Natural hazards in the Abruzzi Apennines (Italy)and the risk to archaeological sites

Fabrizio Galadini[1], Emanuela Ceccaroni[2], Emanuela Falcucci[1], Stefano Gori[1]

[1]Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome, Italy.
Email: fabrizio.galadini@ingv.it
[2]Soprintendenza per i Beni Archeologici dell'Abruzzo, Chieti, Italy.

Abstract

Regulations and advice from different institutions and associations indicate the necessity for preventive measures to avoid future damage to our cultural heritage. To do so, the appropriate knowledge of the various historic catastrophic events (natural or anthropic) that have struck the monuments has to be gained. This knowledge of our archaeological heritage needs: (i) estimation of the risks related to the natural environment, through local geological - geomorphological investigations; and (ii) definition of the natural events that have affected the site of interest, through geoarchaeological and historical investigations. These issues imply, for example, that a typical aspect of the use of our cultural heritage (i.e. the creation of *in-situ* museums) also needs to be planned within the framework of the natural/environmental dynamics. Following these guidelines, four Roman archaeological sites in the Abruzzi Apennines (central Italy) have been investigated. These sites are characterised by a natural criticality that is evident in the archaeological stratigraphy and which is detectable in the local geomorphological framework. We have analysed the effects of: (i) strong earthquakes in the archaeological area of *Alba Fucens*; (ii) the sliding of limestone blocks at Luco dei Marsi (*Angitia*); and (iii) colluvial events at San Benedetto dei Marsi (*Marruvium*) and Castel di Ieri. These processes continue to contribute to the local natural hazard and exhibit problems for actions related to the preservation of these archaeological sites. Therefore, it is evident that their characterization is necessary for mitigation of the risk, and the continued preservation and use of the heritage sites.

1. Introduction

The Italian regulatory framework (e.g. Legislative Decree N° 42, 22 January, 2004) and the documents produced by different institutions and associations (e.g. the International Council on Monuments and Sites [Icomos], http://www.icomos.org; the Italian Ministry for Cultural Heritage [Mibac], http://www.beniculturali.it; the Association for the Renewal of the Built-up Areas [ARCo], http://associazionearco.blogspot.com/) clearly state (i) the need for precautionary measures to preserve our cultural heritage and, as a consequence, (ii) the appropriate knowledge of the various historical events (natural or anthropic) that have affected this heritage.

These concepts arise from decades of methodological discussions and scientific enrichment, with milestones such as the "Athens Charter for the Restoration of Historic Monuments"[1] and the "Washington Charter for the Conservation of Historic Towns and Urban Areas"[2]. The latter includes the principle of the protection of the architectural heritage against natural disasters. More recently, the knowledge of the history of the natural damage at a site, as revealed by historical and/or archaeological approaches, has been considered for inclusion in studies that need to be performed during diagnostic phases preceding any conservational interventions[3,4].

In short, the various requirements can be summarised as the following practical points: (i) procedures for preservation and repair need to include an estimation of any potential territorial fragility that might arise from the natural environment[5]; and (ii) risks need to be assessed through definition of the natural events that have occurred at any site of interest. This means, for example, that the feasibility of *in-situ* museums, the usual use of our cultural heritage, has to be studied within the context of the natural/environmental dynamics.

On the basis of these issues, the present study describes four cases of archaeological sites in the Abruzzi Apennines (central Italy). These are characterised according to the natural criticality that is detectable in the archaeological stratigraphy and is evident from the local geomorphological framework. These aspects represent potential elements of territorial weaknesses, and can cause evident problems in any actions related to the preservation and fruition of an archaeological site. The reader should consider that the described cases have only the function to discuss critical situations that are common for the archaeological heritage of the Apennines. Indeed, numerous other sites may be discussed in order to corroborate this evidence.

The following sections are thus dedicated to an investigation of damaging natural events that have their effects recorded in the archaeological stratigraphy, of ancient settlements in the Abruzzi Apennines. The characterization of these events leads to the information necessary for the definition of an action plan for the protection of archaeological sites from natural catastrophes when they are transformed for cultural and tourist purposes, or which have already been used for these purposes for several decades.

2. Geological framework

The Plio-Quaternary geological history of the Abruzzi Apennines has been characterised by strong chain uplift[6,7] and pervasive normal faulting[8,9]. These geological processes have increased the relief energy, which in turn has generated or accelerated erosion processes and caused the widespread evidence of instability. Faulting has been (and is) responsible for the strong seismicity of this region, which is characterised by earthquakes with magnitudes up to 7.

Considering these geological characteristics, various natural events would have had significant impact on the history of the ancient settlements of the Abruzzi Apennines. In particular, it can be expected that the effects of earthquakes, floods, landslides and climatically conditioned rapid deposition along the mountain slopes have been ‘recorded’ by the archaeological sites. Indeed, this framework of territorial fragility is suitably illustrated by the case studies summarised in the following sections (Fig. 1).

3. Case studies

3.1 The town of Alba Fucens

Alba Fucens is one of the most outstanding archaeological sites of the Abruzzi region. Excavations began at the end of the 1940s, with the uncovering of the remains of an ancient Roman town (Fig. 2a). The town was crossed by the main road that connected Rome, i.e. the Tyrrhenian coastal areas, with the Adriatic regions of peninsular Italy. In the second half of the 20th century, the remains of a Temple dedicated to Hercules, baths, a theatre, an amphitheatre, and a number of ancient shops (*tabernae*) were excavated. In the 1950s, archaeologists hypothesised that the ancient town was destroyed by a strong earthquake. This is based on the findings of impressive collapse units, which include huge portions of walls, columns with juxtaposed capitals, and the remains of roofs sealing pavements and floors[10,11].

Moreover, the collapse units have sometimes included large collections of coins, which indicate that the buildings were abandoned after the destruction.

New excavations performed since 2006 have provided more support for this hypothesis, as further impressive collapse units have been uncovered at different sites in the Roman town, together with the remains of an ancient victim trapped in the ruins following the earthquake[12].

Palaeoseismological investigations performed during the 1990s in this part of the Abruzzi Apennines identified active fault sections that represent the surficial expression of the Fucino seismogenic source[13]. In 1915, this source generated an earthquake of magnitude 7.0, which was responsible for more than 30,000 casualties. The same investigations defined a previous fault activation occurred during the 5th-6th century AD. From an archaeological point of view, the palaeoseismological result is consistent with the evidence of destruction at different sites in the region surrounding the Fucino fault[12]. For example, a bone sampled from the human remains of the above-mentioned victim of the earthquake indicated an age of 435-491 AD/ 509-517 AD/ 529-607 AD (2 sigma calibrated age). On the whole, the data summarised by Galadini et al.[12] allow it to be hypothesised that this seismic destruction of *Alba Fucens* occurred in the 5th-6th century AD.

Alba Fucens was definitively abandoned during the Middle Ages, when a new settlement was built on a hill adjacent to the previous Roman town. But this mediaeval village also experienced seismic destruction. This occurred as a result of the above-mentioned 1915 earthquake, which caused damage at this site that was estimated as 10-11 degrees on the Mercalli-Cancani-Sieberg (MCS) intensity scale[14].

In the framework of this particular seismic history, the results of the archaeological interventions at *Alba Fucens* did not generate significant concern relating to the preservation of the cultural heritage. Indeed, the present visible remains are generally represented by walls a few tens of centimetres high, or little higher than 1 m, with confined foundations. However, the choice that was made during the 1950s to restore some of the pillars and columns in their original positions creates cause for concern. The most impressive case of this action in the past century can be seen in the so called *Via dei Pilastri* (i.e. Street of Pillars). Here, the ruins of the facade of an ancient *taberna* were found in a thick collapse unit that included the remains of three pillars lying across the street (Fig. 2b). This unit indicates sudden toppling during Late Antiquity[12]. Some time after this important discovery, the pillars were assembled again, although they were completely isolated from their original context. This choice was evidently adopted without taking into account the possible effects of any future seismic shaking, even though the seismogenic characteristics of the region were known already in the 1950s, and indeed, the archaeologists at that time were also collecting the evidence on the past seismic destruction of *Alba Fucens*. It should be noted that, in this case, the concern about the damage of these three pillars at *Via dei Pilastri* is not related to the intrinsic value of these as archaeological structures. Instead, over the past few decades, these pillars have progressively become a sort of symbol of *Alba Fucens*, as they have been continuously photographed and used in generations of postcards. For this reason, we believe that this is one of the typical cases where article 29 of Italian Legislative Decree N° 42 should be applied, with reference to the statements on interventions for structural improvements to reduce the present seismic risk.

3.2 The Sanctuary of **Angitia** *(Luco dei Marsi)*

The Sanctuary of *Angitia* was uncovered during archaeological operations between 1999 and 2011. At present, various sacred buildings of the Roman age that were built after the 3rd century BC are visible, and some restoration has been carried out on the exposed walls and remains, to allow the use of the archaeological area.

However, these remains are located at the base of a slope that is characterised by morphological evidence of instability at various scales (Fig. 3). Indeed, gravitational trenches and double crests with axes parallel to the slope have been detected in the uppermost portions of the relief. These landforms are expressions of deep-seated gravitational motion along sliding planes, that here have dimensions that are comparable to the entire slope. The uppermost limit of the unstable mass – i.e. the emergence of the sliding plane – can be seen in plan view by the typical horseshoe-shaped morphological trace. At lower elevations, landslide scarps can be detected in the unstable mass, which testify that this slope has already generated a number of landslides, with the consequent accumulations close to the shore of ancient Lake Fucino. This instability is also evident at even lower elevations, i.e. very close to the archaeological area, where the slope is carved into the pervasively jointed carbonate bedrock. The tectonic joints, which are subvertical and gently dipping towards the valley (Fig. 4a), define prismatic rock volumes with dimensions in the order of some cubic metres. The slope instability is evident in the toppling of rock blocks. Due to the high steepness of the slope and the significant height of the landslide scarp, rolling of such blocks can often follow a collapse. The blocks can themselves cover long distances, with bouncing at different points in their trajectory. These gravitational processes have conditioned the site history during Antiquity, as indicated by the large blocks uncovered in the archaeological stratigraphy within 'Temple B', which relate to a landslide event that was certainly responsible for the damage/destruction of this structure (Fig. 4b).

This mass wasting process is still active; indeed, a collapse and the consequent rolling blocks struck the archaeological site in 2006, resulting in damage to a provisional sheeting made of iron tubes and an arc-welded net (Fig. 4c). It is also worth noting that in the map of the landslide risk scenarios drawn by the regional authority (http://www.regione.abruzzo.it/pianofrane/), this area is classified as R4, a high-risk area, with possible human casualties, damage to buildings, infrastructure and the natural environment.

On the whole, it is evident that the site development has to include the engineering works, i.e. retaining walls, that will counterbalance this slope instability. Without intervention, the integrity of the present archaeological site is at risk even in the immediate future. In light of this, we consider the recent planning phase that involves the territorial authorities that is designed to mitigate the local landslide risk as a necessary and positive aspect.

3.3 The amphitheatre of **Marruvium** *(San Benedetto dei Marsi)*

Within the terms of natural risk, information derived from the archaeological excavations at the amphitheatre of *Marruvium* during the investigations of the earthquake that damaged *Alba Fucens* (and especially that collected during the 2004 archaeological operations) has been used to develop the archaeoseismological perspective of this site. This aspect was discussed in detail in a previous study[12]. For this reason, we will limit our description here to the instability of the slopes bordering on the *cavea* of the Roman amphitheatre. This instability has evidently affected the displacement of the large squared stones that formed the terraces of the ancient structure. Here, Figure 5a shows the chaotic accumulation of the stones supported by silty sediment, and of fragments of various dimensions, which are derived from tiles and bricks. The fine matrix is mainly made up of particles of natural origin that derive from the redeposition of the ancient Fucino lacustrine sediments that form the foundation soils of the amphitheatre. The sedimentological characteristics suggest that the whole accumulation results from mass deposition. This hypothesis on the material's origins is confirmed by the morphology of the different accumulations that can be found in the amphitheatre depression; i.e. small debris fans that suggest local episodes of debris flow (Fig. 5b). Landsliding has certainly been affected by the position of the carbonate blocks of the terraces over the silty substratum. Mass deposition, and therefore the partial destruction of the terraces, occurred before the filling of the abandoned amphitheatre with reworked materials and colluvial sediments. This filling can be attributed to Late Antiquity or to the High Middle Ages, as indicated by the data available on the human presence at an elevation close to the present ground surface[15,16]. In short, the evidence of sliding was sealed by the thick sediment cover that hid the amphitheatre over a many-centuries-long time span.

The archaeological investigations performed in this area since 2001 have uncovered the remains of this monument through the necessary clearance of the sediments that were filling the amphitheatre. The removal of this huge volume of sediments has reinstated the elements of fragility that affected the amphitheatre during Antiquity (Fig. 6). Therefore, it is evident that the use of this site will have to take into account the risk that the remains that are still positioned over the local slopes bordering the *cavea* might again experience gravitation driven motion, as it already occurred during Late Antiquity or the High Middle Ages.

3.4 *The Temple of Castel di Ieri*

The Temple of Castel di Ieri (Fig. 7) was built in the 2nd-1st century BC, and it has been under archaeoseismological investigation for some time[17, 18, 19]. However, the available geoarchaeological data also provide information from the palaeoenvironmental perspective. Indeed, Falcucci et al.[17] described the abundant deposition that is fed by the erosion of the western slope of Mount Urano, and which occurred in the archaeological area after the fall of the temple (probably during the 2nd century AD). The thickness of the colluvial deposits that sealed the archaeological site is larger than 3 m. This depositional phase might be subsequent to the 3rd-4th century AD[20], and therefore it probably occurred during the environmental changes related to a well-documented critical climatic period that began approximately during the 6th century AD[21]. As in the case of Marruvium, the sedimentological characteristics of the debris succession at Castel di Ieri allowed the different units to be interpreted as the result of mass deposition. These depositional events would have been characterised by high energy, as large portions of the collapsed Temple were included in the sediments as a result of their natural transport over several metres (Fig. 8).

It can also be inferred that the high energy deposition was not a sporadic event at this archaeological site, on the basis of the stratigraphic units that were deposited before the building of the temple, and subsequent to the use of this site as a funerary area during the Iron Age. Indeed, archaeological excavations coordinated by the local Archaeological Superintendence between 2008 and 2010 uncovered a thick succession of sediments overlying some circle graves (Fig. 9). A sample of palaeosol collected in the lower part of the excavation provided a radiocarbon age of 838-730 BC/ 692-659 BC/ 652-543 BC (1 sigma calibrated age). This palaeosol, which represented the level where the graves were founded, was sealed by alluvial and colluvial deposits, with a total thickness of about 2 m. On the whole, most of the sediments detected in this archaeological area, as both those covering the remains of the Temple and those sealing the graves of the Iron Age, were fed by the western slope of Mount Urano. This is indicated by the geometry of the layers and by the depositional landforms related to the most recent stratigraphic units. Indeed, the presence of a fault zone along this slope is the reason for the minute carbonate breccias of tectonic origin, which are much more erodible than the slopes that are carved into carbonate masses and are not affected by faults. Therefore, strong rains might rapidly remove a huge volume of rocky fragments that are lying in an unstable position on the slope, which would cause redeposition in the area of the monument. Here, the archaeological excavations have certainly increased the instability by the removal of the sedimentary units that were deposited during Antiquity and the change of the slope profile of Mount Urano that was defined over centuries of erosion and deposition processes. The natural tendency will be new sedimentary filling of the space created during the excavations, until the regular profile of the slope is again obtained.

3 Concluding remarks

The present study describes some geological and geomorphological features that define critical aspects at four important archaeological sites/areas of the Abruzzi Apennines, in terms of their protection against natural hazards. This local fragility is related to the seismicity and/or to the instability of the slopes along which the archaeological remains have been excavated. An analysis of the natural events that conditioned the histories of these sites during Antiquity and the High Middle Ages has allowed a better definition of the potential causes of the present-day damage. Indeed, the natural processes that have conditioned the site histories have to be considered as still being active in all cases investigated in this study, and these might have a significant impact on the present archaeological areas. In this context, the recent landslide event that struck the site of Angitia is, in our opinion, a clear warning.

As indicated in the introduction, the four cases here illustrated represent examples of natural criticality that are quite common for the archaeological heritage of the Apennines. Moreover, these sites are examples of the development policy of the archaeological heritage Therefore, the right choice to use archaeological sites implies plans that will include defence of the cultural heritage and of the safety of the visitor. Considering the present awareness of the potential impact of natural catastrophes on the archaeological sites, we believe that future planning for their fruition will need to consider an analysis of the relationships between the sites and their natural environment, to provide for conclusive risk mitigation.

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Figure captions

Figure 1. Map of the archaeological sites investigated in the present study.

Figure 2. *Via dei Pilastri*, Alba Fucens. A) Panoramic view of Alba Fucens, with the so-called *Via dei Pilastri* (Street of Pillars) in the foreground. B) Collapse unit, which includes the toppled pillars that were uncovered in the 1950s. The pillars were lying across one of the main roads of the ancient town. C) Restoration of the pillars during the 1950s. D) Present situation of the pillars. Panels B and C courtesy of the Soprintendenza per i Beni Archeologici dell'Abruzzo.

Figure 3. *Angitia*, Luco dei Marsi. Plan view and geomorphological sketch of the area.

Figure 4. *Angitia*, Luco dei Marsi. A) View of the slope that dominates the archaeological area. The white arrows indicate some of the joints crossing the rock mass. B) Boulder uncovered during the archaeological excavations of 2003. The collapse occurred during Antiquity and caused significant damage to the ancient buildings. C) Boulder collapse of the archaeological remains in 2006.

Figure 5. Amphitheatre of Marruvium, San Benedetto dei Marsi. A) Collapse unit with the carbonate blocks of the terraces of the amphitheatre, included in a matrix of clay and silts with gravel (black asterisk). B) Panoramic view of the *cavea*, showing where the collapse units form three small fans.

Figure 6. Amphitheatre of Marruvium, San Benedetto dei Marsi. Incipient sliding of the squared blocks (about 0.6 m x 0.6 m) that represent some of the remains of the terraces of the amphitheatre.

Figure 7. The Temple of Castel di Ieri. A) Panoramic view of the eastern flank of the Subequana Valley (western slope of Mount Urano), marked by an evident bedrock fault scarp located behind the archaeological site. B) Present view of the archaeological area. Note that the remains of the temple were uncovered by removing the thick debris successions that were fed by the western slope of Mount Urano. C) Aerial view of the Temple before the

construction of the cover seen in (B) (courtesy of the Soprintendenza per i Beni Archeologici dell'Abruzzo).

Figure 8. The Temple of Castel di Ieri. The remains of the building included in the colluvial deposits.

Figure 9. The Temple of Castel di Ieri. A) Archaeological area showing the remains of the circle graves uncovered in 2008. B) Alluvial and colluvial successions that sealed the remains of the Iron Age. The white asterisk defines the palaeosol that was radiocarbon dated to 838-730 BC/ 692-659 BC/ 652-543 BC (1 sigma calibrated age). The palaeosol represented the foundation soil of the graves.