The ICL Network on "Landslides and Cultural & Natural Heritage (LACUNHEN)"

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Abstract In recent decades, the concept of cultural heritage has evolved into one that encompasses an understanding of the history of humanity, together with scientific knowledge and intellectual attitudes. This changing concept has prompted a subsequent re-evaluation of what constitutes the outstanding universal values of World Heritage sites and the operational methods for implementing the UNESCO World Heritage Convention. The scope has broadened from studying a single monument in isolation to one that values a multidimensional, multiregional, and inter-disciplinary approach and encapsulates vast spans of human history. Within this broader view, landslides and more generally slope instabilities are an important factor endangering cultural heritage sites, especially prehistoric sites, earth/rock monuments, and archaeological sites affected by environmental processes and degradation. Natural and cultural heritage sites, as well as cultural landscapes, are then tied into a common framework that the Geological Society of America has defined "Men's legacy to Earth and Earth's legacy to Man". On the other hand, not too much effort has been expended in the past to develop conservation policies systematically integrating geological, geomorphological, and engineering geological aspects into daily practices. The purpose of the "LAndslides and CUltural & Natural HEritage" thematic Network (LACUNHEN) is to create a platform for scientists and practitioners who are ready to jointly contribute to safeguarding relevant endangered Natural and Cultural Heritage sites (e.g., Machu Picchu). They will share and disseminate their respective experience, demonstrating how these special "objects" require approaches, techniques, and solutions that go far beyond traditional civil engineering perspectives.

Keywords International Consortium on Landslides (ICL) · Cultural and natural heritages · Landslides · Case studies

Introduction

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The purpose of the "LAndslides and CUltural & Natural HEritage" thematic Network (LACUNHEN) of the International Consortium on Landslides (ICL), is to create a platform for scientists and practitioners who are ready to jointly contribute to safeguarding relevant endangered Natural and Cultural Heritage sites (e.g., Machu Picchu). They will share and disseminate their respective experience, demonstrating how these special "objects" require approaches, techniques, and solutions that go far beyond traditional civil engineering perspectives.

Core members of the LACUNHEN Network

After the proposal in 2012, the following institutions, members of ICL, joined the network:

1. ISPRA—Geological Survey of Italy (Dr. C. Margottini)
2. Charles University in Prague, Czech Republic (Prof. V. Vilímek)
3. Cairo University, Egypt (Prof. Y. El Saieb)
4. Gadjah Mada University, Indonesia (Prof. D. Karnawaty)
5. Geological Survey of Canada (Dr. P. Bobrowsky)
6. Institute of Telecommunications and Global Information Space of National Academy of Sciences of Ukraine (Prof. I. Kaliukh)
7. University of Bratislava, Slovakia (Prof. J. Vlčko)
8. University of Florence, Italy (Prof. N. Casagli)

Figure 1 shows the logo of the Network on Landslides and Cultural and Natural Heritage (LACUNHEN).

Activities

Basic and applied knowledge about the rocks and processes acting on planet Earth have been an important element of the perception of the universe by humankind. Indeed, the very existence and survival of every human individual, of the tribe, and of the species *Homo sapiens (as well as of other species of the genus Homo) has always been dependent on knowledge about nature, the application of that knowledge to the utilization of natural products (and on their processing and making of new products), and in avoiding or minimizing natural risks (Zagorchev 2008).*

Relationships between the cultural heritage of humankind and natural hazards are many and complex. Sites of cultural significance may be affected by catastrophic events of either endogenous origin (earthquakes, volcanic eruptions, tsunami) or exogenous origin (landslides, floods, ground collapses, wildfires, cyclones) (Smith 1996), for which little or no warning has been received (particularly prior to the twentieth century).

Fig. 1 The logo of the ICL Network on Landslides and Cultural and Natural Heritage (LACUNHEN)

However, these sites may also suffer from processes which are not catastrophic in the conventional sense (i.e., have not occurred suddenly), but their cumulative effects in the long-term may be highly adverse. These include ground subsidence, especially in coastal settings, accelerated weathering of building stone, sandstorms, and recession of coastal cliffs (Migon 2013).

Potential threats affecting cultural heritage sites are outlined in Fig. 2.

The present network is seeking to exchange experience, methods, and solutions to enhance the conservation of Cultural and Natural Heritage sites affected by landslides. The network is organizing a workshop, session conference, and field trip for the benefit of participating members.

Several case studies are currently under way. They include:

1. The conservation of the Byzantine Monastery of Vardzia (Georgia)
2. The monitoring of instability at Petra and the Siq passage to the city (Jordan)
3. The stabilization of the Bamiyan cliff in Afghanistan
4. Eco-friendly mitigation measurements to preserve the Red Fortress of Shar-e-Zohak (Afghanistan) from soil erosion and weathering
5. Slope stability monitoring at Machu Picchu (Peru)
6. Glacial lake outburst flood hazard evaluation in Huascarán National Park (Cordillera Blanca, Peru)

Conservation of Vardzia Byzantine Monastery (Georgia)

The Byzantine Monastery of Vardzia (Georgia) is affected by continuous rock falls and rockslides which pose serious threats to the conservation of one of the most important Heritage sites in Georgia, in the Caucasus. Ground-based radar interferometry and several field studies have been conducted and information presented to the local communities (Margottini et al., submitted to Landslides) (Fig. 3).

Instability monitoring at Petra (Jordan)

Petra faces diverse risks, ranging from those posed by natural and geological hazards to those attributed to tourism and a lack of adequate site management and emergency measures for tourist and monument safety. The risks to tourists and monuments from slope instability, both at Petra and along the Siq (the narrow rock gorge leading to the site) are high and need to be urgently addressed. The potentially unstable volumes of rock on these slopes vary from <10 m^3 up to >1,000 m^3. Collapse could be catastrophic, depending on the speed of movement and the volume of rock involved, and could be triggered by many causes such as seismic activity and heavy rainfall, or from joint deformation from freeze-thaw cycles and temperature variation. A full recognition of the potentially unstable areas of the Siq is needed through engineering geological approaches, and systematic long-term monitoring of the rock-block deformation with suitable advanced techniques. Suggestions for sustainable mitigation measures are deemed critical for conservation and safety strategies at Petra. To-date, no conservation strategies have been established to address this life-threatening phenomenon and there are no measures in place for risk management and mitigation (Fig. 4).

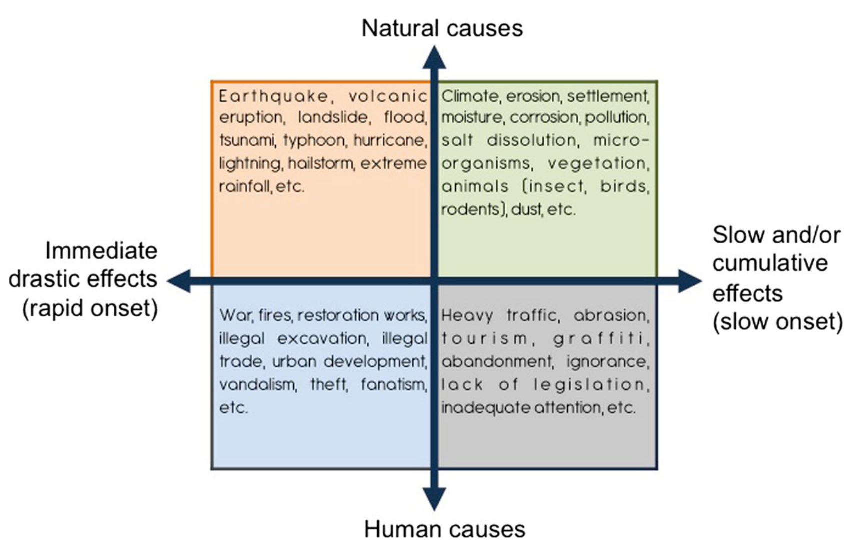

Fig. 2 Threats facing Cultural Heritage sites in general (ICCROM 2006, modified)

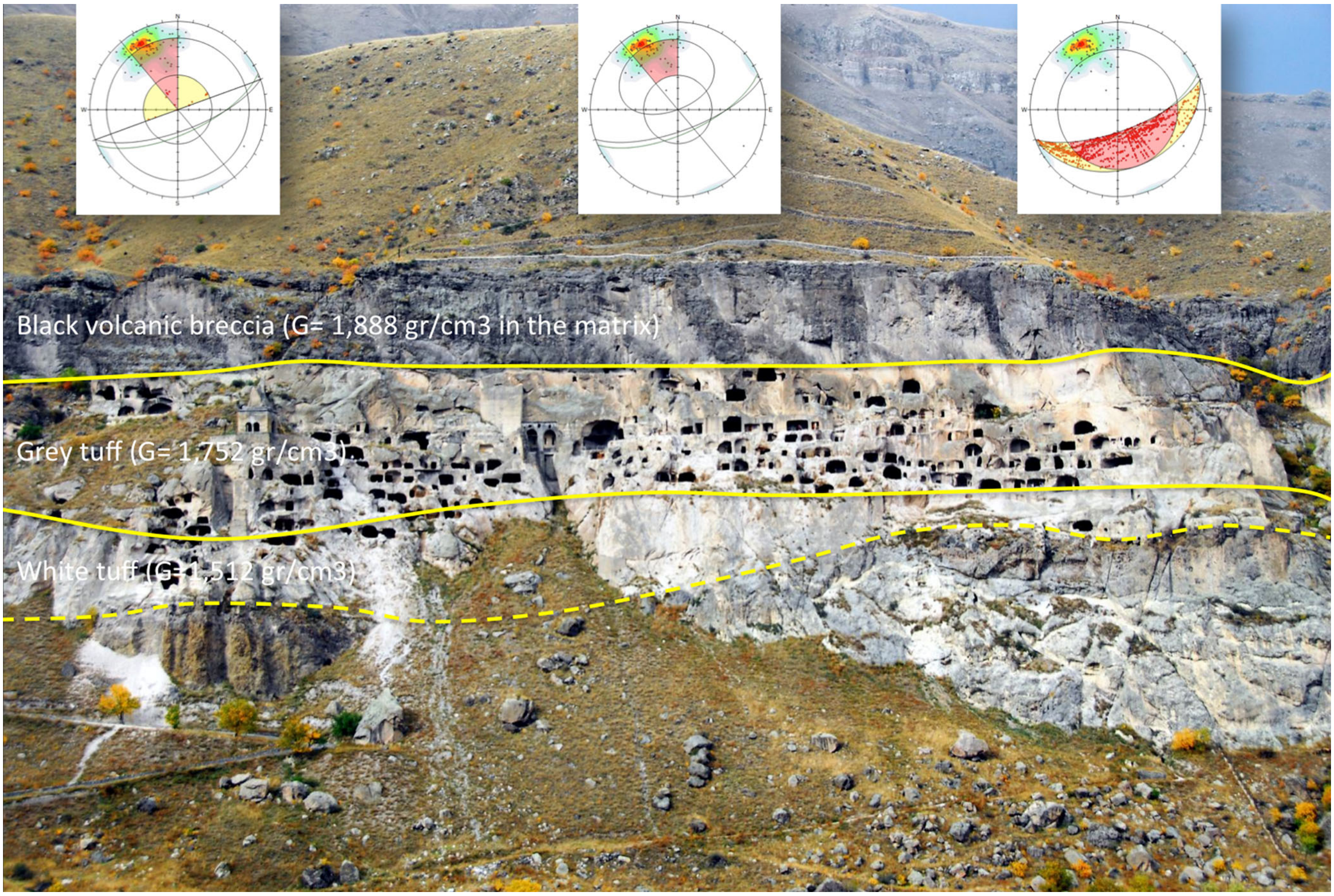

Fig. 3 Panoramic view of the rock-cut city of Vardzia Monastery, showing the main lithologies in the cliffs. Potential slope hazards include, from left to right, direct toppling, planar sliding, and wedge failure

It would be worthwhile to install a monitoring system composed of:

1. Crack gauges, tiltmeters, and a meteorological station, connected in a Wi-Fi environment and easily accessible through remote internet;
2. A reflector-less total station monitoring net, focusing on more than 800 individual points selected during the field work and periodically surveyed.

To support the development of activities, two workshops with local experts and technicians, UNESCO and experts from ICL were conducted in Amman, together with field trips at the site.

Stabilization of the Bamiyan cliff (Afghanistan)

The statues of the Buddhas of Bamiyan, carved around the sixth century into the calcareous cliff of the Bamiyan valley, are the largest Buddhist monuments in the world. These monuments were almost destroyed by bombing perpetrated by the Taleban in March 2001. Since then, UNESCO has been active in the Bamiyan area with the aim of preserving the remaining parts of the Buddha statues and rehabilitating the artistic remains. The complex of Bamiyan was inscribed in 2003 in the World Heritage List of UNESCO as a "cultural landscape". Among the most urgent operations required for the structural rehabilitation of the area is the stabilization of the rock faces within and in the vicinity of the niches, which have deteriorated from both the explosions and natural processes. The emergency measures were also aimed at allowing archaeologists to catalog and remove the Buddhas' rock remains safely (Fig. 5).

At present, after the stabilization of the cliff and niches (Margottini 2004, 2014), the major concern is the stabilization of the back wall of the remaining niche of the Giant Western Buddha and to investigate the potential for collapse within the whole cultural landscape. A manual monitoring system was established on the cliff, showing a potential rock fall on the upper niche of the Giant Western Buddha; this was immediately stabilized in 2013. Field work was conducted by ICL experts (ISPRA and University of Florence) in late 2012 and 2013.

Mitigation measures at the Red Fortress of Shar-e-Zohak (Afghanistan)

The remains of the Shahr-e Zohak fortress are located on a steep hill at the confluence of the Kalu and the Bamiyan rivers, about 15 km east of the city of Bamiyan (Central Afghanistan). The site is thought to have been built during the Buddhist period (sixth–seventh century A.D.), even though the fortification is attributed to the Islamic period. Its position provided both excellent natural defenses and control of the valleys, which are communication routes (Fig. 6).

The fortress is protected by ramparts, built along the steep cliffs bounding the site, which are equipped with several watchtowers.

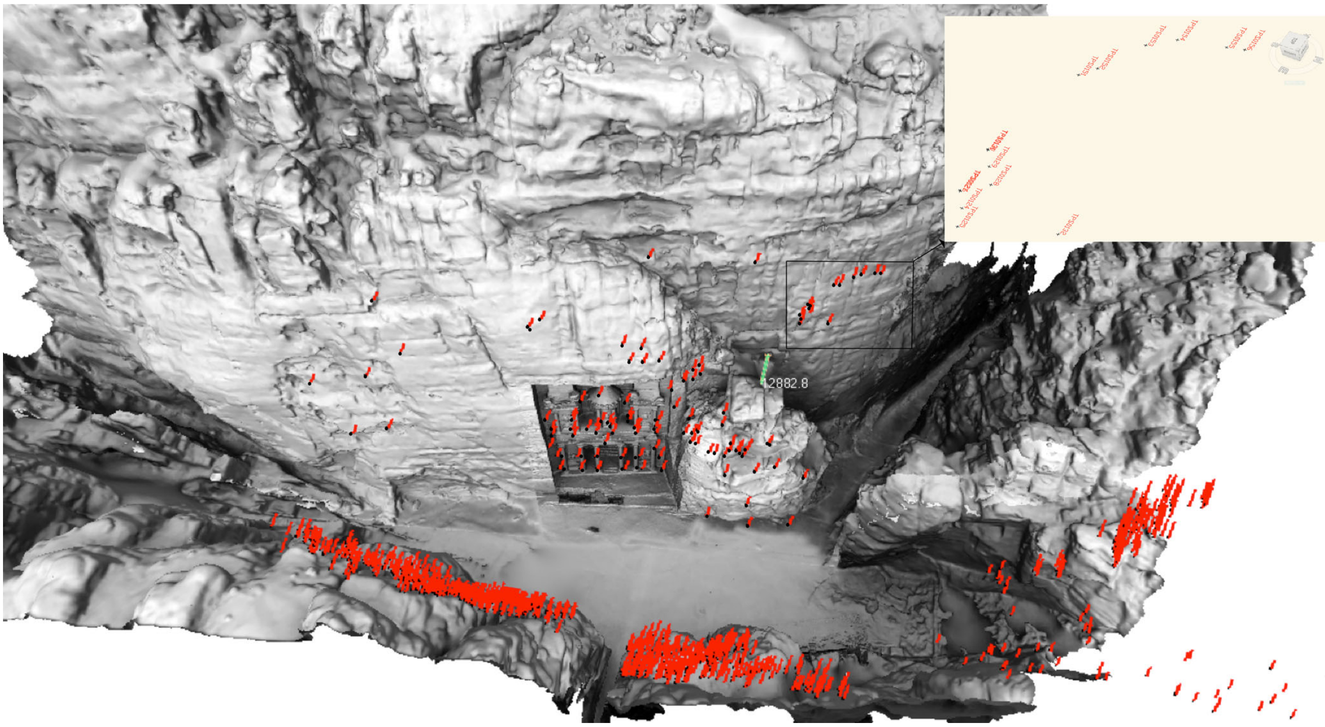

Fig. 4 Reflector-less monitoring points (*black dots*) in the area of the Treasury (Petra Archaeological Park) displayed on a terrestrial laser scan image of the site. Each monitoring point shows the position (*black*) and the relative label (*red text*). On the *right-up corner* an enlargement of a small sector

The citadel is protected by three more ranks of walls, and is located on the topmost part of the hill; on its southern side, it is separated from the plateau by a NW-SE-oriented valley.

The fortress walls are mainly made of mud bricks, made from the local clayey red mud, and placed on top of gravelly foundations. Due to prolonged exposure to weathering, a lack of conservation measures, and damage during periods of war, many constructions have collapsed or are prone to collapse. Wall deterioration is coupled with the lack of an adequate drainage system to collect runoff. Ramparts located on the steep hill slopes are severely affected by gully erosion and siphoning, with depressions infilled by eroded and weathered building material. The access path is locally eroded or buried by debris cones. The western margin of the plateau is rapidly retreating due to collapses, while the citadel is in danger due to diffuse or gully erosional processes on all of its sides.

Currently, after investigation of the geomorphological processes and construction of a digital terrain model of the original topography using a drone and sophisticated computer models

Fig. 5 Climbers at work on stabilization of the left side of the Eastern Giant Buddha niche

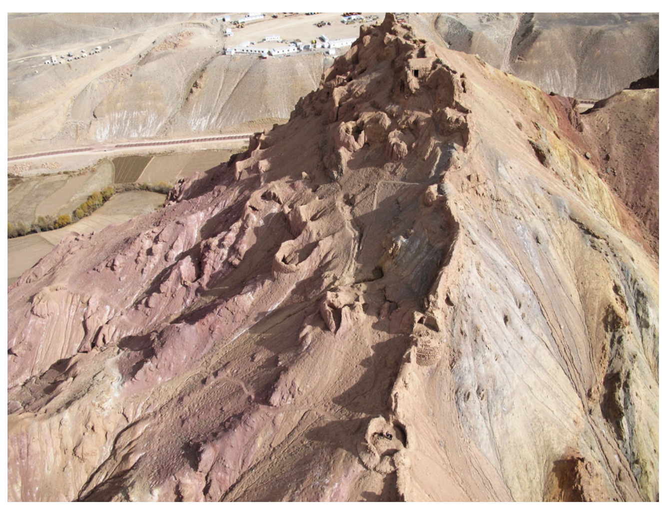

Fig. 6 The upper part of the Shar-e-Zohak red fortress. Damage to buildings and archaeological remains is quite evident. Aerial photo from drone (Courtesy of Iconem)

(Iconem France), some mitigation strategies have been proposed to limit the effect of rainfall and snowmelt, through a new nature-based (ecosystem-based) approach. The latter approach is intended to adopt sustainable, systemic, and cost-effective tools for soil conservation, in order to improve the environmental resilience of the site. Field work by ICL experts (ISPRA and University of Florence) was conducted in late 2012 and September 2013.

Slope instability at the Machu Picchu area (Peru)

According to recent findings, Machu Picchu has been built in the area of a huge prehistoric rock-slide (Vilímek et al. 2005). Part of an ancient mountain which was located between the peaks of Huaynapicchu Mt. (2,700 m a. s. l.) and Machupicchu Mt. (3,051 m a. s. l.) collapsed in prehistoric times. Some blocks remained on the slopes in a state of temporal stability and this area creates the east-facing slope of Machu Picchu (the so-called Front Slope), which is of much lower inclination than general rock slopes in this area (35° compared to 50–80°). At many places inside the archaeological site, as well as on the Front Slope, deep open cracks are visible. Recent monitoring did not show any significant slope movements of these blocks (see also Vilímek et al. 2007). The area appears to be conditionally stable, but "waiting" for another impulse like the one that triggered the huge prehistoric rock-slide (possibly a large nearby earthquake).

Nevertheless, the immediate surroundings of the archaelogical site suffer from various types of recent slope movements. A landslide temporal analysis and susceptibility assessment, as bases for landslide mitigation, was prepared by Klimeš (2013). Most of the tributaries to the Urubamba River produce debris flows during the rainy season. The overview and some recent examples were described by Vilímek et al. (2006).

Natural hazards in the Huascarán National Park (Peru)

Several natural hazards are directly connected with the Cordillera Blanca mountain range, which is now protected as a national park. An overview of different types of natural hazards in this area was published by Zapata (2002). Natural hazards have been described here since 1702. The latest events in recent decades have been described, e.g., by Lliboutry et al. (1977), Vilímek et al. (2000), Carey (2005), and by Hegglin and Huggel (2008). The strong deglaciation following climate changes in this area is responsible for the hazards connected with slope instability (e.g., rock and ice falls, landslides in glacial moraines). Complex phenomena, glacial lake outburst floods have followed the glacial retreat as well (e.g., Klimeš 2012; Emmer and Vilímek 2013; Klimeš et al. 2014). The recently established Glacial Lake Outburst Flood (GLOF) database involves collecting data for a new proper hazard evaluation method with respect to regional specifics of these outburst floods. It is also an IPL project of ICL (Vilímek et al. 2014).

The Cordillera Blanca, as the most widely glaciated mountain range in the tropics worldwide, is a significant natural laboratory for understanding relations between ongoing processes, responses, and threats (Fig. 7). Older landforms document morphological processes in the Quaternary. One locality inside the national park where the direct influence of natural hazards on cultural heritage has to be studied is Chavín de Huantár, an important archaeological and cultural heritage site.

Fig. 7 Lake Palcacocha in the Huascarán National Park, where glacial lake outburst floods recently have been studied

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