Sayhun, and are often converted into multi-functional living rooms (fig. 17, p. 31) which not rarely incorporates various alterations such as a build kitchen, windows and separate Nabataean hewn tombs which now have a cemented floor and serve as either storage rooms or sleeping rooms (Bille 2012, 107-111).
The impact of these anthropogenic factors on Petra’s archaeological park is various however, it has disturbed the quiet nature of Petra which undoubtedly has impact on the naturally occurring biodiversity in terms of plants and animals. Additional to the impact on Petra’s natural environment resulting from (noise-)pollution, increased physical weathering to the sandstone formations, archaeological features and pathways might be another side-effect of these anthropogenic activities, also known as economic impacts in this case, in the park resulting from increased tourist-flows, donkey-, mule- and camel-rides (fig. 18, p. 32) as well due to the erection of the restaurants, toilets, museums and various souvenir shops and the expansion of nearby villages (Bala’awi 2011, 22; Comer 2012, 58-62; www.icomos.org).

Figure 17: The modern interior of one of the ancient Nabataean caves now being reused by local Bedouins as a new home. A multi-functional living room with a kitchen-space (left corner), new window frames (left) and Nabataean graves which are now cleared out, cemented, painted and currently in use either as a sleeping room or as a storage room (source: personal picture collection; 20-05-2015).

A substantial amount of the caves are currently used by local Bedouins from the Al-Bdul community who have refused to live in the government-planned and build village of Umm-Sayhun and choose to continue to live their lives in the traditional style by re-
using caves and converting them into ‘houses’. The effects of modern alterations made to the ancient Nabataean tombs, referred nowadays as caves, are damaging in some ways. Upon field-surveying in Petra, I was confronted with such an ‘act of alteration’ occurring in a cave located on the side of a mountain adjacent to the Wadi Ad-Deir. This action consisted of the placement of a modern window in an ancient Nabataean tomb resulting in the fact that a piece of the cave’s ancient façade had to be removed by means of a hammer. This resulted in the creation of an enlarged opening in the façade of the cave, the instalment of the modern window-frame and the creation of various minor fissures in the surface of the stone (fig. 17, p. 31; left wall). However, the local Bedouins cherish their caves and take all matters in hand to protect their way of life which should be respected by both governmental institutions, archaeologists and visitors.

**Figure 18:** Petra’s position on the UNESCO’s New Seven Wonders of the World List (2007), led to high visitor rates which spiked far above Petra’s carrying capacity. The increased tourist-flow led to the emergence of numerous legislated souvenir-shops, built-in toilets, restaurants and an increase in donkey-, camel- and horse-rides services. These factors contributed to an accelerated physical weathering of (mainly) the ancient Nabataean stairs as well as pathways (source; own picture collection in exception of the left corner picture taken by; Mishelle Shmulovich).

### 3.3 Monuments in the Danger-Zone

Previously, light was shed on past destruction which highlighted the collapse of Tomb
No. 609 located in the Mu’eissra area in Petra. Beside past destructions to Petra’s natural sandstone features and Nabataean monuments, there are also those who are in dire need of protection against further decay to prevent collapse. Various monuments are in the danger zone. However, in order to highlight the various aspects of weathering and the damages to which it can led, two archaeological monuments have been selected for further review.

3.3.1 Urn of the Monastery

Petra is full of magnificent and impressive monuments which were carved by the Nabataeans roughly between 200 BC and 300 AD. In Petra’s archaeological park alone, there are more than 2000 monuments however, some stand attest most attractive in terms of being a tourist-attraction (Bala’awi 2012, 2-4; Paradise 2013, 176).

The first and far out most famous monument is the Treasury, known as the Al-Khazneh, whereas the ‘King’s Tomb’, one of the monuments in the Street of the Facades, and the Monastery, known as Ad-Deir, attract a significant number of visitors as well (see Appendix III, p.79). The Monastery monument can be reached by means of an exhaustive climb on a Nabataean carved stairway, leading through the mountain, consisting of approximately 800 steps. This monument is carved at the edge of a high mountain and has the largest façade in Petra, measuring around 50 meter wide and 45 meter high and is topped with a sandstone urn of approximately 9,5 meter (Maqsood 1994, 117-121; Shawabkeh 2010, 129-130).

Tourists can choose to do the climbing themselves or to take a donkey- or mule-ride upstairs, the latter has a quite devastating impact on the Nabataean carved stairs and tombs in this area (Paolini 2012, 80). Upon arriving at the final destination and in front of the Monastery, the sight of the monument’s massive façade is breath-taking. However, not noticeable from the front neither from a distance is a possible danger lurking around the corner. This danger is caused by physical weathering and could pose a threat to both the monument, its viewers, who often gather in front of the monument, and the locals who are known to be climbing to the very top, the Urn, of this monument in order to entertain the tourists which are viewing the Monastery from down enjoying a drink while sitting at the, opposite of the Monastery located, souvenir-shop (fig. 19, p.
From a distance, such as is seen from the souvenir-shop, not much damage can be seen considering the top of the Monastery however, upon the inspection from a close distance, damage is well-observed and suggests a highly deteriorated part of the Urn which signals the dire need for professional attention in terms of conservation, safeguarding this monument and retaining the archaeological park’s safety (fig. 20, p. 35). Immediate attention is required in terms of preventing further damage as result of the weathering conditions, to which this part of the Monastery is subjected, and the presence of anthropogenic effects, such as the local Bedouins and visitors climbing the monument to reach the Urn which might have contributed and contribute to further and/or increased decay of the Monastery’s Urn, climbing activities occur throughout Petra’s archaeological park and is an anthropogenic factor contributing to the deterioration of both sandstone monuments and stair- and pathways.

The back- and left side of the Urn is heavily damaged by means of erosion and other weathering processes. Another modern factor contributing to the further degradation is anthropogenic in origin and consists of pressure on the rock resulting from climbing activities around and on the Urn itself (fig. 21, p. 35). Various other weathering agents...
have resulted, and continue to result, in this damage. The most effective agents are wind, of varying velocities, and water as result from rainfalls and surface run-off water from the mountainside out of which the Monastery is carved. Water could lead to capillary actions, penetrating the sandstone rock and weakening the internal stability and cause the formation of salts in fissures which leads to damage to the porous sandstone through means of physical stress (Doehne 2002, 1-2).

The wind, especially in this high located area of Petra, is a major contributor to the monument’s physical weathering and enhances the weathering effects resulting from water, such as increasing the formation of salts (Alshawabkeh 2010, 126; Bala’awi 2006 in Bala’awi, 2011, 18-19; Bala’awi 2011, 20-21).

**Figure 20:** This picture is taken from the other side of the Monastery, a view that not many tourists observe. Here the damage on top of the Monastery, its Urn, becomes clear. The danger of falling of significant blocks of sandstone is a possibility (source; [www.mountainelm.com](http://www.mountainelm.com)).

**Figure 21:** Most of the local Bedouins aim to fulfil services for the tourists in Petra, as well by
means of entertainment in the form of music and performances. For example, Bedouins accomplish a thrilling climb to reach Monastery’s urn in order to perform a flute-show which tourists truly enjoy. In this picture; Salem al-Musa (from Umm-Sayhun) performing his own flute-show on top of the heavily eroded urn (source; personal picture-collection).

The possibility of collapse of significant pieces of sandstone rocks deriving from the Monastery’s urn is increasing as long as no measurements are applied to prevent further degradation. Water is drained through the Urn’s minor fissures, stored and evaporated during warmer days which result in the formation of salt. The salt, in turn, expand and widens the fissures to significant extends which finally leads to the loss of sandstone in the form of; rock-fall, break-out and the process of washing-out (Alshawabkeh 2010, 130). The degradation of the Urn, as well as surrounding parts on the top of the monument, result from mainly three types of weathering agents; anthropogenic activities, wind of fluctuating velocities and water as result of rainfall and surface run-off water.

3.3.2 The Corinthian Tomb
In the extended part of the ‘Street of Façades’, in the East of Petra’s archaeological park, are the famous Royal Tombs which incorporates a variety of tombs with elaborately carved façades. The Silk Tomb, Palace Tomb, Urn Tomb, the Tomb of Sextus Florentinus and the Corinthian tomb all belong to this row of Royal Tombs which are located next to each other and carved in the east-side of the Al-Khubta mountain (Guzzo 2002, 177; Maqsood 1994, 105-108). From these Royal Tombs, the best preserved monument is the Urn Tomb whereas the Corinthian tomb is the most affected one in terms of an extremely weathered façade which one will observe directly when standing in front of this monument (fig. 22, p. 37).

Mainly the upper order of the Corinthian tomb’s façade looks quite like a miniature though, similar version of part of the Treasury’s Hellenistic-style façade (Guzzo 2002, 143-147). The Corinthian tomb’s façade however, compared to the Treasury’s façade, is extremely weathered throughout the centuries as result from continuous subjection to physical weathering processes in terms of salt-crystallization (fig. 16, p. 29), solution and transportation of sandstone particles by means of water, biological factors (as plant-
roots), wind ablation and due to the movement in the form of rock-falls which inflicted considerable damage to its façade (Maqsood 1994, 107; Nichols 2009, 93-96). The latter factor, movement under gravity, might occur to the Treasury’s façade in the case of continuing neglect of possible natural hazardous features, such as loose boulders which could fall down during the event of tectonic movements (fig. 11, p. 23).

Figure 22: the heavily worn façade of the Corinthian tomb which is located left, when observed from the front, of the Urn Tomb and is part of the row of ‘Royal Tombs’ in the East of Petra’s archaeological park. The growth of plants is another contributing factor of the physical breakdown of the fragile and already weakened sandstone (source; adapted from Guzzo 2002, 143).
The façade of the Corinthian is mostly affected by surface run-off water, rainfall, anthropogenic factors, wind ablation, biological factors and salt-crystallization (Bala’awi 2011, 24). The erosional effects of wind ablation due to wind-blown sand are most attested at the base of the monument and its façade since this is located in the near range of sand-particles lying on the surface which are picked up by the wind from here (Bala’awi 2011, 20). The Palace Tomb, located adjacent to the Corinthian tomb is the most perfect example for the erosion at the lower, or base, part of the façade which is caused by wind however, as well by possible past flash-floods which could have washed away the lower parts (fig. 23, p. 39).

Water is another, if not the greatest, contributor to the decay of the wonderful Corinthian tomb’s façade as well to most of the other Nabataean monuments in Petra (icomos.com). The effects leading to the façade’s degradation often arises in the form of rainfall and the resulting surface run-off water which primarily leads to the removal of unconsolidated sand-detritus. Sand-detritus that is being transported by water works as a sand-paper on the surface of the rest of the façade causing further erosion. Various of the sandstone monuments incorporates a drainage system, such as the Corinthian Tomb and tomb No. 70, and was most likely once constructed by the Nabataeans for protection and the collection of water however, it is now resulting in the collection of rainwater and a flow of water over the façade’s surface which results in the loss and detachment of stone creating empty spaces and widened fissures such as is seen on façade of the Corinthian tomb and tomb No. 70 (Heinrichs 2008, 659-662; Papamichos 2011, 1130-1131). Secondarily, water on the surface of porous sandstone gives way to salt-crystallization which forms a basis for any further expansion of pre-existing fissures and the destabilization of the rock’s internal structure (Bala’awi 2011, 21-22; Doehne 2002, 1-2; Nichols 2009, 90). The latter could result in the eventual collapse in which a part of the, once consolidated, rock now breaks out and away from the sculpted façade and falls down which could pose a threat to tourists and the surrounding archaeology such as the Corinthian façade itself which has indeed been damaged by previous rock-falls (Heinrichs 2008, 655; Maqsood 1994, 107; Nichols 2009, 93).
Beside the weathering effects of wind and water, biological weathering is as well another factor to which the Corinthian tomb façade is subjected and is another secondary effect of the presence of water. This weathering mainly arises in the form of vegetation (fig. 22, p. 37) in which plant-roots find their way in and widen existing fissures in the soft sandstone and could produce the formation of insect colonisations which further lead to the decay of the Corinthian façade’s internal structure (Bala’awi 2011, 22-24).

Figure 23: an example of erosion at the base of the façade, in this case the Palace Tomb which is located next to the Corinthian Tomb, as result of continuous subjection to wind ablation by means of airborne sand-particles picked up from the surface and possibly by the erosional effects of past flash-floods and surface run-off water (source: personal picture collection).

Various other archaeological sandstone monuments in Petra are deteriorating in a fast or increased rate as result of several weathering agents and the increased tourist flow after Petra’s nomination on the UNESCO’s New Sevens Wonders of the World List. This thesis has been confined to reviewing three of these monuments; Tomb No. 609, the Monastery’s Jar and the Corinthian Tomb Façade. This selection was based on the degree of degradation and the weathering agents contributing to this decay. The following chapter will briefly review and propose conservation methods and safety measurements that could be applied in order to maintain safety for the visitors and local
Bedouin community. Beside aiming for safety, it is well addressing the prevention of further damage to Petra’s archaeology.
4. Better Safe Than Sorry

In the light of the various weathering processes taking place in Petra, the degree of degradation of the Nabataean monuments and the flow of tourism, a consideration of methods to prevent further damage is of high importance. If any plans concerned with the protection for Petra’s archaeological monuments are postponed, it could result in irreversible damage to Jordan’s archaeological heritage in terms of monumental decay and collapse and could form a breach in the park’s safety. Therefore, measurements taken in this aspect are vital for the preservation of the archaeological monuments. Some of the options, regarding the prevention of damage and safeguarding the park’s safety, which are applicable in Petra’s archaeological park will be briefly discussed in the following part of this chapter. Beside the methods that can be applied to protect the park, the local community and its tourists, there will also be an examination of the stakeholders involved concerned with regulations and measurements applied in the archaeological park.

As becomes clear, most, if not all, rock-cut monument and caves in Petra have been largely subjected to physical weathering processes of various degrees throughout the centuries alongside the more recent damaging anthropogenic activities such as the increased flow of tourism, building activities (restaurants, toilets, shops), tourist services and the touching of sandstone walls and other features in the park. As result of this ever increasing deterioration, especially since its assigned function as an archaeological park, Petra has been listed as one of the hundred most endangered archaeological sites in the world by the World Monument Fund in 1998, 2000 and 2002 which aims for its protection and conservation (Alshawabkeh 2010, 125-126; www.wmf.org).

4.1 Possible Methods

Various methods could be applied to protect the fragile sandstone monuments and features in Petra as well to prevent future damage and to uphold the park’s safety for locals and tourists. Data from various (geo-)engineering, geological and geo-archaeological studies could be helpful and even essential prior to any conservation intervention on Petra’s archaeological monuments and features. Data derived from
previous evaluations of weathering processes on a certain monument and the damages inflicted are essential in order to obtain successful results and to prevent destruction to the subjected monument resulting from the application of wrong tools or material during the conservation process, such as happened at the Qasr al-Bint monument in Petra which resulted from applying the wrong type of mortar as a stone consolidant (Al-Saad 2001, 926-927; Alshawabkeh 2010, 142; Bala’awi 2011, 10-11; Khaldoon 2006; 1355-1359). Impregnating porous rocks and existing fissures with mortar has been previously applied to monuments, such as the Qasr al-Bint in Petra, in order to strengthen the weakened structure and to prevent further fracturing and eventual collapse of the sandstone. However, none of the evaluated types of mortar seem to be applicable to Petra’s archaeological monuments and features since it would lead to even further and increased deterioration (Al-Saad 2001, 927-932).

Due to the lack of a single conservation policy in the heritage sector of the Hashemite Kingdom of Jordan, various unaligned conservation interventions, most lacking a well-defined system, have been conducted in the Petra Archaeological Park. Therefore, it is considered important to establish a national conservation policy prior to any conservation acts in the archaeological park. Such a policy could as well prevent confusion about the application of conservation methods, tools and materials and might lead to the prevention of damage as result of the application of the wrong conservation materials without prior evaluation (Bala’awi 2011, 24-25). Weathering resulting from salt-crystallization is not easy to prevent since the monuments have been subjected to this natural force since their creation approximately 2000 years ago. Desalination techniques may neutralize salt-formations and reduce its impact however, this is often applied on urban buildings consisting of porous rocks and on relatively smaller surfaces compared to the massive façades of Petra’s archaeological sandstone monuments. Desalination, along with other stone cleaning techniques, might as well result in side-effects which could lead to a negative outcome for the fragile sandstone façade and other sandstone features (Matyscak 2014, 561-563; Rörig-Dalgaard 2015, 1915-1916; Young 2003, 1125-1129).

Several natural features in Petra which are prone to collapse in terms of rock-fall could pose major threats to visitors in the nearby and distant future. The threshold of existing
fissures will be exceeded, at some point, resulting in the toppling over or sliding down of significant unstable blocks of sandstone especially in the consideration of earthquakes, flash-floods and slope-movements (fig. 24, below). Continuous and professional monitoring of the stability and instability of Petra’s unconsolidated sandstone features, such as the Al-Habis boulder (fig. 10, p. 22) and the boulder at the Treasury (fig. 11, p. 23), and parts of archaeological monuments should be carried out in the archaeological park (Delmonaco et al. in Margottini et al. 2013, 441-446). Such rock-fall analyses could prevent casualties in the case of an unexpected rock-fall in the park’s vibrant tourist areas, moreover it could prevent a breach in the park’s safety towards its visitors and locals.

Figure 24: On the left; an example of a possible present threat located to the right-side of the ancient Nabataean stairs leading to the Monastery monument, both the stairway and the Monastery is a hotspot for tourists indicating the direct threat for the tourists’ and locals’ safety. The large sandstone fragment, when the threshold is exceeded, might either break-away to the side of the stairway or slide-down next to the stairway. To the right is an example of a past threat which has collapsed and got stuck between the Nabataean stairway on the left and the mountainside on the right (source: personal picture collection).
The previous figure (fig. 24, p. 43) is one of the many natural features that could, upon collapse, inflict injury, result in the loss of life of both tourists and locals and lead to considerable damage to surrounding archaeology and present tourist-facilities. Based on the present possible threats, direct measurements for protection are particularly necessary in the case of safeguarding Petra’s archaeological park, its infrastructure, facilities, its visitors and local community. Measurements that could be applied in Petra’s archaeological park are, for example; re-occurring professional risk-assessment of locations susceptible to rock-falls, placement of fences and shields which are capable of fully retaining the rocks or at least reducing the impact-speed of the sandstone rocks or the placement of steel nets (fig. 25, below) in risk-zones in order to absorb the impact’s energy and prevent further downslope movement of rocks (Volkstein 2011, 2617-2639).

**Figure 25:** Top images; Varying types of barrier components designed to absorb the energy of impacts, lower images: various mesh types that could be applied in the construction of steel nets (source: Volkwein et al., 2011)

Beside the application of constructions to prevent damage and threats to visitors and locals, conducting continuous risk-analyses are important as well in order to highlight the areas which are in dire need of protection and the resulting measurements to be taken. Furthermore, tourists should be warned not to partake in climbing activities on the park’s archaeological monuments and natural features in terms of their safety and not to touch, scratch or write on any of the sandstone monuments since this leads to increased weathering and decay of the surfaces.
Preventing tourists from, unconsciously, damaging the archaeological heritage might be achieved by means of placing clear warning signs and, in the extreme case, imposing fines on the individuals who ignore and break the park’s rules.

Various international organisations have been aiming to protect Petra’s archaeological park in cooperation with local-based trusts and corporations. ICOMOS, the International Scientific Committee on Archaeological Heritage Management, for example, is part of UNESCO and is concerned with the protection of archaeological sites, such as that of Petra’s archaeological park. Especially since the increased and harmful tourist-flow after the park’s nomination in 2007. The ICOMOS has brought forward various publications that review and examine the impacts on Petra’s archaeology as result of the increased visitation from people worldwide. This type of research publications should be studied and applied prior to designing and assembling of a heritage management, conservation and protection plan for Petra (Comer 2011, 499-501).

Some of the local Bedouin families who remain living in the ancient Nabataean caves, contribute in their way to partially preserving the archaeological heritage by, for example, applying white wash on the carved walls in order to prevent smoke-damage resulting from fires (Mickel and Knodell 2015, 245). The Bedouin community are aware of Petra’s archaeology and importance. The Bedouins, being the local stake-holders, should be actively involved in public archaeology, decision-making events and training classes which could teach young, as well as older, generations about preservation and conservation of the archaeological monuments.

4.2 Petra’s Stakeholders

As mentioned previously, UNESCO has appointed Petra as an archaeological park for visitors since 1985 and placed in the UNESCO New Seven Wonders of the World List in 2007. These new titles gave way to an increased flow of tourism which exceeded the carrying capacity of Petra and led to the construction of various touristic facilities such as souvenir shops, restaurants and souvenir-shops. As mentioned previously, the ICOMOS is the part of UNESCO that is concerned mainly with the protections and conservation of archaeological sites such as that of Petra and therefore should be mingled with intervening acts in the archaeological park. USAID however, is a
development organization who is rather concerned with further improving the flow of tourism in Jordan (Comer 2011, 508). The World Monument Fund (WMF) might be viewed as another stakeholder in the process since it has listed Petra as one of the most endangered archaeological sites in the world throughout previous years. In order to achieve a long-term strategy plan which aims for the conservation and protection of the archaeology, the World Monument Fund has established corporative ties with the Petra National Trust (PNT) and the Jordan Ministry of Tourism and Antiquities of which the offices are both based in Amman (www.petranationaltrust.org; www.wmf.org).

The local Bedouin, known as the ‘Al-Bdul’ tribe or community, are equally important being the local stakeholders in and around Petra. The Bedouins are trying to make their living from offering guided tours, hiking tours and donkey-, mule- and camel-rides to visitors. The latter service contributes to physical weathering on the ancient Nabataean carved roads and stairs in Petra (fig. 26, p. 47). Beside the local Bedouins, most inhabitants of Wadi Musa, a town adjacent to Petra, claim ownership over Petra since the park’s only build ticket-office and modern entrance is located here. Additionally, Wadi Musa is thriving due to the economic benefits resulting from the increased flow of tourism, which becomes obvious from the massive presence of various hotels, inns and hostels. Beside Wadi Musa’s extensive tourist-accommodations, there is an overwhelming presence of souvenir-shops, restaurants and argileh-bars. Contradicting however, is that in the village of Umm-Sayhun, the government established village for Petra’s Bedouin community, any constructions related to economic advantages and business related to touristic activities are not allowed (Mickel and Knodell 2015, 241-242).

The prohibition on further building activities concerned with the accommodation of both tourists and Bedouin families in Umm-Sayhun might has to do with the resulting distorting effect of high buildings on the view over the enclosing mountains which tourists have when walking in Petra (fig. 27, p. 48). The latter given is quite ironically since it was UNESCO, in cooperation with the Jordanian government, who have forced the Bedouin community to move from their caves into a government-build village where they are now being continuously and extremely limited due to various regulations which, up till present day, forces many members of the Bdul-tribe back in the ancient
caves of Petra where they used to have lived before (Mickel and Knodell 2015, 246). The Bedouins, being a semi-nomadic tribe, attest of great knowledge and skills regarding survival in Petra and surrounding desert areas and encompass specific cultural traditions which contributes for a great part to the intangible heritage of Petra’s archaeological park and neighbouring areas. The Bedouin community might be a partial reflection of ancient communities now being threatened due to modernization, marginalization and the impact of an increased tourist-flow. Whereas the local Bedouin community is in fact the largest present group regarding Petra’s archaeological park yet, they are the least represented and involved in discussions surrounding the conservation and management plans which could negatively influence their cultural and natural environment (Mickel and Knodell 2015, 240). Due to the previous given reasons, the Bedouin community has since 2005 been inscribed on the UNESCO’s list of Masterpieces of the Oral and Intangible Heritage of Humanity in order to protect such culture (Bille 2012, 108-116).

Members of the USAID, the Petra National Trust, the PDTRA (Petra Development and Tourism Regional Authority), ICOMOS, UNESCO, inhabitants of Wadi Musa and especially the local Bedouin community should at all times be collectively involved prior to the application of changes and regulations, future (construction-)plans and measurements applied in the light of the park its conservation and safety (Mickel and Knodell 2015, 252-253). Especially the local inhabitants should be given a fair chance to let their opinions and critique be heard in advance of any application of such changes (Bala’awi 2011, 24-25; Mickel and Knodell 2015, 240-241).

![Figure 26: significant damage can be seen on the stairs leading to the Monastery monument. The result of continuous subjection to the feet of donkeys and tourists (source: Comer and Willems 2011, 502).](image-url)
Further limiting activities related to tourists in Petra aiming to protect the archaeological park could result in various protests. The protests could both be from the inhabitants of Wadi Musa, who offer horse-rides until the Siq, and from local Bedouins who offer donkey-, mule- and horse-rides on a daily basis to various locations in and around Petra and are often financially dependent on these activities.

![Figure 27: In the left image, the red contours are indicating possible future heights of buildings if construction would be allowed in the Bedouin village of Umm-Sayhun in order to economically improve their livelihood. This could affect the tourist’s view over the Sharah-mountains to the left of Petra (source: adapted from aphs.worldnomads.com).](image-url)
5. Conclusion

Petra is one of the world’s most marvellous archaeological sites consisting of ancient Nabataean monuments, sculptures, reliefs and caves and was rediscovered in 1812 by Swiss explorer Johan Ludwig Burckhardt (Bala’awi 2011, 1-2; Harding 1938, 36). Petra’s place on the UNESCO’s World Heritage List (1985) and its 2007 nomination on the list of the New Seven Wonders of the World led to an economic boost for Jordan’s tourism-sector. Petra’s new status as well increased the flow of tourists which reached far beyond the carrying capacity of the archaeological park, resulting in various anthropogenic impacts on its archaeology throughout the years in the form of building activities, tourist services, modernization and an increased weathering of roads and ancient stairs (Bala’awi 2011, 19). Heinrichs 2008, 643; Paolini et al. 2012, 16; Paradise 1999, 353-354). Beside tourism affecting the archaeology, it as well affects the traditional lifestyle of the local Bedouin community who were forced to move out of their natural habitat (fig. 2, p. 7), the ancient caves, into a government constructed village which attests to be unsuccessful in terms of accommodating the Bdul tribe (Abu al-Haija 2011, 93-100; Bille 2012, 107-123; Heinrichs 2008,643; Mickel and Knodell 2015, 246).

Varying degrees of continuous physical weathering, of which salt-crystallization and wind are the most destructive, and the rising anthropogenic activities in the archaeological park are the most present dangers which continue to subject the ancient monuments and caves to further decay (Alshawabkeh 2010, 125-126; Bala’awi 2011, 19-20; Doehne 2002, 51; Sancho 2003, 54-56). The rate of decay in the monuments differs in severity; relatively unaffected to extremely weathered or even collapsed. The latter stage is attested in Petra, such as the collapsed façade of Tomb No. 609 and the façade of an older collapse-event (fig. 14, p. 26 and fig. 15, p. 27).

Up to present day, at least 80% of the ancient monuments inside Petra’s archaeological park are affected by various weathering processes. Due to several threats leading to its degradation, Petra is now on the Monument Fund’s list known as the ‘100 Most Endangered Sites’ (Bala’awi 2011, 19). Even though Petra’s fragile nature is acknowledged, possible dangers are luring around the corner on a daily basis such as the
Al-Habis Boulder and the Treasury Boulder (fig. 10, p. 22 and fig. 11, p. 23). These possible threats could result into significant archaeological destruction and loss of human life when triggered by earthquakes resulting in the downslope movement or rock-fall of unconsolidated natural and architectural features. Beside earthquakes, flash-floods, anthropogenic disturbances and continuous weathering as well contribute to exceeding the rock’s threshold resulting in collapse (Bala’awi 2011, 5; Delmonaco et al. in Margottini et al. 2013 441-446; Heinrichs 2008, 644; Paradise 2013, 176).

We could prevent further damage by means of conducting more and extensive field-surveys focussing on all monuments rather than restricting a risk-assessment only to the ‘famous monuments’. Furthermore, by reducing the impact of tourism, enhancing the involvement of local stakeholders and by applying training- and awareness-programs in and around Petra, a big step in the right direction towards adequate protection and conservation can be achieved. Finally, reviewing Petra’s archaeological and geological research data and installing steel safety nets (fig. 25, p. 44), which are able to contain falling boulders during the occurrence of a collapse and rock-fall, could tremendously contribute to the protection of Petra’s archaeology and undoubtedly leads to an enhancement of the park’s safety (Comer 2011, 499-501; Volkwein et al. 2011, 2638).

To my opinion, it would be highly effective and of great importance to ensure the continuous involvement and engagement of the local Bedouin (Al-Bdul) community. Involving the local Bedouins might attest of positive outcomes due to their high knowledge regarding Petra’s lay-out, its natural features, hazards, risks and present damages attested in the structure and façades of the Nabataean sandstone monuments. There should be aimed for a long lasting and peaceful cooperation between Petra’s various and numerous stakeholders, such as the PDTRA, the PNT, Wadi Musa’s inhabitants, UNESCO, ICOMOS and the local Bedouin community in order to (co)operate within a successful framework in the light of prevention, conservation and overall management of Petra’s fragile monuments, caves and natural features (Bala’awi 2011, 24-25; Bille 2012, 108-116; Mickel and Knodell 2015, 241-253). As well, conservation and preservation strategies and research should be applied with the professional help. Applying professional knowledge deriving from various scientific fields, in order to assess and evaluate damage, could significantly contribute to the prevention of further
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Summary

Petra’s archaeological park (PAP) is a marvellous site full of sandstone artworks hewn by the ancient Nabataeans approximately 2000 years ago. Ever since the creation of this architectural wonder, it has been continuously subjected to various types of weathering processes which occur in this region. As result of this the sandstone wonder is damaged to varying degrees and will further decay as long as neglect continues and no measurements are applied in order to protect Petra’s archaeology.

This research sheds light on two selected hazardous features and three selected Nabataean monuments. This selection was based on the aim to highlight possible dangers in the archaeological park and to review various impacts inflicted on and in the surfaces and structure of Petra’s archaeological monuments.

Preventing further degradation of the sandstone archaeology is of high importance, especially since its 2007 placement on the list of ‘Seven New Wonders of the World’ by UNESCO. Petra’s new status led to an increased tourist-flow benefiting Jordan’s economy however, destroying the very archaeology which tourists come to enjoy. By safeguarding the ancient monuments in the archaeological park, one not only protects an touristic site as well the natural habitat of the local Bedouin community. Steel nets could, for example, be applied in the park in order to direct prevention of further damage. However, the key for protecting Petra’s is peaceful and long lasting collaboration between all stakeholders while giving a voice to the local Bedouin (Al-Bdul) community who have been living here for many centuries and experience Petra as their ‘home’.  

Preserving Petra is not confined protecting the observable, it is about preserving both the tangible and intangible heritage while retaining lasting peaceful bonds between Petra’s stakeholders.
Samenvatting

Petra’s archeologische park (PAP) is een adembenemende site gevuld met gigantische kunstwerken van zandsteen welk ongeveer 2000 geleden zijn uitgehouwen door de Nabateërs. Sinds het ontstaan van dit architecturale wonder, is het constant onderworpen geweest aan de effecten van verscheidene verweringsprocessen welke plaatsvinden in deze regio. Deze processen resulteren in de vernieling van het zandsteen wonder en zal verder afbrokkelen zo lang dit probleem genegeerd wordt en er geen maatregelen worden getroffen met als doel: het beschermen van Petra’s archeologie.

Deze scriptie probeert licht te werpen op twee geselecteerde en mogelijk gevaarlijke natuurlijke elementen en tevens drie Nabateëse monumenten uit het archeologische park. Deze selectie was gebaseerd om de gevaren in het park aan te tippen en tevens om de schade op de oppervlaktes en in de structuur van de fragiele monumenten aan te tonen.

Het voorkomen van verdere degradatie van dit soort kwetsbare archeologie is extreem belangrijk, vooral sinds Petra’s nominatie in 2007 als een van de ‘New Seven Wonders of the World’ (UNESCO). De nieuwe status van Petra heeft geleid tot een toename in het aantal bezoekers welk voordelig uitpakte voor de Jordaanse economie echter, had en heeft een vernietigend effect op de, al zo aangedane, archeologie in het park waar de toeristen voor komen. Door middel van het beschermen van de archeologische monumenten wordt niet alleen een toeristische attractie beschermd, ook wordt hiermee de leefomgeving van de lokale Bedouïnen beschermd. Stalen vangnetten kunnen, bijvoorbeeld, toegepast worden in het archeologische park om verdere schade te voorkomen. Echter, het belangrijkste element wat wederom zal bijdragen aan de bescherming van Petra is een vredevolle en langdurige samenwerking tussen alle stakeholders gedurende welke de lokale Bedouïne (Al-Bdul) samenleving een kans krijgt om zich te laten horen. Het zijn de lokale Bedouïnen die Petra aanschouwen als hun ‘huis’, hun leefomgeving. De Bedouïnen zijn eveneens een deel van het Jordaanse, weliswaar ontastbare, erfgoed. Het beschermen en conserveren van Petra is niet gelimiteerd tot het zichtbare echter, het is beide het ontastbare en tastbare gedeelte van het erfgoed wat aandacht verdiend. Gedurende de preservatie en conservatie is het van groot belang om een constante en vriendelijke band te behouden met alle
stakeholders betrokken in het proces.
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This thesis was a real challenge and therefore I am thankful for every helping hand & mind that came on my path during my stay abroad and field-survey in Petra itself. Back home, the journey through this thesis did not end and became more intense. I experienced great support and advise which truly helped me out. Therefore, I would now like to take the opportunity to thank all of those who have mentally and academically supported, guided and helped me throughout this thesis while being abroad and back home in the Netherlands.

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To my father and mother: thank you for being there for me through all the times in which I succumbed under the heavy loads of stress. Thank you for sharing the tears, as well the joy and laughter;

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