Engineering Geology for protecting Cultural Heritages around the world: some case studies

Claudio Margottini

UNESCO Chair on the Prevention and Sustainable Management of Geo-Hydrological Hazards, University of Florence

President IAEG Italy

President Civita di Bagnoregio Scientific Committee

UNIVERSITÀ DEGLI STUDI FIRENZE
UNESCO CHAIR Prevention and Sustainable Management of Geo-Hydrological Hazards

unesco Chair

Presentation Agenda

01 Global Context and Rationale.

02 Engineering Geology, Geohazards and Cultural Heritage

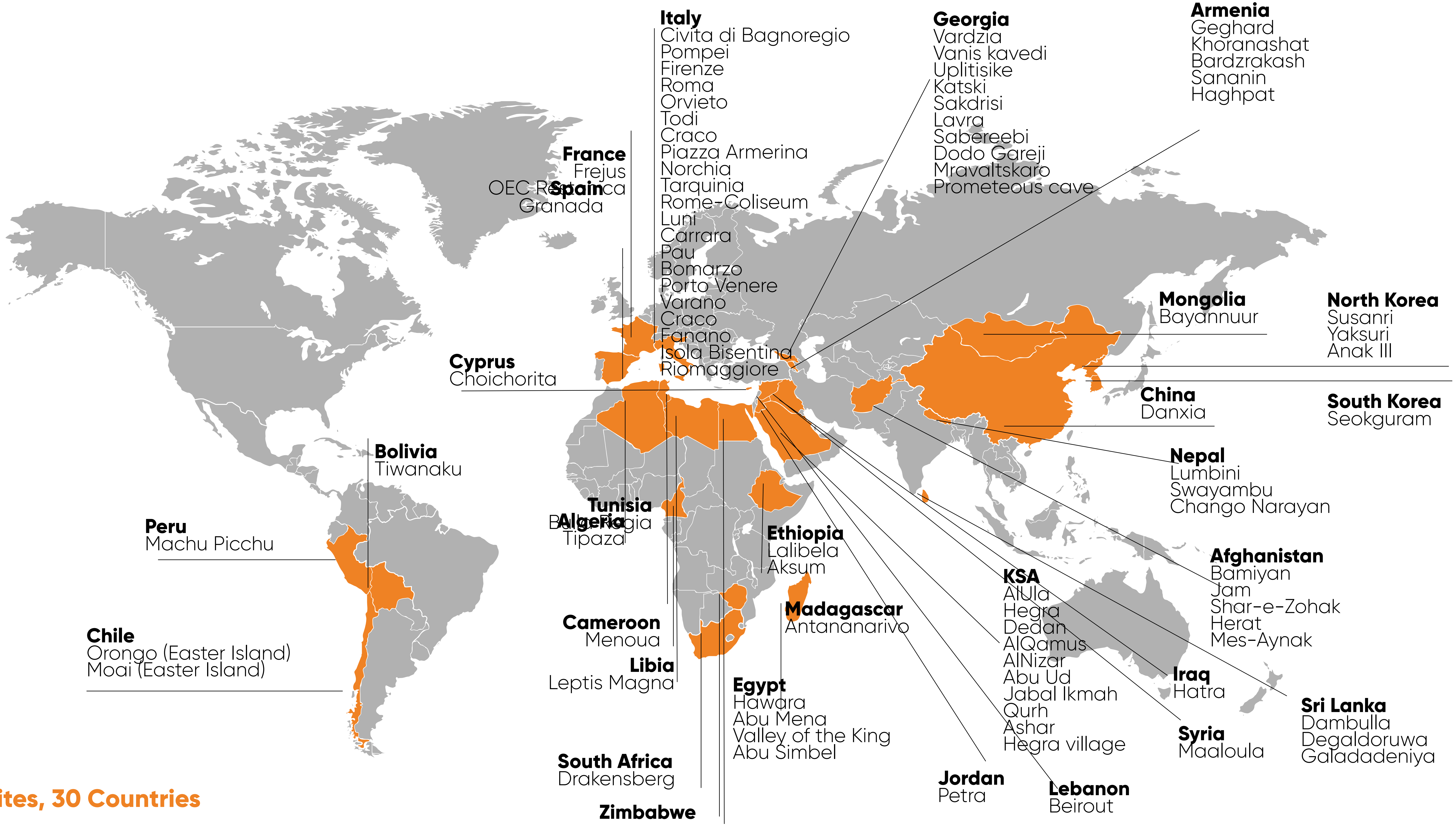
03 Proactive Geoscience Framework

04 Case Studies.

05 Synthesis & Outlook.

Investigated Heritage Sites

Engineering Geology for the Conservation of Cultural Heritages



88 sites, 30 Countries

01

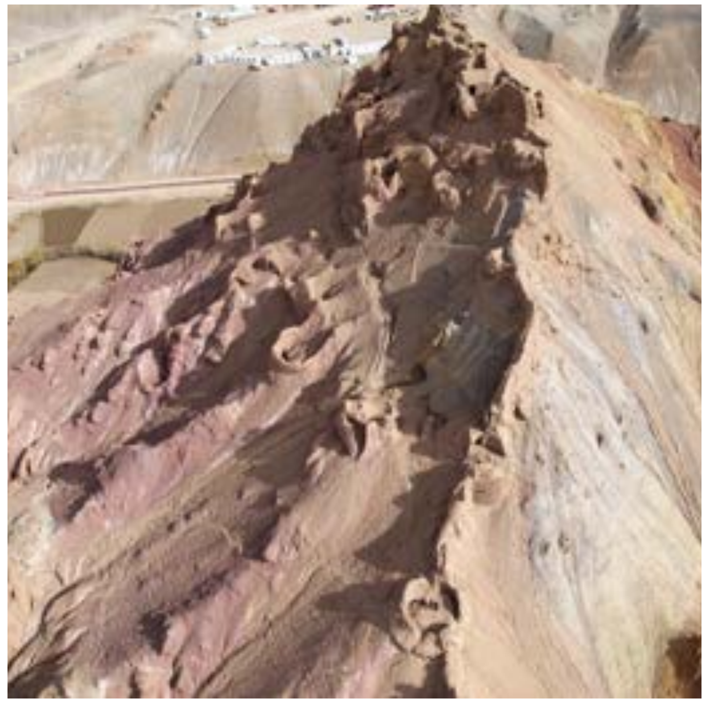
Global context and rationale

Why engineering geology is foundational to heritage conservation

Rationale

Cultural heritage represents the legacy of humankind on planet Earth. It bears witness to millennia of human adaptation to their environment, as demonstrated in numerous monuments, sites, and cultural landscapes. These historical landmarks are subject to continuous changes and the influence of modern growth and development. The impacts and alterations result from various internal and external conditions arising from both natural and anthropogenic factors, such as rapid events (e.g., rockfall, debris flows, slope movements, earthquakes, floods) and slow-onset processes (e.g., geological and geotechnical subsidence, soil and coastal erosion, sinkholes, hydrogeological conditions), including climate change. Today, cultural heritage shows evidence of the impact of geohazards and weathering, underscoring the need to rethink conservation and management plans for these sites. Consequently, Engineering Geology and affiliated empirical research studies such as Geotechnical Engineering, Geomorphology, along with technological innovations, may need to introduce new paradigms for the preservation of cultural properties, providing a resourceful platform for learning.

Heritage **Applications**



Archaeological sites

Site formation processes
Burial and preservation conditions
Landscape reconstruction
Dating and chronology

Built Heritage

Foundation stability analysis
Weathering and erosion assessment
Material sourcing studies
Risk evaluation

Natural Heritage

Landscape evolution studies
Ecosystem dynamics
Geological heritage sites
Conservation planning

Geo-tourism

Cultural landscape
Geosites
Geopark

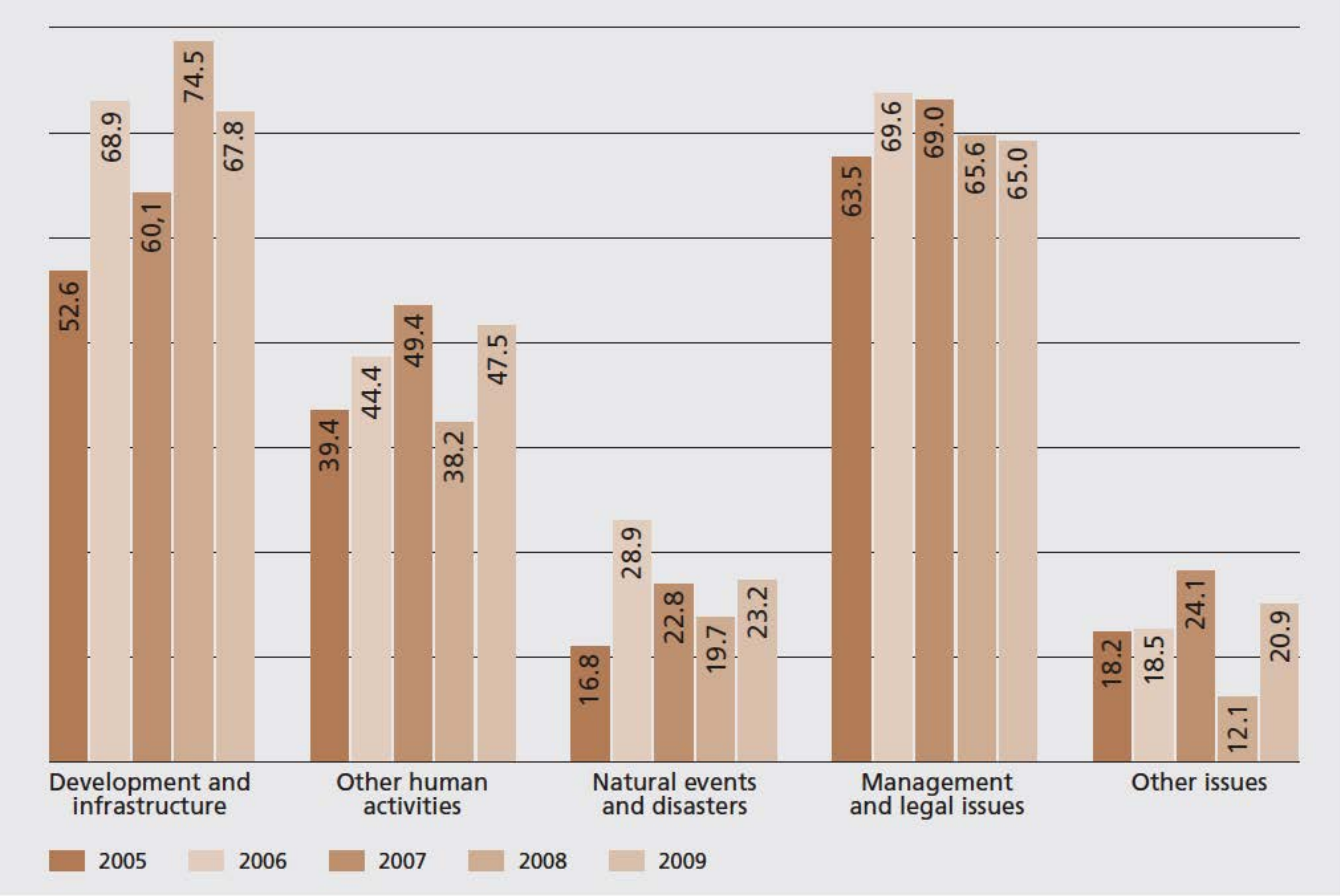
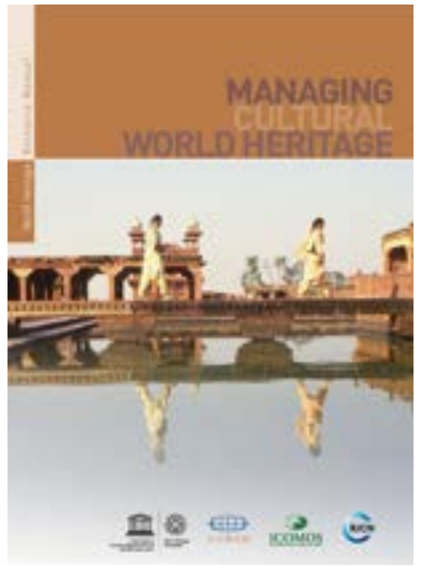


Diagram 4: Percentage of World Heritage properties affected by each primary group of threats (years progressing from 2005 to 2009, from left to right)[30]

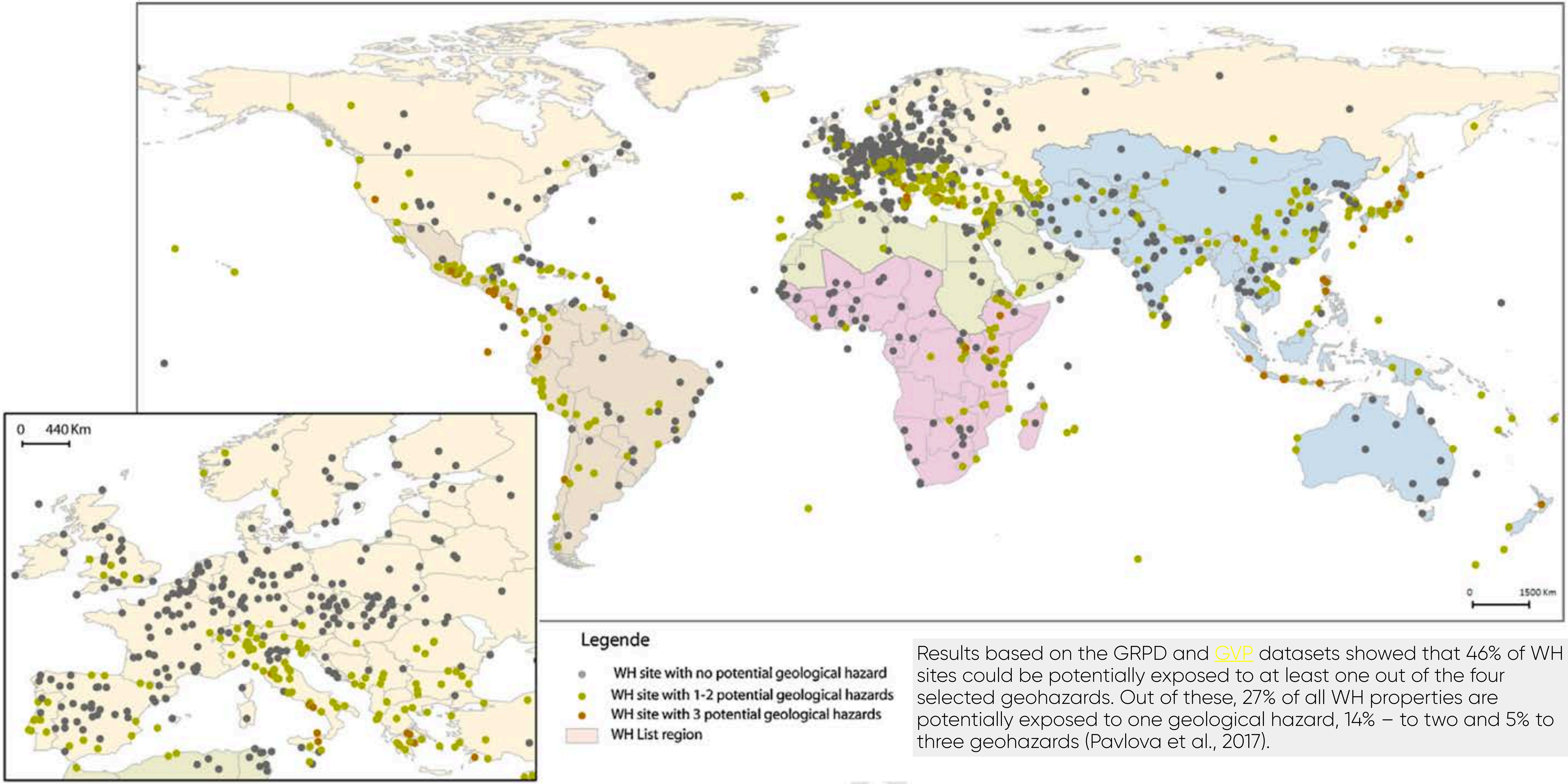


Source: UNESCO (2013)

Considered geological hazards:

tsunamis, landslides, earthquakes and volcanic eruptions

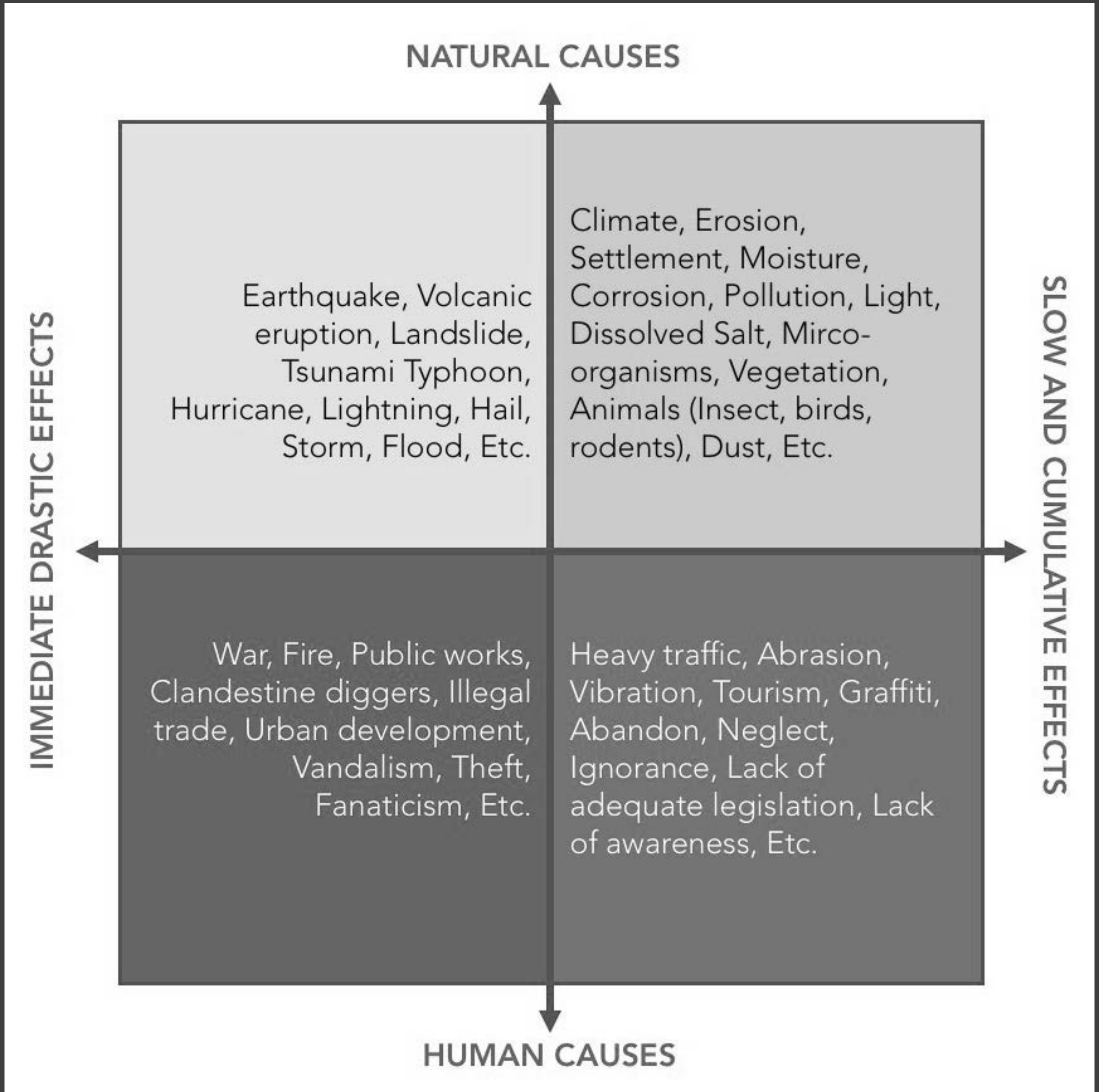
(Pavlova et al., 2017)



Results based on the GRPD and GVP datasets showed that 46% of WH sites could be potentially exposed to at least one out of the four selected geohazards. Out of these, 27% of all WH properties are potentially exposed to one geological hazard, 14% – to two and 5% to three geohazards (Pavlova et al., 2017).

Threats facing cultural heritage

(In this presentation focusing on Geo-Hazards)



(ICCROM, 2006, modified)

Why Heritage Sites Are Inherently Geologically Vulnerable

The deliberate intersection of cultural choice and geological risk

Location selection — rupestrian sites deliberately carved into soft-rock cliffs (UCS < 25 MPa): Bamiyan, Petra, Lalibela, Vardzia, Cappadocia — spiritual symbolism and defensibility at the cost of long-term stability

Artificial topography — tells and mounds (Erbil Citadel, Akapana, Bayannur, Kogurio) created non-natural stratigraphy with extreme heterogeneity; properties change over distances of metres

Age and cumulative deterioration — millennia of weathering, biological colonisation, seismic loading, and inappropriate human intervention irreversibly degrade original rock mass properties

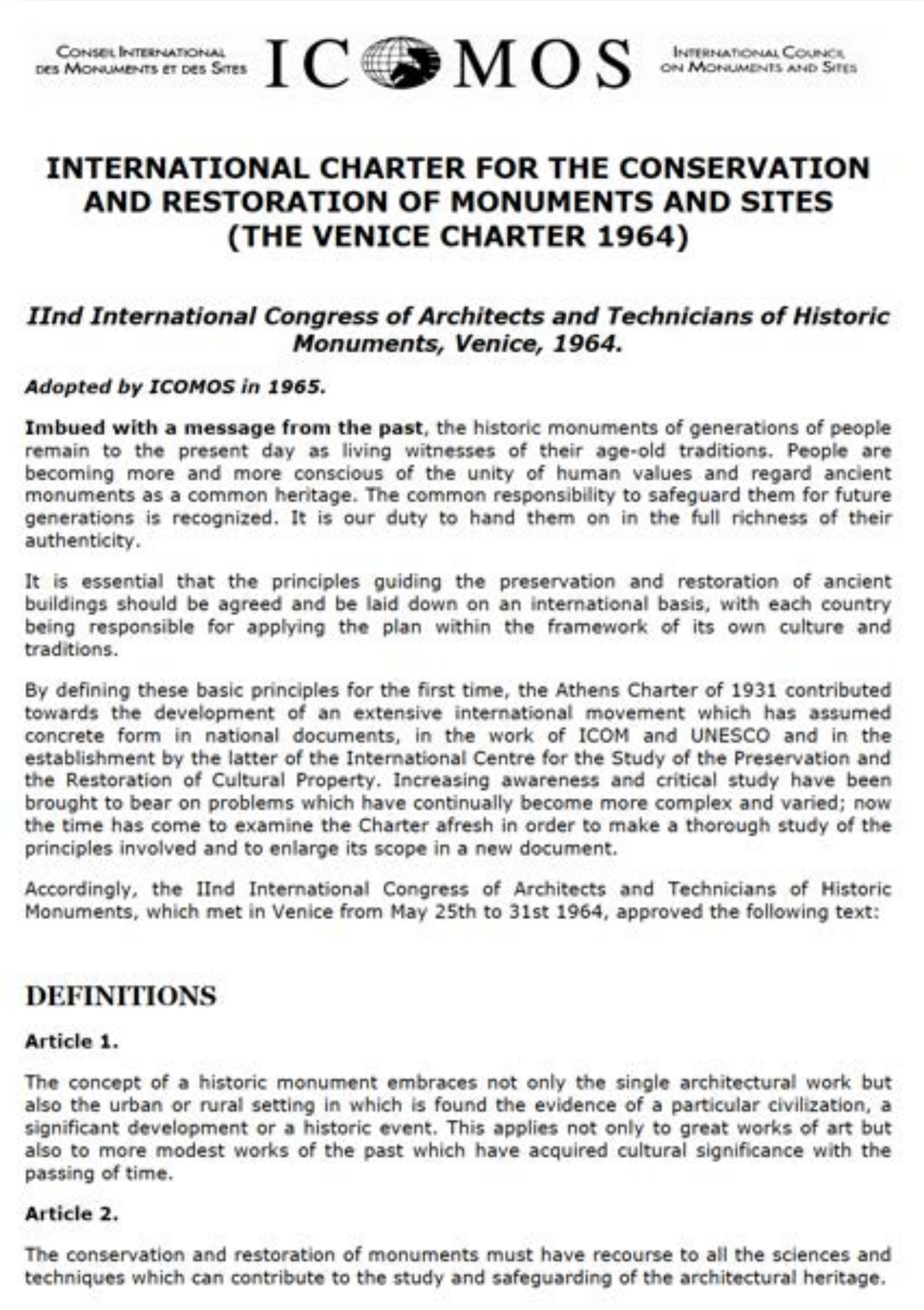
Previous incompatible interventions — legacy cement mortars, impermeable sealants, and drainage modifications have frequently accelerated deterioration: documented at Dambulla, Kogurio, Lumbini.

Absence of systematic monitoring — most sites lack baseline geotechnical data; deterioration trends undetected until visible damage is already advanced and costly to reverse

Logistical and access constraints — cliff edges, restricted archaeological zones, conflict zones, and remote locations preclude conventional investigation equipment: proxy geophysics is not an option but a necessity

Engineering geology for cultural heritage conservation

To support UNESCO World Heritage List



CONSEIL INTERNATIONAL DES MONUMENTS ET DES SITES ICOMOS INTERNATIONAL COUNCIL ON MONUMENTS AND SITES

INTERNATIONAL CHARTER FOR THE CONSERVATION AND RESTORATION OF MONUMENTS AND SITES (THE VENICE CHARTER 1964)

IInd International Congress of Architects and Technicians of Historic Monuments, Venice, 1964.

Adopted by ICOMOS in 1965.

Imbued with a message from the past, the historic monuments of generations of people remain to the present day as living witnesses of their age-old traditions. People are becoming more and more conscious of the unity of human values and regard ancient monuments as a common heritage. The common responsibility to safeguard them for future generations is recognized. It is our duty to hand them on in the full richness of their authenticity.

It is essential that the principles guiding the preservation and restoration of ancient buildings should be agreed and be laid down on an international basis, with each country being responsible for applying the plan within the framework of its own culture and traditions.

By defining these basic principles for the first time, the Athens Charter of 1931 contributed towards the development of an extensive international movement which has assumed concrete form in national documents, in the work of ICOM and UNESCO and in the establishment by the latter of the International Centre for the Study of the Preservation and the Restoration of Cultural Property. Increasing awareness and critical study have been brought to bear on problems which have continually become more complex and varied; now the time has come to examine the Charter afresh in order to make a thorough study of the principles involved and to enlarge its scope in a new document.

Accordingly, the IInd International Congress of Architects and Technicians of Historic Monuments, which met in Venice from May 25th to 31st 1964, approved the following text:

DEFINITIONS

Article 1.

The concept of a historic monument embraces not only the single architectural work but also the urban or rural setting in which is found the evidence of a particular civilization, a significant development or a historic event. This applies not only to great works of art but also to more modest works of the past which have acquired cultural significance with the passing of time.

Article 2.

The conservation and restoration of monuments must have recourse to all the sciences and techniques which can contribute to the study and safeguarding of the architectural heritage.

Five major principles sum up the Charter:

The concept of historic buildings - this concept has been extended as regards both isolated buildings and groups of buildings.

Conservation - in order to secure the conservation of a building, its use is actually necessary, but no change of lay-out or decorationi should be permitted. The surroundings should be protected. No transfer should be allowed nor any removal of ornaments (except in case of emergency).

Restoration - will be undertaken only when necessary. No reconstruction should be admitted; the structure and authenticity of materials must be respected. Any new element should be distinguishable. Whenever traditional techniques prove to be inadequate recourse may be made to modem but well-tried techniques.
Elements of value of any period should be respected.
Falsification in replacing missing parts is to be ruled out.

Archaeology -Excavation should be carried out only by specialists. Rehabilitation of archeological sites should not alter the buildings to enhance understanding.

Documentation and publication -any action taken should be accompanied by a report to be deposited with the public archives.
Publication is recommended.

02

Engineering Geology, Geohazards and Cultural Heritages

Rapid-onset catastrophic events to slow weathering and deterioration

Rocky cliff instabilities

Rapid onset

Falls and cave collapses in the monastery of David Garenji (Georgia)

Falls and tombs collapses in the Nabatean site of Petra - Jordan

Falls and tombs collapses in the Nabatean site of AlUla – Kingdom of Saudi Arabia

Coastal erosion

Rapid onset

Tipaza, Algeria

Tharros, Italia

Earthquake Phenomena

Rapid onset

IRAN, Bam
26 December 2003 - IRAN

NEPAL Katmandu
Durbar Square 25th April 2015

Landslides in soil material

Slow onset

Earth slide deforming the andenas of Machu Picchu - Peru

Likely earthquake-induced landslide in Bardzrakash, Armenia

Soil **Erosion**

Slow onset

Erbil, Kuridstan, Iraq

Bearing Capacity

Slow onset

Afghanistan, Herat

Afghanistan, Jam

Weathering

Processes

Slow onset

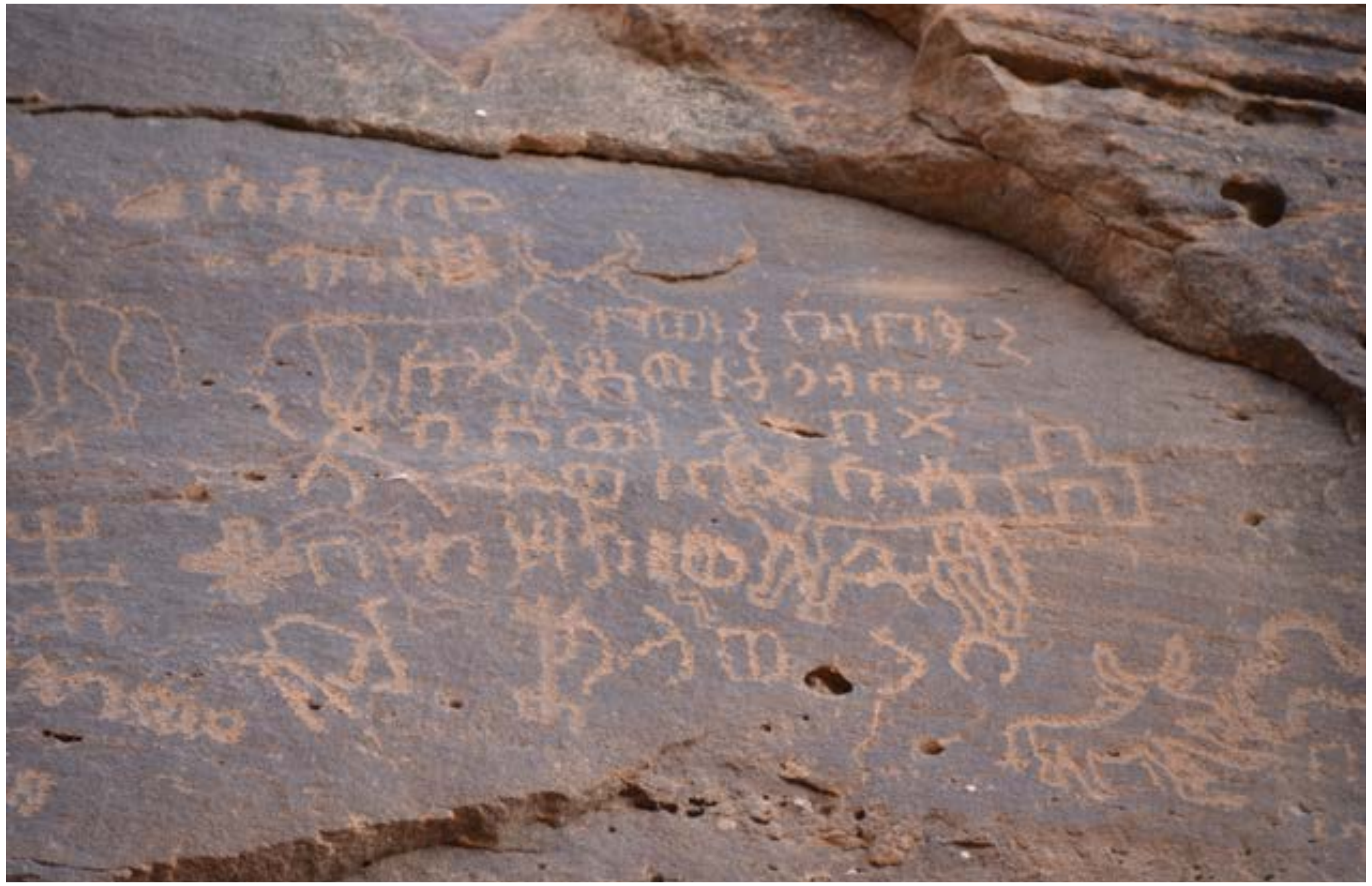
Ethiopia, Lalibela

Jordan, Petra

Kingdom of Saudi Arabia, AlUla

Surface
erosion

Slow onset



Abu Od, Al Ula, Saudi Arabia

Uplitsike, Georgia

Structural
Stability

Slow onset

Mongolia, Bayannuur

Italy, Pompei

Tunisia. Bulla Regia

Flood Event

Rapid onset

Foto © G. Boccardi

Water and Monuments

Slow onset

Cambodja (Angkor Watt)

Floods, heavy rainfall (occasionally)

Water table (Permanently, seasonally, ephemeral)

Nepal (Lumbini)

Jordan (Petra)

Rising damp, capillarity

Seepage (seasonally)

Condensation (moisture)

(occasionally)

Rome (Italy)

War

Afghanistan, Bamiyan

03

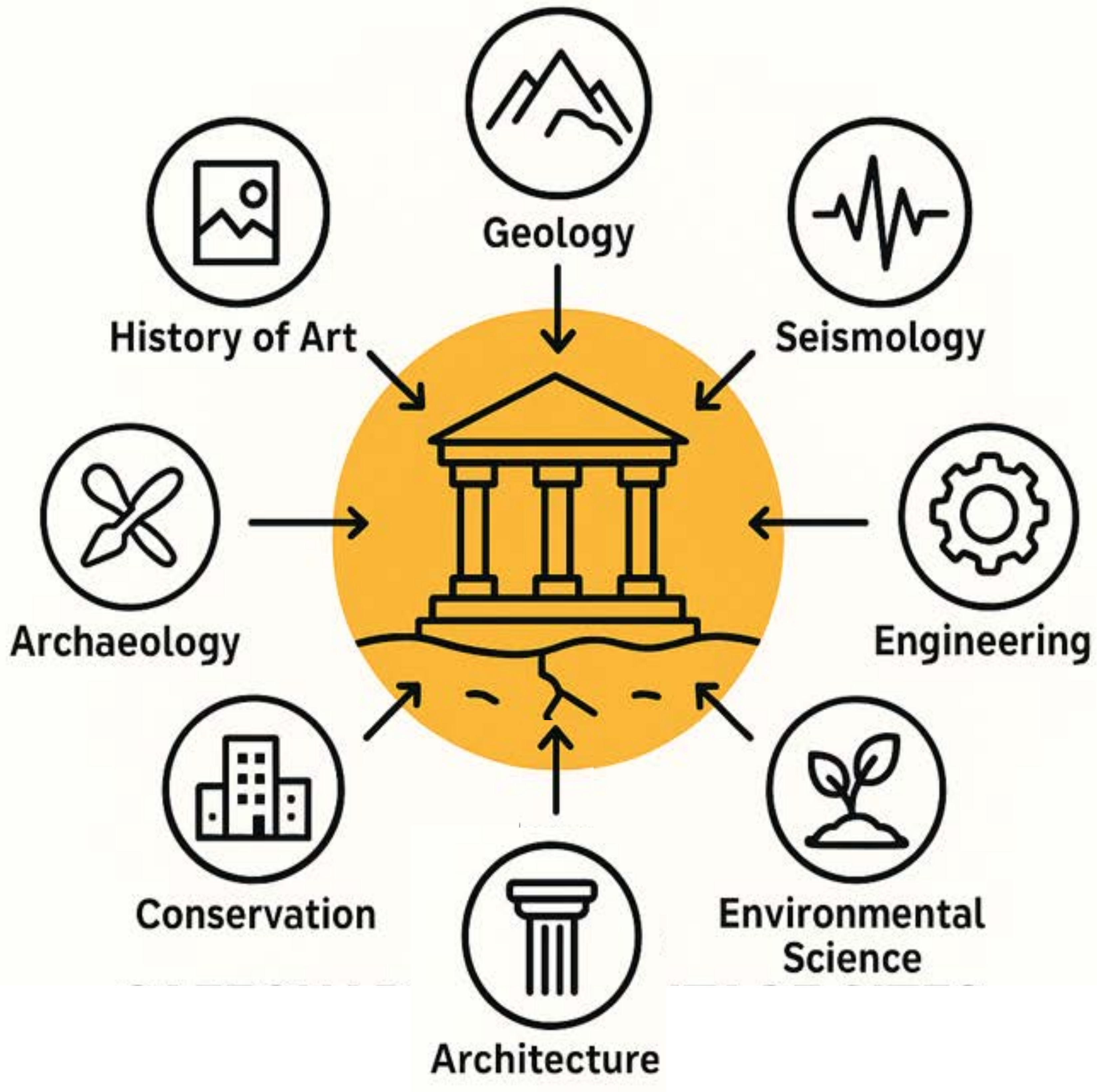
The proactive geoscience framework

From reactive emergency response to
anticipatory conservation

Reactive vs. Proactive A Paradigm Shift

REACTIVE APPROACH (conventional)	PROACTIVE APPROACH (new)
Intervene only after visible deterioration or structural failure has occurred	Characterise hazard processes before deterioration becomes critical or irreversible
Emergency decisions with incomplete geotechnical understanding of failure mechanisms	Build a 3D Engineering Geological Model as the scientific foundation for ALL interventions
Incompatible materials applied without process diagnosis	Non-invasive, low-impact investigation as the first choice — intrusive only where geophysical proxies are insufficient
Investigation limited to the immediate crisis zone; adjacent areas ignored	Iterative model refinement: field → model → investigation → updated model → intervention → monitoring
Post-conflict emergency: Bamiyan 2001 required immediate response with no prior geotechnical baseline	Monitoring as a permanent operational tool, not a one-off survey
Knowledge gaps persist; deterioration resumes after intervention; cycle repeats	Sustainable, reversible interventions compatible with Outstanding Universal Value and local traditional knowledge

Safeguarding Heritge Sites against geo-hazards

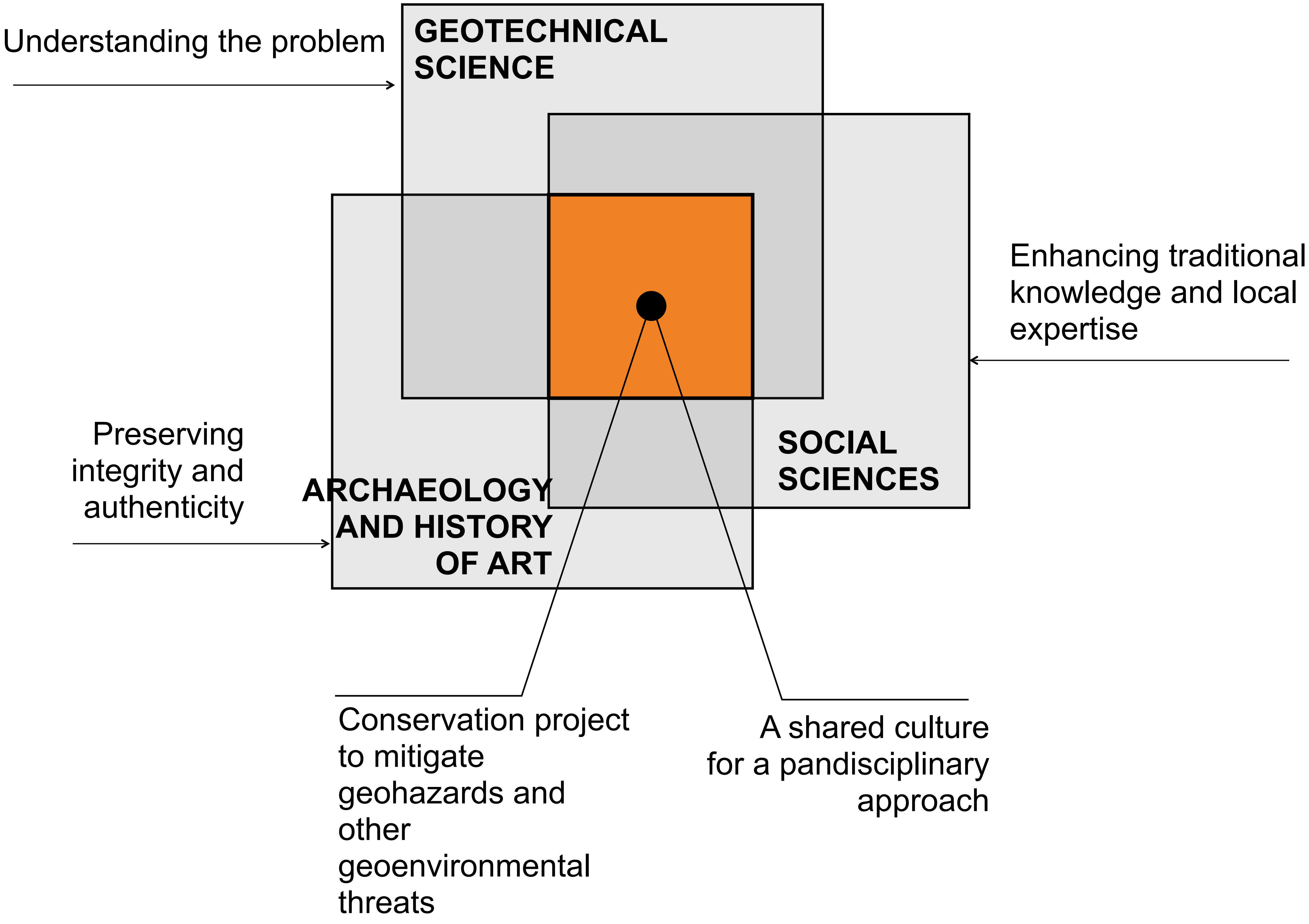


The diagram illustrates the interdisciplinary collaboration required to safeguard heritage sites from geo-hazards. At the center stands a symbolic monument representing cultural heritage, surrounded by key contributing disciplines—**geology, seismology, engineering, environmental science, urban planning, architecture, conservation, archaeology, and history of art**. Each discipline contributes specific expertise, from understanding geological risks and structural stability to preserving artistic integrity and historical authenticity, ensuring a holistic and sustainable approach to heritage protection.

The contribution of each discipline is site depending.

Engineering Geology for Cultural Heritages Conservation

A new discipline?

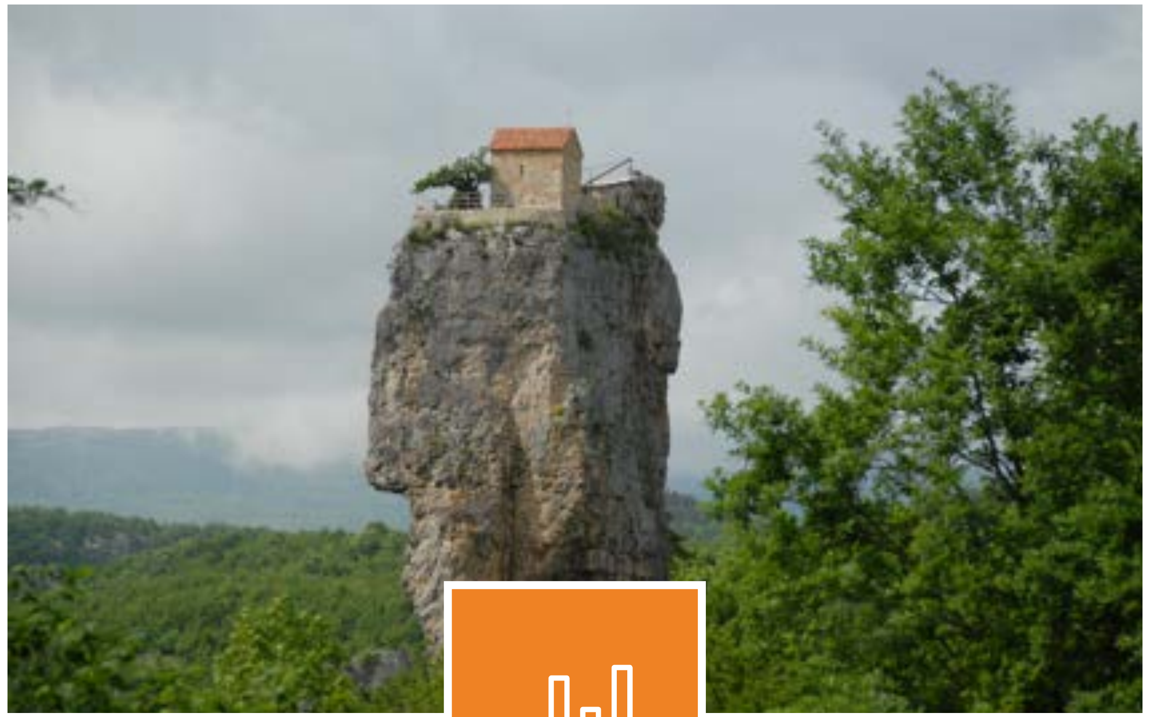


04

Case studies

UNESCO and other heritage sites – 4 continents – more than 30 years of personal field work

The contribution of **Geomorphology**



Landform Analysis

Study of rnountains, valleys, plains, and coastal features that influence heritage site fornation and preservation

Process Understanding

Erosion, weathering, sedirnentation, and other processes that affect heritage sites over time

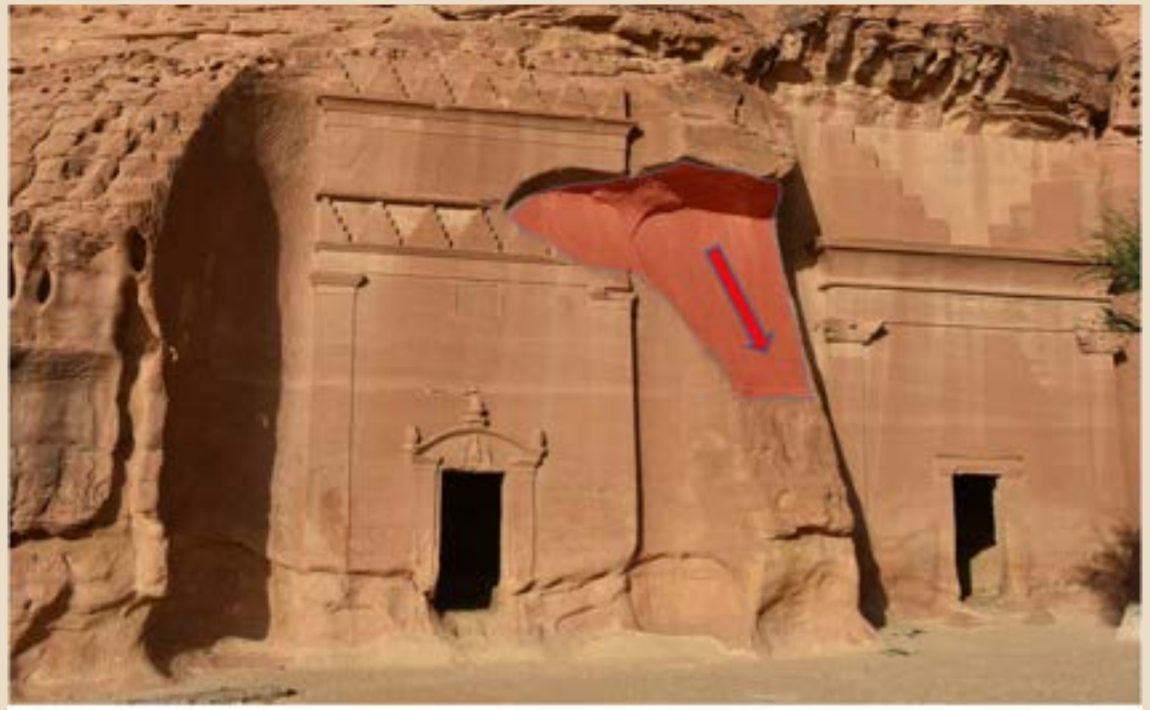
Temporal Perspective

Understanding landscape evolution from geological to human tirnescales tor heritage context

Hegra 131 Nabatean tombs

KSA

Hegra Major threats



Rock-fall and slide

Rock fall of large block (overhanging portion) on a left side and planar sliding on the right side.

Planar sliding

Fall

Example of overhanging and unstable block collapsed

INSTABILITY PROCESSES (FROM SMALL TO MEDIUM TO LARGE DIMENSIONS) AFFECTING BOTH THE ROCK FACADE AND SLOPES IN WHICH THE TOMBS ARE CARVED

Hegra Major threats

Tomb facade partially collapsed

Roof collapse

Roof collapse inside the Jabal Idilib and Al Diwan complex

Façade deterioration

Fractures and weathering processes affecting the tombs facade

INSTABILITY PROCESSES (FROM VERY SMALL TO MEDIUM DIMENSIONS) AFFECTING DIRECTLY THE ARCHITECTONIC STRUCTURE OF THE TOMBS

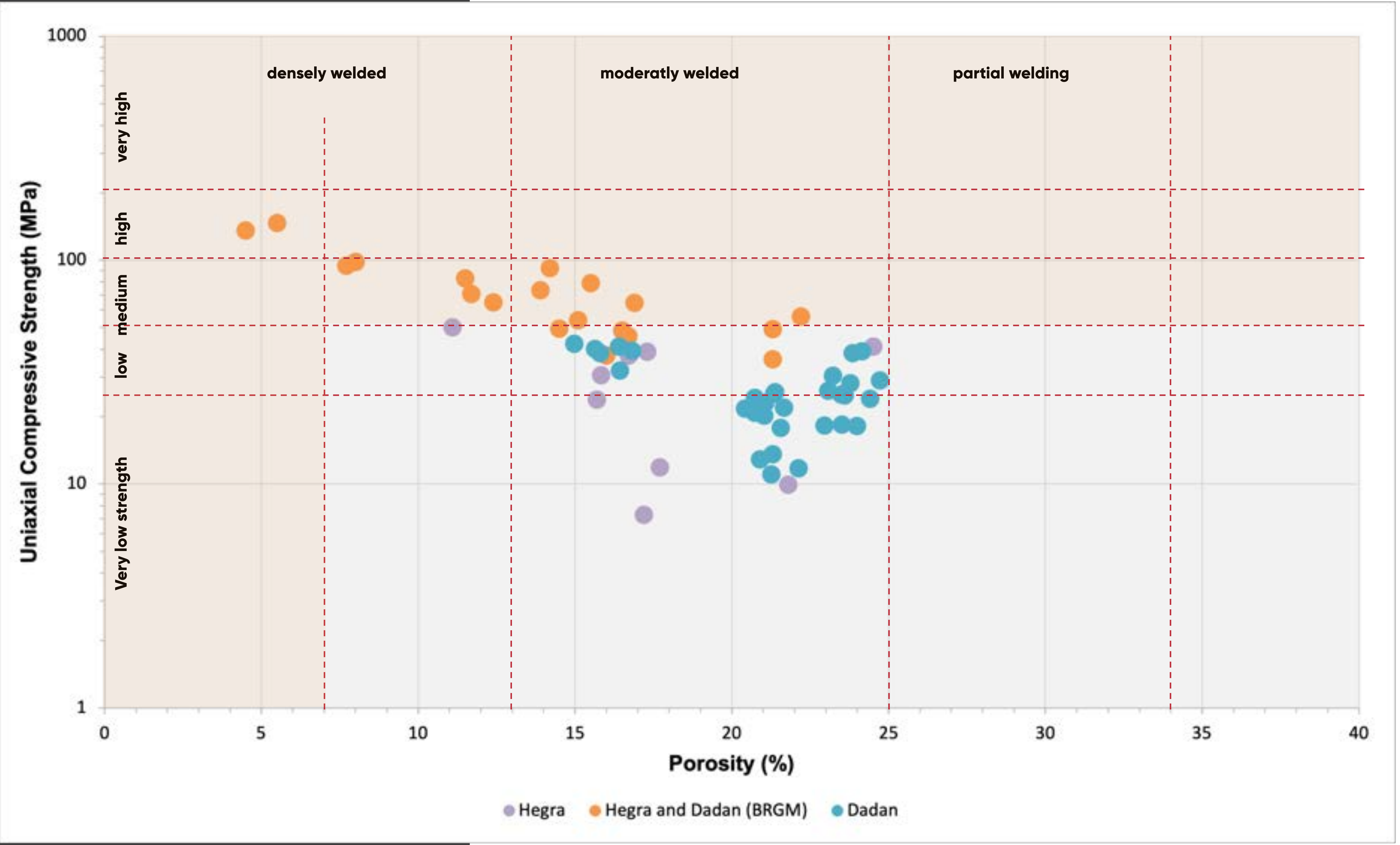
Hegra Major threats

Example of erodible base layer

Example of erodible base layer

Surface erosion of Quweira sandstone

WEATHERING AND EROSION PROCESSES (FROM SMALL TO LARGE SCALE) AFFECTING BOTH THE SLOPE FACADE AND TOMBS

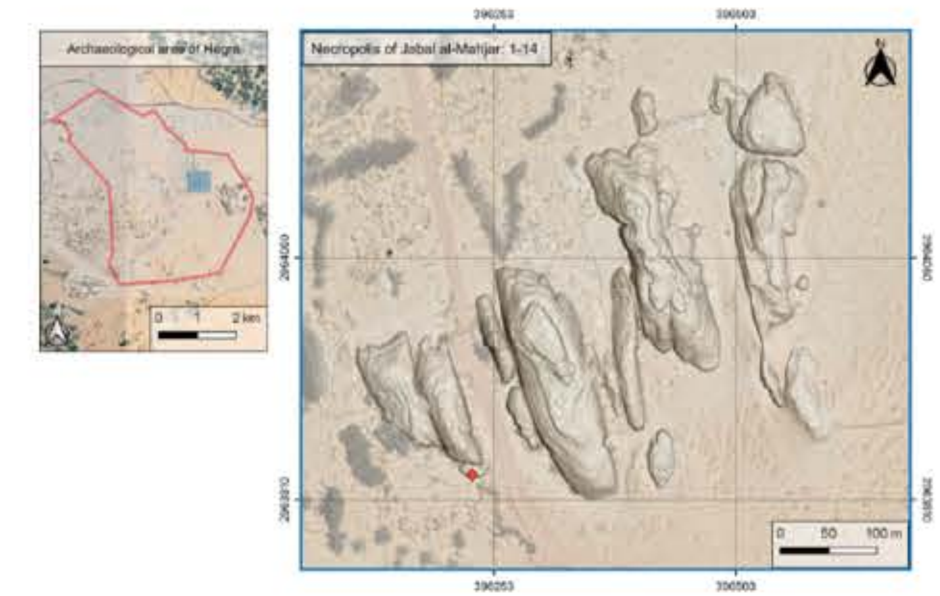


Characterization of materials

Porosity versus UCS plot data from authors investigations and BRGM (2019). A classification of strength (Deere and Miller, 1966) and welding (Quane and Russell, 2005) are reported for reference.

Hegra Atlas (131 tombs)

TOMB 1 - Necropolis of Jabal al-Mahjar



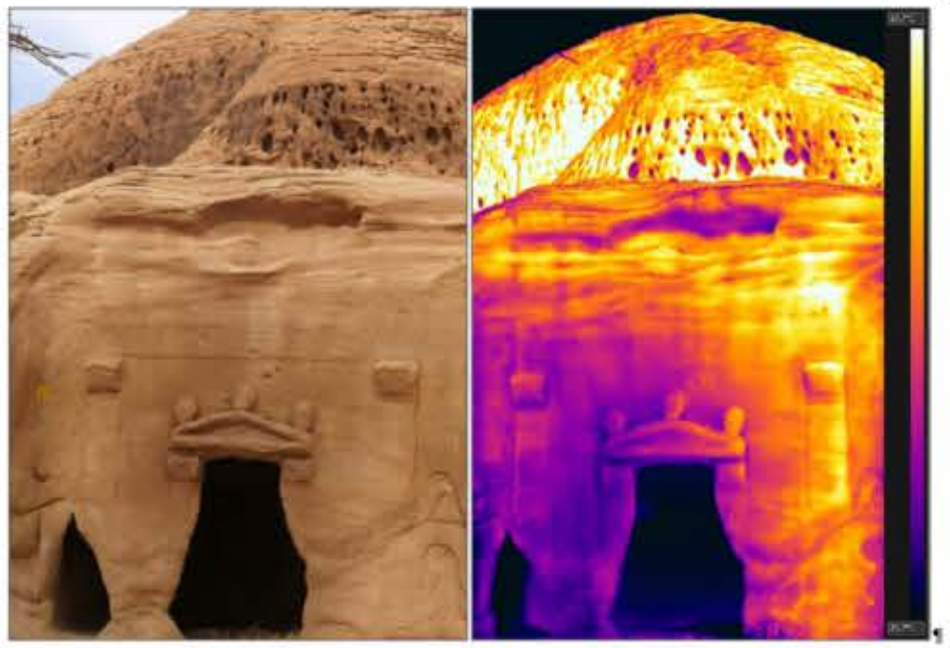


Fig 1: Photo entrance tomb 1 and correspondent mosaiked thermogram

ID TOMB: 01

State of conservation from visual inspection: Very low

Geomorphological Phenomena: Centimetre exfoliation of the ceiling and erosion of the pillars; deep basal erosion.

Possible monitoring: Terrestrial laser scanner acquisition (documentary purpose); visual annual inspection (left pillars thinning monitoring).

Potential evolution or risk: instability of the lateral portions of the tomb both right and left; potential collapse of the pillars.

Notes: future temporary supports must be provided to avoid the collapse of the left facing.

Tomb height (m): 4.5

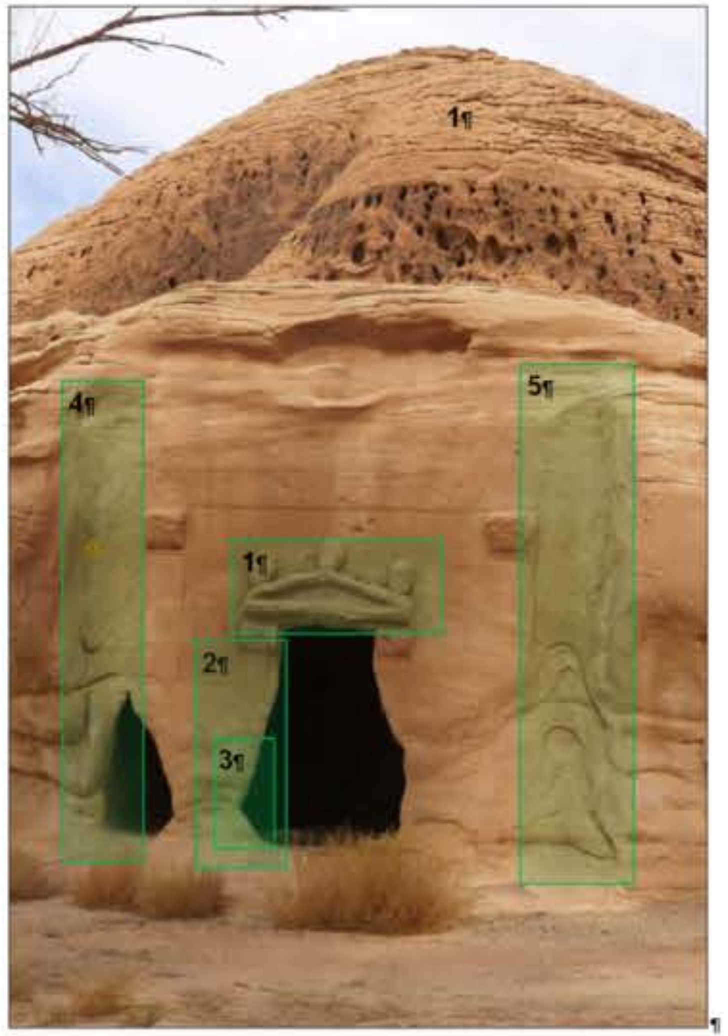


Fig 2: Photo entrance tomb and details of geomorphological phenomena

Fig 3: Details of geomorphological phenomena: Centimetre exfoliation of the ceiling and erosion of the pillars; deep basal erosion

ID Tomb	Sector	Coordinates	Slope face	JCS	JRC
1	Jabal al-Mahjar	396241.2 2963833.4	160°/90°		

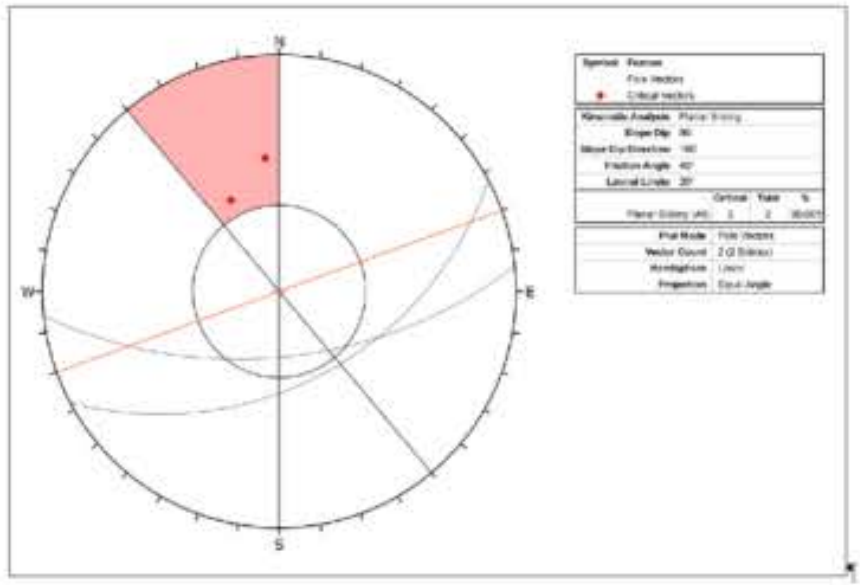
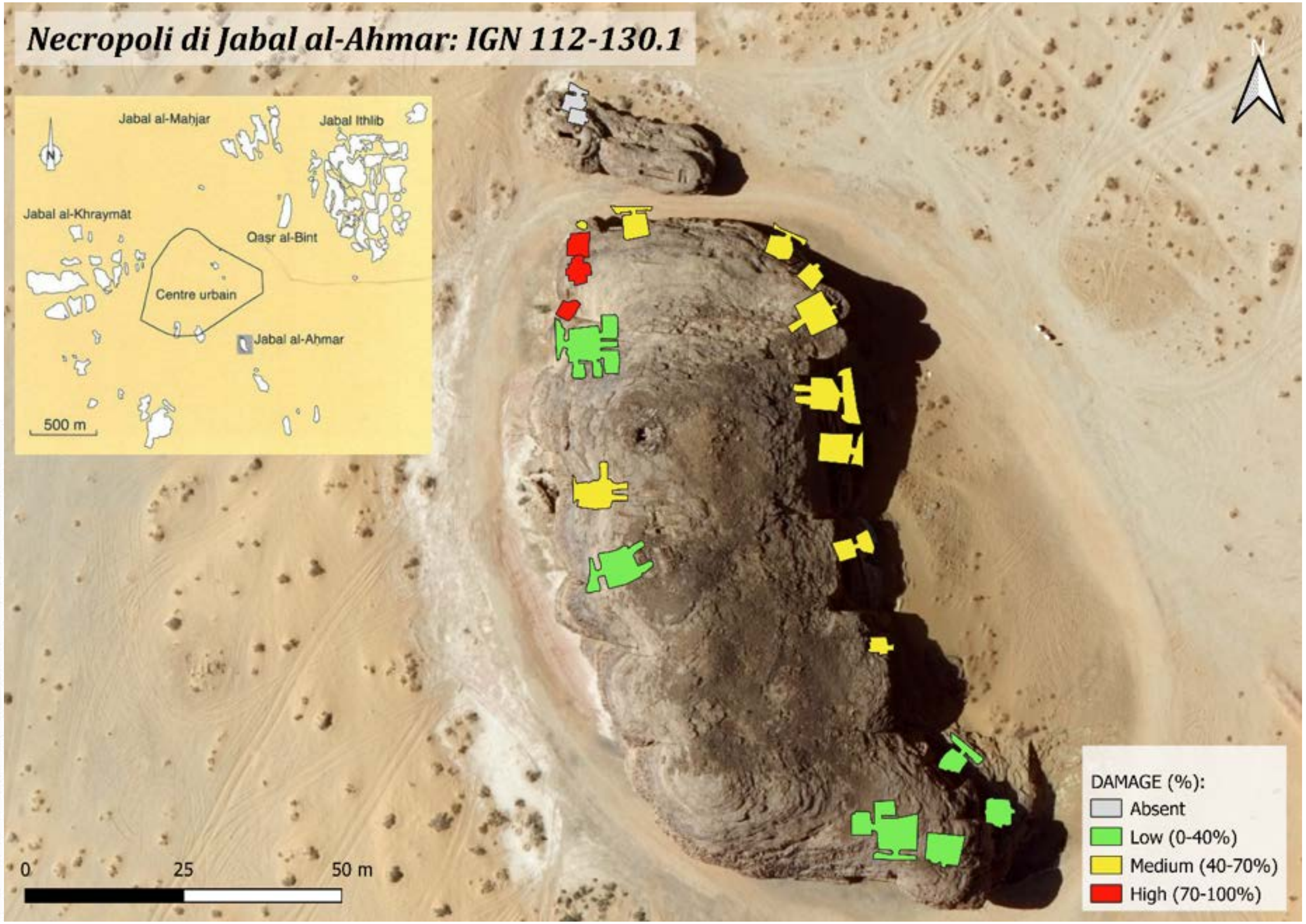


Table 1 - Geomechanical data and informations of Tomb

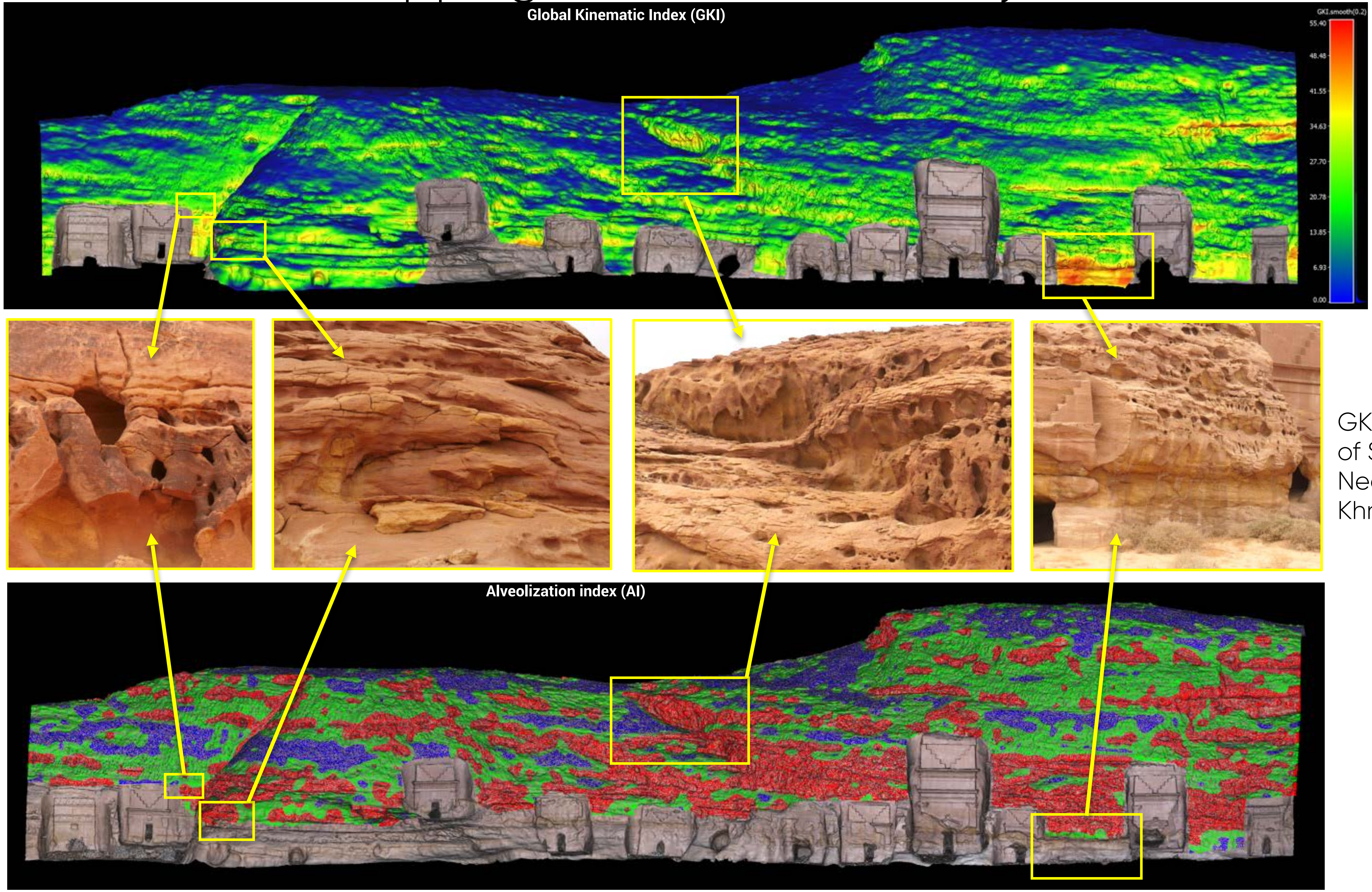
Necropolis of **Jabal al-Ahmar**

ID tomb	State of conservation	Geom. Phenomena	Damage	Geology	Groundwater	Kinematic analysis	Slope face	Possible monitoring	Potential evolution or risk	notes	estimated tomb height (m)
112	75%	E(b), I	L	Q	N	2	190/87	VI	Ev(l,u)	Cl(u), Di	10
113	75%	E(b), K	L	Q	N	1	185/85	VI	EvK(i)	NR	10
114	75%	S(u)	L	Q	N	1	78/85	VI	EvK(e,u)	Cl(u), Di	7
115	75%	S(u)	L	Q	N	1	40/88	VI	EvI, Co	NR, Co(e,l)	7
116	50%	O(u)	M	Q	N	2	92/70	VI	EvI(u)	Im(a)	2
116,1	50%	S(u)	M	Ab	Ab	0	65/89	VI	Ev(u)	Im(a)	4
117	50%	S(u)	M	Q	N	2	102/90	VI	Ex(i), Ck(fa)	NR	5
118	50%	S(u), K(fa), De(i)	M	Q	N	0	260/90	VI	EvI(l), K(c)	Pr	8
119	50%	E(b),In(fa)	M	Q	N	0	66/90	VI	C(u)	Di	8
120	50%	E(b), In (fa)	M	Q	N	0	56/90	VI	In	Di	7
121	50%	E(b)	M	Q	N	0	30/85	VI	EvI(l), Rf(u)	Im(a)	6
122	50%	E(b)	M	Q	N	0	175/85	VI	EVI(l), Rf(u)	NR	7
123	25-50%	C	M	Q	N	0	284/90	VI	EvC(l,i)	Ua	2
124	20%	C, I(u)	H	Q	N	1	285/90	VI	C(r)	Su, Co	3
125	20%	I, O(f)	H	Q	N	0	285/90	VI	C(f)	Di	2
126	20%	E(fa), C(r)	H	Q	N	0	285/90	VI	C(r)	Su	3
127	75%	K, In	L	Q	N	0	276/90	VI	K	Ks, Im(a)	6
128	25-50%	C, E(b), K(a)	M	Q	N	3	265/90	VI	C(a), I(l), Rs, Rf(u)	Su, Di	7
129	75%	E(b), I(l), O(u), De(ev)	L	Q	N	2	253/90	VI	F	Di	7
130	Ab	Ab	Ab	Q	N	Ab	Ab	Ab	Ab	Ab	Ab



Cavernous weathering (alveolization)

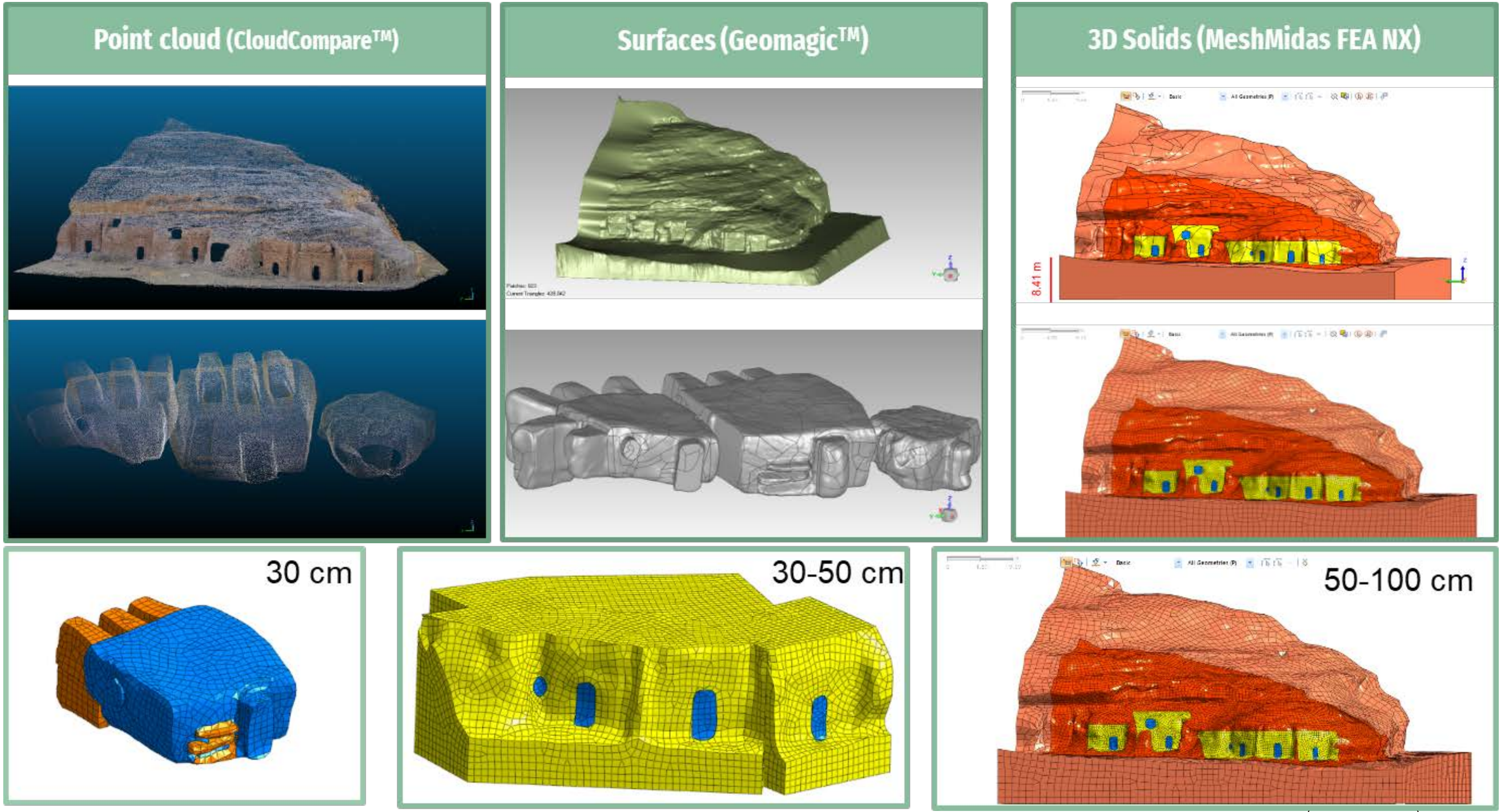
automatic mapping, 3D Kinematic analysis, and evolution



GKI applied to Rock masses of Sector II Necropolis of Jabal al-Khraymāt)

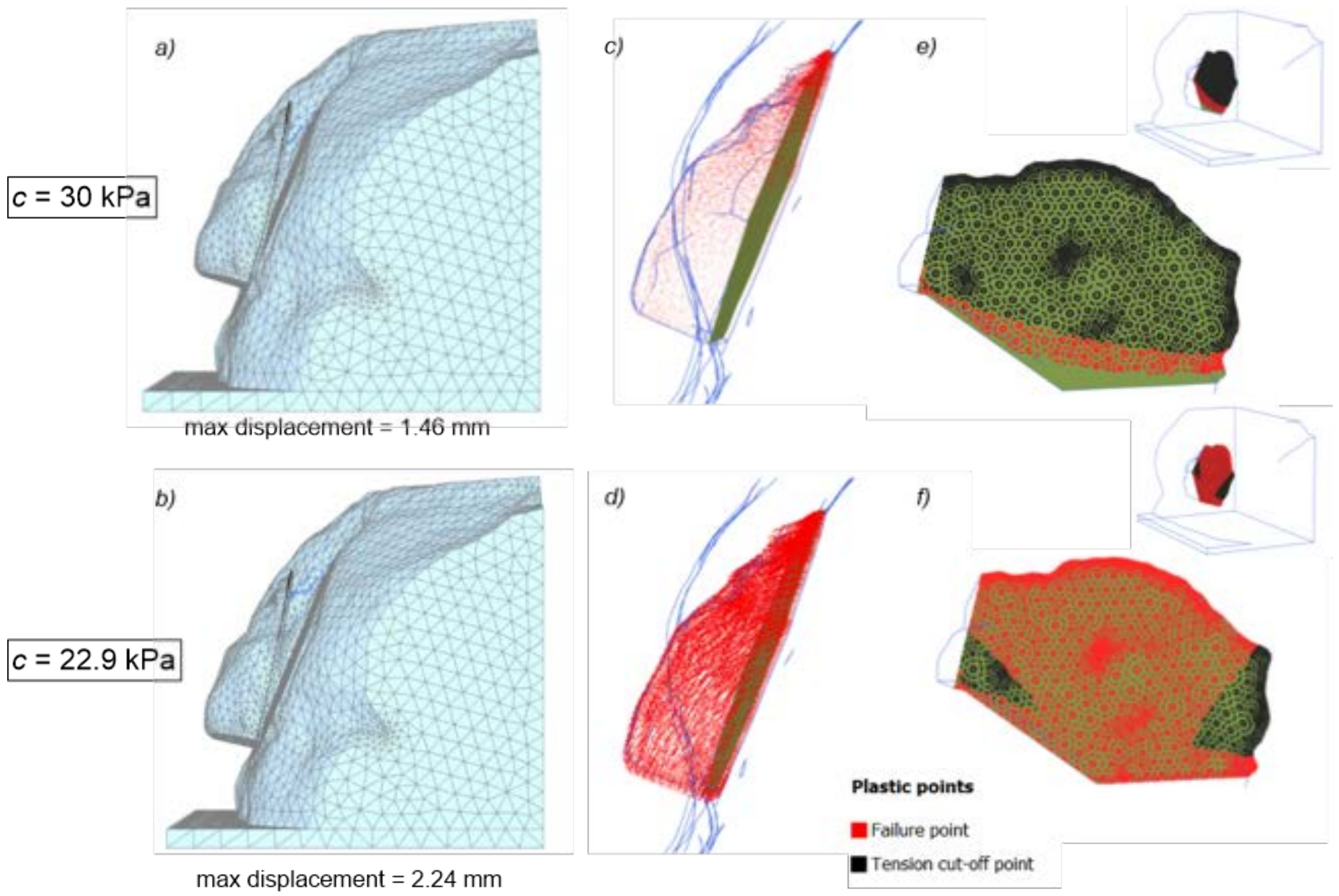
Beni et al., 2025)

Finite element analisys

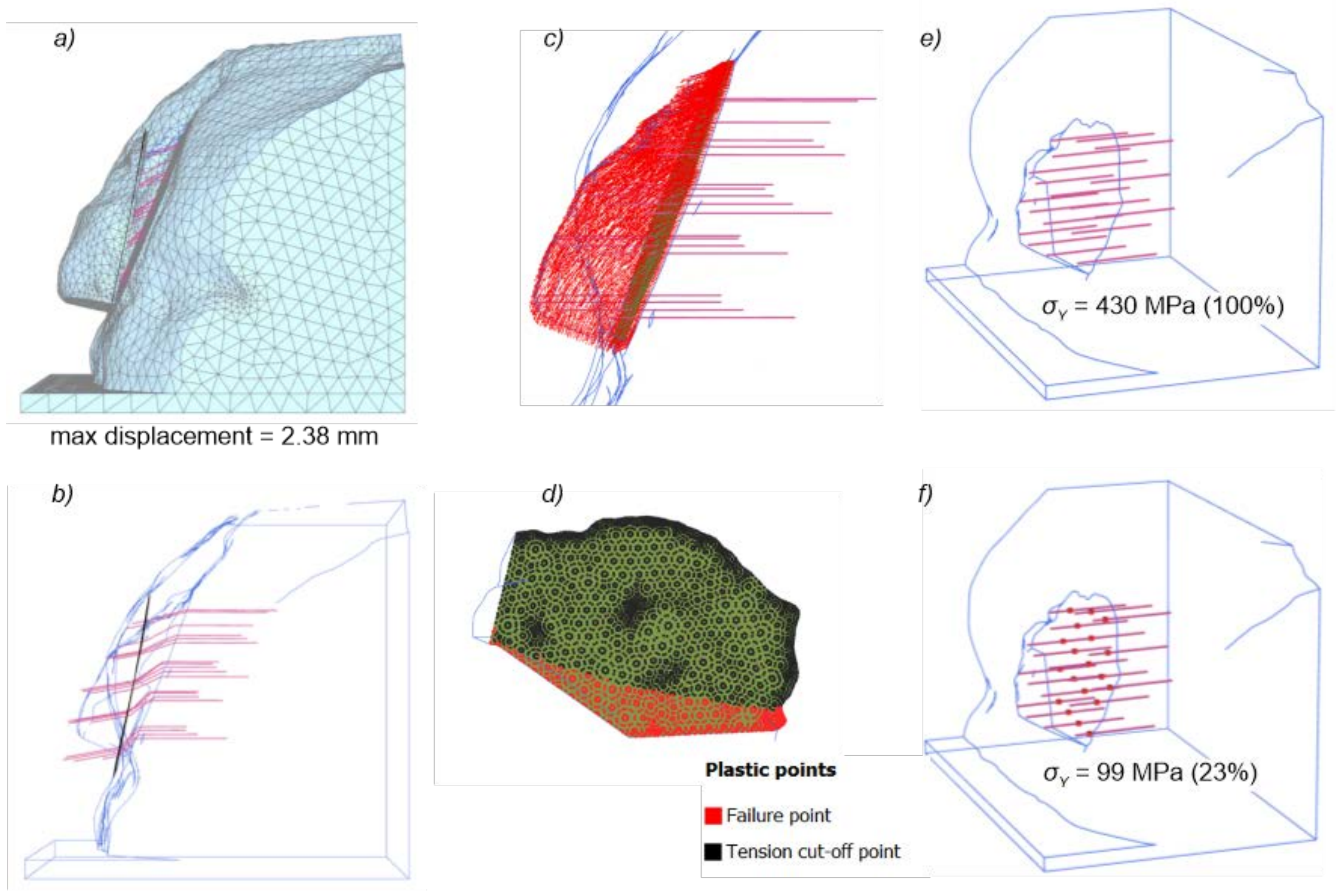


Frattini et al. (in printing)

From 3D geotechnical model to mitigation design

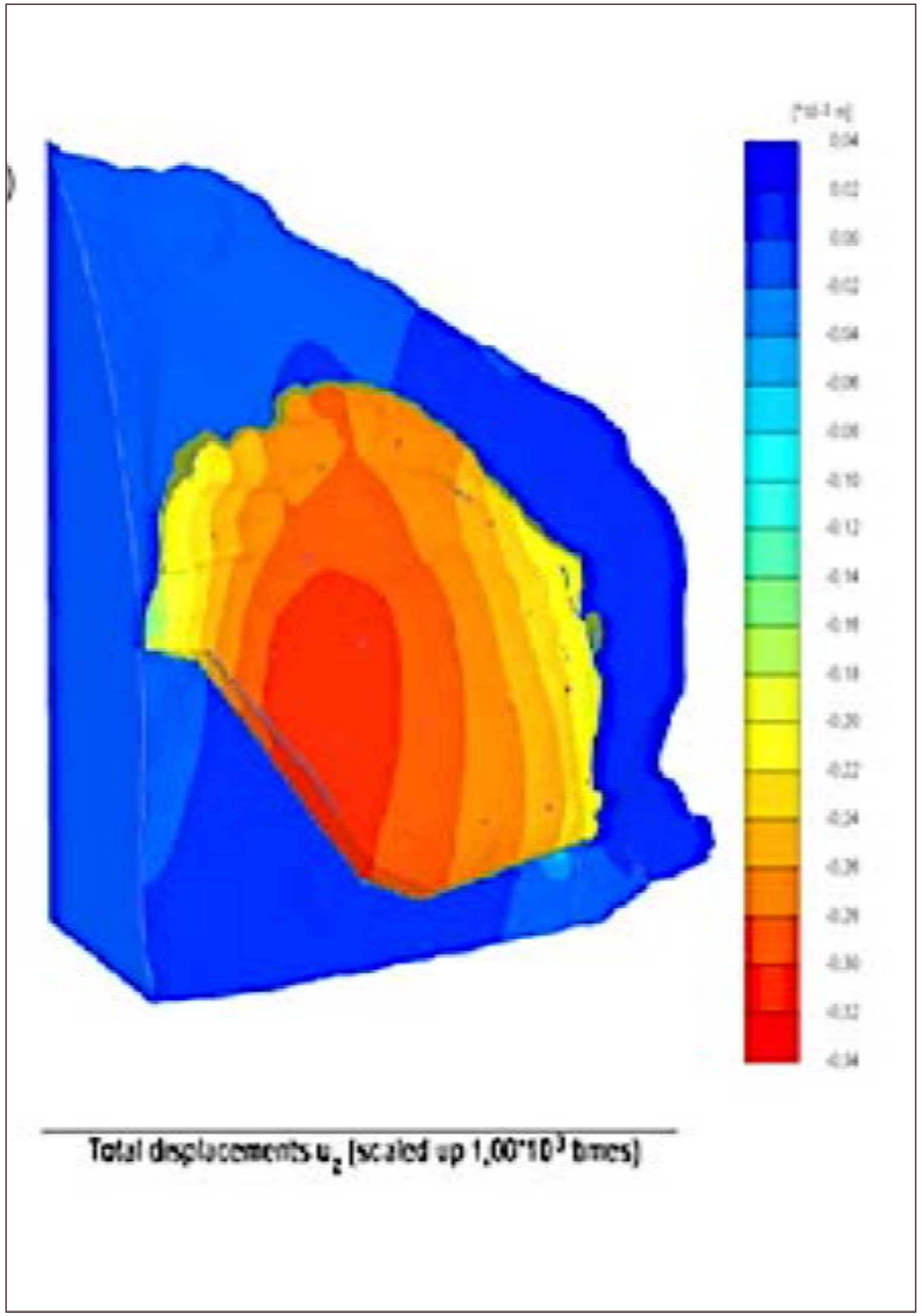


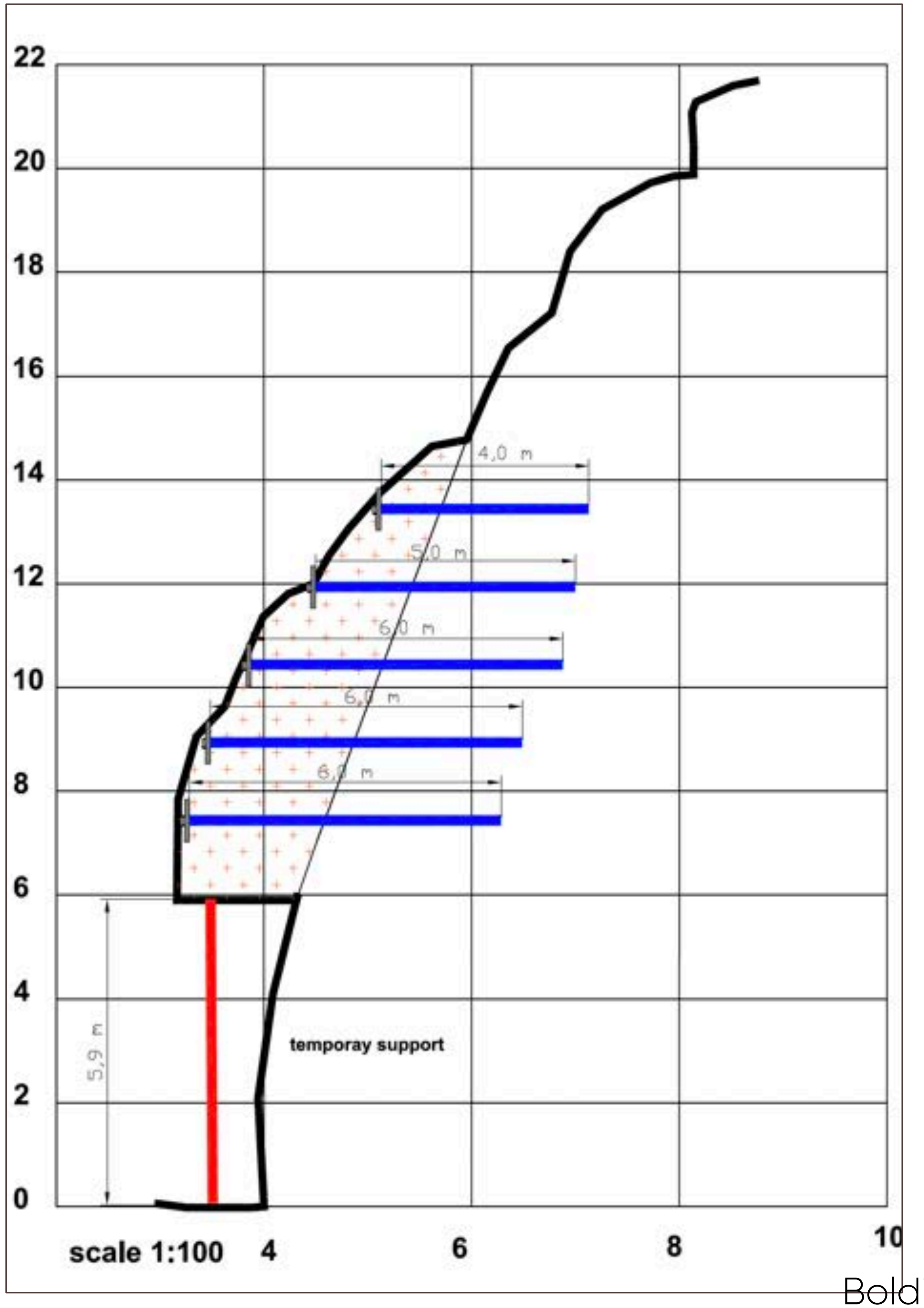
Deformed mesh (× 1000) (a, b); total displacements (× 200) (c, d); plastic points (e, f) for a cohesion of 30 kPa and 22.9 kPa along the joint, respectively



Deformed mesh (× 1000) (a); deformed dowels (× 1000) (b); total displacements (× 200) (c); plastic points along the joint surface (d); plastic points in the dowels for the nominal yield stress (e); and the reduced at 23% of the nominal value (f).

From 3D geotechnical model to mitigation design





Boldini et al., 2026)

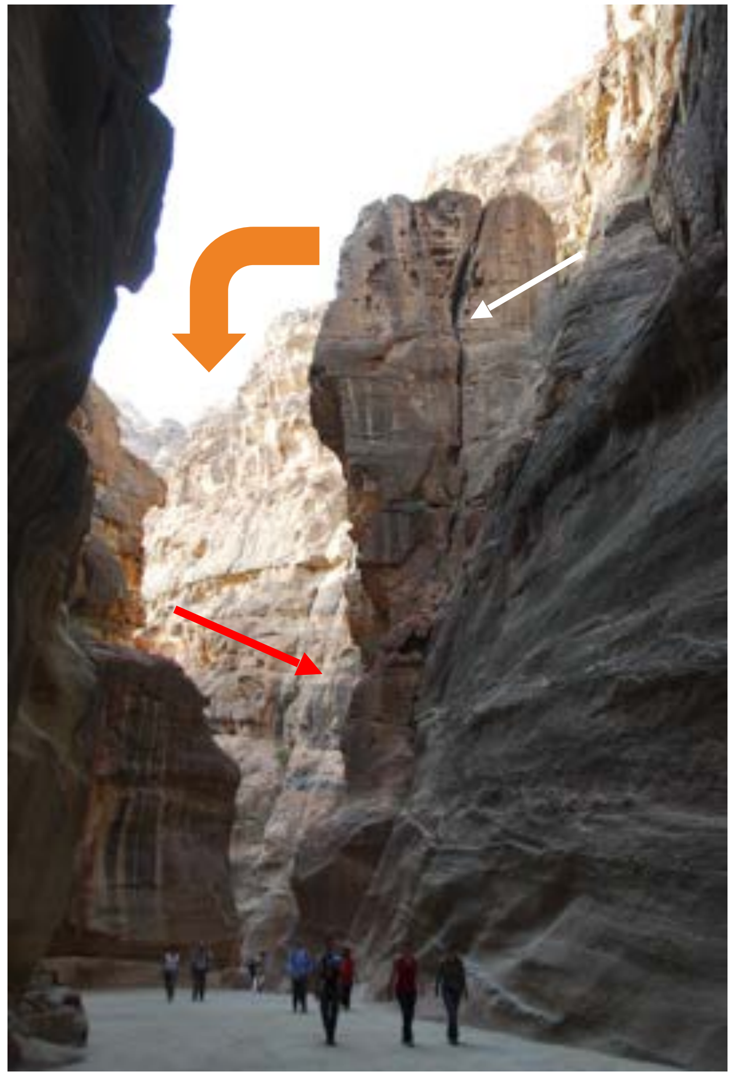
Petra rockfall, flash flood, weathering

Jordan

PETRA (JORDAN)

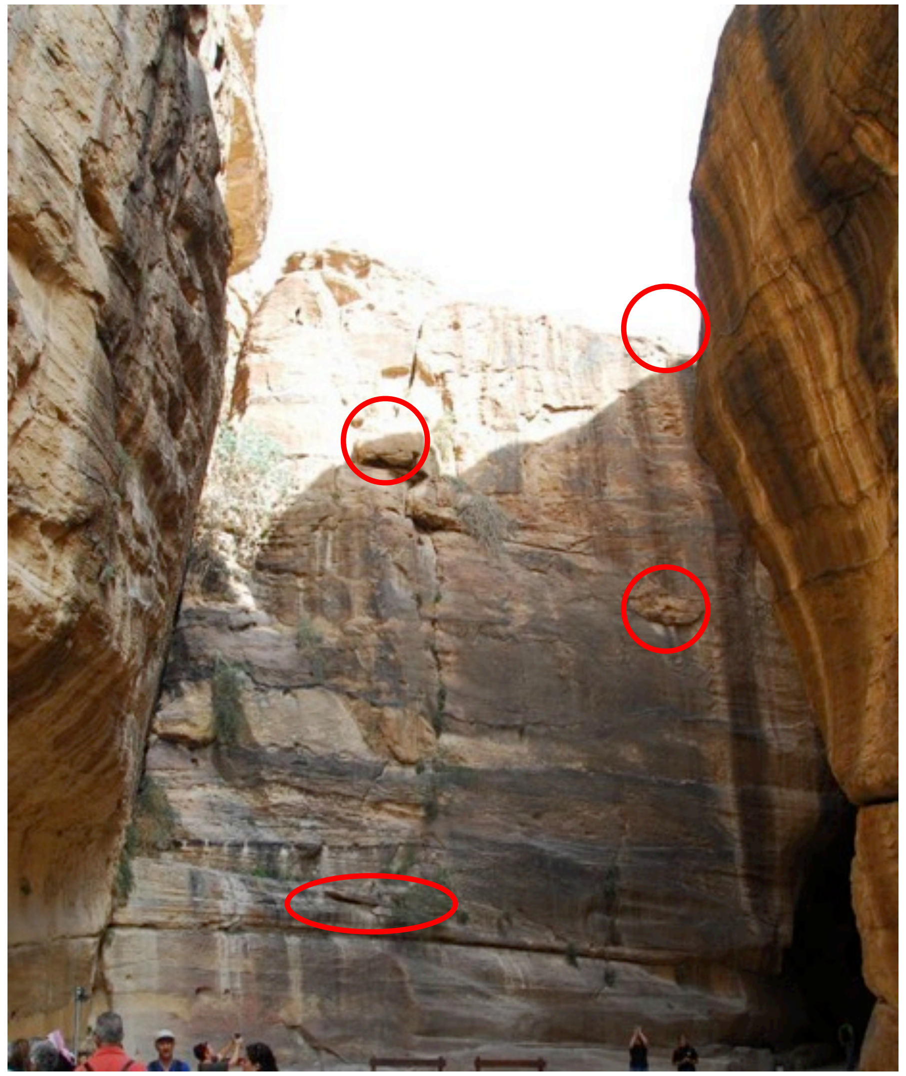
Carved directly into red, white, pink, and sandstone cliff faces, the prehistoric Jordanian city of Petra was "lost" to the Western world for hundreds of years. Located amid rugged desert canyons and mountains in what is now the southwestern corner of the Hashemite Kingdom of Jordan, Petra was once a thriving trading center and the capital of the Nabataean empire between 400 B.C. and A.D. 106. In 1985, the Petra Archaeological Park was, and in 2007 it was named one of the new seven wonders of the world.

The problem: rock falls/slides, magnitudes and examples



Large blocks volumes
(volumes > 15m^3)

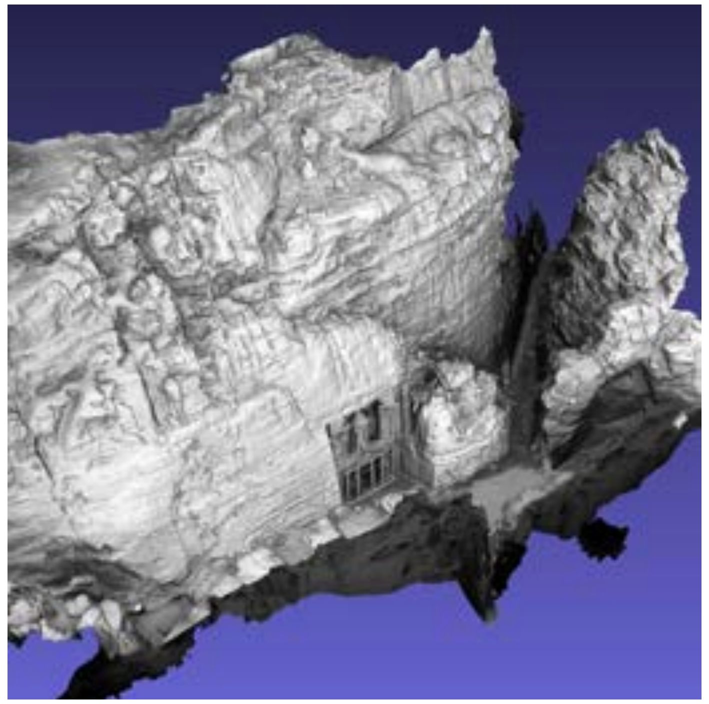
Medium blocks volumes
(volumes 5m^3÷15m^3)

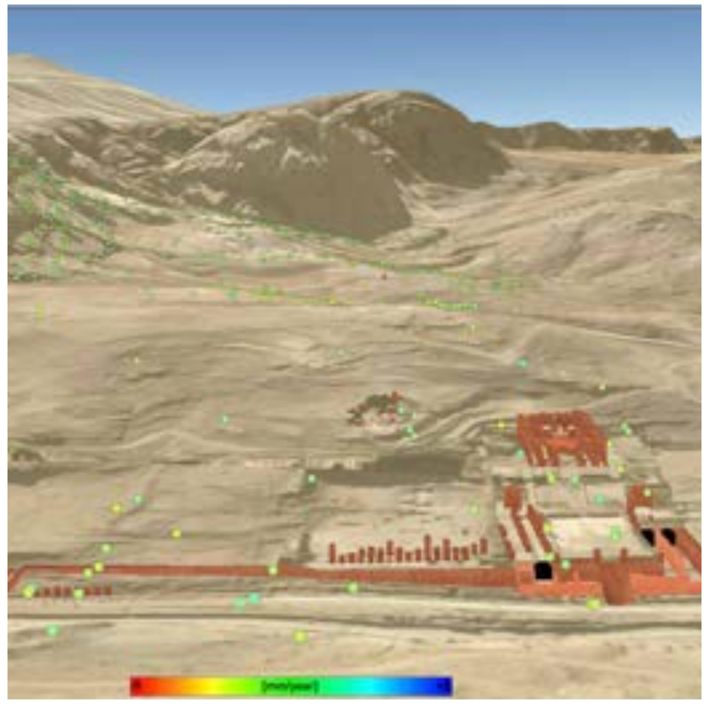


Small blocks volumes
(volumes < 5m^3)

Petra rockfall

Jordan





Preparation

Collapse of Muesra Tomb

Investigation

Geomatic, geological, geomorphological and geotechnical surveys. Identifying threats.

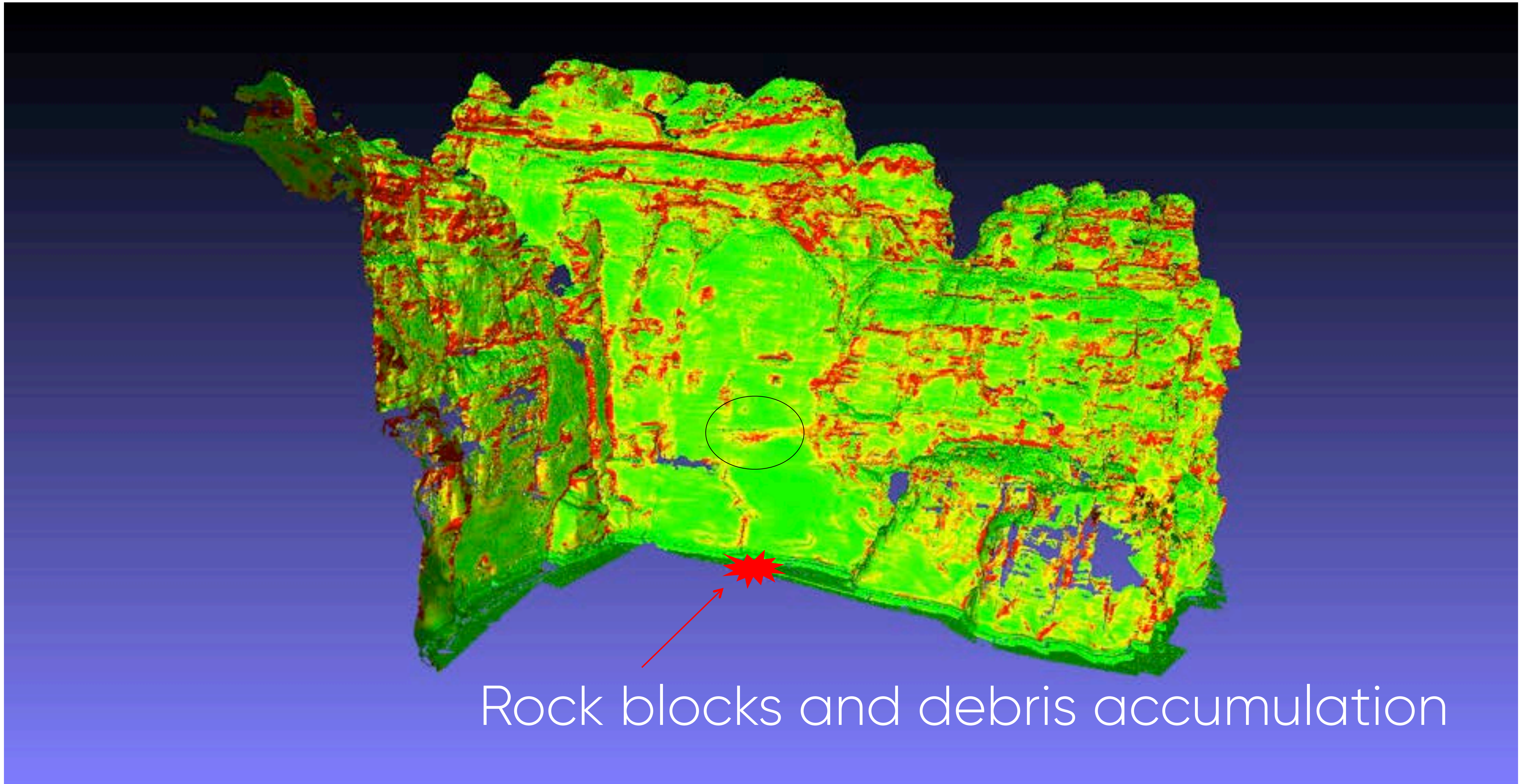
Monitoring

Integrated monitoring system, Geotechnical monitoring is settled in W-Fi in the site. Geomatic monitoring in reflectorless modality. PS from satellite radar interferometry.

Conservation

Cleaning the site- Draining the water. Fixing unstable blocks. A Guideline has been provided.

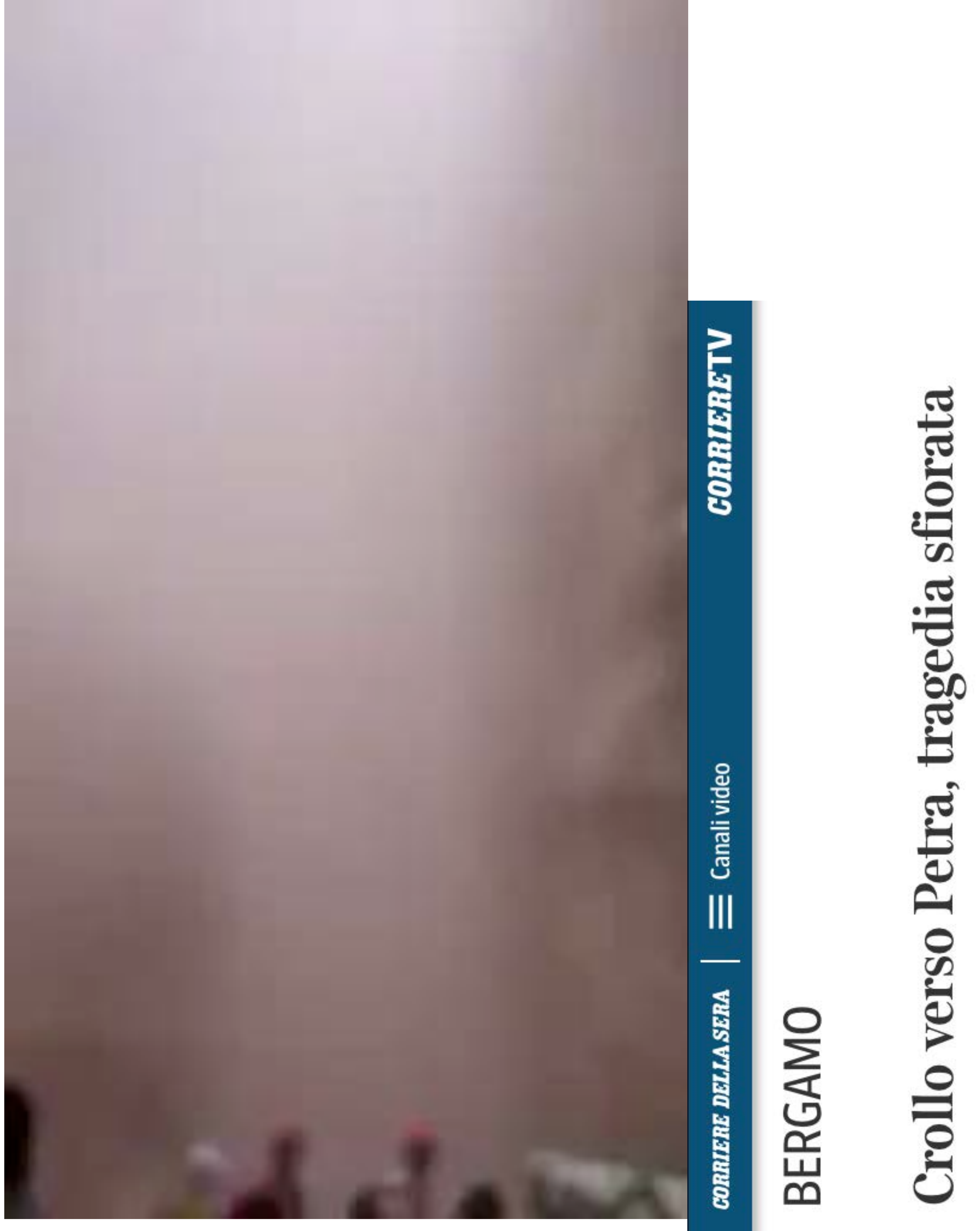
A comparison between this map, in terms of global index including all the categories of landslides, and the source region detected in the Siq, clearly allow the identification of such source region as one of the most hazardous in that cliff (black circle in the this figure).
In other words current methodology is capable to distinguish the portion of the Siq where the condition to fall are more probable.
The timing of collapse is more complicate and need a proper monitoring.



The rockfall of 28th May 2015

in the morning (11,30) or early afternoon (15pm)

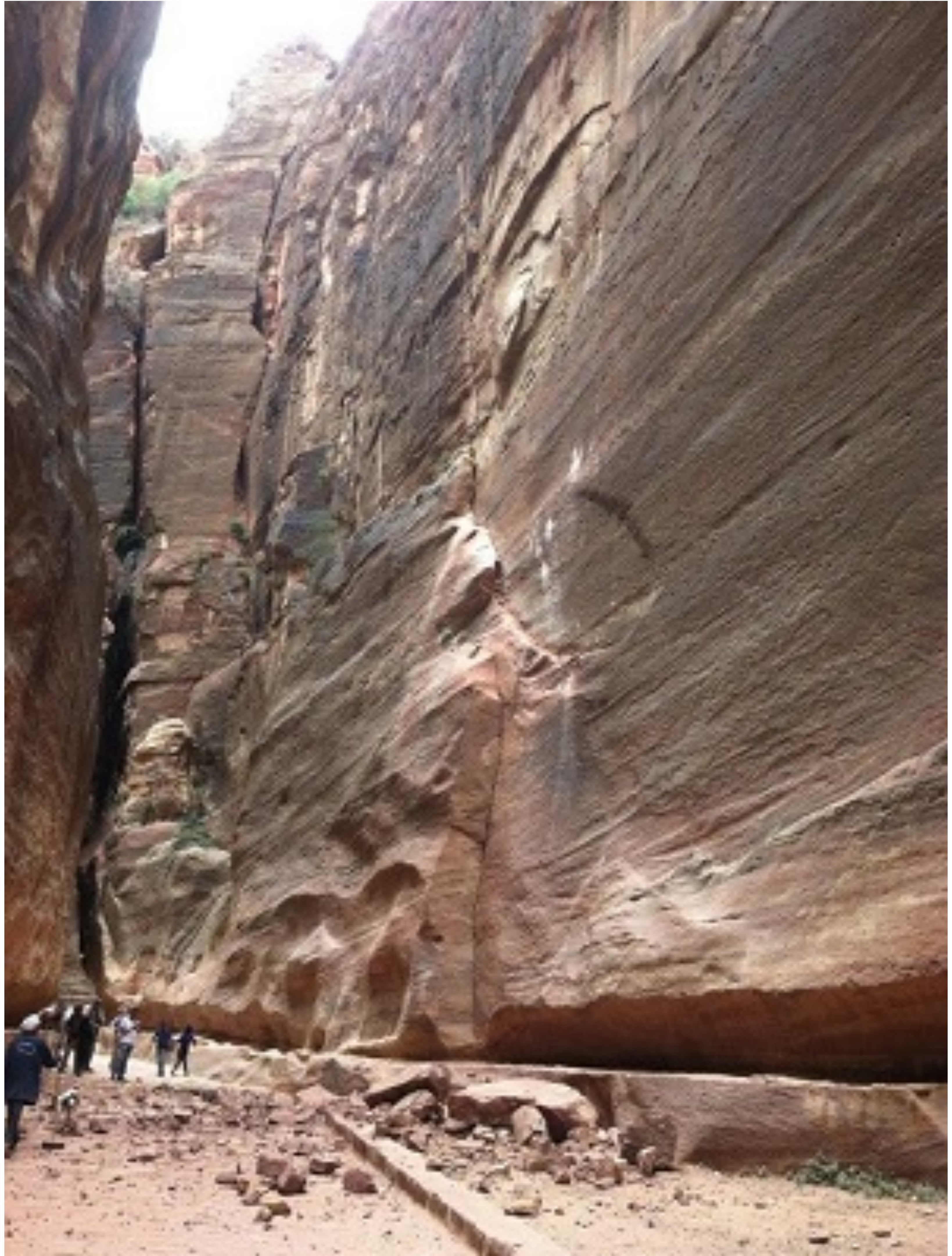
During the collapse



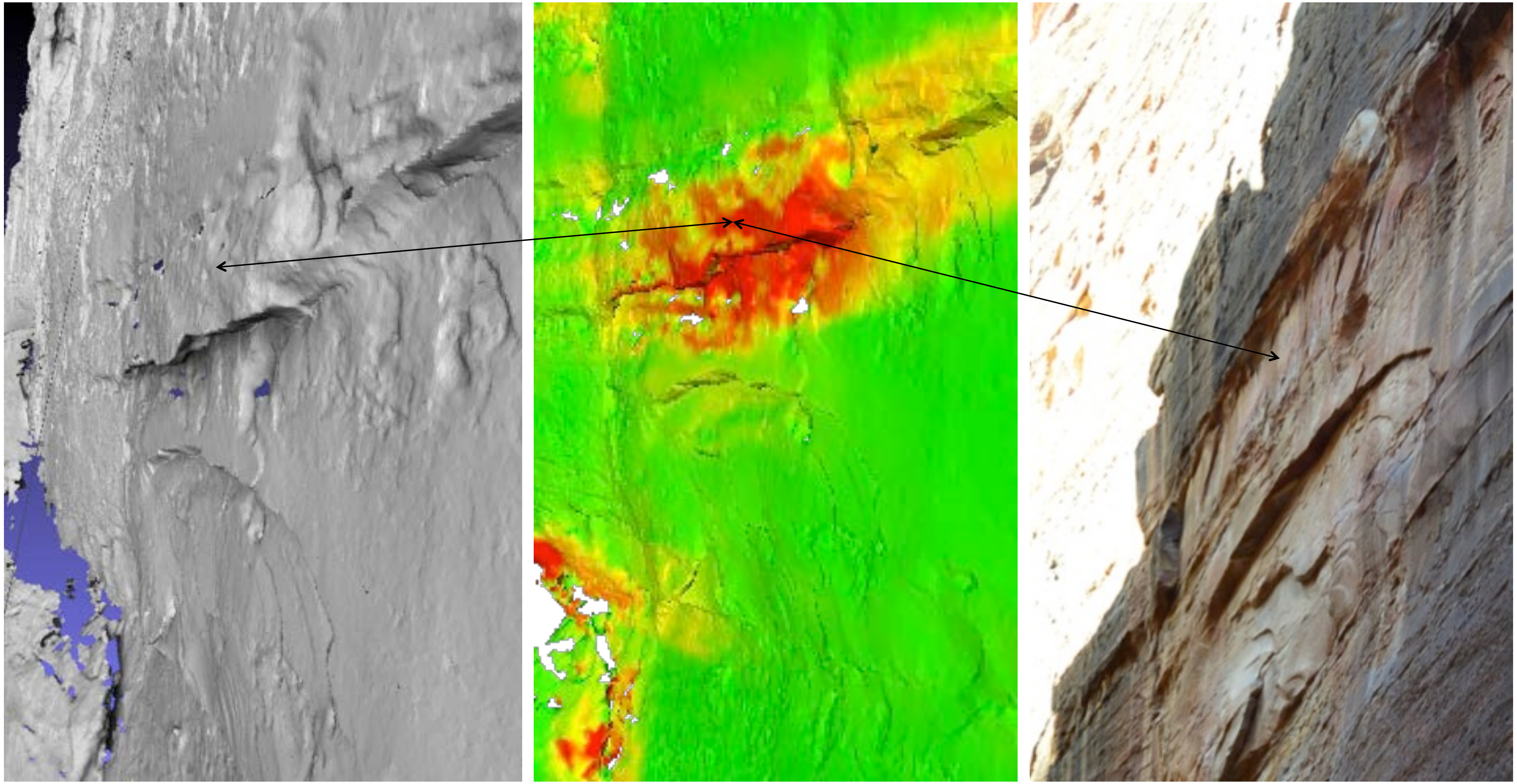
The rockfall of 28th May 2015

in the morning (11,30) or early afternoon (15pm)

Few minutes after the collapse



Potentiality of the **Global Kinematic Index**



Machu Picchu landslide

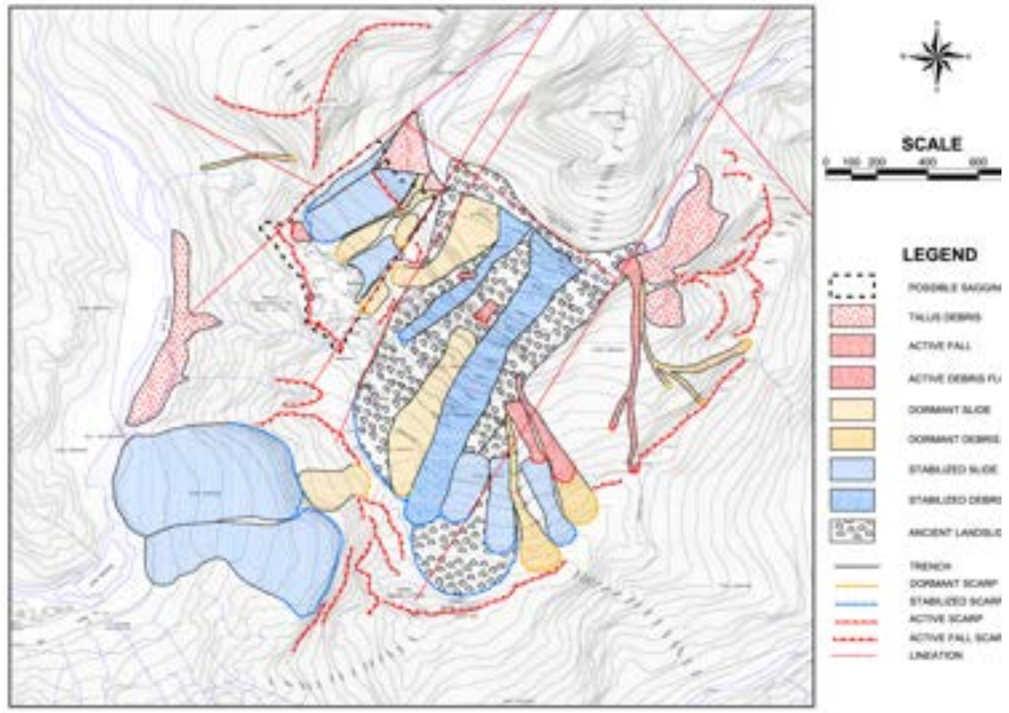
Peru

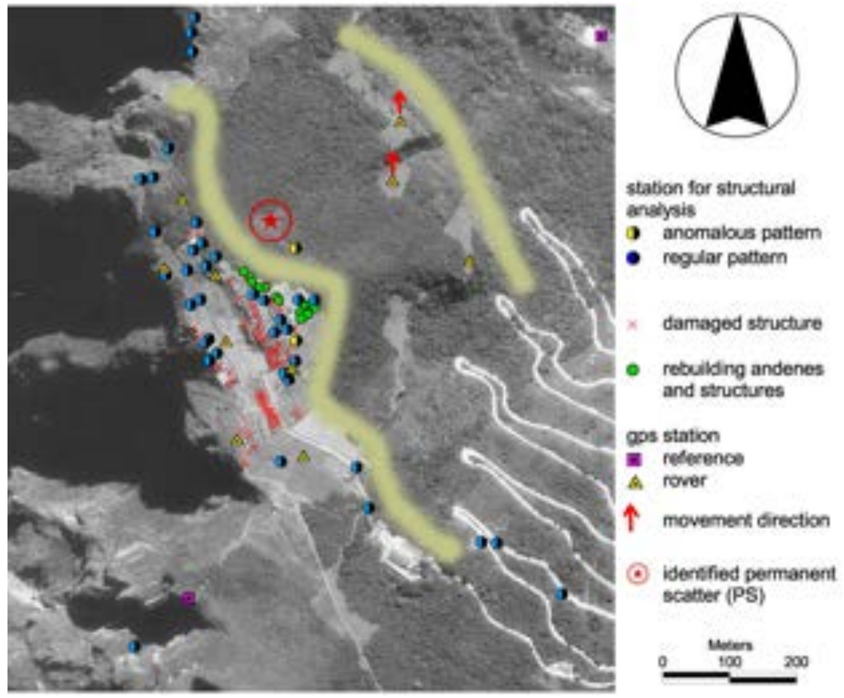
Machu Picchu (PERU)

Machu Picchu is a 15th-century Inca citadel located in the Eastern Cordillera of southern Peru on a 2,430-meter mountain ridge. It is located in the Machupicchu District within Urubamba Province above the Sacred Valley, which is 80 kilometers northwest of Cuzco. The Urubamba River flows past it, cutting through the Cordillera and creating a canyon with a tropical mountain climate

Machu Picchu

Peru





Preparatory

A large landslide was identified in 2001. This was generating a relevant decreasing of tourism in Peru

Investigation

UNESCO organized an international working group, to study in deep the geomorphological processes of the site

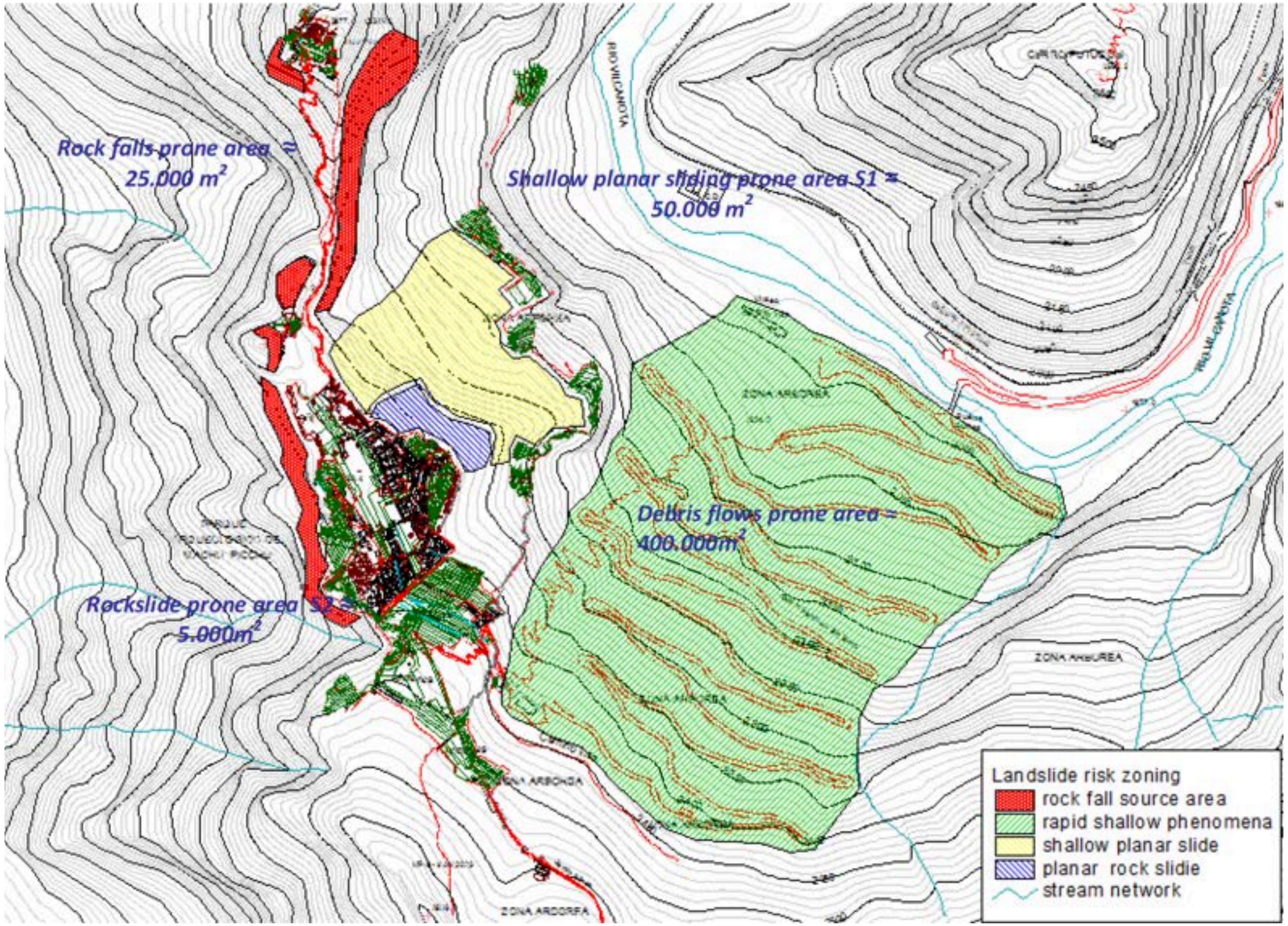
Monitoring

Italy contributed with a manitoring project, funded by MIUR. Integrated monitoring

Design

All monitoring data and geological information did not confirm the existence of a large landslides affecting machu Picchu. Thus, minor rock fall, slide and debris flow are evident and need mitigation..

Machu Picchu Landslide



Tiwanaku soil erosion

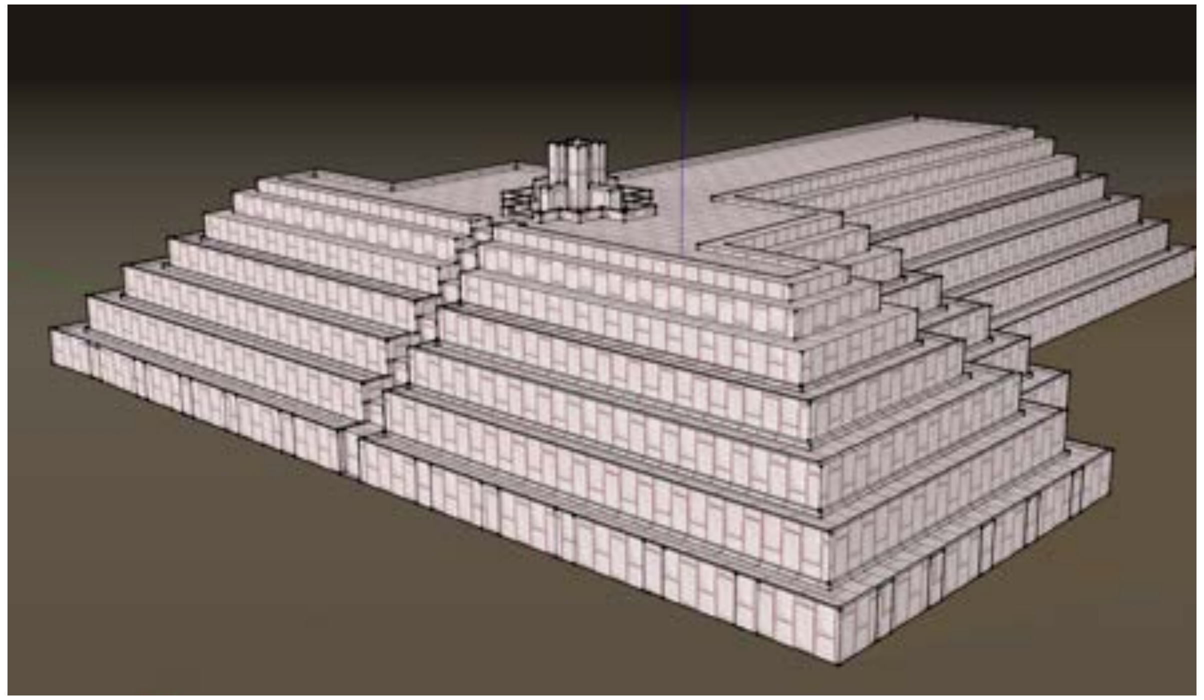
Bolivia

Tiwanaku (Bolivia)

Tiwanaku (Spanish: Tiahuanaco or Tiahuanacu) is a Pre-Columbian archaeological site in western Bolivia near Lake Titicaca, about 70 kilometers from La Paz, and it is one of the largest sites in South America. Surface remains currently cover around 4 square kilometers and include decorated ceramics, monumental structures, and megalithic blocks. The site's population probably peaked around AD 800 with 10,000 to 20,000 people. The site was first recorded in written history in 1549 by Spanish conquistador Pedro Cieza de León while searching for the southern Inca capital of Qullasuyu.

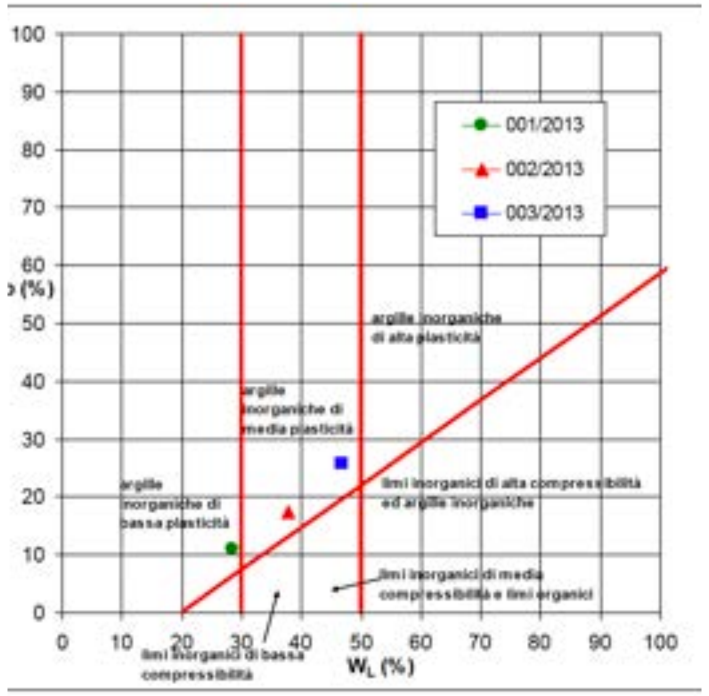
Akapana Pyramid Tiwanaku

Bolivia



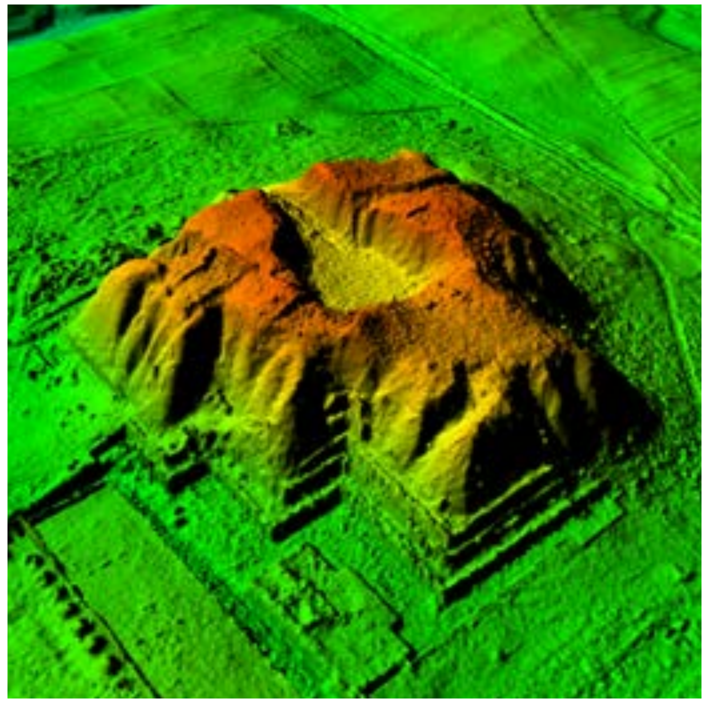
Preparatory

Pre-colombian step pyramid covered by rocky blocks, later on used as a quarry for rock. Also a central excavation, for gold search were implemented by colonials.



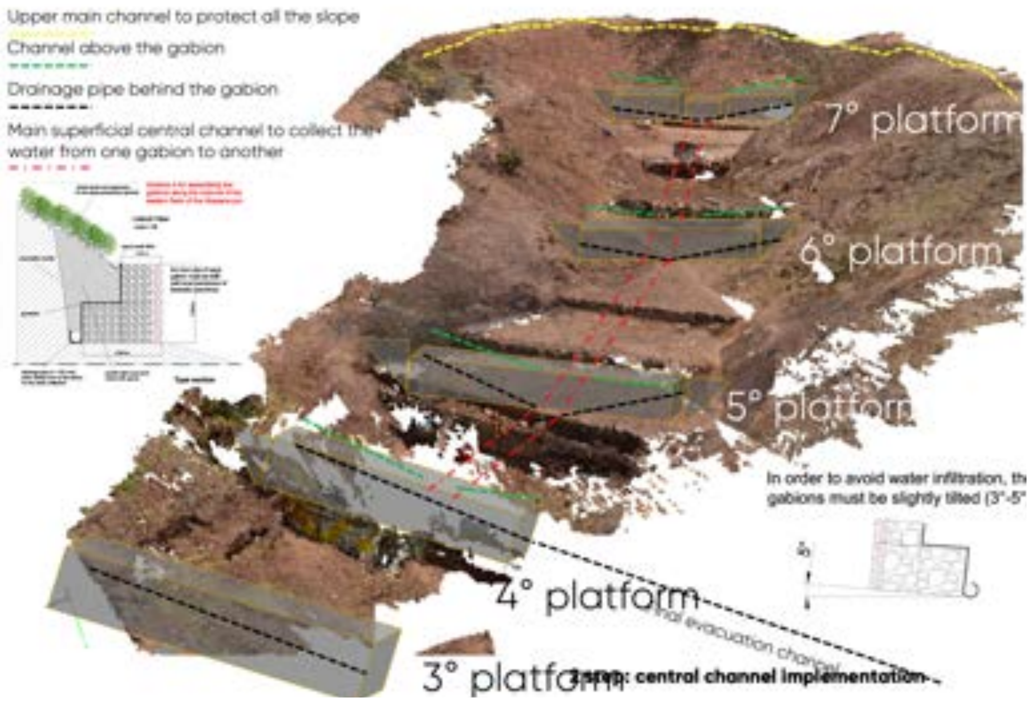
Investigation

Drone, geophysical and laboratory test to investigate the composition of the artificial inner pyramid.



Investigation

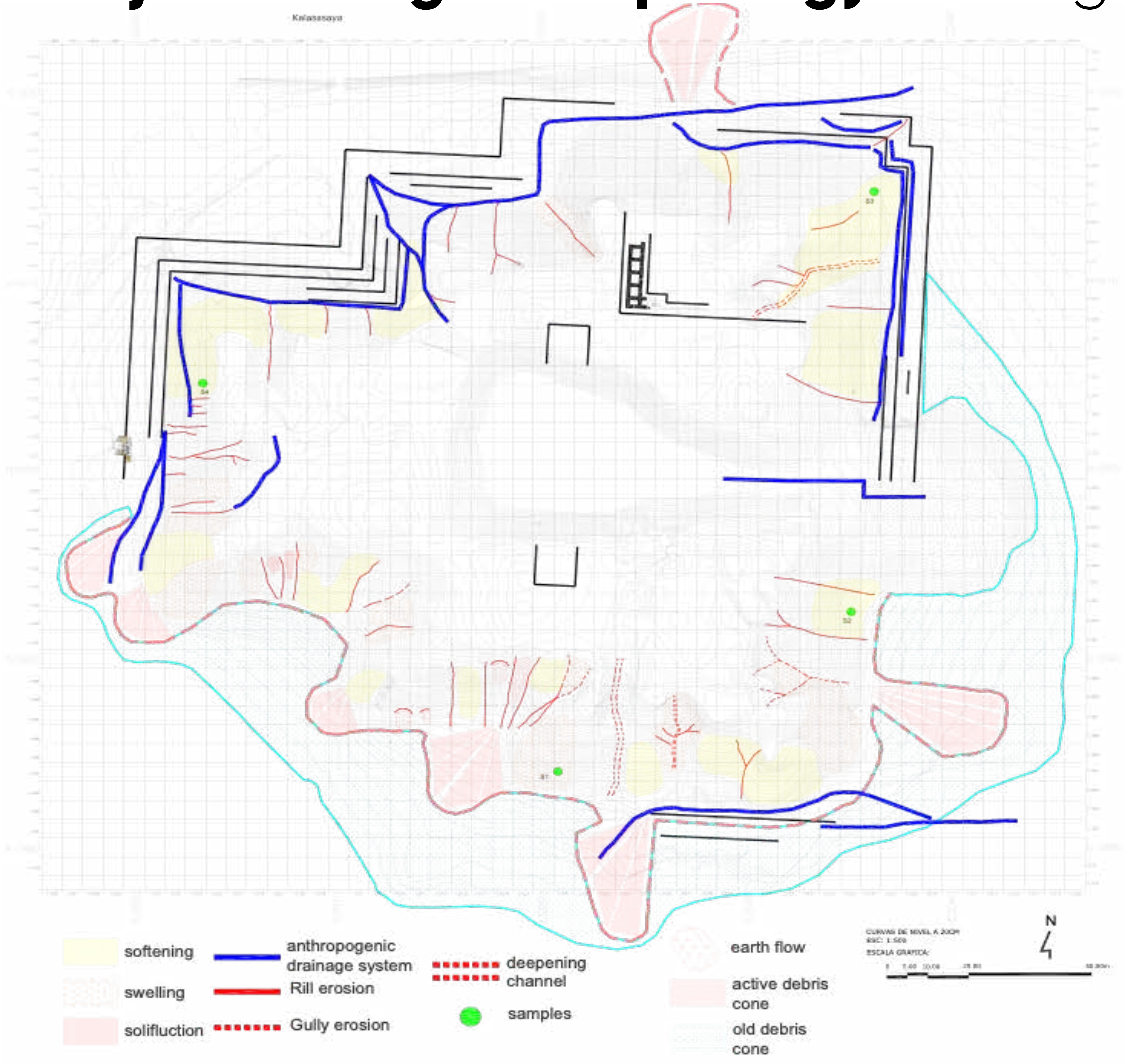
Geomorphological approach to an artificial structure. Rill and gullies, areal erosion, missing of drainage network.

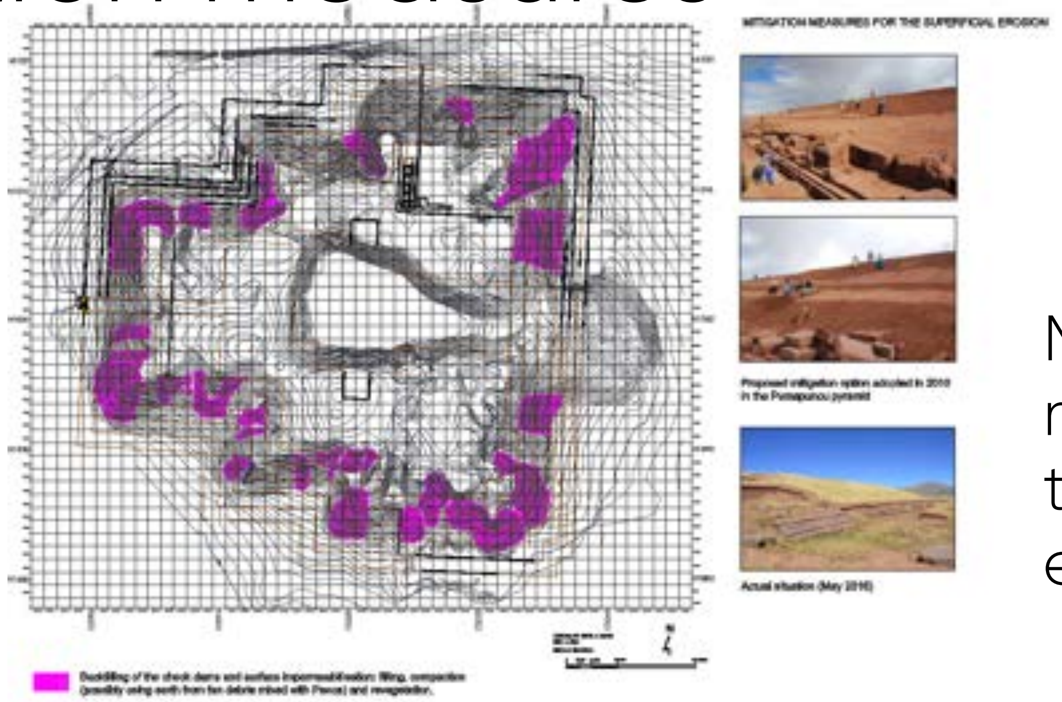


Project

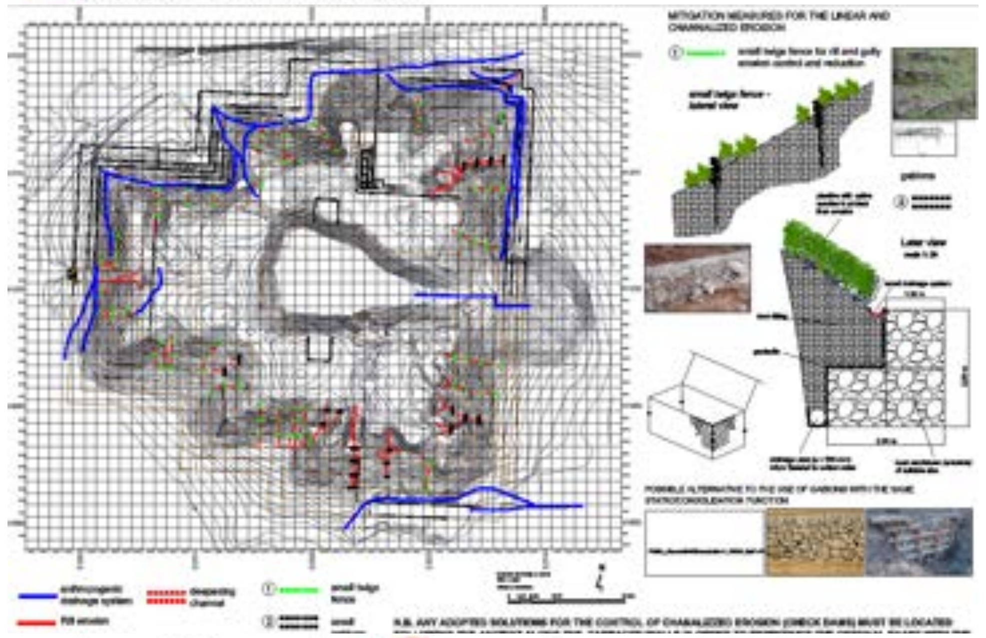
Gabions located in the exact position of original steps, to reconstruct the ideal ancient skyline. Impermeabilization with Penka.

Project from geomorphology to mitigation measures

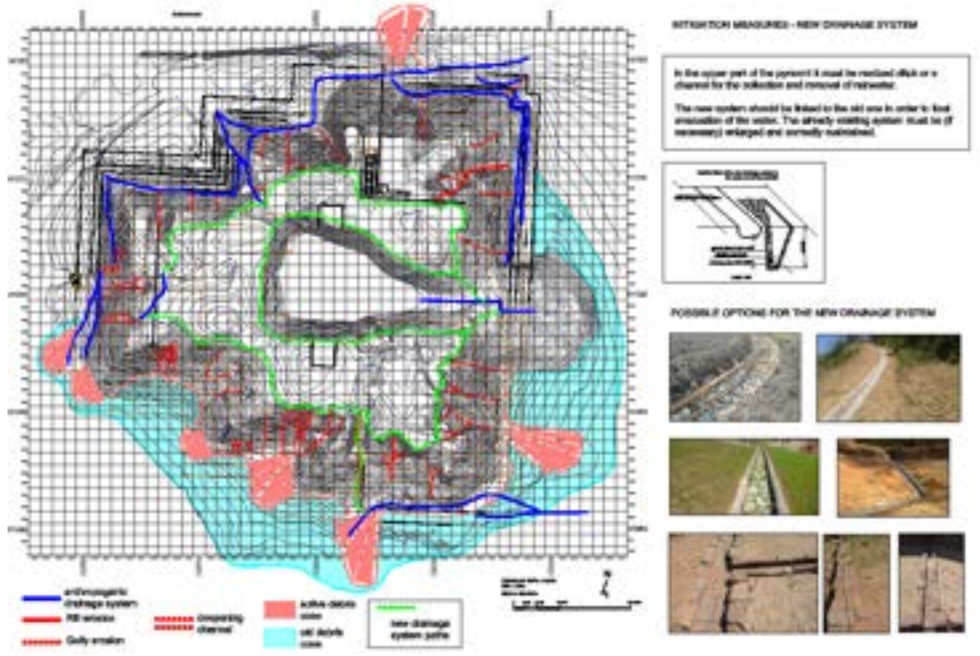




Mitigation measures for the surficial erosion

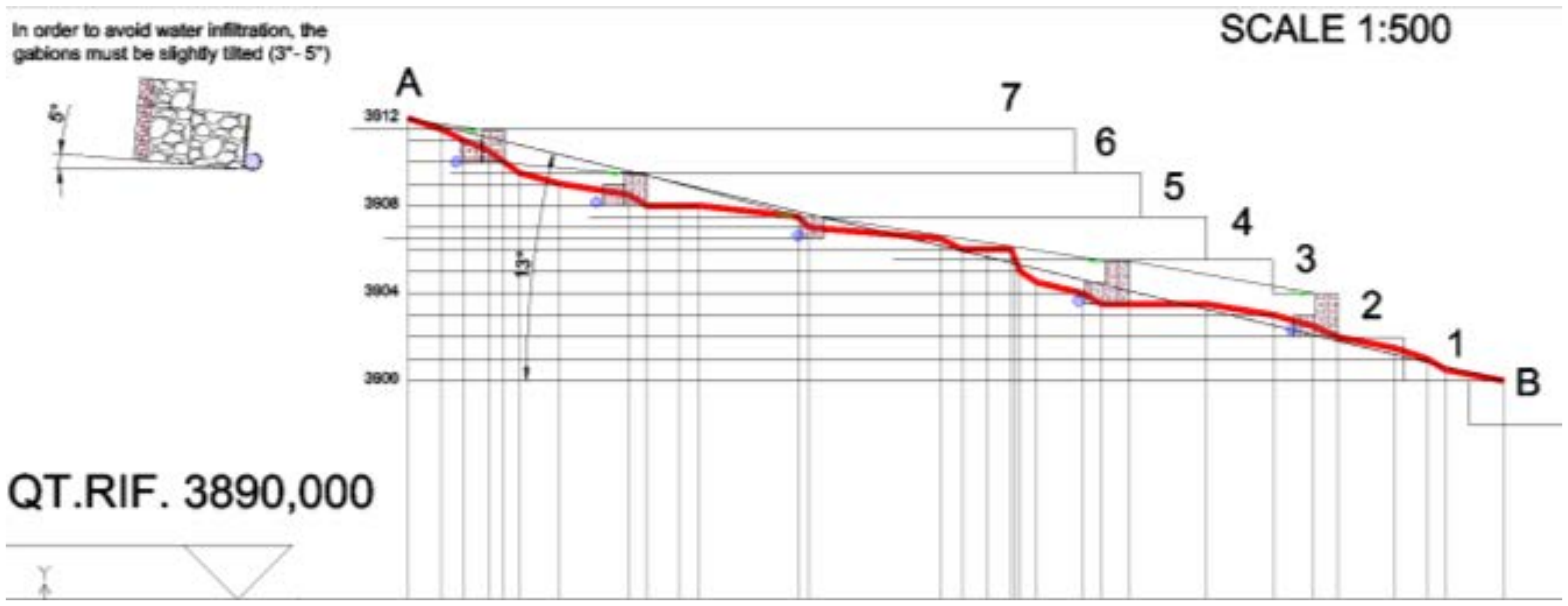


Mitigation measures for the linear and channalized erosion (rill and gullies)



New Drainage system

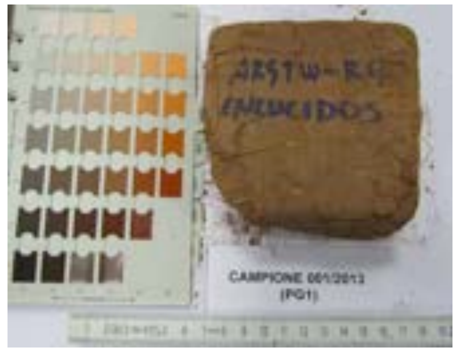
From geomorphology to mitigation measures



From geomorphology to mitigation measures

The areas with deep incisions (2018): construction of gabions

Impermeabilization and compaction



From geomorphology to mitigation measures

The areas with deep incisions are now completely re-vegetated (2024)

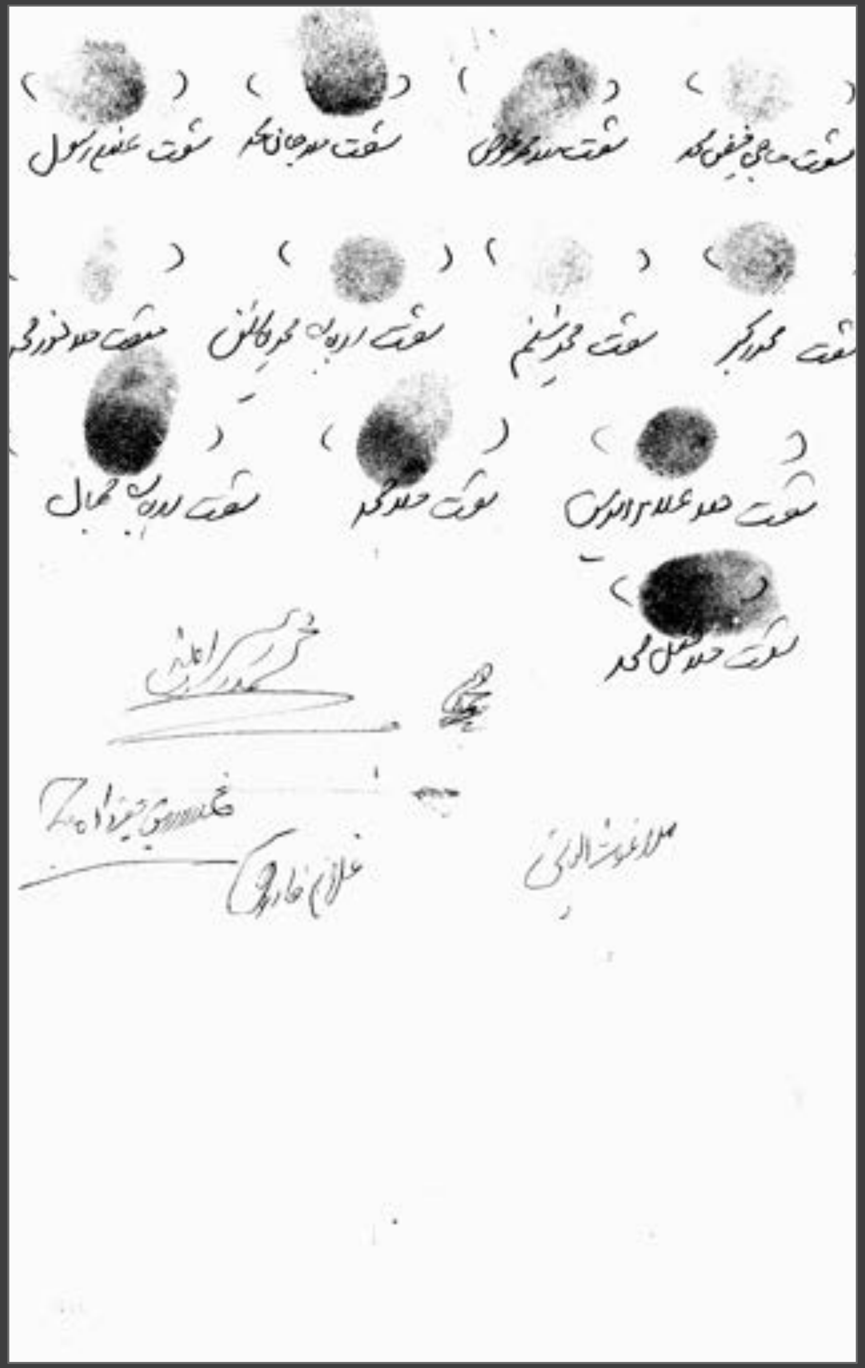
Jam minareth (Afghanistan)

PAYAM-E- GHOR
REHABILI TATION
&
ORGANIZATION
DATE:
RAF :

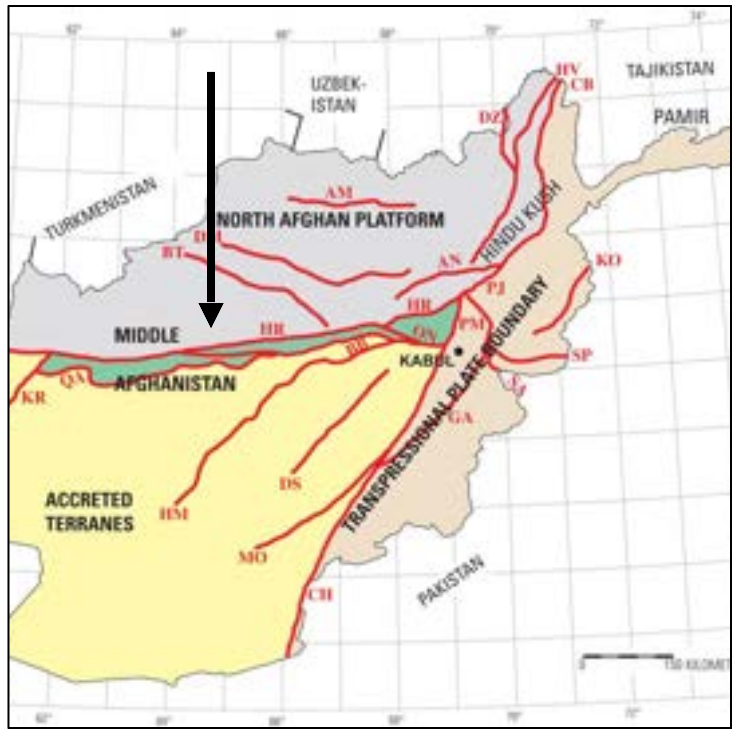
P·G·R·O

ADDRESS
Kocha -E- Gulfrashi
Tel 33371

14/July 1999



Permit issued to Prof. Andrea Bruno, authorizing the inspection of the Jam site, and signed in 1999 by both warring factions – the Taliban and the Mujahideen. The frontline of the conflict at that time passed directly through the Jam area.(courtesy and © Andrea Bruno).



Major
Threats

Earthquakes

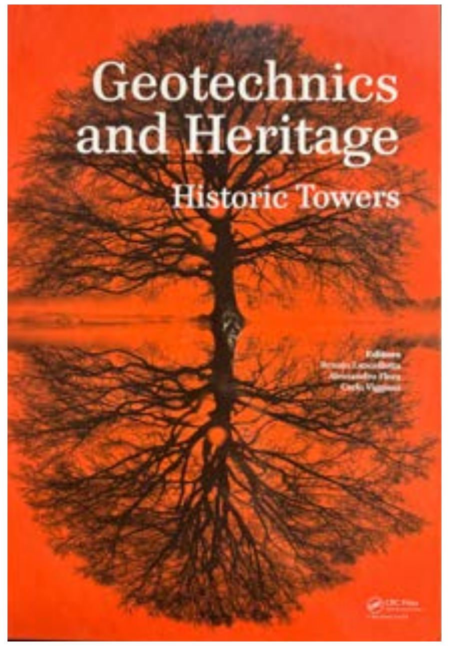
Flood and flash floods

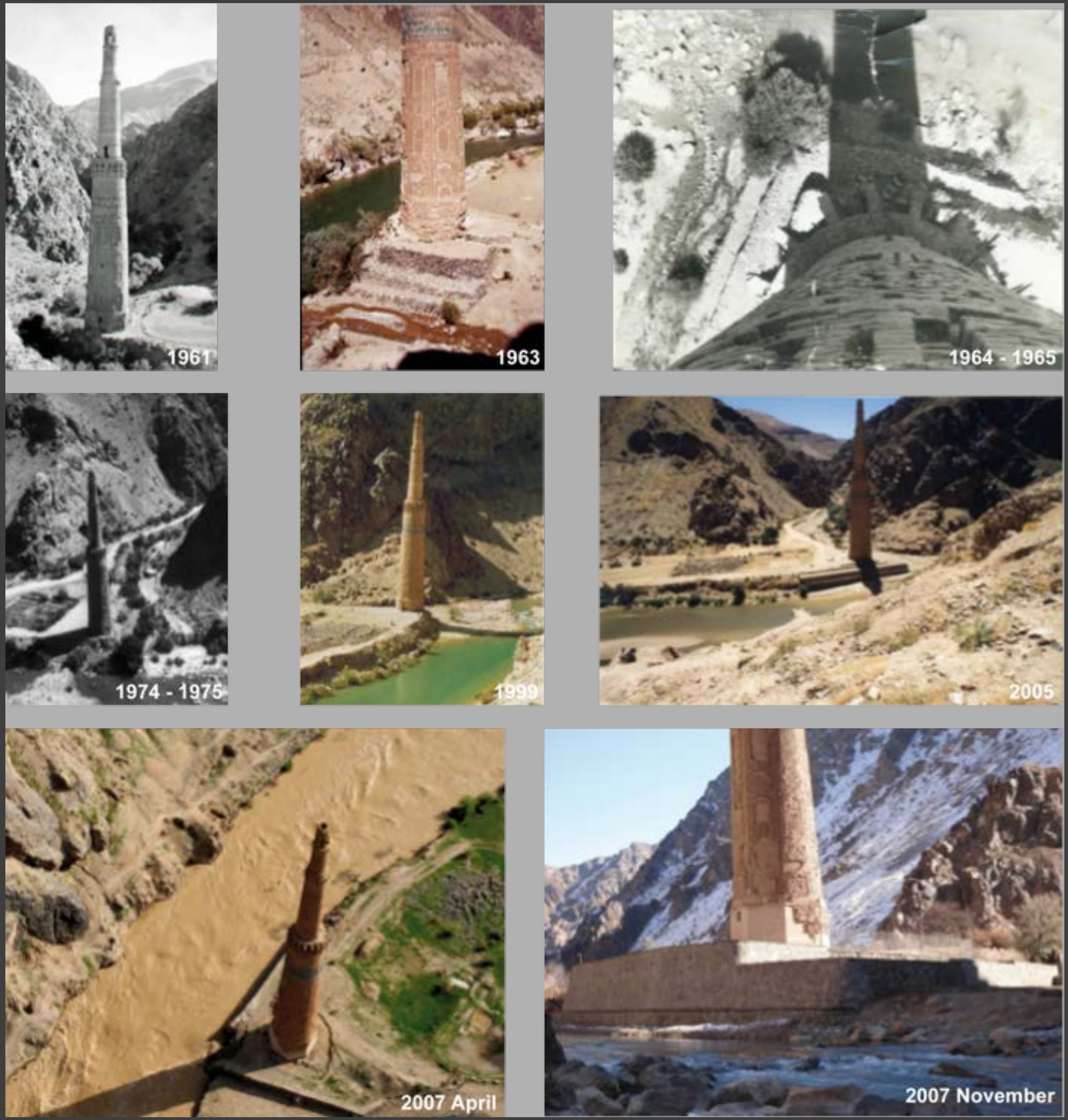
River under-excavation (erosion)

Rising of water table

River

Under-excavation

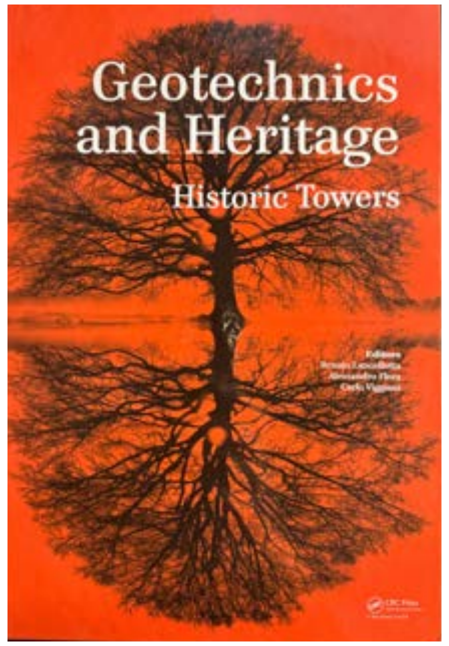




The minaret and associated embankment in 1961, 1963, 1964–65, 1974–75, 1999 and 2005; in April 2007 after flooding destroyed the gabions; in November 2007 after the reconstruction of a protective wall (Margottini et al., 2017)

River

Under-excavation



The Minaret of Jam with the Hari Rud close to the structure (photo A. Bruno, 1961)

Jam
Afghanistan

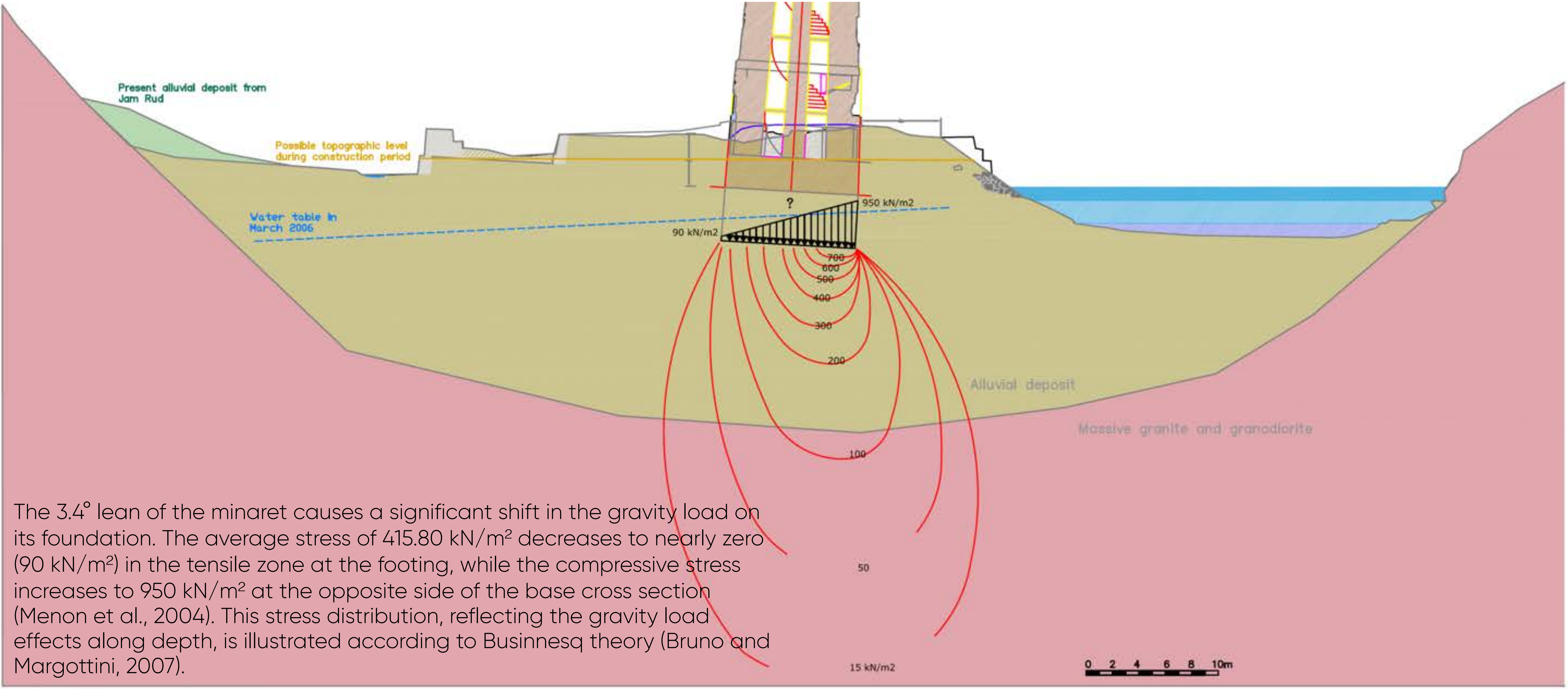
After the flood of 2007 an emergency action was implemented in Afghanistan. Due to the war scenario in the area, experts of Ministry of Culture were trained in Kabul, to manage the project and to coordinate local people, A proper stone wall was constructed in Jam, in the Hari Rud. The result was successful. Currently there is still a major problem for flash flood coming from the tributary Jam Rud.

A new project is on the way in Afghanistan, coordinated by UNESCO.

Image from May 2024 flood

Ultimate bearing capacity

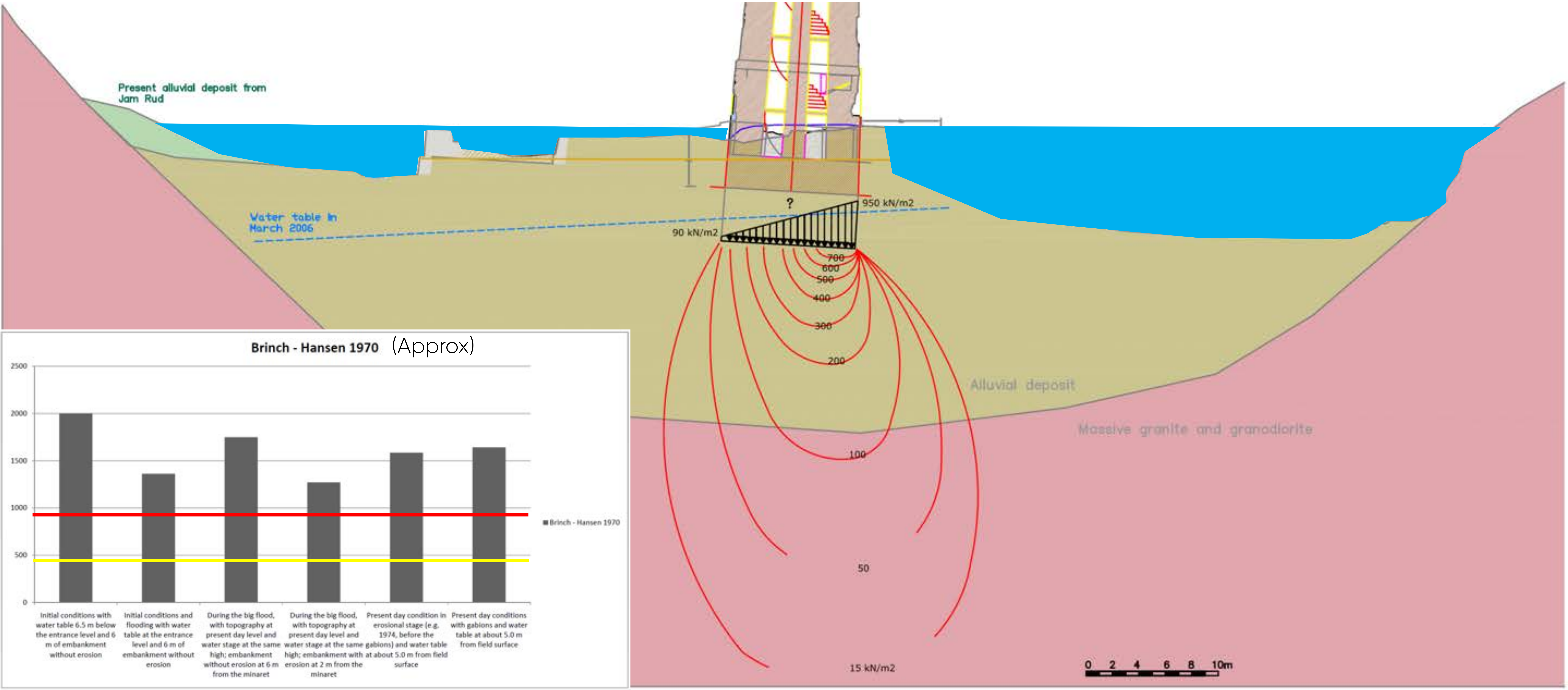
In normal conditions

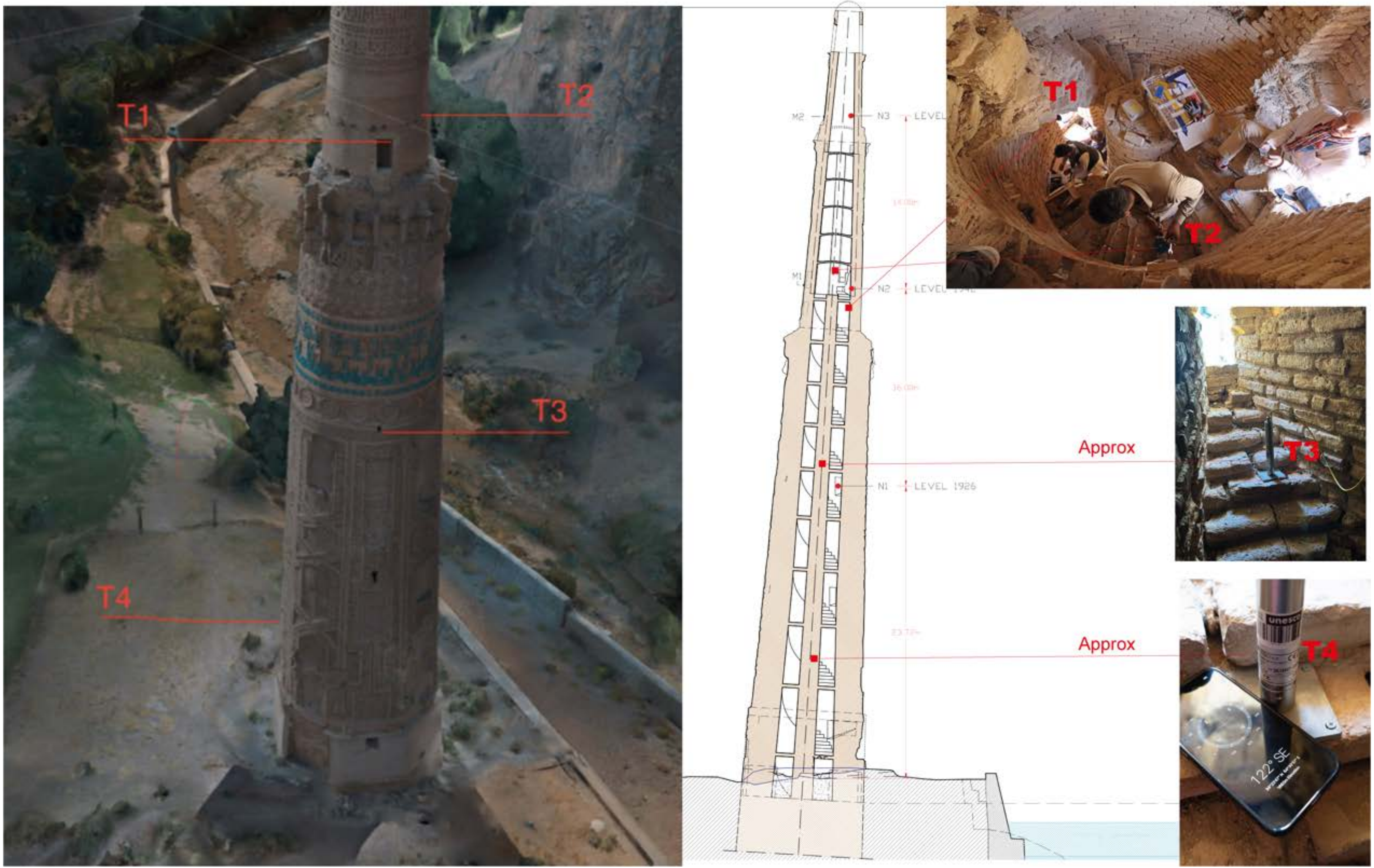


The 3.4° lean of the minaret causes a significant shift in the gravity load on its foundation. The average stress of 415.80 kN/m² decreases to nearly zero (90 kN/m²) in the tensile zone at the footing, while the compressive stress increases to 950 kN/m² at the opposite side of the base cross section (Menon et al., 2004). This stress distribution, reflecting the gravity load effects along depth, is illustrated according to Businnesq theory (Bruno and Margottini, 2007).

Ultimate bearing capacity

In extreme conditions




T1
T2
T3
T4
M2
N3
LEVEL
M1
N2
N1
LEVEL 1926
Approx
Approx
122° SE
unesco

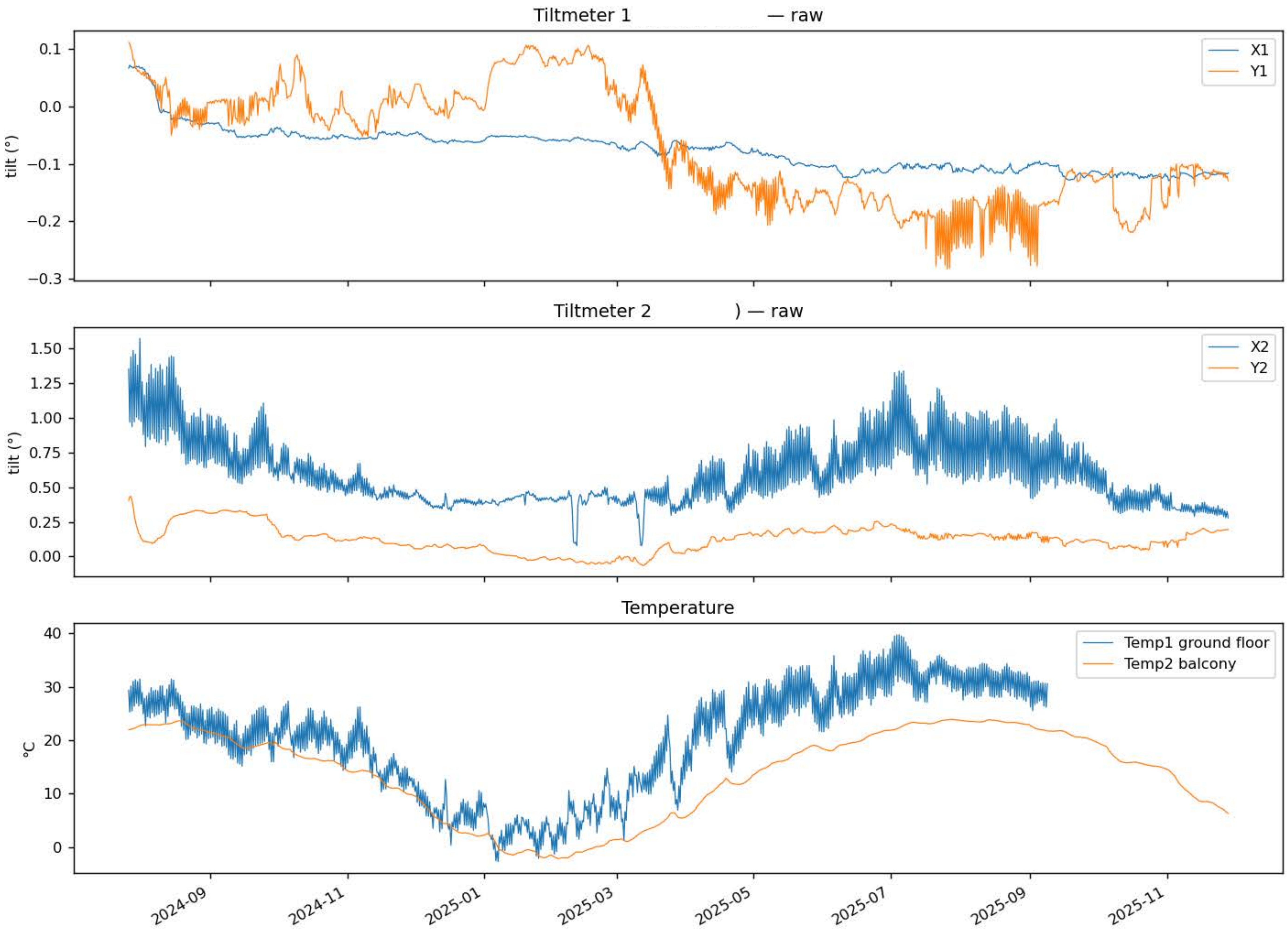


Figure 1 — Raw tilt series (top: tiltmeter 1; middle: tiltmeter 2) and temperatures. Note the failure of Temp1 in September 2025.

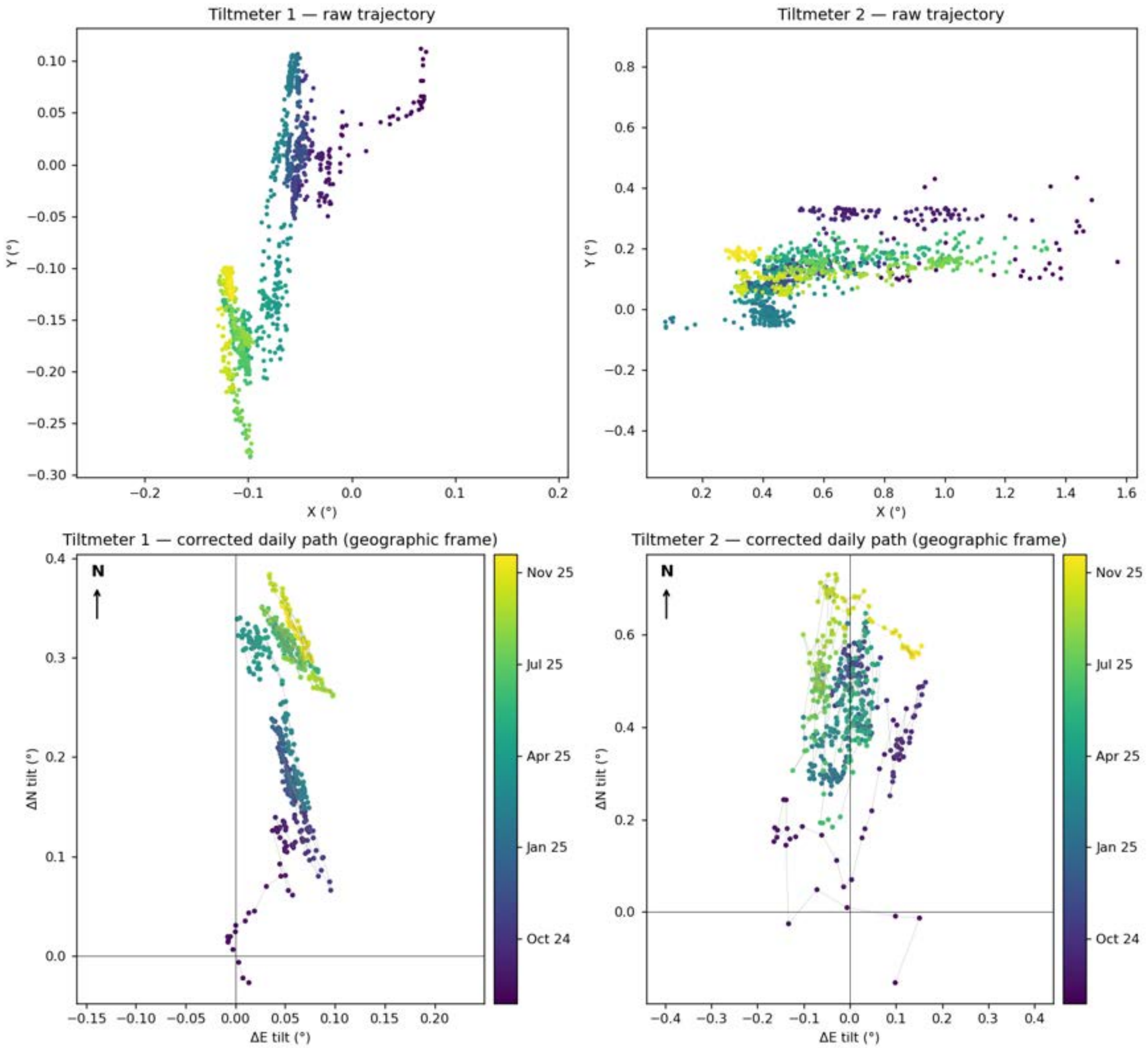


Figure 3 — Tilt trajectories in the X–Y plane, raw (top) and thermally corrected daily means (bottom), coloured by time.

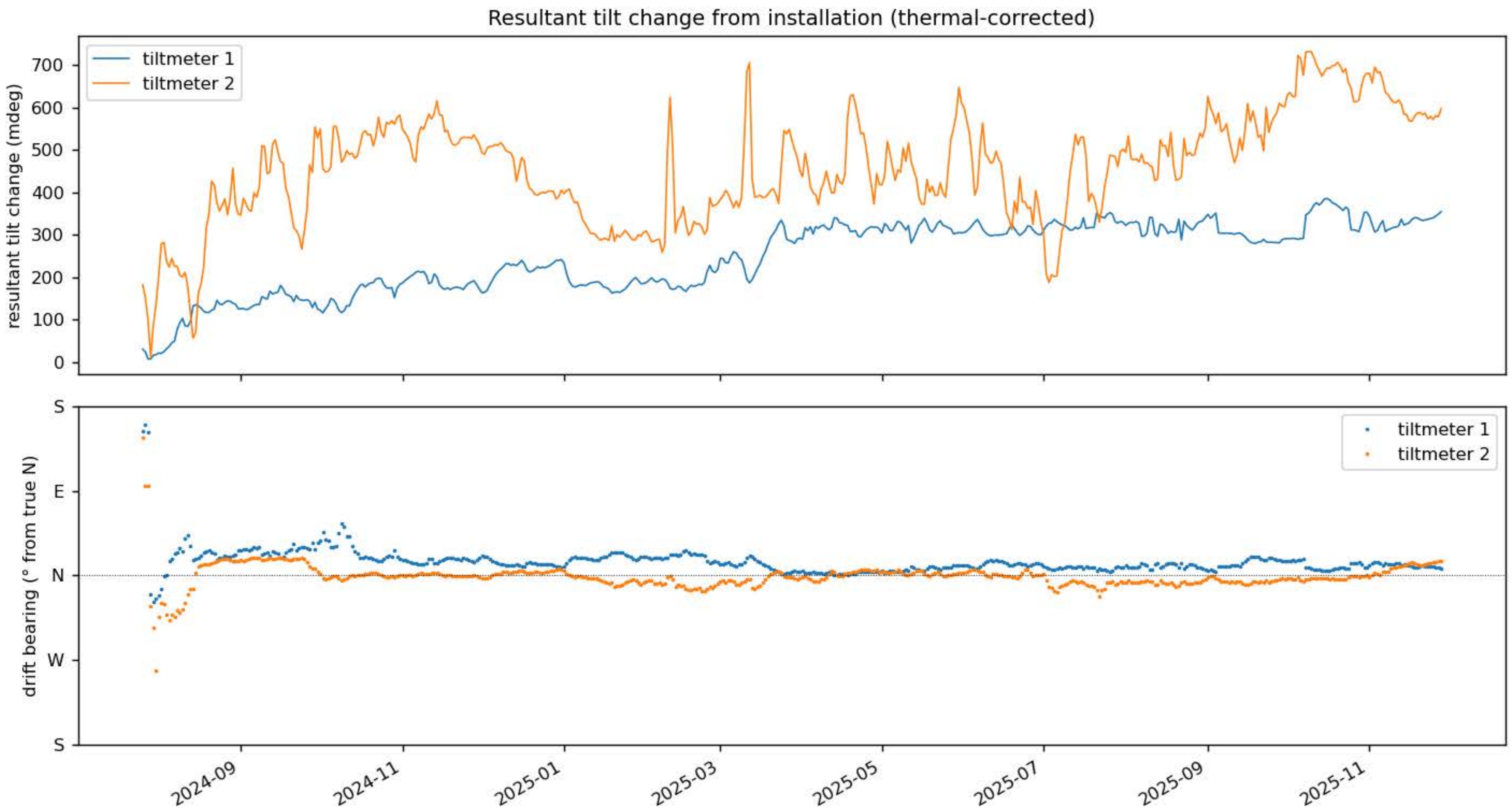


Figure 5 — Resultant tilt change from installation (top) and azimuth of the tilt vector (bottom), thermally corrected daily means.

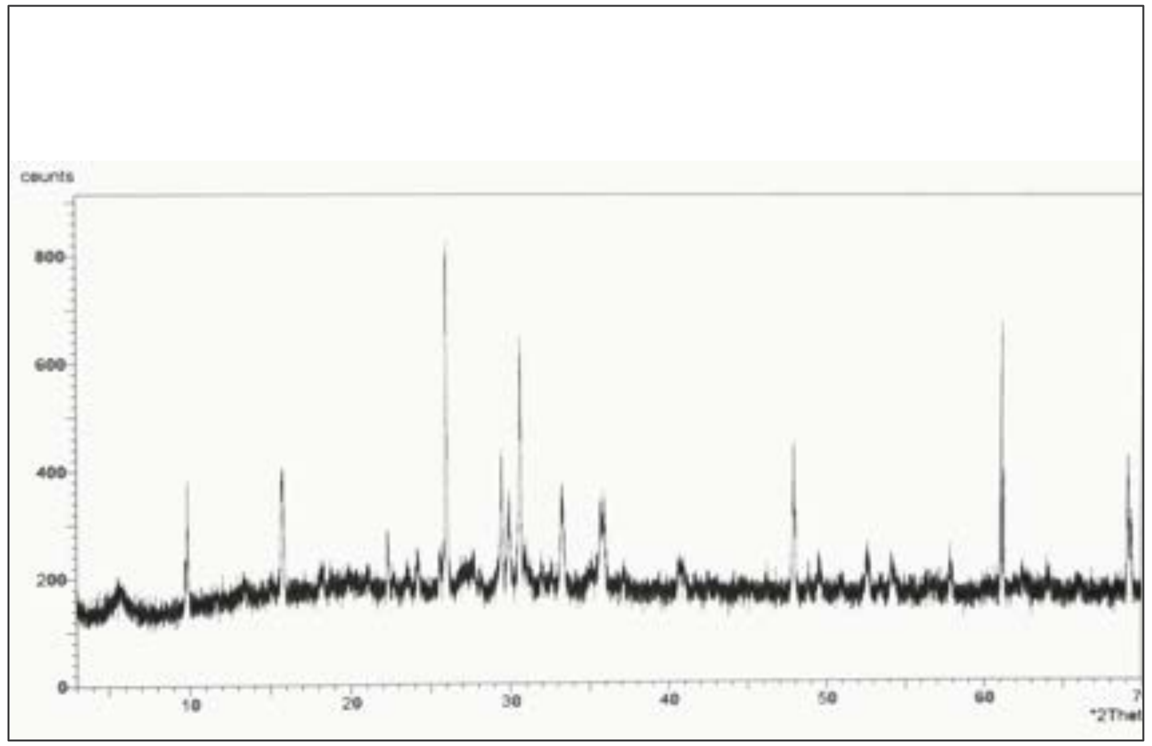
25 July 2024 - 28 November 2025 Tiltmeters 1 and 2 corrected for temperature, with the same scale


Lalibela
Ethiopia

11 Churches

In Lalibela

Example: weathering of the roof



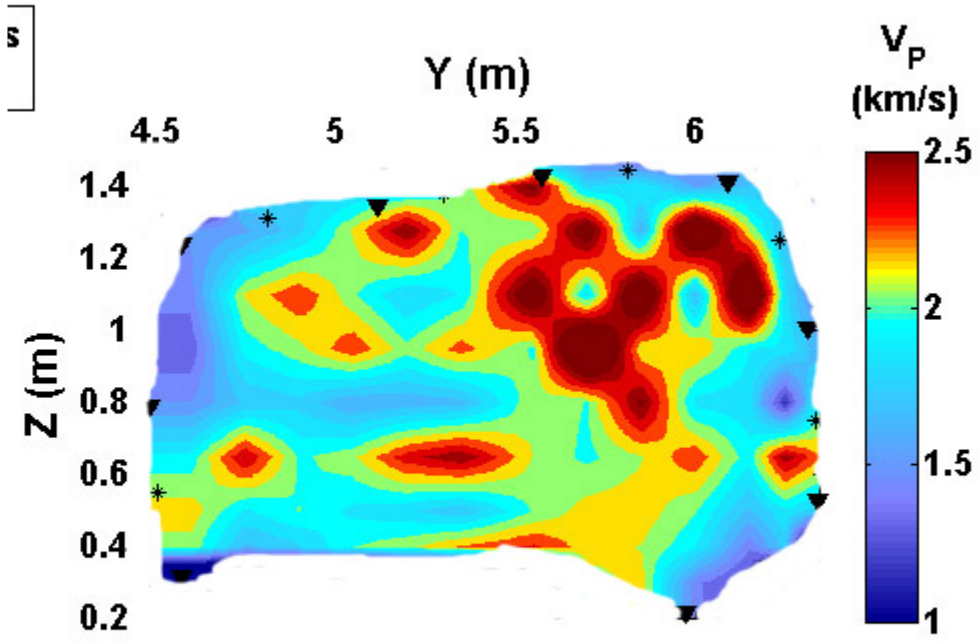
Discovering of Montmorillonite (X-ray diffrattometer, scanning electronic microscope, thin sections, etc.)

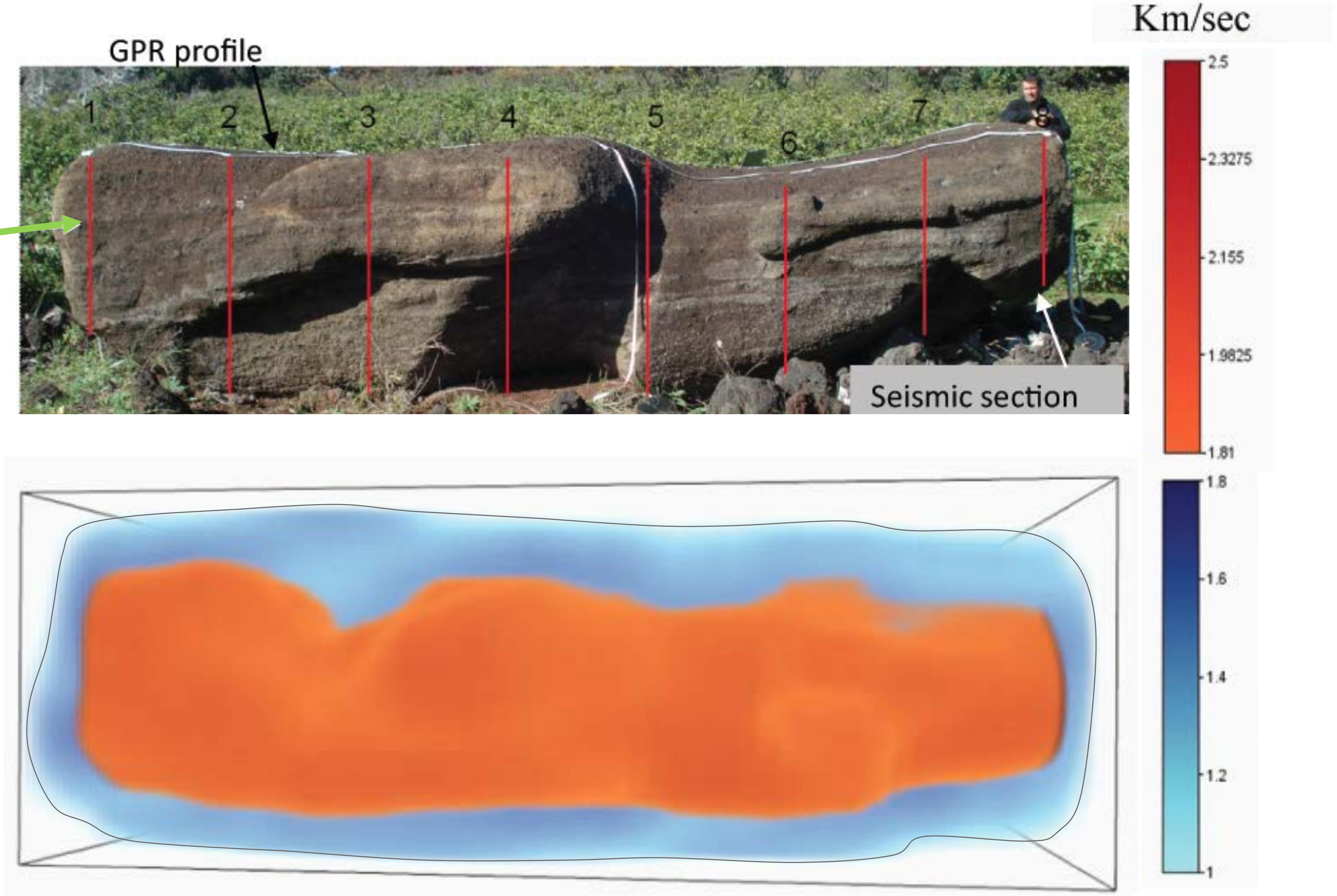
Cover from EU Project

Moai Rapa Nui, Easter Island, Chile

Seismic tomography and gpr for weathering

Moai Statue, Rapa Nui, Easter Island (Chile)

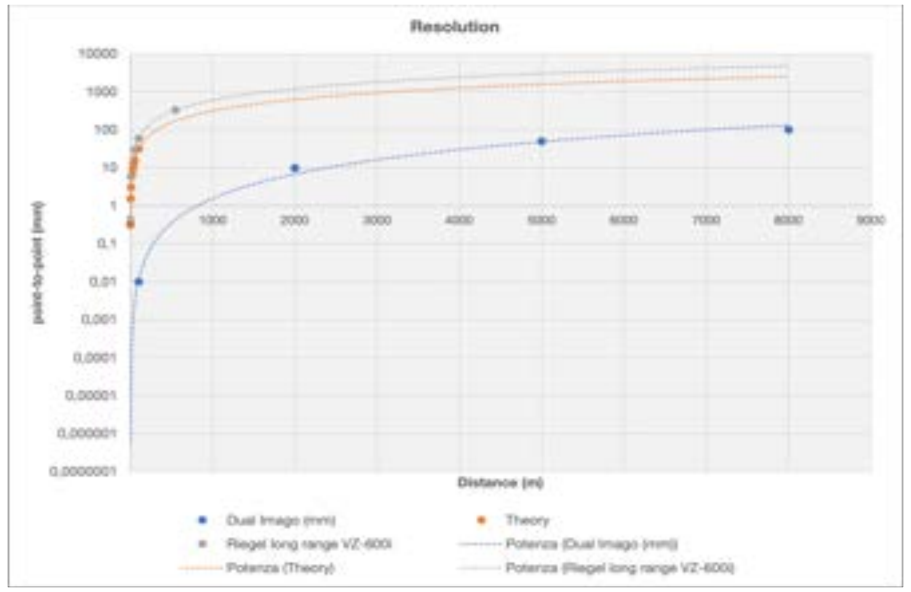


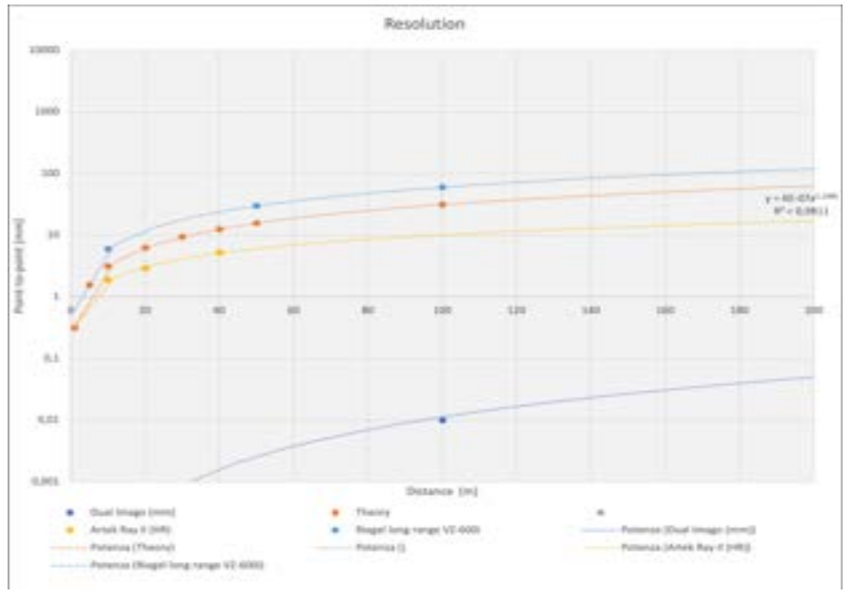


Picture of the statue (on the top) and 3D seismic thomograph (on the bottom). The seismic velocities are mapped with a threshold of 1.8 km/s.

Abu Ud UNESCO memory of the earth (KSA)

Comparative analysis





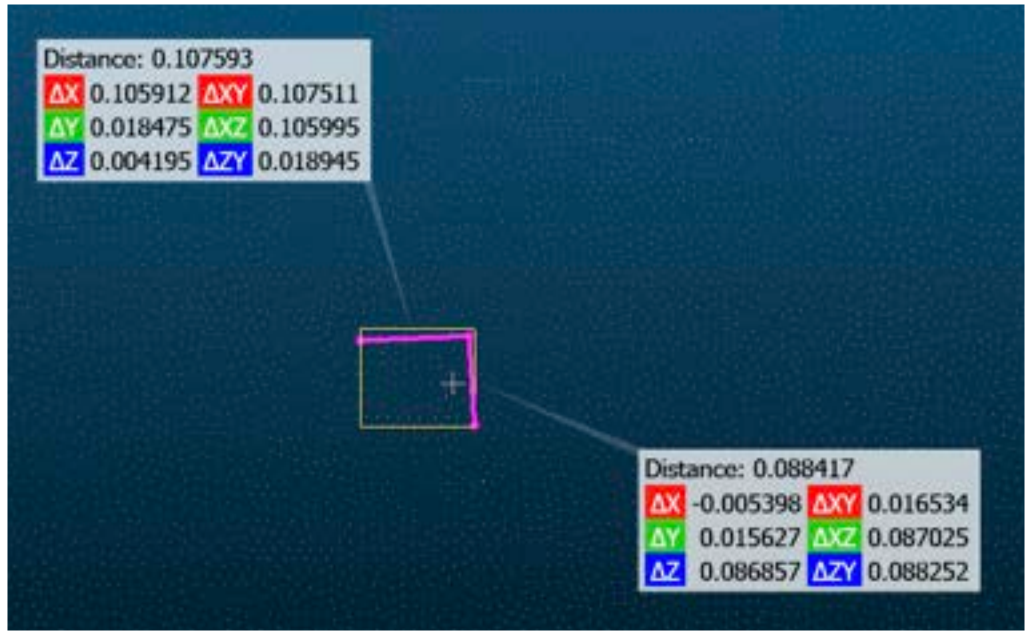
1 pixel/point per cm²
(100 m distance)

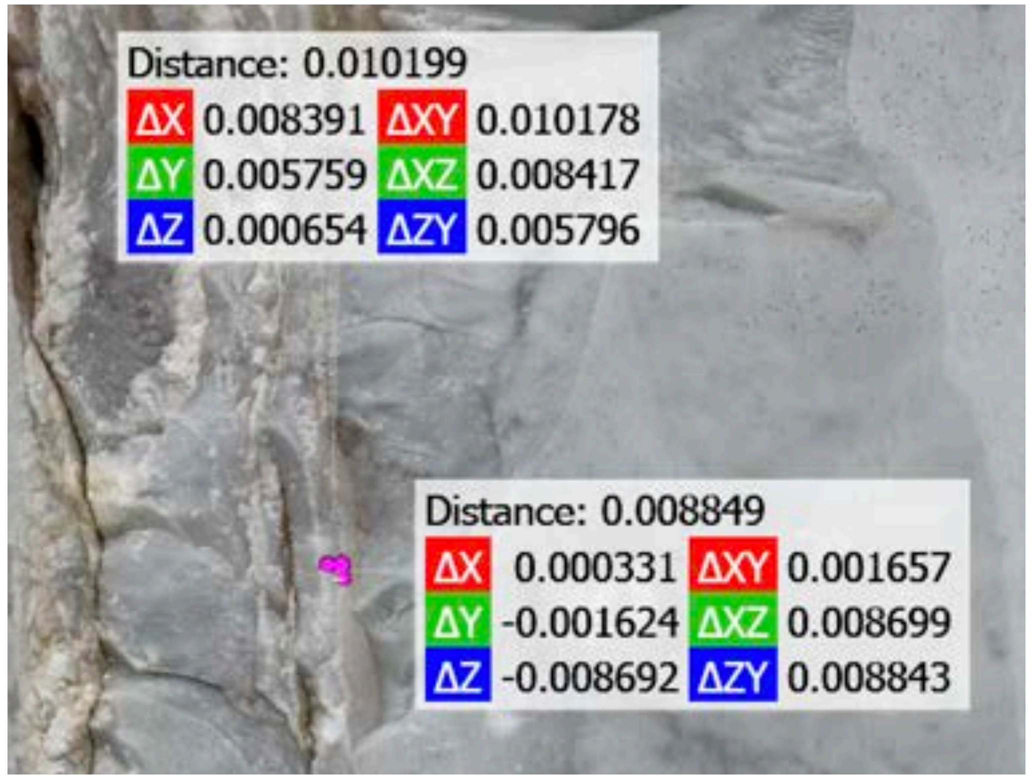
1 cm

1 cm

5000 pixels/points
per cm²
(100 m distance)

1 cm





The Dual Imago methodology is allowing an accuracy of 0,01 mm at 100 meters and about 50 mm at 5 Km; a resolution of about 5.000 pixels at 100 m.

3D vectorial reconstruction of rock art

Survey on the field with traditional or advanced cameras (1 or few photos)

Identification of Rock Art elements by using proprietary methodologies

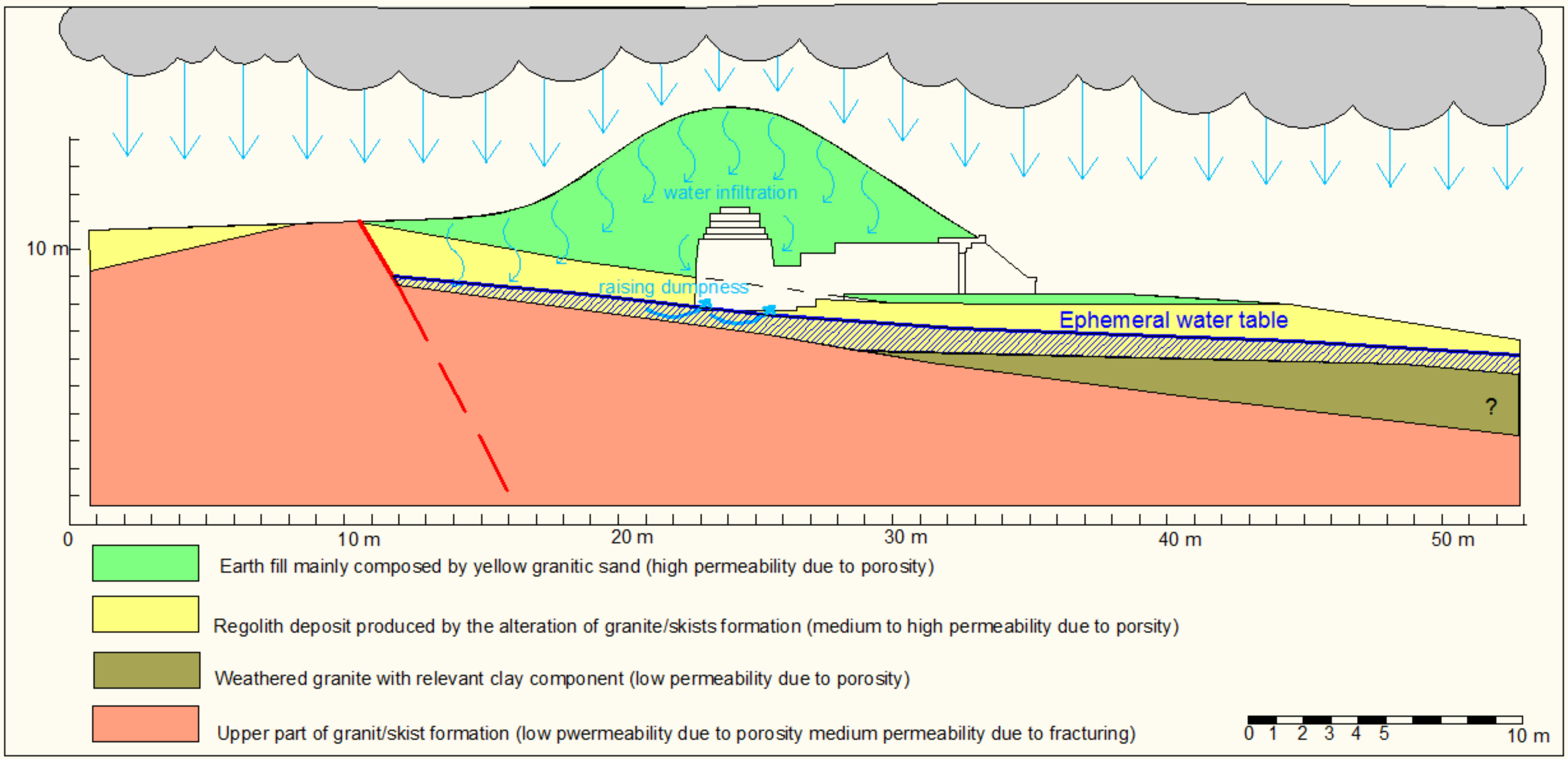
Digitalisation of Rock Art elements by using proprietary methodologies

3D Vector of Rock Art elements by using proprietary methodologies

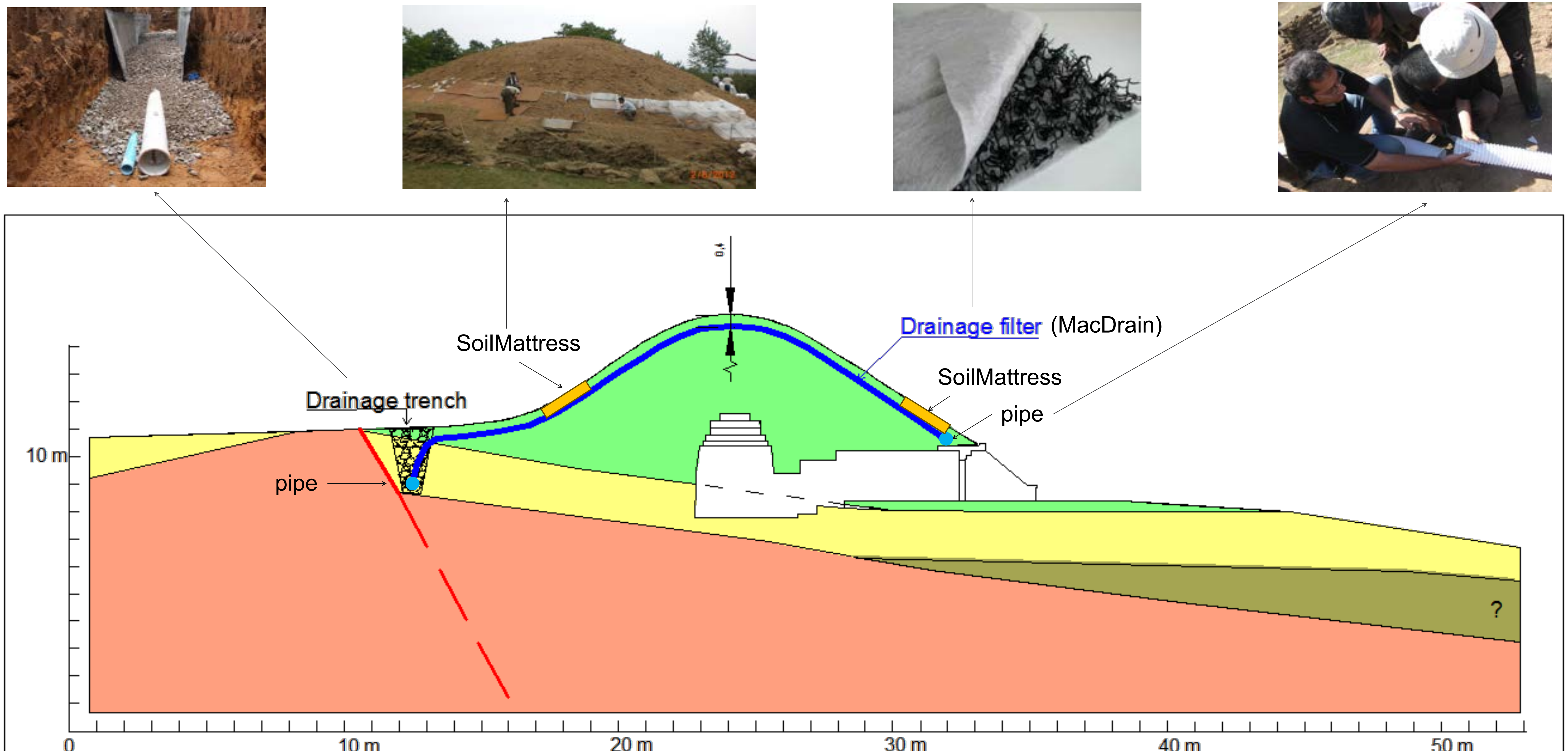
Kogurio, Susanri (North Korea)

Water infiltration and flooding during heavy rainfall

Model for rising dampness



Concept



SoilMattress
Drainage filter (MacDrain)
SoilMattress
pipe
Drainage trench
pipe
10 m
?
0
10 m
20 m
30 m
40 m
50 m

Kogurio, Susanri
(North Korea)

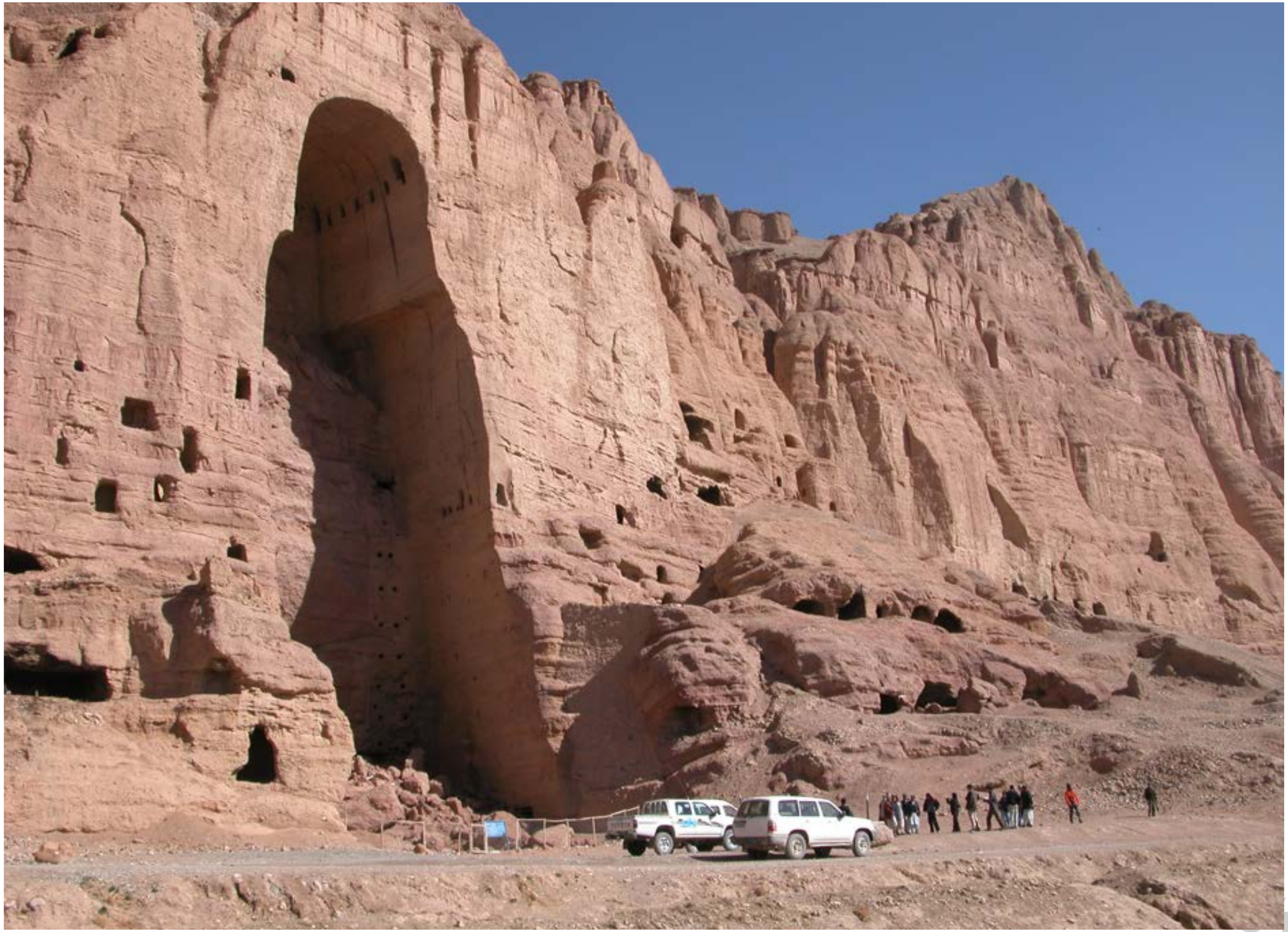
Damage on mural paintings

Investigating the underground and monitoring

Waterproofing the tombs

Bamiyan

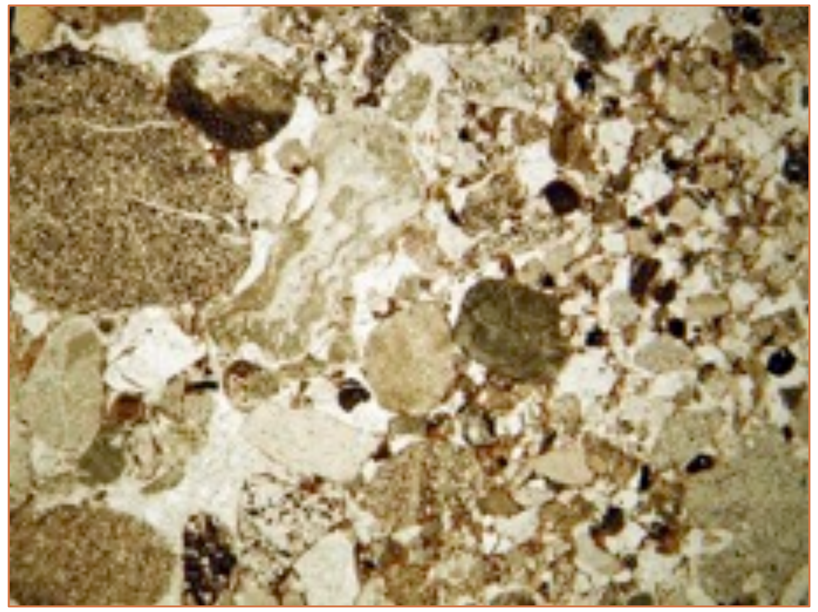
Afghanistan

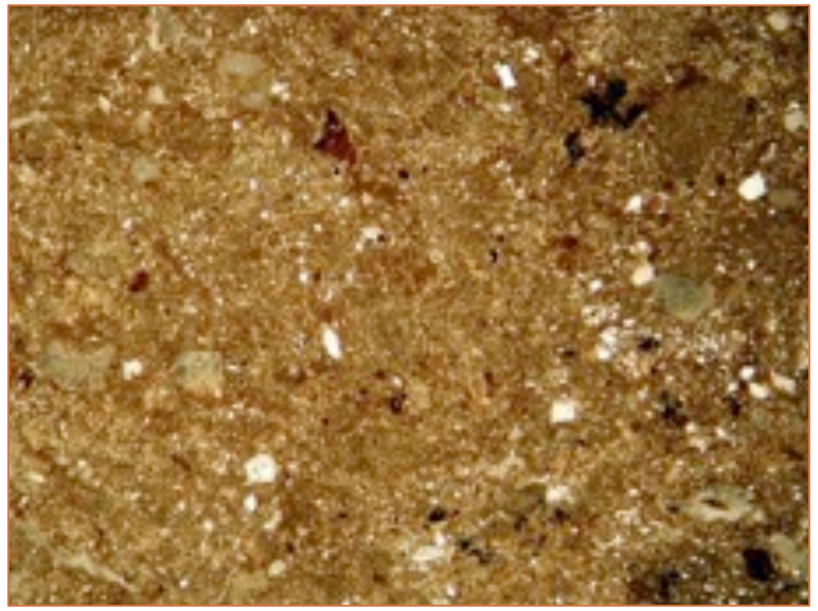


14 March 2001

The destruction of Bamiyan Buddhas. 6 charges of dynamite, each of them about 250 Kg

The parent material





Geology of the site: slaking materials

Balancing Vibration and Slaking

Heavy equipments

Roto-percussion hummer. Limited vibration allowed and high attention to cooling of rotary head.

medium-heavy equipments

Rotary. High attention to cooling of rotary head.

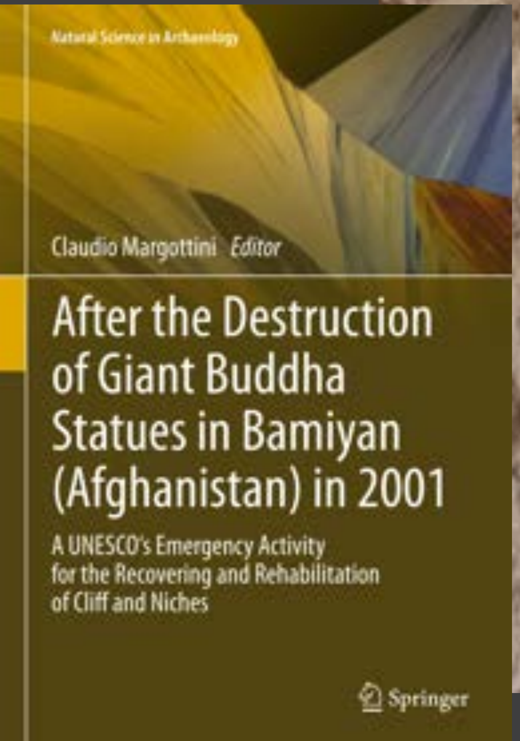
light equipments

Rotary. High attention to cooling of rotary head

Very light equipments

Rotary. High attention to cooling of rotary head

Involvement of Local Community

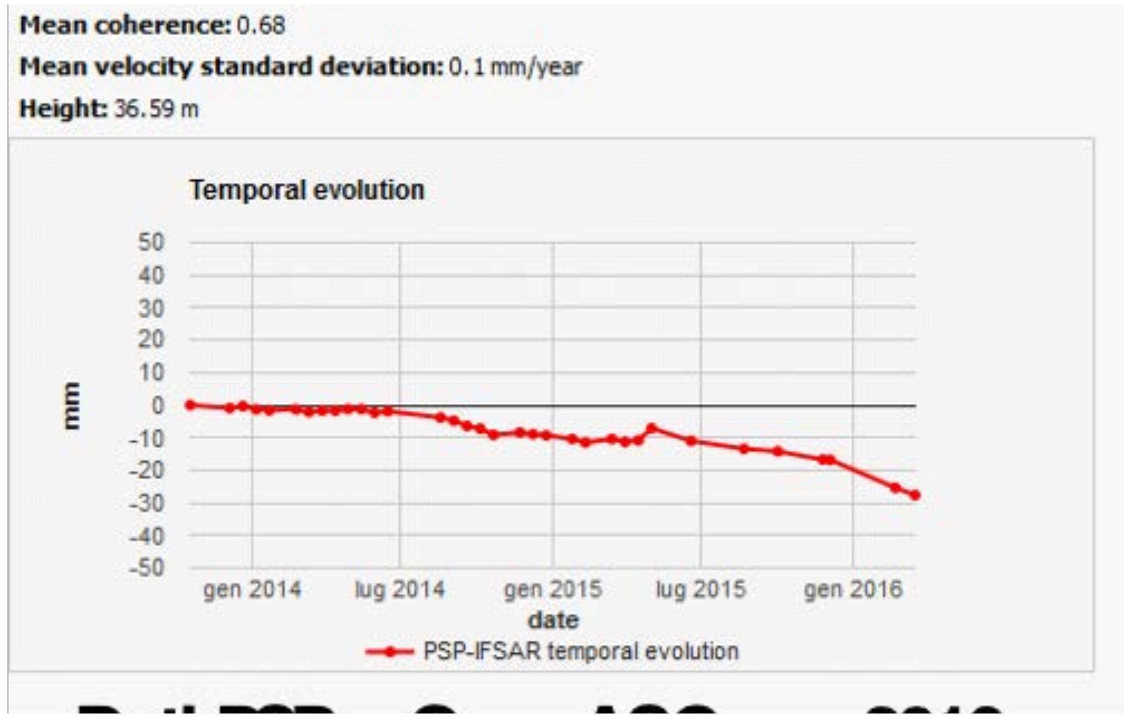



Pompei Italy

Pompei monitoring

Area with unstable buildings

PS monitoring

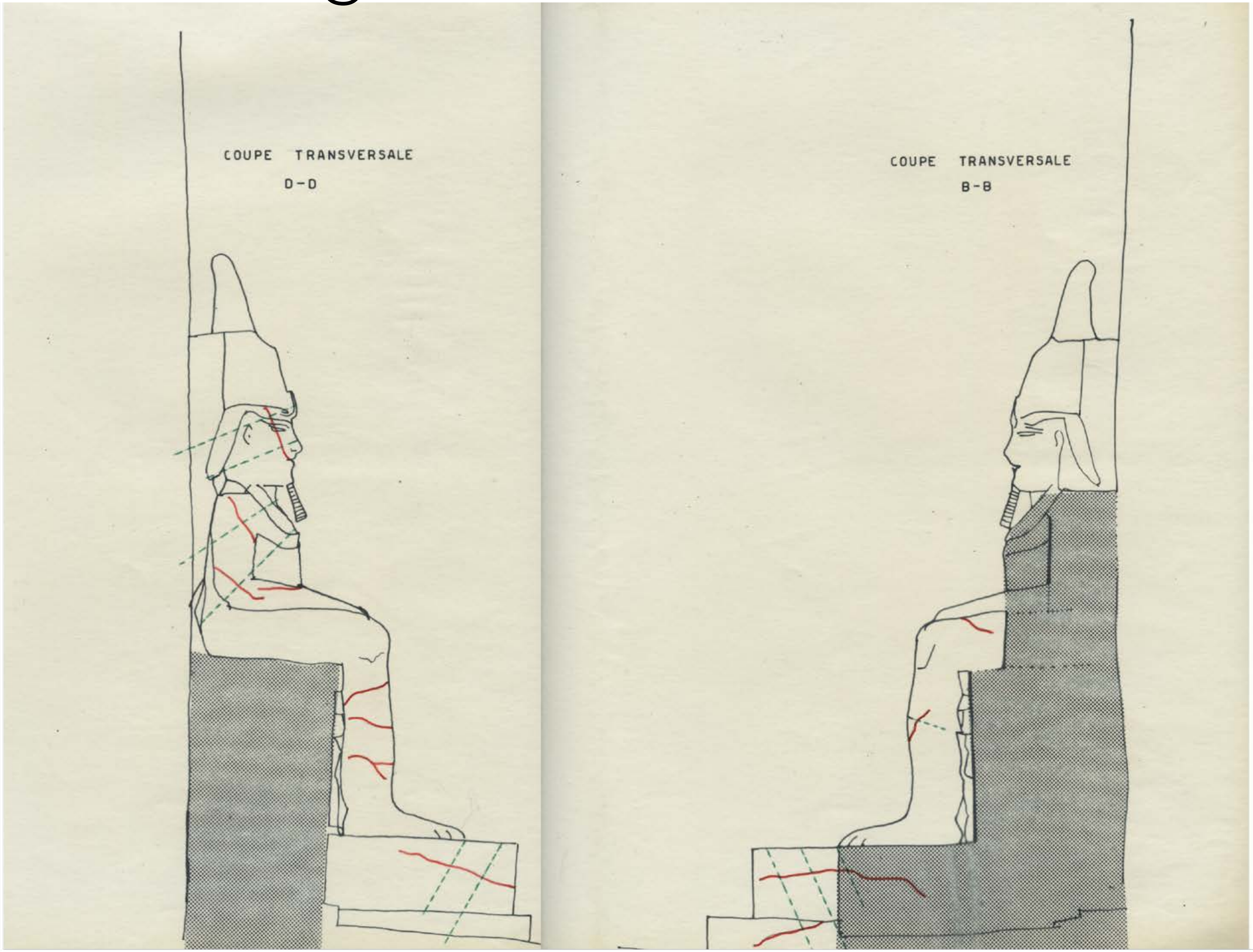


Time history

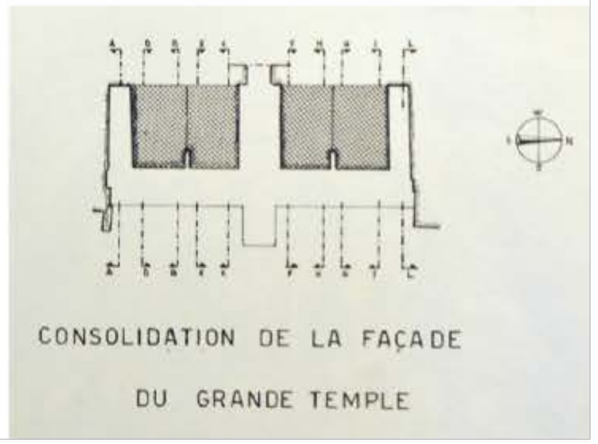
Radar Interferometry to anticipate the collapse of historical buildings in Pompei

Abu Simbel
and Piero Gazzola (1959)

Great temple: discontinuities (red) and bolts (dashed green) for consolidation of statue 1



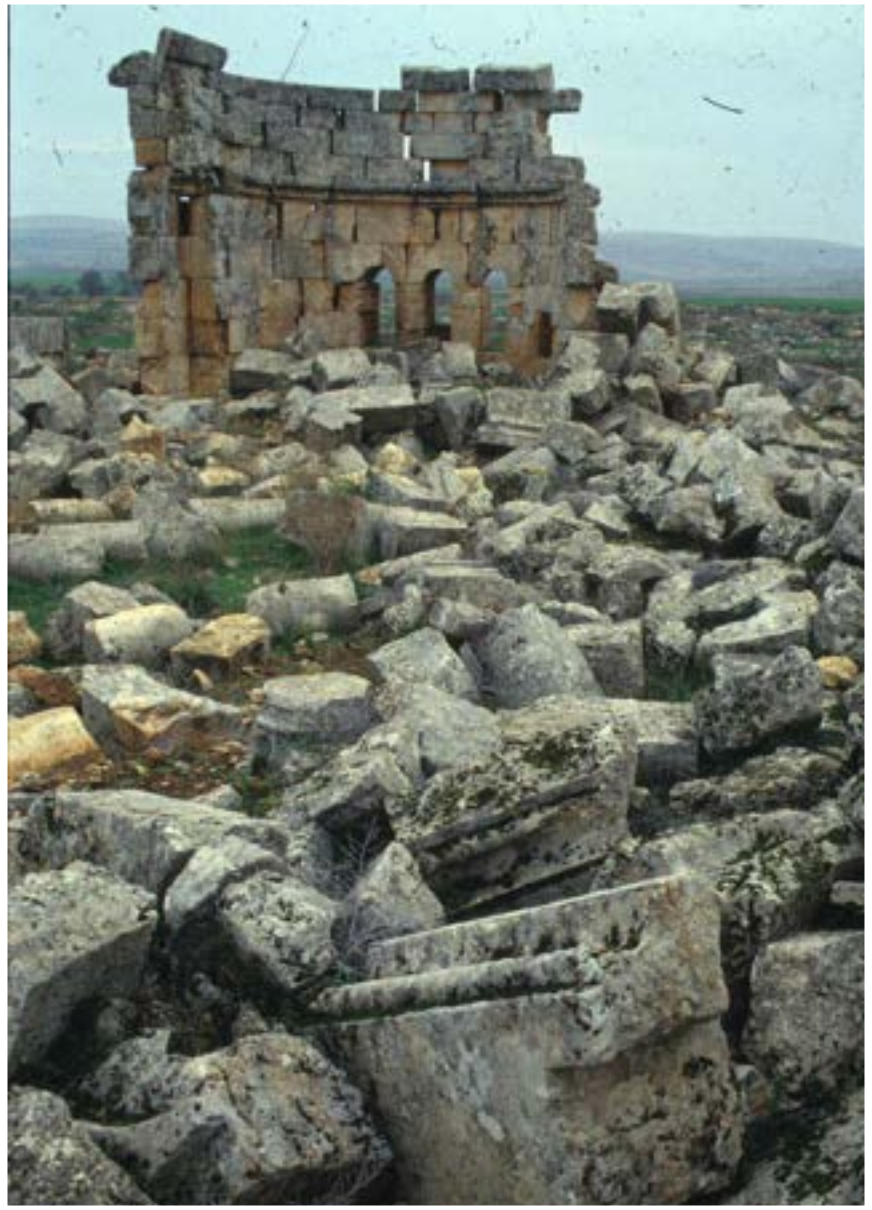
Credits:
Piero Gazzola at the orginof Rock Mechanics forCultural Heritage.
The first project to saveAbu Simbel in 1960.
Curators of exhibition
Claudio Margottini and Silvia Dandria
14 MAY - 20 MAY 2022
Faculty of Engineering, Cairo University
Cairo, Egypt



Seismicity

Petra, Jordan

Syria dead towns

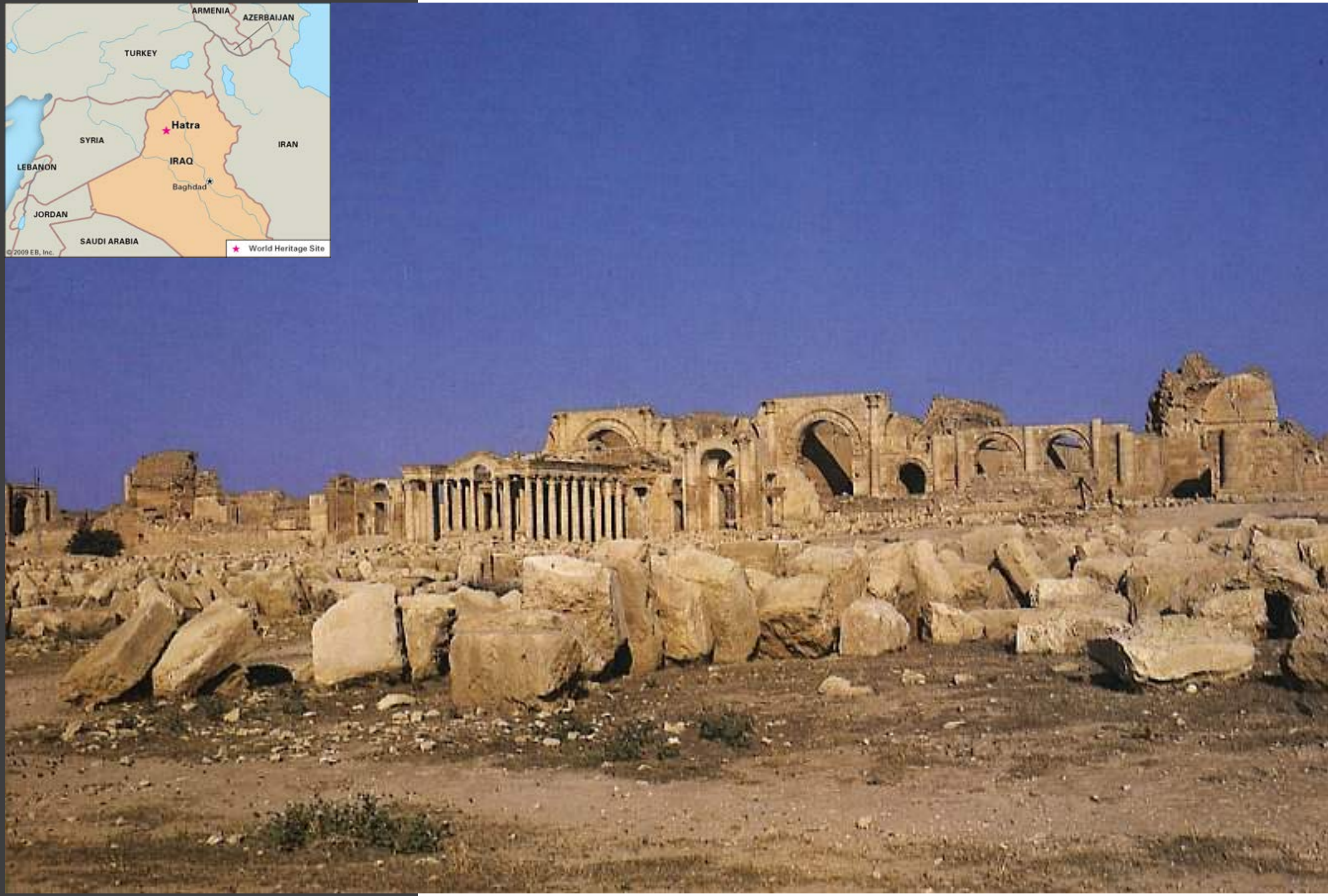


Mais

Dahes

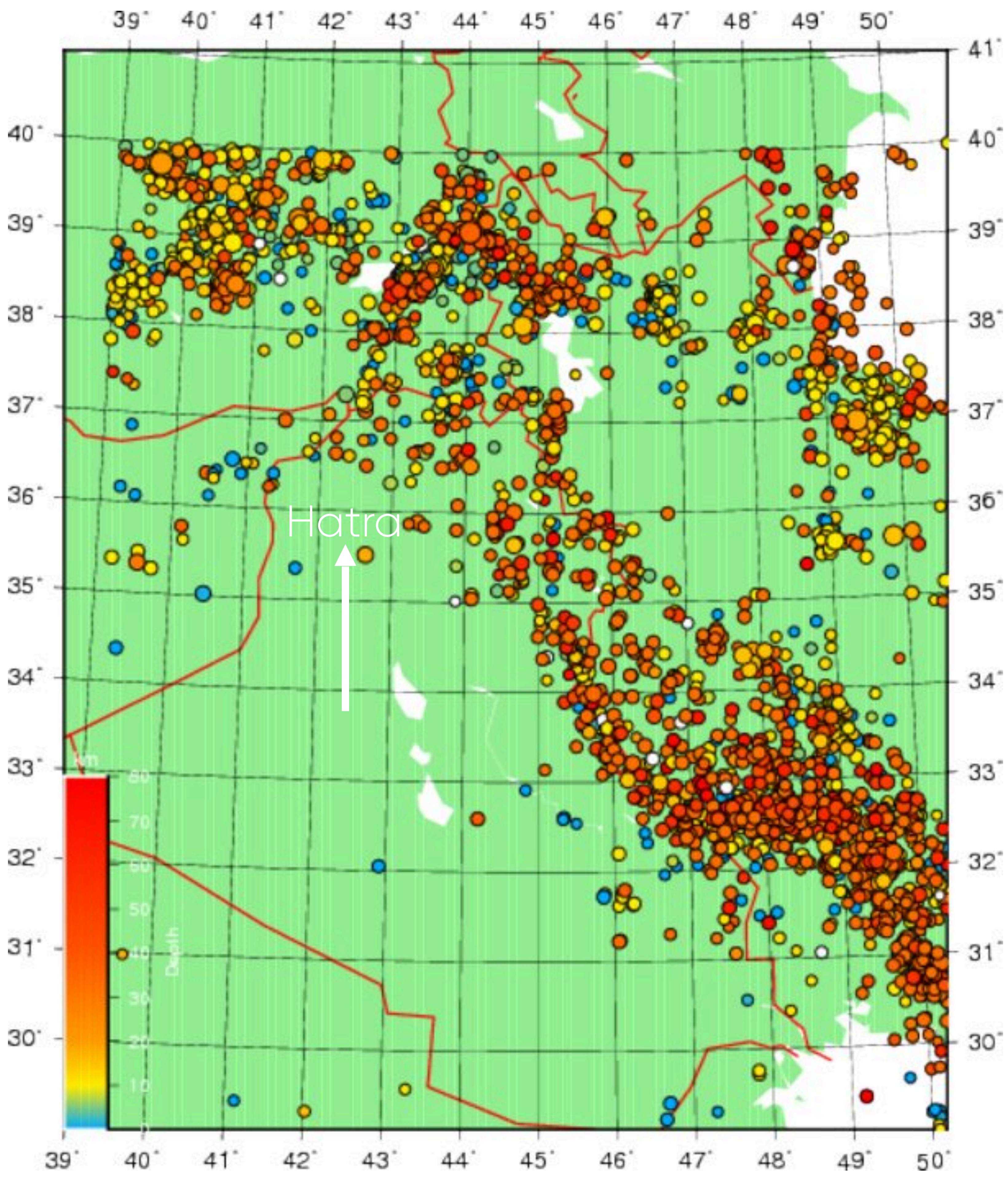
San Simon

Mushabak Palace

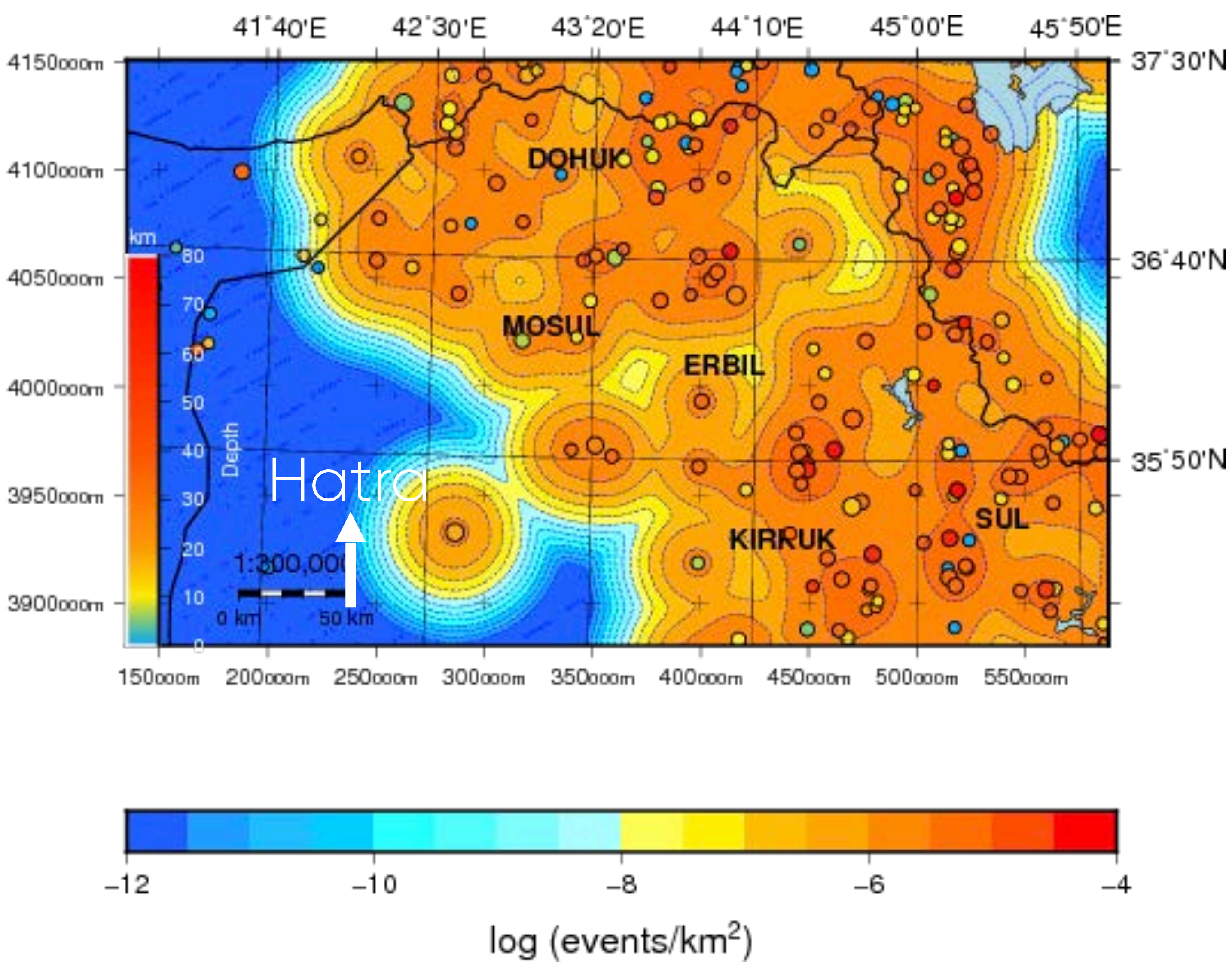


Hatra, Iraq

Hatra is an archaeological site, located 80 Km SW of Mosul (Central Iraq). It was a very important town in the 2nd century when it was the capital of a small state, independent form both Roman and Parthian Empires. The city is situated between the rivers Tigris and Euphrates, in the northern desert, near the river Tharthar. The history of this city falls mainly between the 1st century BC. and the 3rd century AD... It was inhabited by desert tribes and was an important commercial, religious and military centre due to its location on the main caravan routes across the desert, running east to west and north to south.



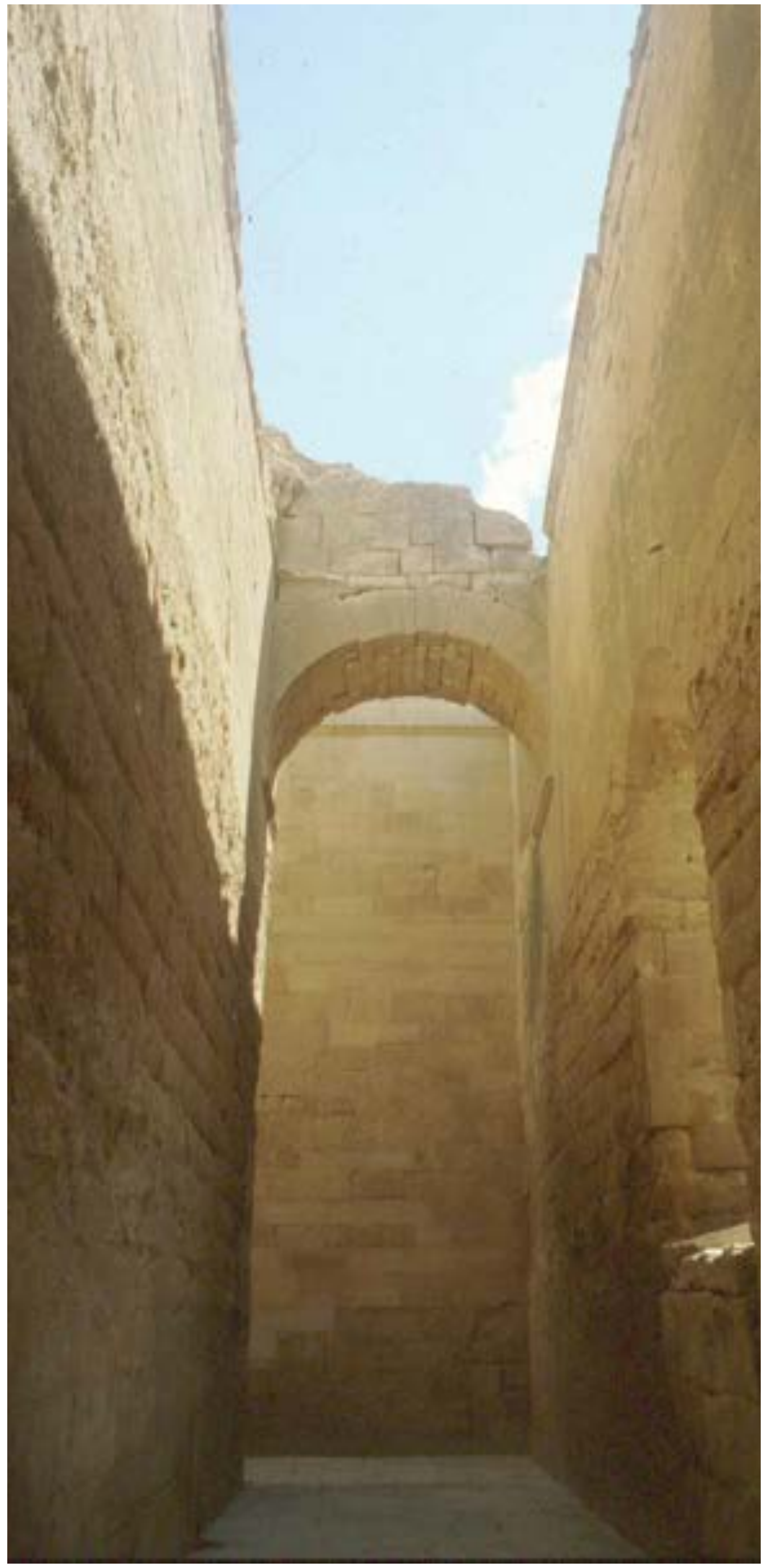
Seismicity of Iraq, between 1924 and 2015



Aleqabi and Ghalib, 2014

Hatra
Damage assessment

The result of this research performed in the historical site of Hatra demonstrated that probably, one or more earthquakes occurred near the city since its destruction in 250 A.D. The present damage likely referred to seismic motion(s) exibit partial collapses and heavy deformations and fracturings, likely for the effects of different shocks. Nevertheless, the assessment of occurrence of vibratory ground motion is still controversial, even if some effects, like the ones of the enlargement of walls in North direction and the collapse of part of the walls in the same direction, are very difficult to explain with other reasons.



Gurpinar and Margottini, 1996

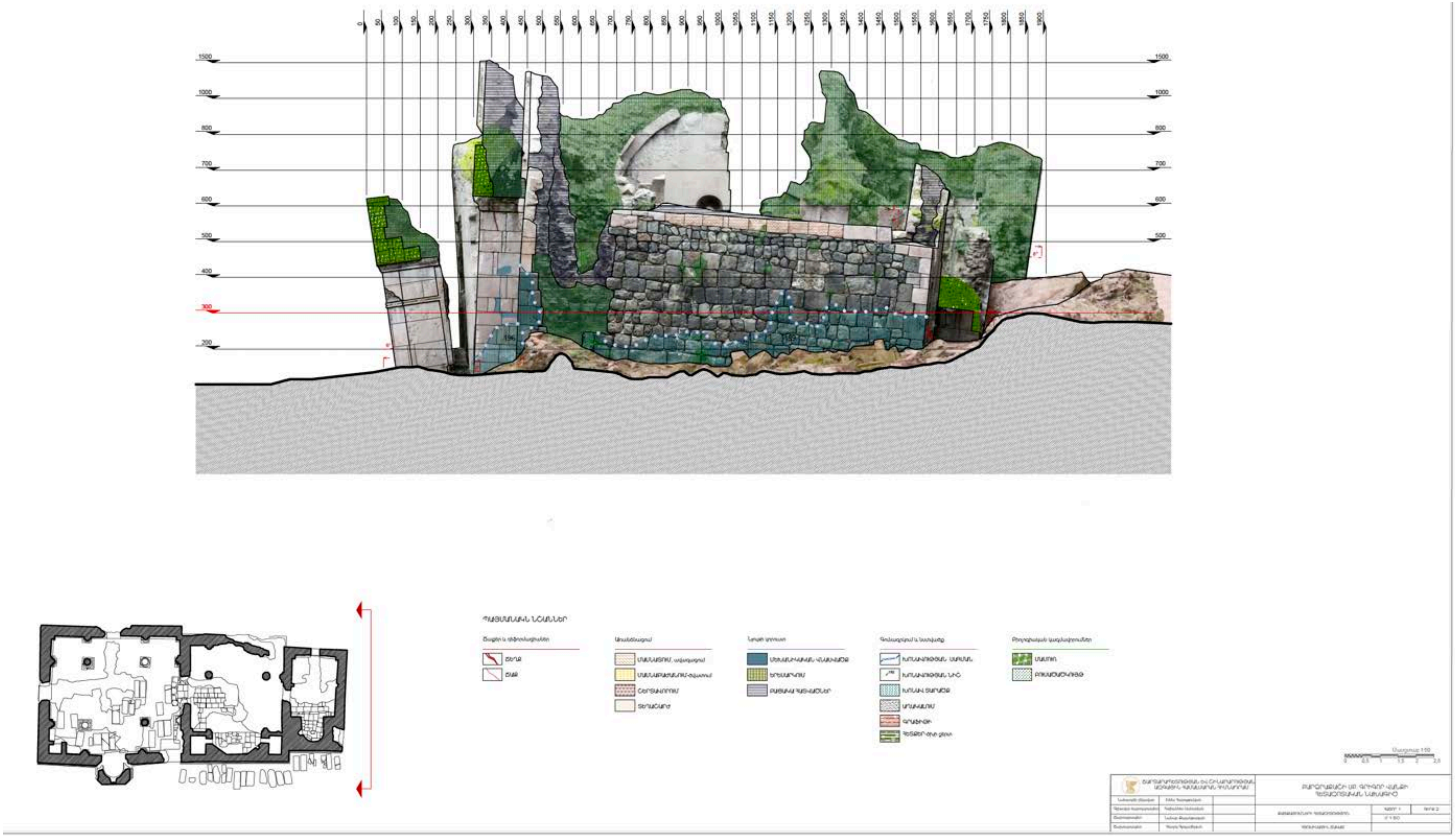
Hatra 2015 March 7

Bardzrakash
Armenia

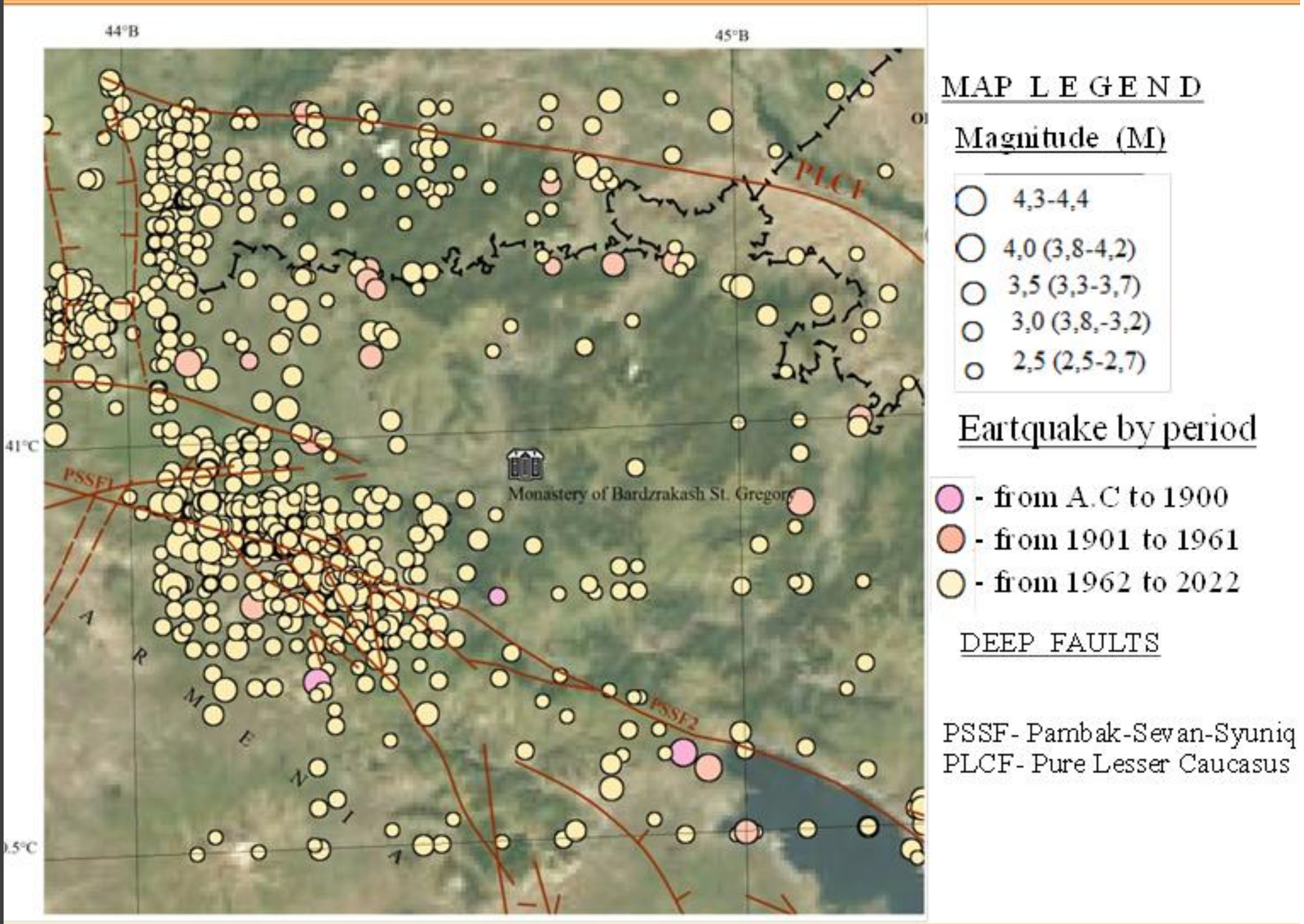
Saint Gregory Monastery

Bardzrakash
Armenia

St. Astvatsatsin church
Gavit
St. Grigor church


1500
1000
800
700
600
500
400
300
200
0 0.5 1 1.5 2 2.5

Seismicity



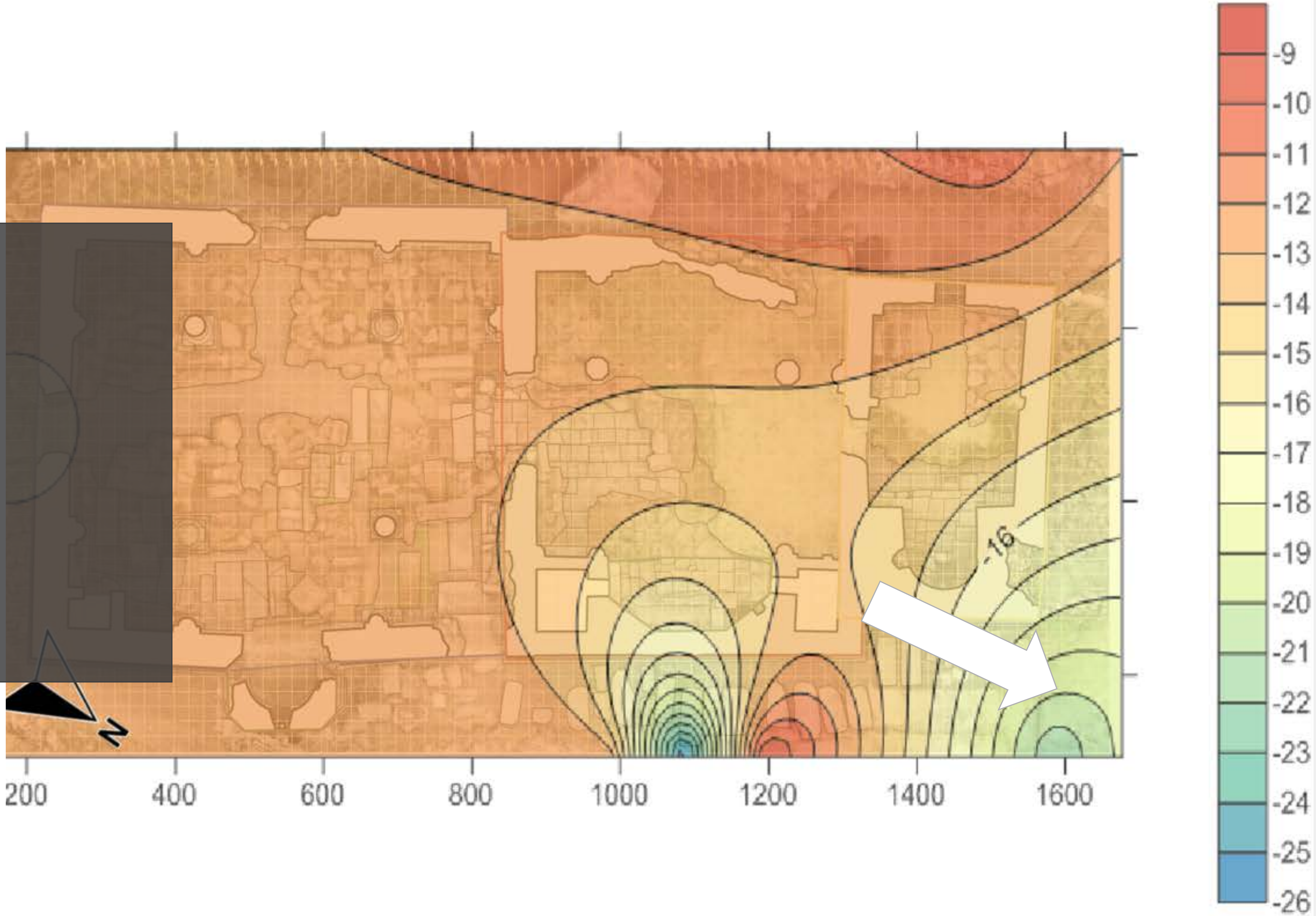
Map showing earthquake sources (2.5 < M < 4.5) and active faults in the territories adjacent to the Bardzrakash St. Gregory Monastery, within a radius of 50 km from the site, from antiquity to 2022.

Direction of the out-of-plomb
(red arrow) for the existing walls.

Sketch of interpretative geophysical sections

3D

Rocky bedrock

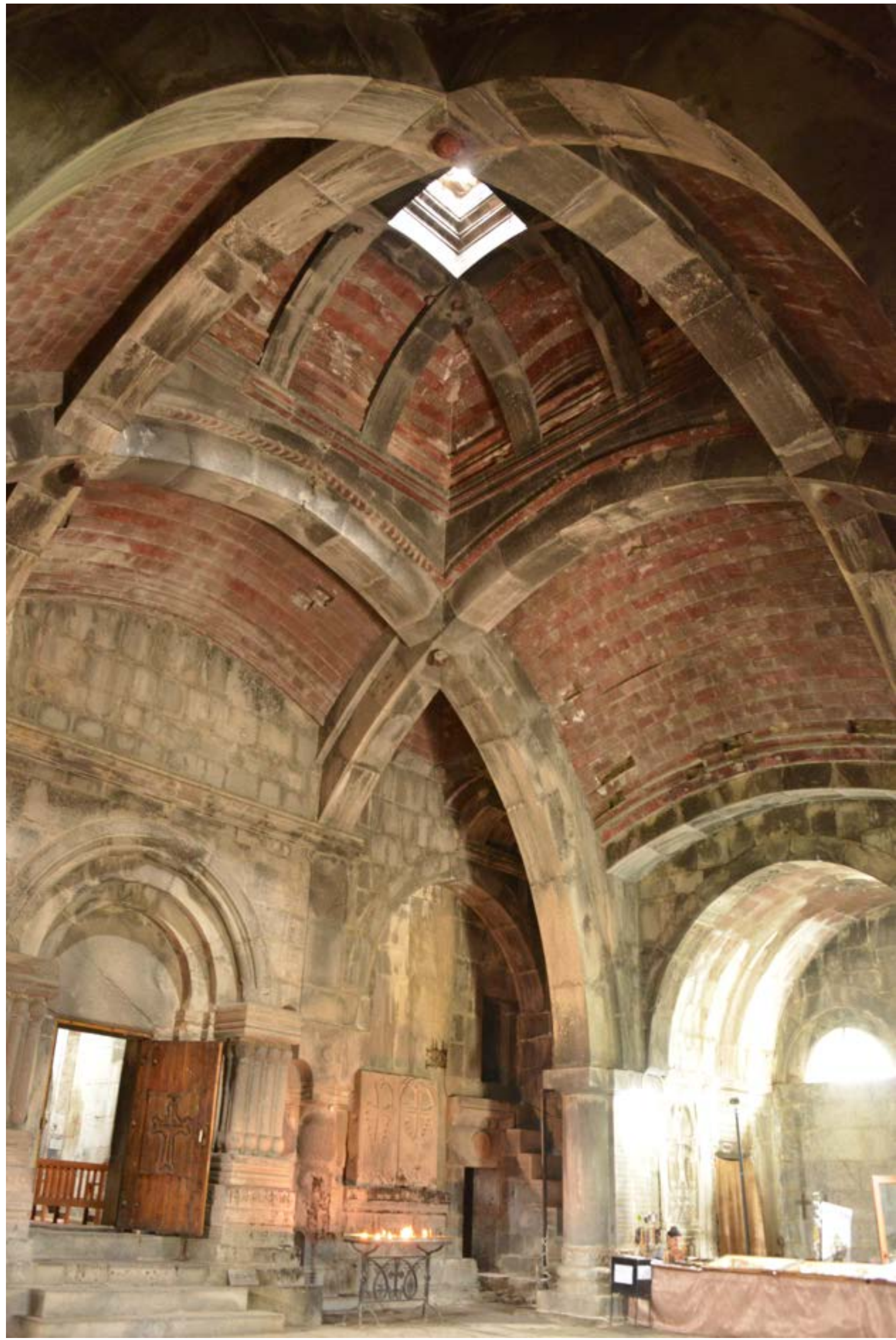


Bardzrakash (Armenia)

Conclusion

- the monastery is lying on a morphological terrace along a steep slope;
- the underground, according to Karapetyan et al. (2022) is constituted by 10 to 20 meters of coarse-grained soils ($\rho 1$= 300 ohms), soils with sandy clay filling ($\rho 2$= 100 ohms), loamy soils ($\rho 3$= 25 ohms). The bedrock is represented by andesite porphyrites ($\rho 4$ > 100 ohms). Preliminary and interpretative geophysical sections are reported, representing an average value among the data obtained in the field;
- the bedrock is not uniform under the Monastery and even not clear from the geophysical data. The northern part with the older church overly a thicker strata of soil material and the rocky bedrock is at 20 m in average. The Southern Church from 13th C. is standing over 12 meters of soil material before the bedrock. The central part is representing a passage zone from South to North; also, in this area the bedrock seems to be higher than in other parts, suggesting a possible rocky separation/discontinuity between the two sides;
- the bedrock, with its anomalies, is reproducing the surface topography;
- the oldest part of the Monastery, from 10th C., it only leans Southward (in direction of the rocky cliff), while the other masonry walls lean towards the outside of the structure (Fig. 2);
- the leaning of the oldest small church (10th C.,) can be preliminarily explained with a surface deformation along a hypothetical slow moving sliding plane, below the surface and corresponding to the lowering of the strata between South and North zones of the Monastery;
- The seismicity of the area, very relevant according to the study of Karapetyan et al. (2022) could have played a role, most likely as trigger mechanism for a slope instability more than a direct damage. This assumption is because the direction of walls leaning are not in a unique direction, as expected for strong vibratory ground motion.

Haghpat Monastery

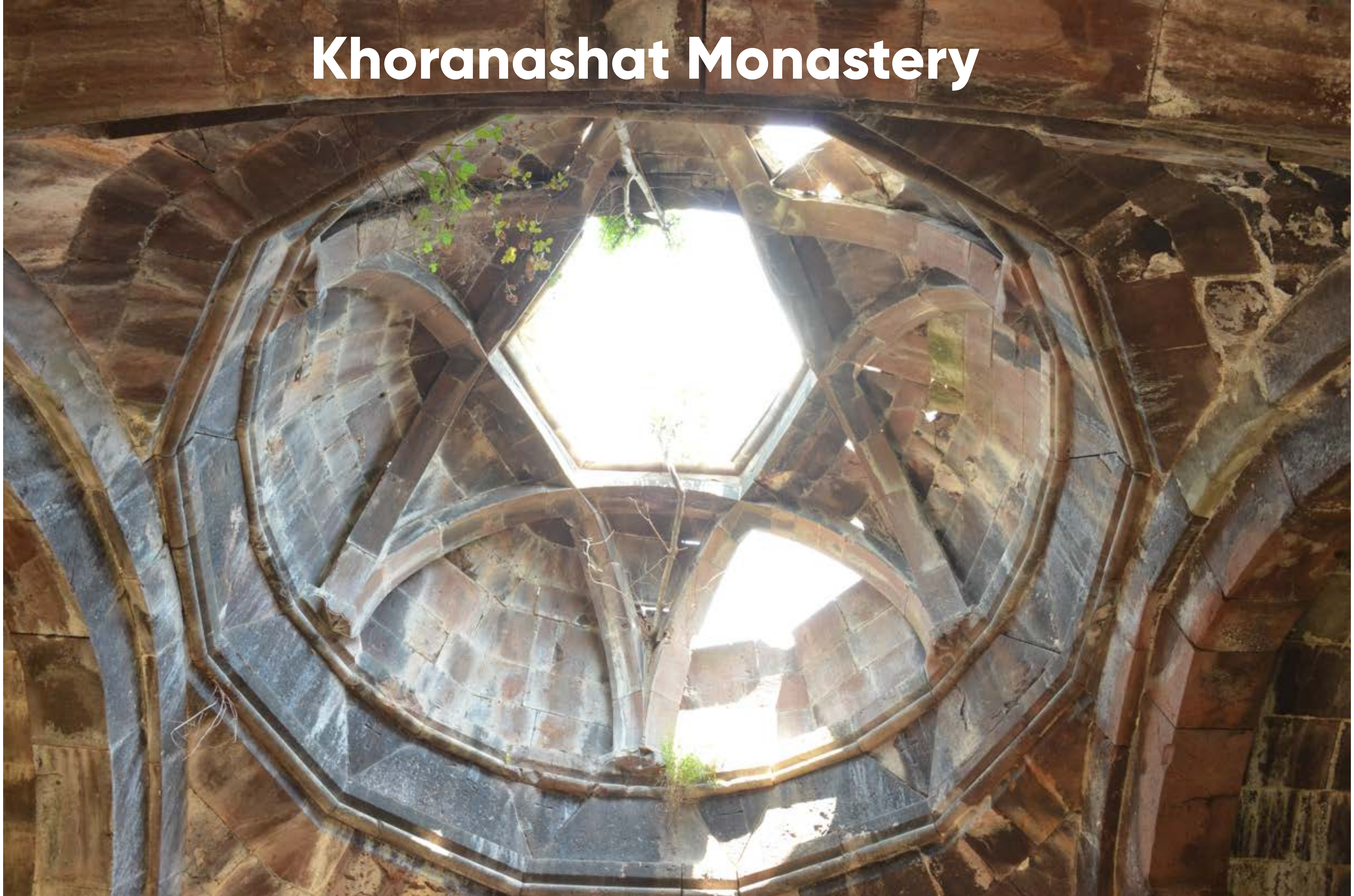


Haghpat Monastery

Haghpat Monastery

Khoranashat Monastery

Khoranashat Monastery

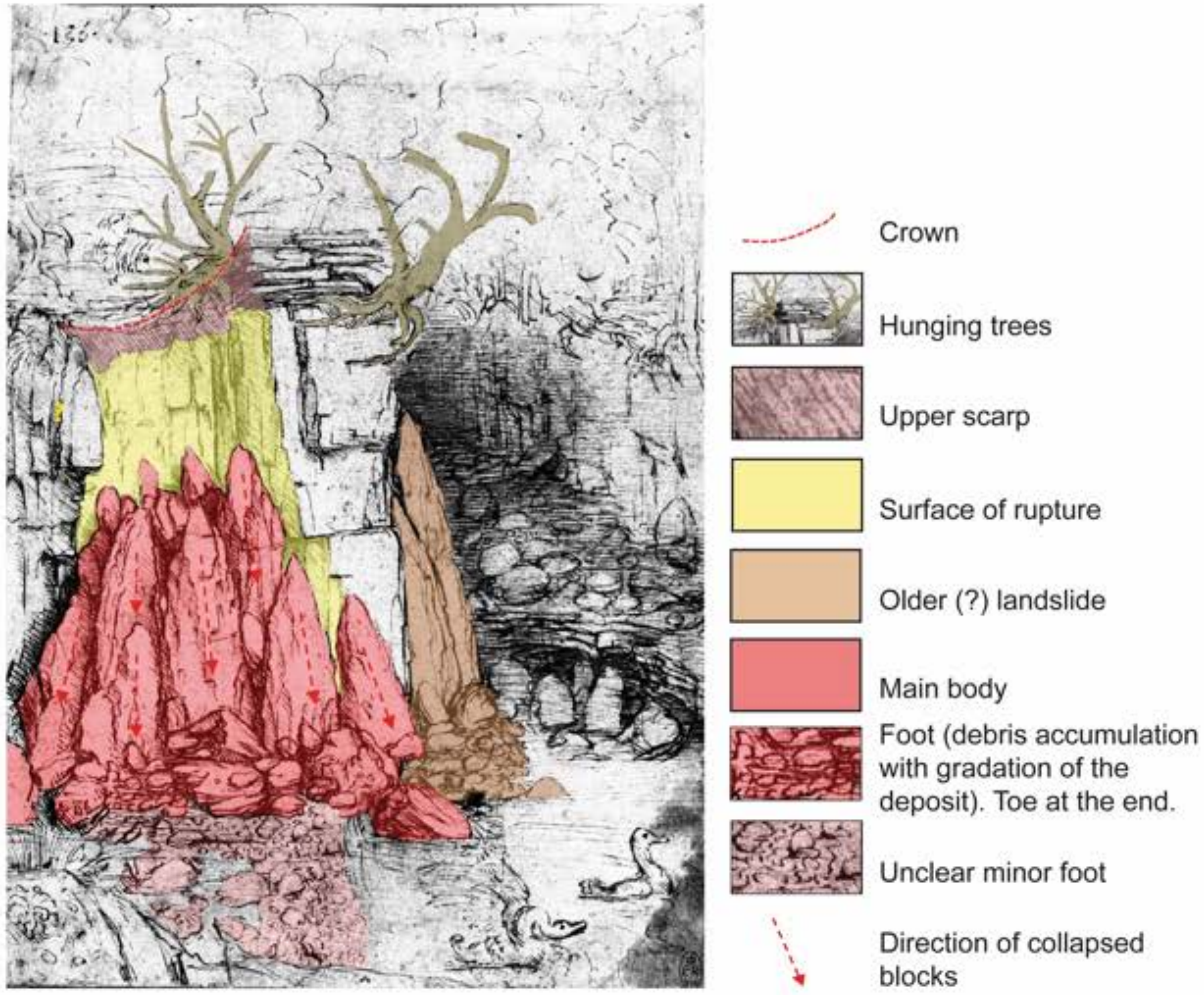


Leonardo da Vinci 1482 – 1485

Leonardo during his life demonstrate a clear interest in natural phenomena, such as landslides.

The first drawing was probably prepared in the period between 1482-1485, which coincides with his moving to Milano in 1482. The sketch, "A ravine", pen and ink (22.0 x 15.8 cm), is currently displayed at the "The Queen's Gallery, Buckingham Palace", London (UK). It should be clarified that the word ravine identifies a small narrow steep-sided valley that is larger than a gully and smaller than a canyon and that is usually worn by running water (https://www.merriam-webster.com). In other words, the art expert's attention was mainly devoted to the canyon and not the slopes.

Leonardo da Vinci the first detail landslide in the history of art



Margottini, 2021

05

Synthesis and outlook

Lessons from 30 years and tens of heritage sites on 5 continents

Conclusion

- Protection and conservation of cultural heritage is a science at the border between earth sciences and rock mechanic, archaeology and history of art and, finally, social sciences when operating in low income Countries. To maintain the authenticity and integrity of the site, any mitigation project has to provide effective solutions, very often innovative, to be combined with original architecture and environment. The harmonization of advanced solutions with historical heritage further require a mitigation project (sometimes pioneering), with a design that is minimizing the impact of new intervention, possibly recovering traditional materials and/or solutions or the re-use of original construction techniques. In Low -Income Countries, the usage of original construction techniques also ensures maintenance by local workers, thus enhancing sustainability.

- Viggiani (2013) reports that the conservation of monuments and historical sites is one of the most challenging problems facing modern civilization. It involves a number of factors belonging to different fields (cultural, humanistic, social, technical, economical and administrative) intertwining in inextricable patterns. The complexity of relationship between earth sciences and cultural heritages is increasing when adding the geomorphological processes and related threats.

- As a consequence of such complexity, for most engineers, the interaction between Geotechnics and the protection of ancient buildings is seen only from the standpoint of the design and execution of consolidation measures (Calabresi, 2013).

- A Pan-disciplinary approach is required.

Six strategic pillars

Synthesis of conclusions — 87 sites, 30 countries, 30 years of fieldwork

01

Proactive model works

Tested at about 87 sites across 30 countries — consistently outperforms reactive emergency response in both cost-effectiveness and conservation outcome.

02

Non-invasive first

Modern geoscience technologies deliver the information needed to understand hazard mechanisms without compromising heritage integrity. Even accurate monitoring should be less impacting as possible.

03

Diagnosis is non-negotiable

Wrong diagnosis leads to interventions that accelerate the very deterioration they are meant to prevent.
Precise diagnosis – supported by accurate investigations and monitoring – is fundamental.

04

Authentic, minimising intervention

Mitigation must combine effective solutions with original architecture — recovering traditional materials and techniques, minimising impact on heritage fabric.

05

Traditional knowledge is science

Local expertise is not inferior — it is scientifically validated and sustainable. It must be respected and integrated into every conservation strategy.

06

Climate change is already here

Measurable at documented heritage sites. Proactive, anticipatory management is not a luxury — it is urgent. The downscaling gap must be closed.

The operative sequence

Without this sequence, every intervention is a decision taken in ignorance of the process it is meant to arrest

1 Understand the hazard process

Engineering geological model · Geomechanical characterisation · Non-invasive investigation · 3D diagnosis before any intervention

2 Design in order to Preserve integrity & authenticity

Venice Charter · Nara Document · Reversible, compatible materials (NHL) · Minimising footprint · Innovative solutions respecting OUV

3 Enhance traditional knowledge

Local expertise as science · Original construction techniques · Community capacity building · Sustainability in low-income countries

> "Protecting heritage from natural hazards is not a luxury, but a fundamental humanitarian consideration — especially at a time when traditional knowledge that provided protection from natural hazards is being progressively abandoned."
>
> Proactive, anticipatory management is not optional. It is urgent.


THANKS FOR WATCHING!
GRAPHICRIVER.NET