Il Quaternario
Italian Journal of Quaternary Sciences
***22**(1), 2009 - 73-82*

DEFINING THE CAUSES OF ANCIENT BUILDING COLLAPSE (STRUCTURAL DECAYING VS. SEISMIC SHAKING) IN ARCHAEOLOGICAL DEPOSITS OF CENTRAL ITALY

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ABSTRACT: F. Galadini, *Defining the causes of ancient building collapse (structural decaying vs. seismic shaking) in archaeological deposits of central Italy.* (IT ISSN 0394-3356, 2009).
Deposits that result from the collapse of buildings are usual in geoarchaeological records. Deposition can result from natural processes or can be induced by human actions. The investigations at archaeological sites (in particular of the Roman Imperial Age) in central Italy indicate that the analysis of the sedimentological-stratigraphic characteristics of collapse layers allows hypotheses as to the origin of a deposit. In the case of layers formed by building decay or seismic destruction, the stratigraphic analysis defines substantial differences that are indicative of different origins. Indeed, the stratigraphy of collapse deposits due to building decay is made up of fine-to-coarse grained layers, due to the slow accumulation of materials, which are capped by huge fragments of buildings following the final collapse of the structure. For seismic destruction, large fragments of walls or entire pillars and columns, plus the coarse-grained ruins, usually lie over floors and pavements without interposed layers of abandonment. The characterisation of a collapse deposit has implications in archaeoseismological research, i.e. the identification of traces of past earthquakes during archaeological excavations or through the analysis of the archaeological monumental heritage.

RIASSUNTO: F. Galadini, Cause del crollo di edifici dell'Antichità (decadimento strutturale vs. scuotimento sismico) dall'analisi di depositi archeologici in Italia centrale*. (IT ISSN 0394-3356, 2009).*
Depositi che testimoniano il crollo di edifici sono piuttosto comuni nelle stratigrafie geoarcheologiche. La deposizione può derivare da processi naturali o essere causata da azioni umane. Indagini condotte in alcuni siti dell'Italia centrale (in particolare in riferimento a stratigrafie di età romana imperiale) evidenziano che l'analisi sedimentologico-stratigrafica delle unità di crollo permette la formulazione di ipotesi sull'origine delle stesse. Crolli dovuti a vetustà e decadenza degli edifici o a scuotimento sismico si caratterizzano stratigraficamente in maniera diversa. Nel primo caso, l'unità di crollo è costituita da sedimenti a granulometria fine alla base e più grossolana verso l'alto. I depositi nella parte basale, al di sopra dei piani di calpestio originari, testimoniano dell'abbandono dell'area in cui la struttura si colloca e del conseguente lento disfacimento della stessa. L'aumento della granulometria verso l'alto indica il coinvolgimento in crollo di parti di edifici sempre più consistenti, fino al collasso di enormi frammenti (in genere delle parti più alte delle strutture, spesso soffitti o porzioni sommitali di pilastri, ecc ...). Le porzioni a granulometria maggiore definiscono in genere la fine della sedimentazione, probabilmente a testimonianza di crolli che investono gran parte dell'edificio coinvolto. In caso di distruzione dovuta a scuotimento sismico, l'unità di crollo è costituita da grandi frammenti di pareti o interi pilastri e colonne, nonché da resti delle coperture, individuabili direttamente al di sopra dei piani di calpestio, senza interposti strati di abbandono. La caratterizzazione di un deposito di crollo ha evidenti implicazioni nella ricerca archeosismologica, vale a dire ai fini dell'identificazione delle tracce di terremoti del passato, rinvenute nel corso di scavi archeologici o mediante l'analisi di emergenze archeologiche facenti parte del patrimonio monumentale di una regione.

Keywords: Archaeoseismology, geoarchaeology, collapse deposit, building decay, central Italy.

Parole chiave: Archeosismologia, geoarcheologia, unità di crollo, decadimento strutturale, Italia centrale.

1 - INTRODUCTION

Deposits derived from the collapse of buildings can be present in archaeological stratigraphies. Their origins can be due to a number of reasons, which are basically related to natural events and human actions. Earthquakes, volcanic eruptions, landslides and floods have been frequently mentioned in the archaeological literature as being among the natural destructive agents, while wars, urban evolution and land-use are the most frequent among the human destructive interventions (Fig. 1).

Understanding the origin of a collapse deposit is important for two reasons. On the one hand, it casts light on the site history, and in case of a natural origin, it contributes to the improvement of our knowledge on the responses of societies to extreme natural occurrences. On the other hand, the study of naturally induced collapse units has fundamental implications for research aimed at providing a defence against natural catastrophes (e.g. see Guidoboni and Santoro Bianchi, 1995; Galadini *et al*., 2006, for collapse units and archaeoseismology). Indeed, finding synchronous evidence of natural destruction at several archaeological sites (e.g. synchronous collapse deposits) can allow the definition of the extent of damage associated with a natural catastrophe. In the case of an earthquake, in particular, this is fundamental for the definition of the parameters that depict the associated energy through analyses of the extent of the damage (Gasperini and Ferrari, 1997; Bakun and Wentworth 1997 and 1999; Sirovich *et al*., 2001 and 2002).

The main diagnostic problem is that collapse units with different origins will appear similar at a superficial level. However, in many cases, the sedimentological-stratigraphic features of a deposit can provide diagnostic evidence. This means that the geoarchaeological practice at an archaeological site can cast light on the origins of a collapse layer.

This study provides a geoarchaeological analysis of collapse units that originated – among the possible different causes of destruction – from building decay and seismic shaking. The data have been gathered over about 15 years of field activity in central Italy, in archaeological excavations that are mainly related to buildings from Antiquity (particularly of the Roman Imperial Age; 1st century AD-5th century AD). After a brief introduction on the seismicity of the investigated region and a short section dedicated to the necessary definitions and nomenclature, some cases will be illustrated to define the types of standard stratigraphies that can directly or partially define the origin of a deposit. Although these considerations cannot be thought as exhaustive within this complex issue, the author considers it as a short contribution that should be useful for field practices of geoarchaeologists interested in better understanding complicated mixed human-natural archaeological site histories.

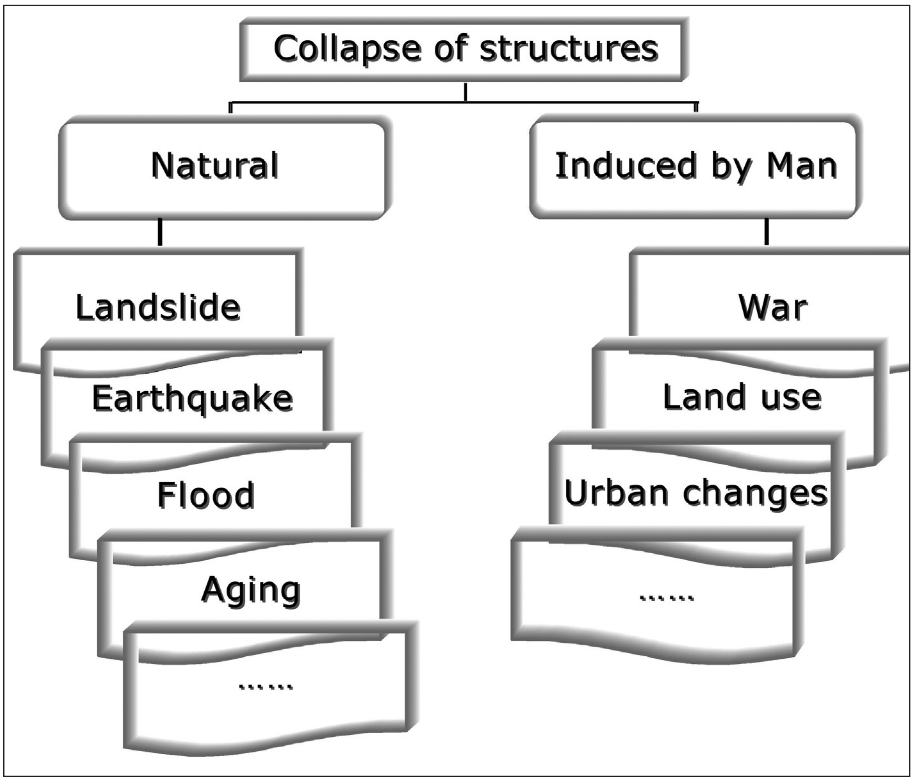

Figure 1 - The natural events and human actions that can be responsible for the collapse of structures and the formation of collapse deposits.

Eventi naturali e azioni umane potenzialmente responsabili del crollo di strutture e della formazione delle unità di crollo.

2 - SEISMICITY OF CENTRAL ITALY

The investigated region is seismically active and has been struck by numerous destructive earthquakes with Magnitude up to 7, as indicated in the CPTI seismic catalogue (Working Group CPTI, 2004). The historical large magnitude events have originated along the Apennine chain (e.g., Jun. 5, 1688; Jan. 14, 1703; Feb. 2, 1703; Nov. 3, 1706; Jul. 26, 1805; Jan. 13, 1915; respectively with magnitude Mw 6.7, 6.8, 6.6, 6.6, 6.6 and 7.0, as indicated in Working Group CPTI, 2004). The largest event has been actually a seismic sequence, occurred in 1456. The number of events composing the sequence is presently matter of debate. It is reported on CPTI04 (Working Group CPTI, 2004) as being composed by two major events, both occurred on December 5 in the southern Apennines and characterised by magnitude 6.9 and 6.7. All these large magnitude events have been caused by seismogenic sources mainly characterised by normal motion, related to the general extension of the inner Apennine domain. The damage to towns and villages of the mountainous areas has been generally very high and estimated with Intensity MCS up to 11 (e.g. in the case of the 1915 earthquake; see STUCCHI *et al.*, 2007). The major events were also responsible for damage to Rome (this occurred in the case of the 801 AD, 1349, Jan. 14 1703, Feb. 2 1703 and 1915 earthquakes; STUCCHI *et al.*, 2007). Paleoseismological and archaeoseismological investigations have also indicated that the earthquake which damaged the Colosseum in Rome, close to 484 or 508 AD, was originated by the same seismogenic source responsible for the 1915 earthquake (i.e. the Fucino fault; GALADINI and GALLI, 2001; GALADINI, 2007).

Other strong earthquakes struck the investigated region during the Antiquity. The possible damage distribution related to the 2nd century AD earthquake in the Sulmona area has been recently defined by means of archaeoseismological investigations (CECCARONI *et al.*, 2009).

Damage in the studied region was also caused by numerous moderate magnitude historical earthquakes (M 5.5-6.0) (Working Group CPTI, 2004).

3 - DEFINITIONS

To better understand the content for discussion, the introduction of some definitions is necessary. A collapse deposit contains archaeological remains (chaotically dispersed or arranged) for which the deposition and attitude are derived from the destruction of the buildings. Such a deposit will contain portions of walls, tiles and bricks, columns and piers, capitals, epigraphs, among other materials. The collapsed materials may represent particular archaeological deposits. Indeed, they may be made of remains of human origin (whatever the size of the remains), without any naturally formed particles within the matrix (CARANDINI, 2000). In some cases, however, the collapse deposits also contain particles of natural origin, the presence of which is fundamental to the diagnostic aspects (especially for landslide destruction, although not discussed here). I also intend that the materials have not experienced further transport after a collapse, i.e. no processes (cultural or natural) have occurred that have changed the post-collapse attitude.

From among the different causative events summarised in Figure 1, information on the origins of a collapse deposit can be derived from (mainly sedimentological and stratigraphical) features of the deposit itself, as in the cases of destruction illustrated in the next sections. As mentioned in the Introduction, the definition of the origins of collapse deposits has significant implications for the detection of the impact of past natural catastrophes. One of the most widespread applications is the reconstruction of ancient earthquake effects. This is the typical goal of archaeoseismology (e.g. GALADINI et al., 2006, and references therein), i.e. the analysis of the traces of past earthquakes at archaeological sites or on ancient monuments, through multidisciplinary approaches.

4 - THE INVESTIGATED SITES

4.1 - Rome, Foro della Pace (site 1 in Fig. 2; Fig. 3a)

The recent (since 2000) excavations made at the Foro della Pace, in the area close to the basilica of Massentius and the church of Santi Cosma e Damiano, uncovered remains of the southernmost sector of the forum (FOGAGNOLO, 2006). The remains (particularly impressive are the marble floors and parts of huge columns in granite) were covered by a thick succession of debris (Fig. 3a). The attitude of the layers suggests that the materials were originated by the progressive weathering of the adjacent upper portions of the Basilica of Massentius. From the sedimentological point of view, a coarsening upward of the debris is evident. The lowermost layers are made of sand and coarse sand, while the upper layers are made of gravel. The deposition of the fine materials probably defines the abandonment of the area and the consequent lack of cleaning in this sector of the forum. The coarse-grained layers and their attitude can be more directly related to the progressive destruction of the Basilica of Massentius, representing the long-term effect of the lack of maintenance.

4.2 - Larino, amphitheatre (site 2 in Fig. 2; Fig. 3b)

The Amphitheatre, described in TRIA (1744), was built in the 1st-2nd century AD (COARELLI and LA REGINA, 1993). It was probably abandoned at the end of the 3rd century AD and re-used for burials during the 6th-7th century AD (DI NIRO, 1991; IASIELLO, 2008). The preserved remains of the amphitheatre indicate that in a moment of its long history the building experienced some collapse. Indeed, the attitude of huge parts of the structure suggests the occurrence of sudden collapse. However, the collapsed parts are not lying directly over the floor. In most cases these portions of walls or of the vaults are overlying layers of debris. As in the previously described case, the most evident sedimentological characteristics of these layers is the coarsening upward of the grain size (Fig. 3b). Indeed, the lower layers are mainly made of sand while the uppermost are made of gravel. This succession is generally closed by huge blocks as in Figure 3b. In the whole, this suggests an abandonment of the area and the consequent lack of cleaning and accumulation of rubbish (lower layers).

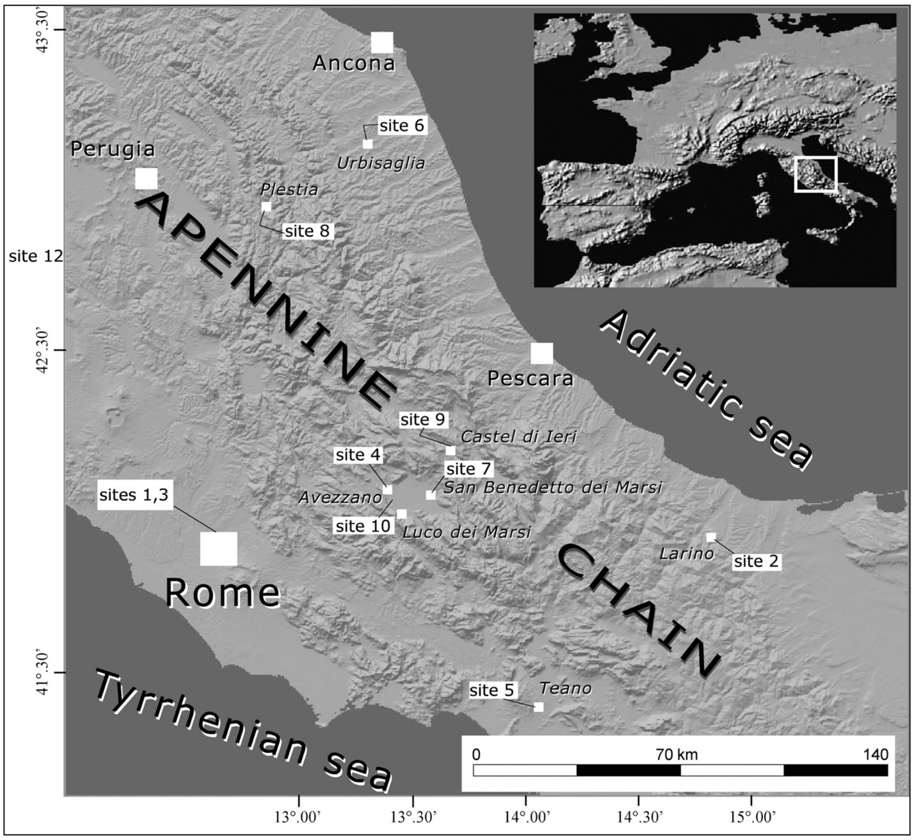

Figure 2 - Location map of the sites investigated in Central Italy. Sites: 1) Rome, Foro della Pace; 2) Larino, amphitheatre; 3) Rome, Foro della Pace; 4) Avezzano, *villa rustica* of Macerine; 5) Teano, theatre; 6) Urbisaglia, structures of the Roman town; 7) San Benedetto dei Marsi, amphitheatre; 8) Plestia, *domus*; 9) Castel di Ieri, rooms behind the temple; 10) Avezzano, structures of Vigne Nuove.

Ubicazione dei siti indagati in Italia centrale. Siti: 1) Roma, Foro della Pace; 2) Larino, anfiteatro; 3) Roma, Foro della Pace; 4) Avezzano, villa rustica *in località Macerine; 5) Teano, teatro; 6) Urbisaglia, strutture della città romana; 7) San Benedetto dei Marsi, anfiteatro; 8) Plestia,* domus*; 9) Castel di Ieri, ambienti adiacenti al tempio; 10) Avezzano, resti di strutture in località Vigne Nuove.*

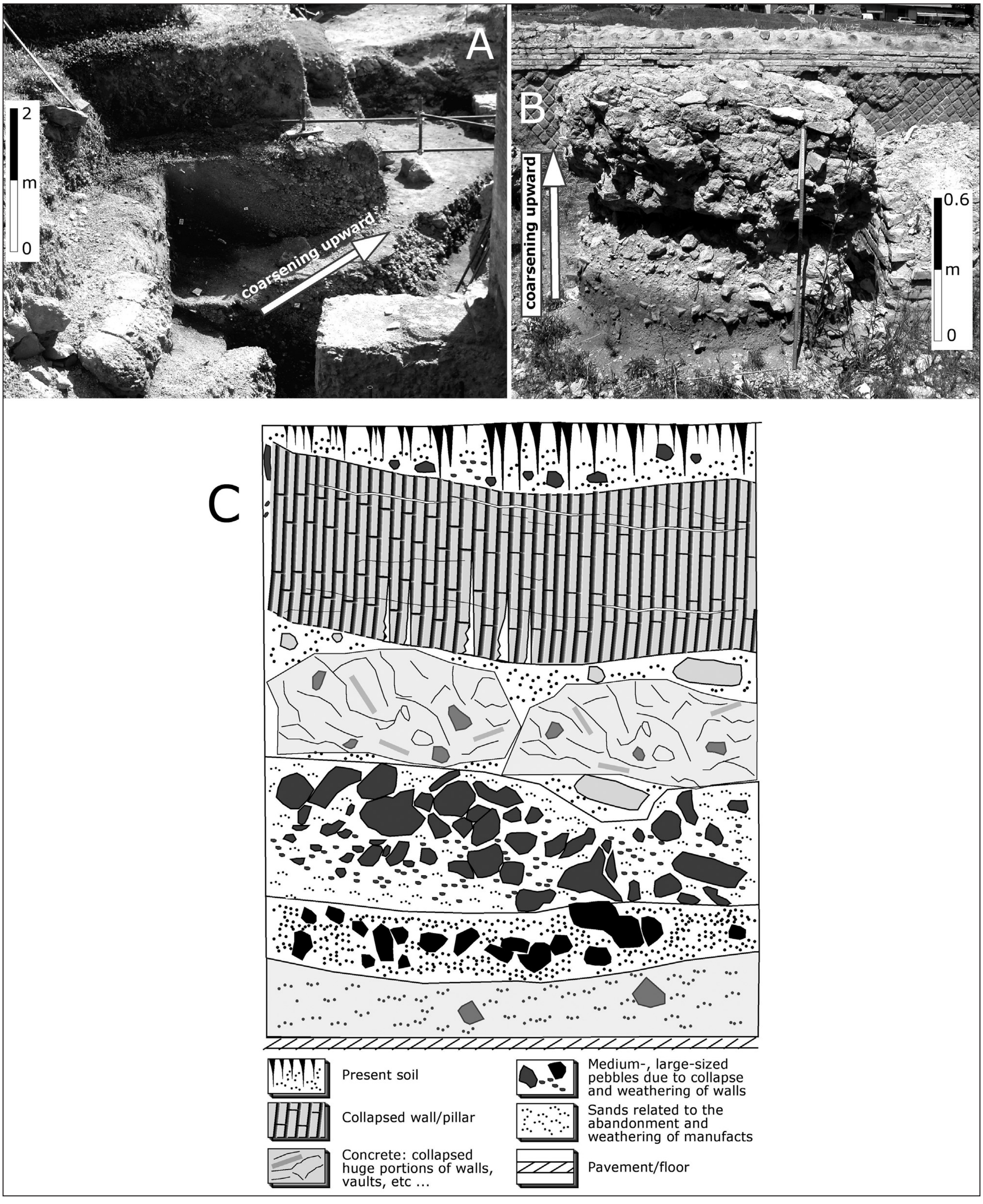

Figure 3 - Collapse and building decay. A) Accumulation of debris at the base of the structures related to the Basilica of Massentius, in the Foro della Pace in Rome (site 1 in Fig. 2); note the dipping of the layers towards the right of the observer and the upward coarsening of the grain size; B) Layers of abandonment and collapse at Larino (site 2 in Fig. 2); note the upward coarsening of the grain size and the huge block of concrete that seals the stratigraphic succession; C) Stratigraphic scheme of an archaeological deposit consistent with the collapse of structures due to building abandonment and decay.

Crollo e decadimento strutturale. A) Accumulo di detriti alla base dei resti della Basilica di Massenzio, nel Foro della Pace, Roma (sito 1 in Fig. 2); si noti la pendenza degli strati verso la destra dell'osservatore e l'aumento della granulometria verso l'alto; B) Strati di abbandono e crollo a Larino (sito 2 in Fig. 2); si noti l'aumento della granulometria verso l'alto e l'enorme resto murario in opera cementizia che sigilla la successione stratigrafica; C) Schema stratigrafico relativo a un deposito archeologico compatibile con il crollo di strutture dovuto all'abbandono e al progressivo decadimento strutturale.

The lack of maintenance resulted in the structural decay which evolved in the final collapse.

4.3 - Rome, Foro della Pace (site 3 in Fig. 2; Fig. 4)

Another part of the Foro della Pace, north of that described at section 4.1, was excavated in 1998-2000 (La Rocca *et al*., 2001). Here, columns were uncovered lying over a thick unit of debris and reworked materials (Fig. 4). This unit accumulated over the floor of this important area of the ancient Rome. The accumulation evidently indicates the lost of importance of the area and probably its abandonment, during the Late Antiquity or the High Middle Ages.

Figure 4 - Columns collapsed over a layer of abandonment in the area of the Foro della Pace in Rome (site 3 in Fig. 2).

Colonne in giacitura di crollo al di sopra di uno strato di abbandono nell'area del Foro della Pace, Roma (sito 3 in Fig. 2).

4.4 - Avezzano, villa rustica *at Macerine (site 4 in Fig. 2; Fig. 5a)*

Since 2004, the archeological excavations have uncovered the remains of buildings related to a settlement of the *villa rustica* type. The traces of a violent fire were evident throughout the entire archaeological site. Remains of large fragments of wooden beams, burnt during the fire, were found everywhere. These fragments were included in the thick collapse layers (Fig. 5a) lying over the floors of the destroyed buildings, without an interposed layer of abandonment (Borghesi *et al*., 2007). The fact that the destruction occurred when the building was still in use is also corroborated by the numerous remains related to the daily life uncovered within the collapse layer (Borghesi *et al.*, 2007).

4.5 - Teano, theatre (site 5 in Fig. 2; Fig. 5b)

Hypotheses about a Late-Antique coseismic destruction of the theatre (Fig. 5a) were produced by Gasperetti (1999) and Galadini and Galli (2004). Part of the architectural decoration and statues have been found in the position of collapse. Architectural parts of the *scaena* were ejected towards the *cavea* (Fig. 5b). Walls and pillars showed evidence of differential rotation around the vertical axis, along the largest bricks (*bipedalis*) (Galadini and Galli, 2004). Further reworked material sealed the collapse.

4.6 - Urbisaglia, porticus *(site 6 in Fig. 2; Fig. 5c)*

The remains of the ancient town of Urbs Salvia in the Marche region are presently well preserved and visible within the museum area. The evidence of collapse involving huge parts of the structures is diffused throughout the entire site were the remains are visible. The collapsed structure reported in Figure 5c is one of the most impressive cases. The image reports the remains of the cryptoporticus of the Temple of the Salus in Urbs Salvia (see http://www.archeomarche.it/scai.htm, for further information and photographs). The collapse occurred suddenly, as indicated by the preservation of the geometry of the entire structure after the collapse. It also occurred when the building was still in use, as indicated by the fact that the ruins are lying over the floor without interposed layers of abandonment. This fact, plus the widespread evidence of destruction throughout the entire town, suggests that the collapse is related to a seismic event. No information is available which may define the age of the destruction.

4.7 - San Benedetto dei Marsi, amphitheatre (site 7 in Fig. 2; Fig. 5d)

The excavations made during 2004 have uncovered the remains of the northern sector of this building. The evidence of damage due to seismic shaking consists in the rotation of parts of the piers at the northern entry of the amphitheatre and a corner expulsion in a major room. Moreover, the huge rectangular stones bordering the cavea were found within the collapse unit over the floor, without interposed layer of abandonment, and with a "domino" attitude, defining a sudden collapse (Fig. 5d). The collapse has been tentatively attributed to the 484-508 AD earthquake by Galadini (2007). This event is reported in the available seismic catalogues (e.g. Boschi *et al.*, 1995) and paleoseismologically associated to the faults adjacent to San Benedetto dei Marsi by Galadini and Galli (1999).

4.8 - Plestia, domus *(site 8 in Fig. 2; Fig. 5e)*

During 1998 the remains of a *domus*, partially excavated during preceding campaigns, were uncovered in the area struck by the 1997 seismic sequence in central Italy (with events characterised by M up to 6.0;

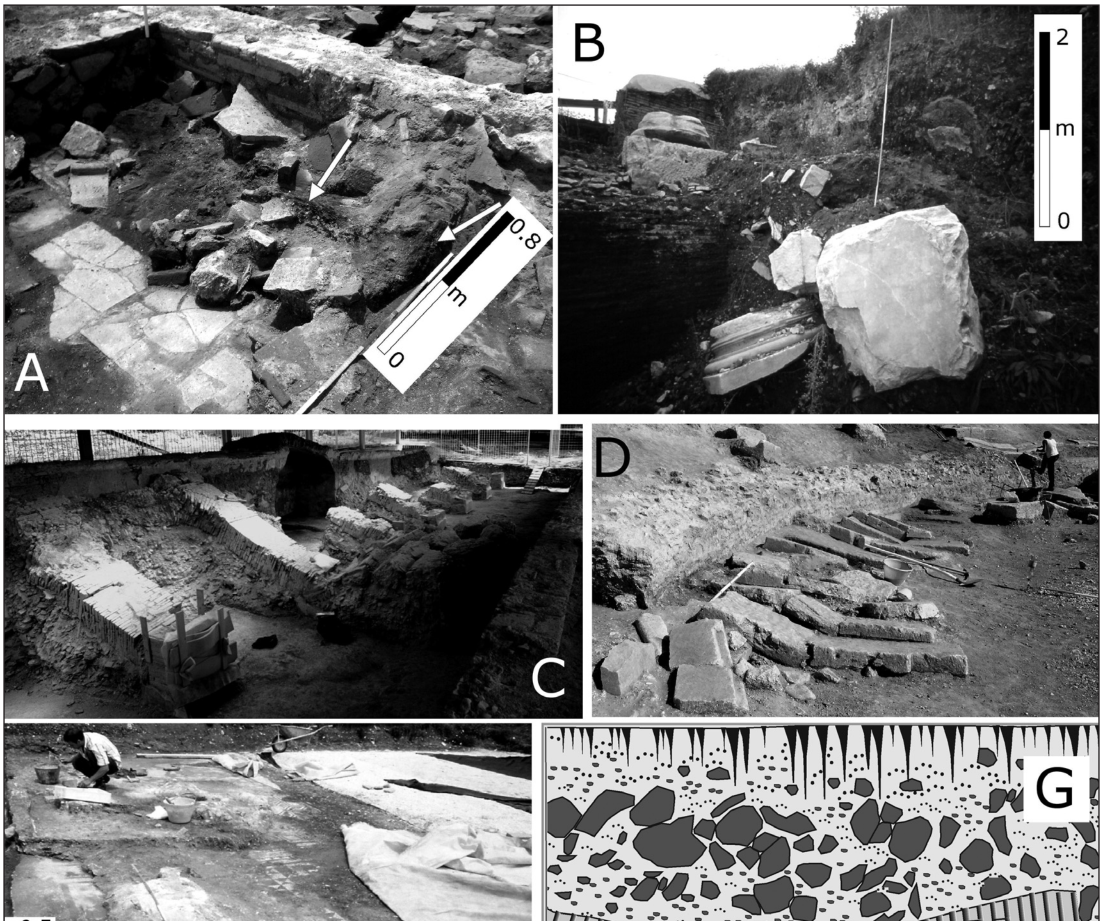

Figure 5 - Sudden collapse consistent with the occurrence of seismic shaking. A) Materials of the roof and the highest parts of a building collapsed over the floor (layer of abandonment is lacking) at Avezzano-Macerine (site 4 in Fig. 2). The arrows indicate the remnants of a burnt wooden beam; B) Evidence for launching of capitals and parts of columns towards the *cavea* of the Teano theatre (site 5 in Fig. 2); C) Synchronous and oriented collapse of pillars of a *porticus* in the old town of Urbisaglia (site 6 in Fig. 2); D) Sudden collapse of the slabs bounding the *cavea* of the amphitheatre at Marruvium-San Benedetto dei Marsi (site 7 in Fig. 2), with no layer of abandonment interposed between the collapse unit and the floor; E) Collapse of the plaster on the mosaic floor at Plestia (*domus*) (site 8 in Fig. 2), with no layer of abandonment interposed between the collapse unit and the floor; F) Toppled wall and collapse of a decorative element in the rooms behind the temple at Castel di Ieri (site 9 in Fig. 2); G) Stratigraphic scheme of an archaeological deposit consistent with the sudden collapse of structures that did not experience abandonment, due to seismic shaking.

Crollo improvviso compatibile con gli effetti dello scuotimento sismico. A) Resti del tetto e delle parti alte di un edificio crollato sopra al piano di calpestio, nel sito di Avezzano-Macerine (sito 4 in Fig. 2); si noti l'assenza dello strato di abbandono tra unità di crollo e piano pavimentale; le frecce indicano i resti combusti della travatura in legno; B) Unità di crollo comprendente capitelli e parti di colonne "lanciate" verso la cavea *del teatro di Teano (sito 5 in Fig. 2); C) Crollo improvviso, sincrono e isorientato di pilastri di un* portico *nella città di Urbisaglia (sito 6 in Fig. 2); D) Crollo improvviso delle lastre del balteo nell'anfiteatro di Marruvium-San Benedetto dei Marsi (sito 7 in Fig. 2); l'unità di crollo si trova al di sopra del piano di calpestio, senza che tra le due unità sia interposto uno strato di abbandono; E) Crollo di intonaco sul pavimento musivo di una* domus *a Plestia (sito 8 in Fig. 2); lo strato di abbandono è assente tra piano pavimentale e unità di crollo; F) Ribaltamento della parete di un edificio e collasso sull'asse verticale di un elemento decorativo negli ambienti rinvenuti davanti al tempio di Castel di Ieri (sito 9 in Fig. 2); G) Schema stratigrafico relativo a un deposito archeologico compatibile col crollo cosismico di edifici che non avevano subito in precedenza abbandono.*

e.g. AMATO *et al*., 1998). The *domus* was built during the 1st century BC, (see for information the website of the Superintendence: http://www.archeopg.arti.beniculturali.it/geco2fe/Default.aspx) The beautiful mosaic visible in Figure 5e was sealed by a well preserved layer of plaster. This material originally covered walls made of clay or silt (a typical building technique of the Antiquity; see also the case of Castel di Ieri, below). The distribution of a homogeneous layer of plaster over a large portion of the mosaic suggests that the collapse occurred suddenly. The absence of a layer of abandonment between the mosaic and the collapsed material suggests that the destruction affected a building which was still in use at the time of the catastrophe. This renders the hypothesis of a aging-induced destruction less reliable than that of the collapse due to external causes.

4.9 - Castel di Ieri, rooms behind the temple (site 9 in Fig. 2; Fig. 5f)

Well preserved and restored remains of a temple's *podium* can be observed at this site as a result of excavations made during the 80s. New excavations made in 2006 uncovered three rooms located in front of the temple, representing parts of a sacred edifice built before the main temple. Evidence of sudden collapse is, in this case, impressive (Fig. 5f). In particular the toppling of a large portion of wall together with the vertical collapse of a decorative element was detected. The remains were lying over the frequented floor (FALCUCCI *et al*., 2008). The collapse cannot be conclusively constrained from the chronological point of view. CECCARONI *et al*. (2009) hypothesise that the destructive event may be identified in the 2nd century AD earthquake, reported in the seismic catalogues (e.g. Working Group CPTI, 2004).

4.10 - Avezzano, villa rustica *at Vigne Nuove (site 10 in Fig. 2; Fig. 6)*

The *villa rustica* at Vigne Nuove was excavated during 2005. It is part of the ancient system of farms and settlements surrounding the Fucino Plain and related to the ancient town of Alba Fucens, 4 km north of Avezzano (e.g. BORGHESI, 2007). The remains of the different buildings composing this settlement were completely modified by interventions during the Antiquity which hinder a conclusive interpretation of the available stratigraphy and of the remains in terms of geometry, function and history of the settlement. It seems probable that the site suffered the effects of a destructive event. After this event, the construction of new floors by using the ruins of previous buildings (Fig. 6) can be considered among the interventions following the destruction.

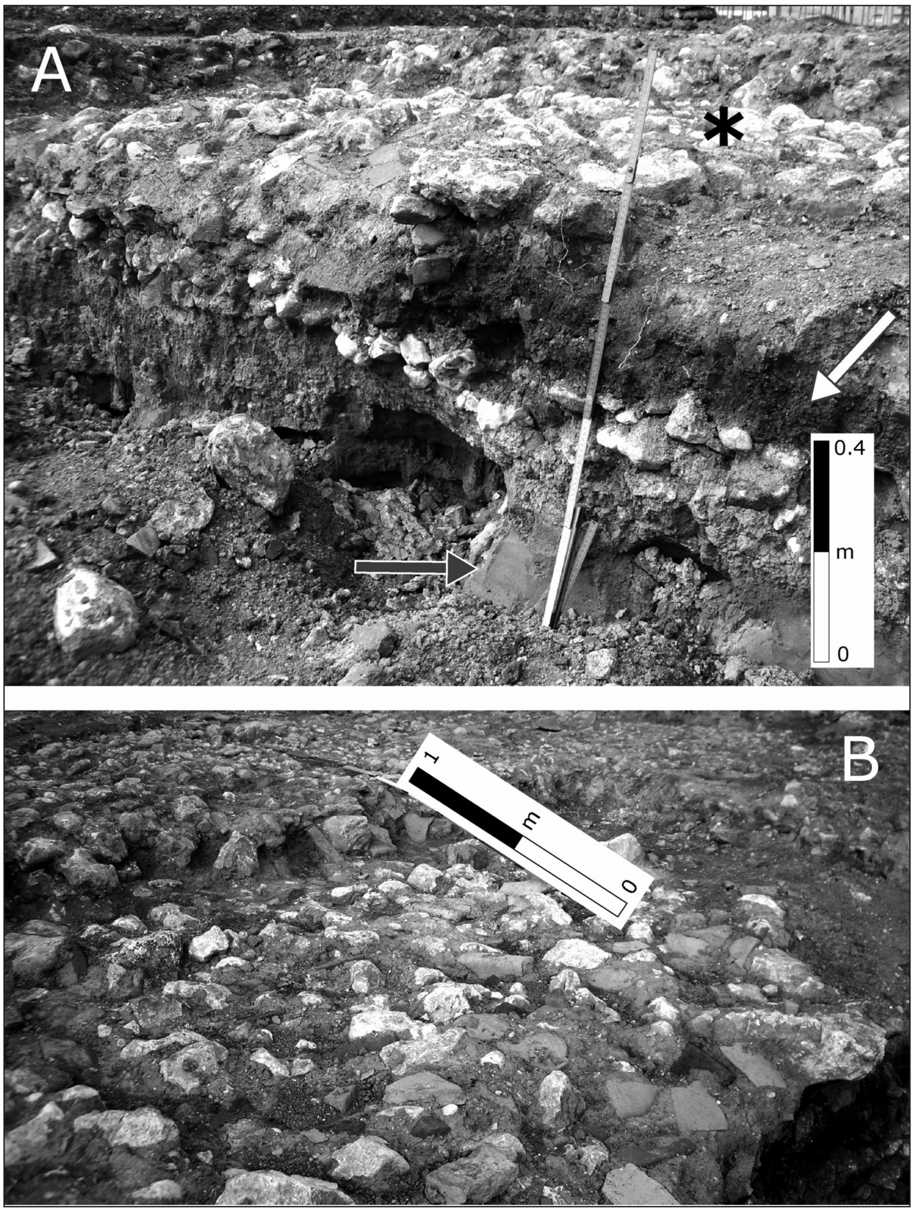

Figure 6 - Re-organisation of collapsed materials at Avezzano-Vigne Nuove (site 10 in Fig. 2). A) The original ruins are stratigraphically located between the lacustrine sandy substratum (grey arrow) and reworked material made of coarse sand particles demonstrating widespread burning (white arrow). The asterisk indicates the new floor/pavement obtained by manipulation of the ruins; B) Panoramic view of the post-destruction floor/pavement.

Riorganizzazione dei materiali di crollo nel sito di Avezzano-Vigne Nuove (sito 10 in Fig. 2). A) I resti originari sono stratigraficamente collocati tra il substrato lacustre sabbioso (freccia grigia) e materiali di riporto costituiti da sedimenti a granulometria sabbiosa grossolana, con evidenti tracce di combustione (freccia bianca). L'asterisco indica il nuovo piano di calpestio ottenuto dalla riorganizzazione dei resti del crollo; B) Panoramica del piano di calpestio ricostituito dopo la distruzione.

3 - CHARACTERISTICS OF THE COLLAPSE UNITS AND THEIR FORMATION

The cases described in the previous section help in defining some stratigraphic aspects which may be diagnostic as for the origin of the archaeological deposit. The next sub-sections will be dedicated to find the general sedimentological and geomorphological features which may represent the link between the effects (the type of collapse unit) and the causes (the origin of the collapses).

3.1 - Collapse and building decay

The progressive deterioration of buildings derive from physical and chemical processes, and as RAPP and HILL (1998) indicated, these can include: chemical dissolution, mechanical actions due to water temperature changes (especially in joints and pores), abrasion due to wind-transported particles, and exfoliation due to rapid thermal changes. Humans can also contribute with bad restoration or, in contrast, with spoliation.

The cases analysed in the previous section (subsections 4.1 to 4.3) converge to a sort of stratigraphic model that records the main event responsible for the decay, i.e. building or site abandonment, and its consequence (Fig. 3c). In the cases investigated, abandonment is testified by small-sized detrital particles and sands with sparse pebbles (i.e. fragments of pottery, tiles, stones from walls) due to the inception of the decay of the structure. Sporadic frequentation may occur during the abandonment phase, and this can be testified, for example, by remains of fireplaces recurring within the stratigraphy. The abandoned site may also become a place for the accumulation of reworked materials that are transported from elsewhere, or a massive dumping site. In this case, the deposition of fine materials may be interrupted by the accumulation of grossly stratified coarser debris, which will generally include fragments of tiles, bricks, pottery and stones, but also rubbish resulting from human practices (see also GOLDBERG and MACPHAIL, 2006). The main phase of structural decay begins with the deposition of coarser building elements, usually represented by parts of the roof, i.e. fragmented wooden beams and tiles (Figs 3a and 3b). Stones from the walls or coarser portions of walls made of cemented stones and bricks overlie the layers related to the beginning of the collapse. The stratigraphic succession ends with huge portions of the building which presumably indicate the final collapse (Figs. 3b and 4). This collapse may represent the last act of the degradation history, conditioned by gravitational forces. Alternatively, it may be caused by external dynamic forces, such as seismic shaking. But in this case there are few chances to discriminate the origin of the collapse from the stratigraphic point of view, since the convergence of forms is total. However, if the coseismic collapse has been ascertained by means of other information, the presence of a layer of abandonment has some important implications in quantifying the characteristics of the earthquake. For example, if the similarly oriented columns of Figure 4 collapsed synchronously for a seismic action (as generally admitted, though debated, in the international literature for suddenly collapsed and similarly oriented columns) the presence of a layer of abandonment below them indicates that maintenance of the collapsed structure was lacking during the years preceding the destruction (Fig. 4). This means that the structure probably suffered from aging. The entire picture can define a quite high vulnerability of the collapsed structure, where this high vulnerability implies an overestimation of the energy associated with the destructive event.

When the cases investigated are considered in connection with the above description, this clarifies the main rule within an archaeological deposit that arises from decay and collapse of a structure: the upward coarsening of the grain size (Fig. 3c). This results from the fact that the process of decay is continuous and progressive, and involves ever larger portions of the structure.

3.2 - Sudden collapse of non-abandoned structures due to seismic shaking

Among the natural processes that can produce the sudden collapse of buildings still in use (Fig. 1), seismic events can rarely be identified by the presence of natural sediments that suggest the occurrence of an earthquake (e.g. sands re-deposited after liquefaction). In contrast, other natural processes can be more easily identified by the association of the collapse units with landslide accumulations, or volcanic or alluvial deposits. Generally, the association with natural deposits is the main diagnostic aspect in deciphering the origins of the natural destruction.

In the case of seismic destruction, the stratigraphic succession which may be derived from the discussed cases is quite simple (Fig. 5G). A layer of abandonment is not detected over a pavement or a floor. The first evidence of the collapse is seen as a chaotic accumulation of materials that have derived from the highest portions of the building, i.e. tiles and fragments of wooden beams. This results from the "opening" of the structure, from the motion of the walls in different directions during shaking and the related lack of support for the roof. In many cases, the wooden fragments are evidently burnt (Fig. 5A), with traces of burning also being seen on tiles and stones. Widespread burning was, indeed, a quite usual consequence of seismic shaking in Antiquity, and it was probably related to the wide "indoor" use of fire. The grain size of the deposit is usually coarse (tiles and beam fragments) with a sparse matrix. Particles of natural origin are absent in this type of collapse deposit. The fragments are in contact with each other, and no layering can be seen. In some cases, the presence of lintels or capitals far from their original position suggests the "launching" of the structure and its decorative elements as a result of severe shaking (Fig. 5B).

The first layer indicating destruction of the highest part of a structure (abundance of tiles and wooden beams) is overlain by huge portions of walls, pillars and columns, which sometimes lie with a preferred orientation, in response to the polarity of the causal seismic event (Fig. 5C, D).

This description of the collapsed layers can be considered to be reliable when materials still have their primary attitude following the collapse. Indeed, the collapsed materials have often experienced subsequent manipulation and transport (Fig. 6; site 10 in Fig. 2). In such cases, the collapse stratigraphy is not preserved and inferences are not possible. Sometimes, manipulated ruins have been detected as overlying the original collapse deposit. These layers of materials in secondary attitude represent the effects of the chaotic filling with reworked deposits, or attempts to give an organisation to the collapse deposit in order to produce a new floor/pavement in the destroyed area (Fig. 6).

These discussed features can also result from other destructive actions. Burning within a house that is not triggered by an earthquake can result in destruction of a building. However, evidence of synchronous collapse at different sites over a large area allows the certainty of the co-seismic origin, since a strong earthquake forms synchronous destruction layers (such as those previously described) throughout a region to a greater extent than other natural or human events. This is the so-called "territorial" approach to the detection of archaeoseismic traces (for case histories and methodology see Guidoboni *et al*., 2000; Galadini and Galli, 2004; Ceccaroni *et al*., 2009). Also, human actions related to wars can have destructive effects on buildings, although in such cases, the investigated sites should show evidence of such a struggle. Numerous cases of destruction by invaders are reported for the Aegean area and the eastern Mediterranean (Nur and Cline, 2000, and references therein); an Italian case can be seen in the recently excavated Medieval site of San Genesio di Vico Uualari in Tuscany, central Italy (Cantini, 2005). In all of the cases, the destruction levels are rich in remnants that demonstrate the conflagration (for example, abundance of arrow-heads).

4 - CONCLUSIVE REMARKS

The cases described give a partial view of the possible types of collapse deposits, both in terms of stratigraphic features and in terms of possible origins. However, the above descriptions indicate that the sedimentological-stratigraphic characteristics of collapse deposits can represent one of the key indicators for the definition of the origin of the destruction.

Within the archaeoseismological perspective, which is definitely one of the main reasons for the analysis of collapse deposits, the described cases clearly indicate that the ability to distinguish between structural decay due to abandonment and that due to sudden effects of seismic shaking is, in theory, possible. However, the stratigraphic evidence related to seismic shaking and discussed above should only be considered as "consistent" with the dynamic causal event, rather than conclusively related to it. This is a quite important point if one considers that the occurrence of an earthquake has probably been the most invoked cause of destruction at archaeological sites in the archaeological literature (debated since the pioneering study by Karcz and Kafri, 1978). The conclusive evidence relating to seismic shaking has to be obtained by supplementary investigations, such as geomorphological analyses to exclude the occurrence of natural events other than earthquakes and the search for synchronous destruction at other sites, and also a geophysical-engineering approach to evaluate the local seismic response (see Galadini *et al.*, 2006, on this topic). On the whole, the cases discussed here and the related stratigraphic models confirm that geoarchaeological investigations of collapse deposits represent one of the fundamental ingredients for the solving of archaeoseismological issues.

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Ms. ricevuto il 22 aprile 2008
Testo definitivo ricevuto il 13 marzo 2009

Ms. received: April 22, 2008
Final text received: March 13, 2009