

## **IPL Project (IPL-259) Annual report 2023-2024**

July 2022 to March 2024

- 1) **Project Number and Title:** IPL-259 Landslide Risk assessment in AlUla Archaeological sites – Kingdom of Saudi Arabia
- 2) **Main Project Fields**
  - (1) Technology Development
    - B. Hazard Mapping, Vulnerability and Risk Assessment
  - (2) Targeted Landslides: Mechanisms and Impacts
    - B. Landslides Threatening Heritage Sites
  - (3) Capacity Building
    - A. Enhancing Human and Institutional Capacities
  - (4) Mitigation, Preparedness and Recovery
    - B. Mitigation
- 3) **Name of Project leader** - Claudio Margottini

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Core members of the Project:

Names/Affiliations: Daniele Spizzichino - The Italian Institute for Environmental Protection and Research – ISPRA, Rome, Italy);

José Ignacio Gallego Revilla (Royal Commission of AlUla, Executive Director, Kingdom of Saudi Arabia, Tel. +34651309284 / +966553565026, j.revilla@rcu.gov.sa),
- 4) **Objectives** - The focus of the project is to mitigate the risk from rockfall in the spectacular cultural heritages of AlUla archaeological area (HEGRA, DADAN and AlUla old Town), as well as to raise the awareness against geomorphological processes within the site's management plan. Capacity building with local authority will be carried out as a first step for training local expertise in landslide risk assessment and for enhancing resilience and landslide risk perception of the local Oasis community.
- 5) **Study area** – The site is located in the North of Saudi Arabia, 1100 km West from Riyadh, AlUla covers an archaeological area (e.g., necropolis, quarries and settlements) of more than 22,000 m<sup>2</sup>. The project is covering the 130 Nabatean tombs of Hegra, the 1,7 km long cliff of Dadan, where mainly Dadanite tombs are located as well as a huge archaeological quarry, and the surrounding of AlUla old Town. Its best-known site is Hegra, the first UNESCO World Heritage Site in Saudi Arabia, main southern city of the Nabataean kingdom, and a Roman outpost, that conserves over 130 monumental tombs with elaborated facades carved into the sandstone rock. In addition to Hegra, AlUla

hosts a number of fascinating historical and archaeological sites such as its Old Town, surrounded by an ancient oasis; Dadan, the capital of the Dadan and Lihyān kingdoms, considered one of the most developed cities of the first millennium BC in the Arabian Peninsula.

6) **Project Duration** – 3 years (July 2022 – June 2025)

7) **Report -**

a) Progress in the project in 2023-2024

Many rock-cut monuments are affected by different natural threats such as surface weathering and erosion, rising dampness, rock surface detachment and large-volume slope instabilities. To ensure the long-term conservation of sites affected by such natural threats, detailed investigations, monitoring and consolidation measures are required, specifically developed for rupestrian cultural heritage sites (Spizzichino et al. 2016; Boldini et al. 2017; Margottini and Spizzichino 2022 ). The activities are characterized by a thorough multi-disciplinary approach including competencies in archaeology, engineering geology, rock mechanics, landslide risk assessment and management as well as in conservation, protection and mitigation measures.

The entire area is characterized by the presence of low to medium strength sandstone formations. More in detail, the north area shows the outcropping of the Quweira Yellowish sandstone unit while in the central and Southern area (Old Town and Dadan) and further south the Siq Red Sandstone appears, divided into three main sub-units (Lower, Middle and Upper). The poor geological and geomechanical characteristics of these two formations affect the potential instability and weathering of the cultural heritage sites carved into them.

The geological formations are characterized by a significant internal variability, both vertical and lateral. The Quweira Yellowish Sandstone, of interest for the site of Hegra, is mainly interested by diffused weathering and erosional phenomena as well as rockfall connected to internal structural asset. The archaeological areas in the Siq Red Sandstone, i.e. Dadan and Old Town, are mainly affected by rockfall and slides as a consequence of the local discontinuities pattern.

To define the main physical and mechanical proprieties of the rock materials, two laboratory test campaigns were carried out, in 2020 and 2021. The structural setting of the rock-mass (bedding planes, joints, faults), related to the strati-graphical genesis, the tectonic activity of the Red sea, and the geomorphological evolution of the slope, was identified and classified. Local rock-mass conditions were found to promote slope instabilities (e.g., rockfall, sliding, toppling) that may affect both the heritage itself and visitors.

This preliminary assessment of prevailing kinematics and potential geo-hazards allowed the implementation of a general master plan, to be considered as a first step for the following detailed design stage. The master plan is containing a first selection of the most appropriated mitigation and consolidation measures, characterized by a low environmental impact and employing, as much as possible, traditional knowledge to site preservation.

Following is a picture with unstable blocks affecting the archaeological site of Dadan and a Nabatean tomb partially collapsed in Hegra.

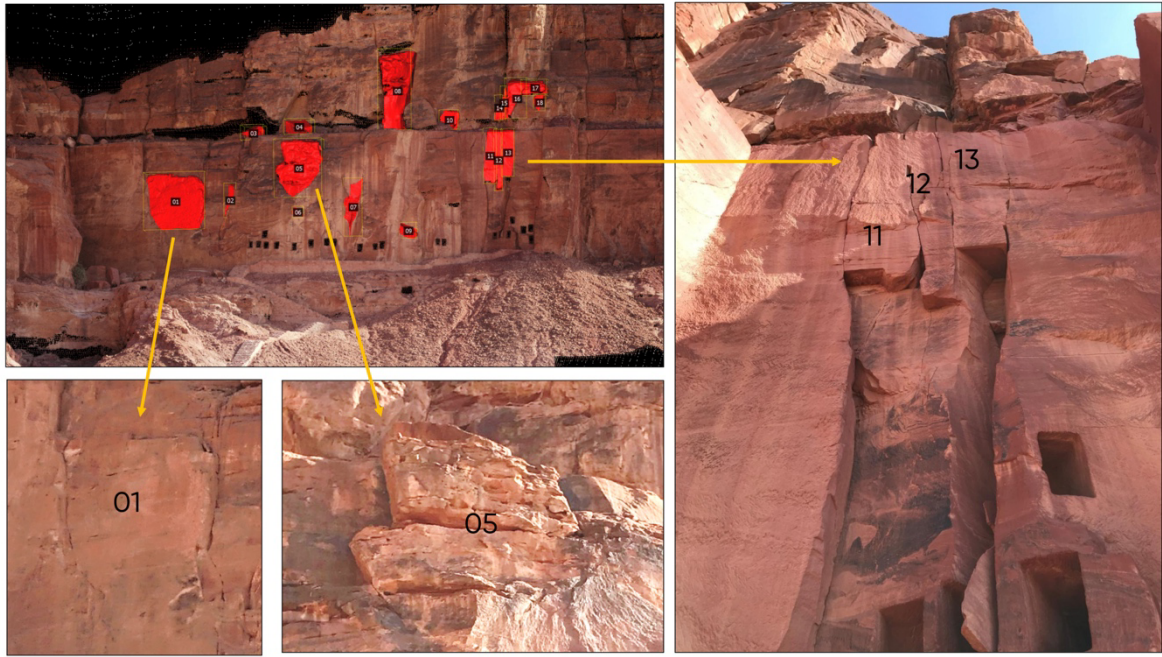


Fig. 1 Dadan, the ancient capital of Dadan and Lihyan kingdoms



Fig. 2 Hegra, the second important town of Nabatean Kingdom, after Petra; a UNESCO World Heritage Site

b) Planned future activities

In the period 2024 and 2025, the area of investigation has been enlarged, including the archaeological sites of Khaybar, where some villages on top of hills, are suffering for slope instability processes that are conditioning a possible future development. Khaybar is an oasis in Medina Province, Saudi Arabia, situated some 150 kilometres South of AlUla. Prior to the arrival of Islam in the 7th century, the area

had been inhabited by Arabian Jewish tribes until it fell to Muslim conquerors under Muhammad during the Battle of Khaybar in 628 CE.

In the meantime, the archaeological part of Hegra, where the people used to live, was investigated to understand the general condition assessment.

c) Beneficiaries of the projects.

The Royal Commission for AlUla (local conservation Agency), is the main beneficiary of the project, since it is responsible for the conservation and management of the archaeological site. The project is also providing an innovative approach in conservation of rock-cut heritage sites that may be applied in other sites of the region, for the benefit of local restorers and conservators. Local and Governmental authorities, including site managers, will finally benefit from this project, having a site protected for the medium-long term and allowing tourists to visit the area in a safer manner. A special meeting with site managers was organized in 2023.

d) Results

Tommaso Beni . Daniela Boldini . Giovanni Battista Crosta . William Frodella . Jos. Ignacio Gallego . Edoardo Lusini . Claudio Margottini . Daniele Spizzichino (2023). Rock instabilities at the archaeological site of Dadan (Kingdom of Saudi Arabia). Landslides DOI 10.1007/s10346-023-02122-7

Tommaso Beni, Lorenzo Nava, Giovanni Gigli, William Frodella, Filippo Catani, Nicola Casagli, Jos'e Ignacio Gallego, Claudio Margottini, Daniele Spizzichino (2023). Classification of rock slope cavernous weathering on UAV photogrammetric point clouds: The example of Hegra (UNESCO World Heritage Site, Kingdom of Saudi Arabia). Engineering Geology 325 (2023) 107286

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