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## Geomorphology and rock slope instabilities in the archaeological site of Petra (Jordan)

Margottini, C.<sup>1</sup> and Spizzichino, D.<sup>2</sup>

<sup>1</sup>ISPRA – Dpt. Geological Survey of Italy

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Rapid onset natural phenomena, such as earthquakes, floods and landslides, pose a major threat to cultural heritage and visitors in Petra (Jordan) [1]. In 1963, 22 tourists died as a result of a sudden flash-flood in the Siq, a 1,2 km canyon representing the main access to the archaeological site.



Petra is situated on the eastern side of the Dead Sea-Wadi Araba tectonic depression, interpreted, according to available studies, as Dead Sea rift, a transform valley, a ca. 15 km-wide topographic low formed by shearing along the transform separating the Arabian and Sinai plates [2]. The hand-carved rock monuments of Petra are entirely carved in the sandstone of Umm Ishrin and Disi; moreover, many quarries in use in different historical period attest to the fact that the same sandstone was employed as construction material [2].

*Figure 1: The Mu'essira tomb with the collapse likely occurring on March 2010 (www. Petranationaltrust.org).*

The geomorphological aspect of Petra is the result of various long and short-term factors affecting this part of the territory. Active tectonics related to the Dead Sea-Wadi Araba transform system has produced steep, high rock-relieves, spaced out by fault fault-bordered narrow troughs as the “Petra Valley” [2]. The Siq slopes are the result of tectonic uplift, erosion due to runoff, differential erosion and weathering of sandstone materials.

The Siq has a general E-W orientation and a meandering course. It is the natural prolongation of Wadi Musa before the Nabataeans diverted it through the Wadi Mudhlin tunnel. Field geological and geo-structural investigation of potential rock slope failures conducted in the Petra area have determined that failure modes affecting the rock masses of the slopes can be classified into the following categories, according to the type and degree of structural control (kinematic movement): planar failure, wedge failure, toppling, free fall and collapse of unstable block and debris located in the upper part of the cliff. The latter, together with sudden flash flood occurring periodically, may pose important attention, to local authorities, for the safety of tourists.

After a UNESCO project focused only on the Siq, the site is now exhibiting an advanced landslide monitoring network (reflectorless robotic total station and traditional geotechnique instruments in a WiFi net) aimed to forecast potential collapse mainly affecting the visitors of the site. All the information and survey data allowed the preparation of a Guideline for sustainable management of the site to protect from slope instabilities. The Petra Archaeological Park is now implementing such guidelines,

together with the traditional knowledge and local expertise that has been used in the past to protect against geomorphological hazards.

*References:*

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