Geological Evidence of Paleotsunamis at Torre degli Inglesi (northeast Sicily)

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Abstract

Two layers of fine sand of marine origin occur in a sequence of organic rich colluvia in an archaeological excavation at Torre degli Inglesi, on the Ganzirri peninsula, northeast Sicily. Stratigraphic and micropaleontologic analyses support the hypothesis that these layers are related to deposition due to paleotsunami waves. Their ages are constrained both with radiocarbon and archaeological dating. The age of the oldest layer is coincident with the 17 A.D. earthquake that hit Reggio Calabria but for which no tsunami was previously reported. The age of the youngest layer can be only constrained in the range 3rd-19th century and is tentatively associated to the 6 Feb. 1783 event.

1. Introduction

The disaster caused by the 2004, Sumatra tsunami dramatically highlighted the importance of mitigation strategies based on efficient Early Warning systems and correct inundation scenarios. Numerical models of tsunami wave propagation can be calibrated with historical data on location and frequency of past events [e.g., *Tinti et al.*, 2001]. However, historical information depends strongly on the settlement evolution of the territory and is generally limited to the past hundreds of years. Only in special cases (e.g., Italy, Greece, Turkey, Japan) can historical data be extended to the past two millennia. Because the return interval of tsunamis can be of the order of millennia a useful integration to the knowledge of tsunami occurrence can be derived using geology as well. In fact, geological studies can provide the exact location, distribution and age range of inundation through the recognition and dating of paleotsunami deposits [e.g., *Atwater and Moore*, 1992; *De Martini et al.,* 2003*; Cochran et al*., 2006]. The recognition of these deposits may confirm or add to knowledge already existing from the historical record or may be related to pre-historic or unknown historical events. The social impact and potential for paleotsunami research to contribute to Civil Protection purposes is very high.

In this paper we present preliminary geological evidence of two paleotsunamis from the site of Torre degli Inglesi, in the Ganzirri Peninsula (northeast Sicily - Figure 1).

2.Tsunamis in Eastern Sicily

Eastern Sicily is probably the region of Italy most prone to tsunamis in fact, during the past millennium it was frequently hit by large tsunamis that inundated coastal areas, plains, and towns. The best known tsunamis are those that followed the 1169, 1693, 6 Feb 1783, and 1908 earthquakes (Figure 1A). In the Ganzirri Peninsula there are descriptions for only the two most recent tsunamis but with reference to the village of Torre Faro in the southern coast. There, the 6 Feb 1783 tsunami flooded the shore for about 400 steps (~ 400m) inland depositing a large amount of silt and dead fish [*Sarconi*, 1784]. Conversely, the 1908 tsunami inundation decreased substantially to the north of the town of Messina and produced a wave that, according to Baratta [1910], flooded at Torre Faro for only 5m inland.

3. Torre degli Inglesi

Torre degli Inglesi (literally the English Tower) is a defence tower built on a local height of the Ganzirri peninsula, about 5 m a.s.l., and about 40 m from the present shoreline (Figure 1B). The tower sits at the back of the sand dunes bounding the present sand-beach. Superficial sediments in the surroundings of the tower are mainly composed by dark organic and reddish-tan granular sands, generally massive or poorly layered.

The history of the tower is under investigation by the Superintendence of the Archaeological heritage of Messina. The tower was first built in Roman times, and the original structure of the quadrangular basement, staircase, cobbled paving, and rain water cisterns is clearly visible in the recent excavations (Figure 2). This structure is dated between the 1^{th} century B.C. and 1^{st} century A.D. The cisterns are filled with material containing ceramics of the 2^{nd} and 3^{rd} centuries. This is suggestive of the abandonment of the main structure after the 3^{rd} century A.D. (an earthquake? fire? assault?). Filling of the ground around the tower and the building of new structures (pillars and beams) affecting the Roman structure occurred after this event and before the building of the Torre degli Inglesi in the 16^{th} century. This latter structure cuts and overlays all the previous constructions (Figure 2). Although some repairs and remodelling due to aging and effects of local earthquakes (e.g., 1509, 1783, 1908) have taken place, the 16^{th} century tower is essentially what we see today. The latest modification of the tower dates to the second half of 19^{th} century when it was restored by the Bourbon kingdom and fencing walls were built in the surrounding area (Figure 2).

The main building phases at Torre degli Inglesi can be thus summarized as follows: (i) 1^{st} century B.C. construction of the Roman Tower; (ii) abandonment in the 3^{rd} century or soon after and rebuilt of a new undefined structure between the 3^{rd} and 16^{th} century; (iii) 16^{th} century construction of the Torre degli Inglesi; (iv) second half of the 19^{th} century repairing and construction of enclosure walls (Figure 2).

4. Stratigraphy

We have examined and sampled stratigraphic sections of the excavation made by the Superintendence of Messina at Torre degli Inglesi (Figure 2). The excavation runs along the NW side of the tower and exposes a 1.5 m thick sequence of deposits overlying the Roman cobbled paving and covered by the 19^{th} century structures. The sequence is mainly composed of debris or reworked deposits including human artefacts: ceramics, animal bones, teeth, and glass (Figures 3 and 4). Their matrix is the granular dark organic sand that forms the upper cover of the Ganzirri coastal plain. The lowermost ca. 0.5 m of the section is regularly layered and rarely contains anthropic material (units 100, 90, 80 in Fig. 3). The upper part of the sequence is characterised by highly variable deposits with many irregularities (Fig. 4) indicating the area may have been used as a dumping ground after the abandonment of the Roman structure (see previous chapter).

Deposits have been separated in units that are synthetically described in the following from bottom to top. Unit 100: c.20 cm-thick orange-brownish sand layer above the cobbled Roman paving. Unit 90: up to 5 cm-thick grey clean siliciclastic well sorted sandy layer, with sharp, erosional contacts at the base and top; the top locally contains small white siliciclastic well-rounded, white pebbles (up to 3 cm). Unit 80: dark-brown sand with small angular pebbles with rare ceramics. Unit 70: coarse-grained brownish sand of variable thickness (0-50 cm). Unit 60: yellow fine sand with small ceramic fragments, 5-10 cm-thick. Units 50 to 30: debris containing ceramic material and up to 10 cm-long angular tile fragments in a dark organic matrix with patches of disaggregated mortar and ceramics; very irregular layering; total thickness 50-60 cm. Unit 20: dark, coarse-grained sand with a sub-horizontal, gradual contact at the bottom; contains tiles, shells, bones, glass fragments and fire remnants. Units 10, 10a, 10a1: similar to unit 20 but eroded into it; fragment size varies between the two sections; total thickness is variable up to 40-50 cm. In the northwest part of the excavation a beam supporting a wall related to the second building phase (Figure 2) lies on top of unit 10. In the northern part of the excavation (Figure 4) unit 10 is overlain by unit 1, which comprises a c.15 cm-thick grey, well sorted, siliciclastic sand layer containing flat well-rounded cobbles arranged in a chaotic pattern. Unit 1 is covered by structures of the fourth phase (Figure 2).

Units 90 and 1 were studied in detail because they are unusual with respect to the prevailing deposits in the excavation. They are composed of clean, well-sorted, siliciclastic fine sand (sandstone, quartz and mica) or well-rounded cobbles contrasting with the organic, colluvial, anthropic nature of the other units. The clean siliciclastic matrix and pebble components do not occur elsewhere in the onland local area. They do not contain ceramics or mortar thus, they are unrelated to human activities and, given the lack of weathering and soil development, appear to be deposited rapidly. We performed micropaleontological analysis on samples collected from these anomalous layers. The lowermost grey sand (unit 90) contains frequent fragments of mollusks and corals, rare benthonic (*Cibicides refulgens, Miniacina miniacea*) and planktonic foraminifera (*Globigerinoides* spp., *Globigerina* sp.), together with algae remnants. The upper sand with well-rounded flat cobbles (unit 1) contains frequent mollusk shell fragments. To verify that units 1 and 90 are truly anomalous in the exposed sequence, additional micropaleontological analyses were also carried out on samples from units 100 and 80. These samples are basically composed of badly sorted and heterogenic sands containing ceramics (mm in size), rare shell fragments, and pulmonata (terrestrial) gastropods (mainly in unit 80).

These results suggest that units 90 and 1 are not local deposits related to colluvial processes around the tower (as it is the case for units 10 to 80, and 100), but are of marine origin. These layers could represent either storm or tsunami deposit. We suspect they are likely to be of tsunami origin because: (1) the site is located in the back dune area at an elevation exceeding 5 m a.s.l.; (2) flat rounded cobbles (unit 1) are not found on the local beach but may come from the offshore area; (3) there are sharp basal erosional contacts; (4) the presence of benthonic and planktonic foraminifera, coral and mollusks fragments; (5) these deposits are rare in the stratigraphy (i.e., storms are more frequent than tsunamis); (6) large storms able to overtop the beach dunes are uncommon in the region.

5. Dating of the deposits

According to the archaeological stratigraphy, the age of the sequence exposed at Torre degli Inglesi ranges between the 1st century B.C. and the middle of 19th century A.D. To constrain the age of the depositional events, we have obtained radiocarbon ages for 6 charcoal fragments (Figures 3 and 4 for location). Dating was performed at the AMS facility of the Poznan Radiocarbon Laboratory, and measured ages were dendrochronologically corrected according to Calib REV5.0.2 [*Stuiver and Reimer*, 2005]. Four samples were collected from units 100, 90 and 80 and provide age control for the lowermost part of the section (Figure 3). Unit 100, on top of the Roman cobble paving, yielded a calendar age of B.C. 50 to A.D. 70, confirming the age of construction of the Roman tower. The same time span of A.D. 0-135 was obtained for samples from units 90 and 80. Two more samples from units 70 and 40 yield consistent ages that are between A.D. 135 and 335 (Figure 4). The similarity of this ages coming from layers well separated in the stratigraphy indicate that the deposits contain an important fraction of reworked material or that they have been deposited rapidly. Interestingly, the archaeological age of the ceramics found in the water cisterns filling is 2nd-3rd century. This suggests that a probable destruction (fire, earthquake, attack, etc.) occurred after the 3rd century and generated most of the debris contained in unit 70 and younger ones. The deposits found in the cisterns and around the tower accumulated after this event, in an unknown period of time, but before the 16th century.

The fact that archaeological and radiocarbon ages agree allow us to make inferences on the ages of the two possible layers of tsunamis deposit (units 90 and 1). Unit 90 is younger than B.C. 50 and older than A.D. 125. Because the unit contains samples dated at A.D. 0-125 the age range could be further narrowed to this interval. Age constraints for unit 1 are less solid. This unit lies below the fourth phase structures that are dated to the end of 19th century, and above units 10 and 20 that are younger than A.D.135-335 (Figures 2 and 4). Thus, unit 1 may have been deposited anytime between the 3rd and the 19th century.

Unfortunately, no direct relationship between this unit and the 16th century structure was found. However, for the following three reasons, the age of unit 1 is likely to be closer to the younger part of the interval (i.e., closer to A.D. 1861 when the Bourbons left Sicily): (1) the ground level of the 16th century tower was very close to the present one, (2) unit 1 appears to be the very last deposit before the 19th century pavement, (3) the time elapsed between unit 1 deposition and the building of the pavement should be short otherwise loose sand of the matrix would have been removed by surface processes.

6. Earthquake triggered Tsunamis?

If the anomalous units are tsunami deposits as we argue, then the most obvious cause, as occurred several times in the past millennium, is either a offshore fault dislocation or a landslide triggered by large local earthquakes. There is also the possibility that tsunamis are related to far-field events or volcano collapse but, from a single site, we cannot evaluate these possibilities.

Earthquakes that could have triggered a tsunami and deposition of the anomalous layers at Torre degli Inglesi occurred in B.C. 91, A.D. 17, mid- 4^{th} century, 853, 1169, 1693, 1783, 1894, 1908 [*Guidoboni et al*., 1994; *Boschi et al*., 2000; *Working group CPTI*, 2004; *Guidoboni and Comastri*, 2005]. For the oldest events (before the 16^{th} century) no reliable information on damage and natural effects are available, thus, their epicentral locations have large uncertainties.

The age of unit 90 (A.D. 0-125) is consistent with the A.D. 17 event, that is known as the Reggio Calabria earthquake, but no knowledge that a tsunami was associated with this earthquake existed until now. The evidence presented here for tsunami associated with this local earthquake adds to the tsunami hazard database of the region and also to the understanding of the A.D. 17 earthquake source (currently the epicentre is assumed to be on the eastern flank of Mt. Etna and M5.2). Although there are considerable uncertainties related to the age of unit 1, it is most likely a deposit of the 1783 Feb 6 tsunami that is well known to have strongly impacted the nearby village of Torre Faro.

No evidence for the 1908 tsunami was found and this can be the result of several factors. Firstly, the different orientation of the coast at Torre degli Inglesi with respect to the village of Torre Faro, for which historical reports for these events exist. Moreover, the area was built up since the 16^{th} century, thus, even if a tsunami wave reached the tower, the structures around it (e.g. the 19^{th} century 1.5 m-high garden wall) prevented the deposition of tsunami debris at the site or these latter may have cleaned up by tower occupants.

7. Conclusions

On the basis of the detailed survey of the deposits exposed in an archaeological excavation at Torre degli Inglesi we found two layers (units 90 and 1) totally different from most of the deposits exposed at the site and nearby. These are composed of clean, gray, siliciclastic sands and rounded cobbles, very different from the dark organic colluvia-rich in anthropogenic units. Micropaleontological analyses confirmed the marine origin of the deposits comprising units 90 and 1. The nature of these layers, coupled with their sharp erosional contacts and their relative infrequency (i.e., if they were storm deposits, they should be more frequent), allow us to interpret them as paleotsunami deposits. Combining archaeological, historical and radiocarbon data we correlate the oldest tsunami layer (unit 90) with the 17 A.D. earthquake, for which no prior knowledge of tsunami generation was known. The age of the youngest layer (unit 1) is poorly constrained between the 3^{rd} and 19^{th} century but tentatively associated to the 6 Feb. 1783 event. The study area is characterized by rapid residential growth and large infrastructure projects such as the Messina bridge. Our study has identified probable tsunami inundations that need to be taken into account when assessing hazard associated with urban development and large infrastructure projects.

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Figure Captions

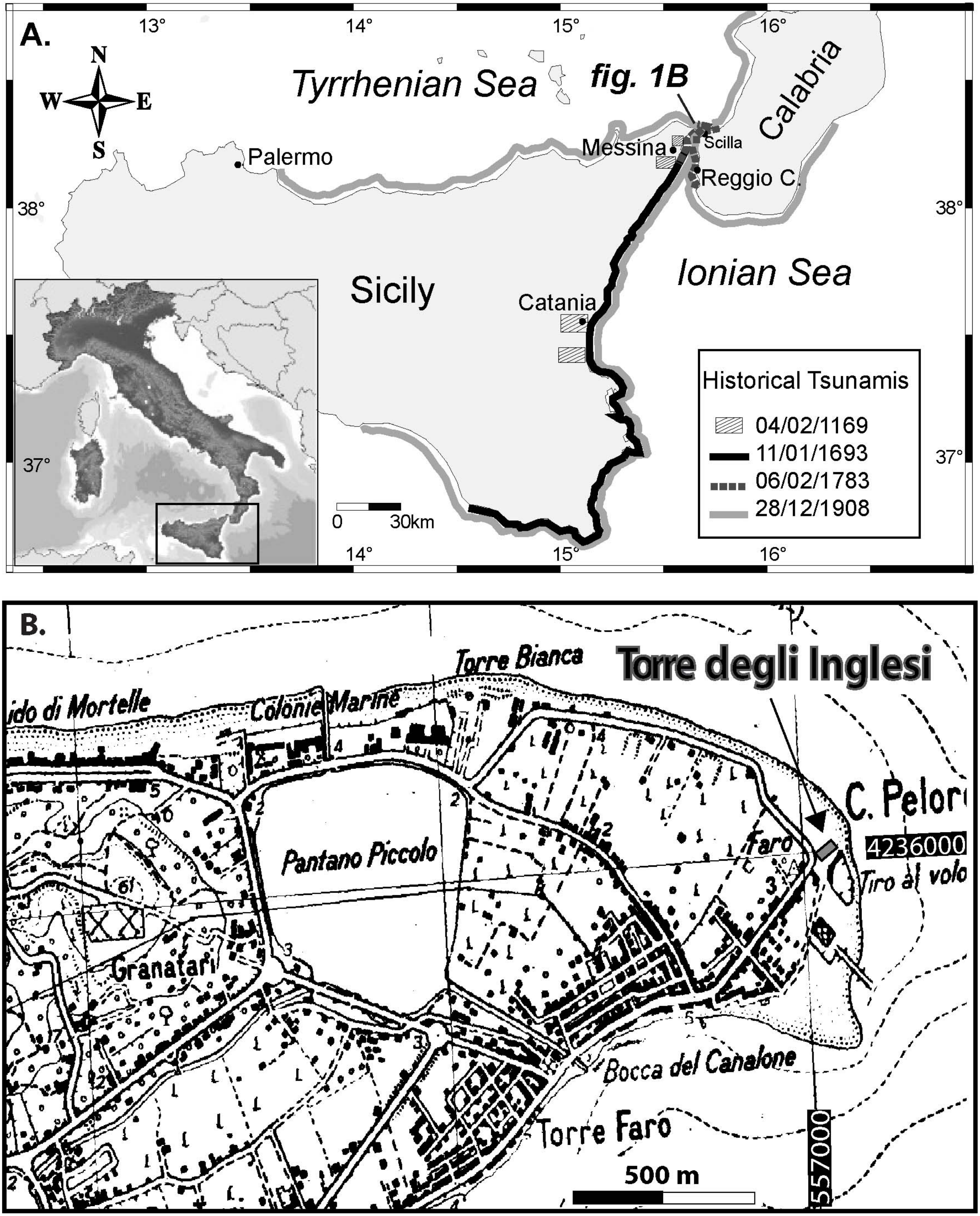
Figure 1. (A) Tsunami inundation in Eastern Sicily: lines with different gray tones and patterns and small striped rectangles indicate the inundated coastal areas. (B) Topographic map of the Ganzirri peninsula with the location of Torre degli Inglesi (arrow) near Capo Peloro, and of the village of Torre Faro located on the southern coast (from IGMI 1:25000 scale topographic maps, zone 33S, surveyed in 1954).

Figure 2. View of the archaeological excavation on the NW side of Torre degli Inglesi. The main building phases (i to iv) are visible and it is possible to observe the relative chronology. Different

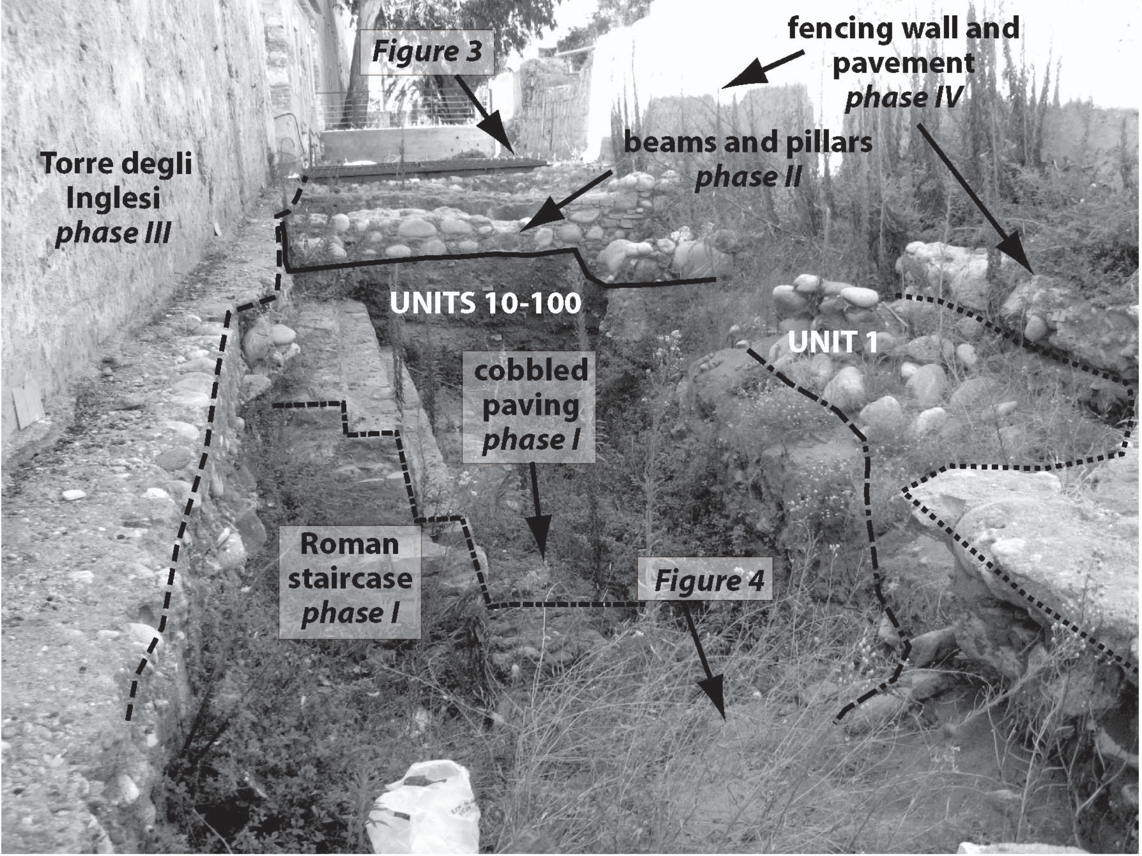
patterns highlight the major relationships between features of different age. Labels figure 3 and 4 indicate the view of photographs shown in the relative figure.

Figure 3. View of the NW wall of the excavation at Torre degli Inglesi (see Figure 2 for location). Numbers refer to stratigraphic units described in the text, white triangles are location of dated charcoals. Measured and 2σ dendrochronologically corrected ages of samples are reported as yr BP. An approximate scale is shown in the lower right corner, consider the excavation was narrow and there is important deformation of the photo. Lower left inset shows a detail of the area enclosed in the rectangle in the middle of figure.

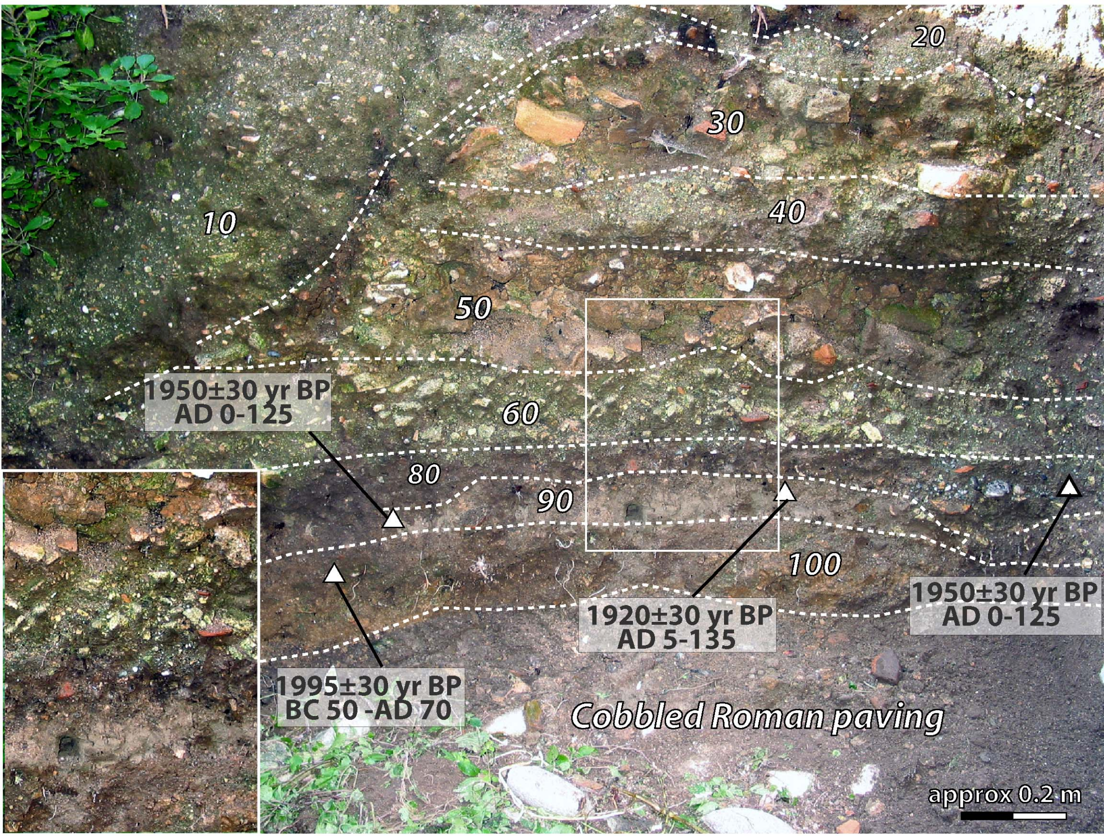
Figure 4. NE wall of the excavation at Torre degli Inglesi (see Figure 2 for location). Numbers and symbols as in Figure 3. Dashed red line highlights a fracture probably related to the 1908 earthquake. Scraper in the middle of the photo (highlighted in black) is about 0.3m tall and should be used as a scale considering that there is important photographic deformation. Lower left inset shows a detail of unit 1 (outside this picture).



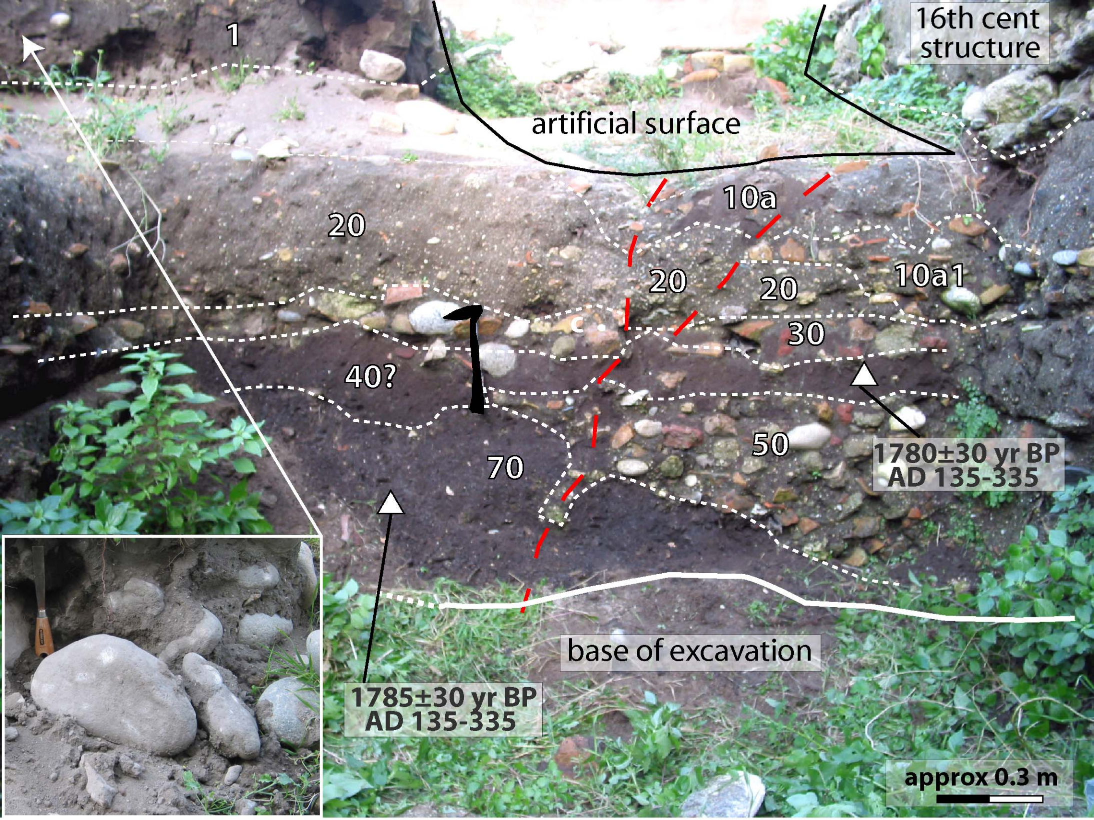
Pantosti et al. Figure 1



Pantosti et al. Figure 2



Pantosti et al. Figure 3



Pantosti et al. Figure 4