Identification of paleotsunami deposits in the Augusta Bay area (eastern Sicily, Italy): paleoseismological implication

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In this paper we present the geological evidence of paleotsunamis in the Augusta area together with some paleoseismological implication derived from the discovery of multiple inundation events. It is well known that eastern Sicily has been affected in historical time by large earthquakes (CPTI Working group, 2004) and its southern sector in particular was strongly hit by the 1693 and 1169 events that were followed by devastating tsunamis. The Augusta Bay area is one of the locations where the information available from historical reports on tsunami effects (hit localities, inundated areas and run-up distribution) stimulated our curiosity in searching for the geological signature of tsunamis. The research was carried out through a multi-theme approach consisting of historical studies, geomorphological and geological surveys, coring campaigns, laboratory analyses (paleontological, radiometric, SEM, X-Ray, susceptibility, tephra, etc.). We mainly concentrated on marsh or lagoon areas where both the chance of tsunami deposit sedimentation/preservation and the possibility of finding datable material are expected to be quite high for coring survey. This preliminary work was based on a detailed geomorphological study of the whole Augusta Bay coast line, through aerial-photographs and satellite images interpretation and field surveys.
The geomorphological and historical approaches (De Martini et al., 2006; Gerardi et al., 2006) allowed us the selection of two favorable areas: Augusta and Priolo (Fig. 1).

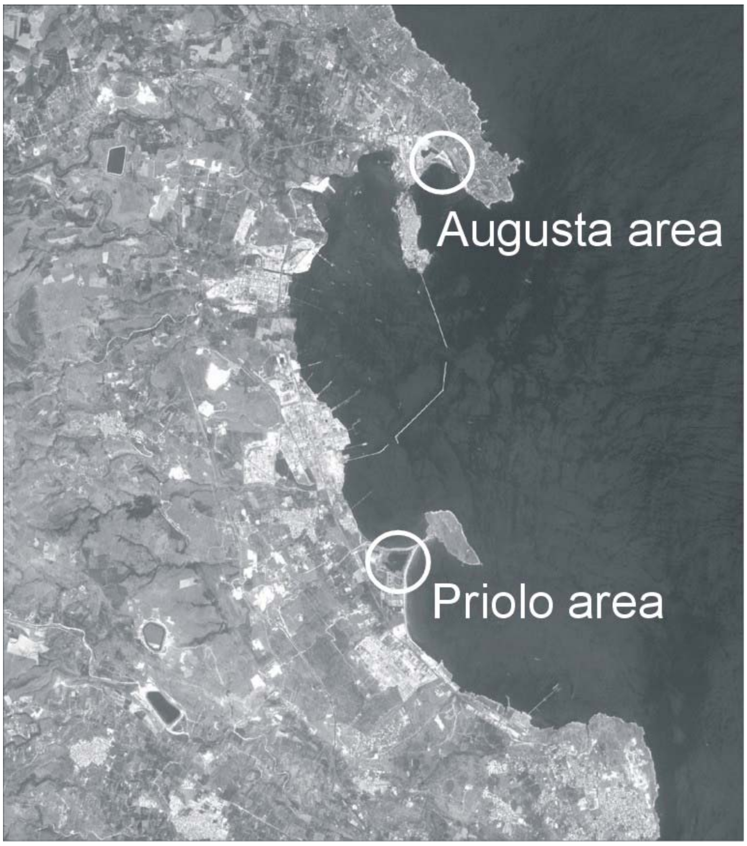

Fig. 1 - Location of investigated areas within the Augusta Bay.

In the two selected areas we carried out coring campaigns using both hand auger equipment and a vibracoring (gasoline powered percussion hammer). Preliminary stratigraphical and sedimentological descriptions together with photographs of the core deposits were performed directly in the field (Smedile et al., 2006; 2007). Once an interesting stratigraphic sequence was found we were properly equipped to collect 100 cm long undisturbed sample (within specific pvc tubes) down to 5 m maximum depth. Coring was always accompanied by GPS surveys for the exact positioning of cores with respect to present shoreline.
All the selected cores sampled with pvc tubes have been transported to the laboratory in order to perform accurate sedimentological descriptions and to collect all the needed samples for micropaleontological tephra analyses and isotopic dating. Micropalentological analyses were carried out on samples collected in all the performed cores in order to detect the possible marine component of a tsunami deposits in a marsh or lagoon sequence (e.g recovering of planktonic foraminifera, that are exclusive of the marine realm, and/or benthic forams exclusive of peculiar marine depth range). Tephra identification and radiocarbon analyses were used to constrain the age of the sediments, to derive sedimentation rates and to correlate potential paleotsunami deposits with historical earthquakes. Magnetic and X-ray analyses were performed on some selected cores to look for susceptibility variations and peculiar small-scale sedimentary structures (e.g. sharp contacts, convoluted layers, etc.) usually not clearly detectable trough the standard stratigraphic analysis.

Augusta area

In the Augusta area we dug 9 cores down to a maximum depth of 4.3 m, at a maximum distance from the sea of 460 m. The stratigraphic sequence is composed mainly by fine sediments, from clay to silt, with the exception of some well distinctive gravel layers (up to 10 cm thick) and one peculiar bioclastic deposit (at 190 cm depth). From bottom to top, the micropaleontological analyses show the occurrence of a high energy event (bioclastic layer) within an old brackish lagoonal environment, followed by a fine, probably alluvial, deposits characterized by rare reworked microfossils and some small potsherds. Moving up, a normal shallow marine environment appears to develop, interrupted upwards by possible artificial leveling of the site (or detritus cover).
In detail, the yellowish bioclastic layer (Fig. 2) found at about 190 cm depth is composed by few entire gastropods (*Hydrobia* spp., *Pirenella conica*), abundant shell fragments (mollusks, corals and echinoderms), few ostracods, often broken benthic (*Ammonia* spp., *Bolivina* sp., *Cassidulina laevigata*, *Cibicides lobatulus*, *Haynesina germanica,* miliolidae, *Pullenia bulloides*, *Rosalina* spp.) and few badly preserved planktonic (*Globigerina* spp., *Globigerinoides* spp., *Globorotalia inflata*, *Turborotalita quinqueloba*) foraminifera (Fig. 2).

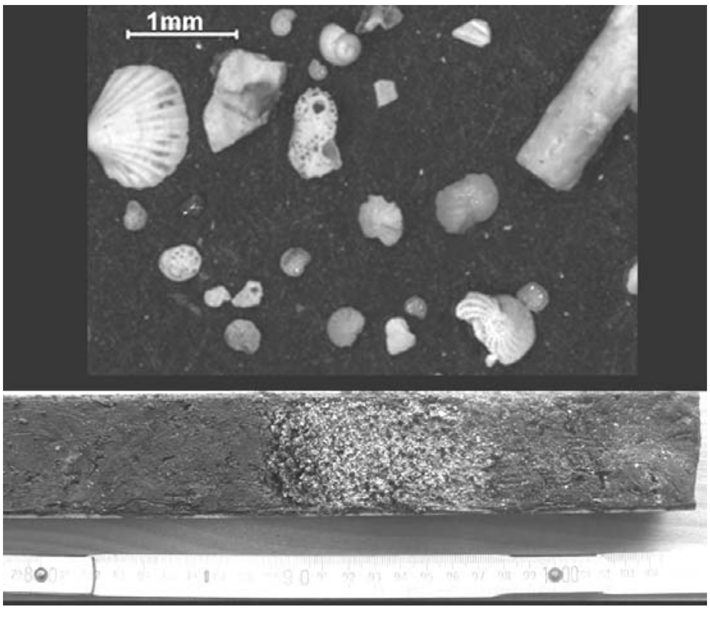

Fig. 2 - Augusta area: picture of the OSA-S6 core with yellowish bioclastic layer (below); macro and micro paleontological assemblage from the same layer (above).

This layer was found within a gray to dark gray fine silt deposit (20-30 cm thick) characterized by abundant ostracods (*Cyprideis torosa*), several entire gastropods (*Hydrobia* spp., *Pirenella conica*) and well preserved benthic foraminifera (*Ammonia parkinsoniana, A. tepida*, *Haynesina germanica*). It showed a sharp, possibly erosional, basal contact. The erosional behaviour of this bioclastic layer coupled with striking micropaleontological results allowed us to interpret it as tsunami deposit, with a high level of confidence.
Radiocarbon dating was performed on 3 samples, collected just above, within and below this bioclastic layer; OSA-S6-C1, C2 and C3 (Table 1) gave coherent results, constraining the paleotsunami age to the interval 1000-800 BC, and, being very close in time, validated the hypothesis of a sudden inundation rather than a gradual transition to higher energy environment.

Tab. 1. Measured and calibrated ages (according to Calib REV5.0.2 by Stuiver and Reimer, 2005) of the samples collected in the cores.

Sample	**Type**	**Measured age B.P.**	**Calibrated age 2 σ**
OSA-S6-C1	Organic sediment	2685± 30	**898-802 BC**
OSA-S6-C2	Shells	3310± 30	**1264-826 BC**
OSA-S6-C3	Organic sediment	2745± 30	**975-819 BC**
OPR-S11-43	Shell	890± 30	**1420-1690 AD**
OPR-S1-9	Shell	3970± 35	**2100-1635 BC**

Priolo area

The Priolo area was investigated at one site (Fig. 1), where we dug 17 cores down to a maximum depth of 4.2 m, as far as 530 m from the sea. The stratigraphic sequence is composed mainly by fine sediments, from clay to silt, with two distinctive bioclastic layers (A and B found at 10-15 and 30-40 cm depth, respectively), one detritic deposit (C at 90 cm depth) and one peculiar sand layer (D at 160 cm depth). Combining micropaleontological and X-ray analyses (Fig. 3): a) the entire stratigraphic sequence appears to belong to a lagoonal environment; b) both bioclastic layers, characterized by sharp basal contact, present an abnormal concentration of shell fragments and entire gastropods (all arranged in a chaotic pattern) and B layer shows also an increment in the benthic foraminifera specific diversity; c) the detritic deposit C (2-3 cm thick) shows a anomalous assemblage made by macromammal bone fragments together with rare and badly preserved benthic (*Cassidulina carinata, Cibicidoides pseudoungerianus, Melonis barleeanum, Planulina ariminensis*) and planktonic (*Globigerinoides* sp.) foraminifera; D layer marine microfauna appear well preserved, differently from the association characterizing the fine to very fine deposits above and below. Thus, we may interpret all the four layers A-B-C-D as tsunami deposits but we can assign to A and B layers a medium-high level of confidence, whereas the detritic deposit C and the peculiar sand layer D have a low level of confidence.
Moreover, preliminary magnetic, petro-chemical and morphoscopic analyses on one blackish volcanic coarse sand, normally graded, found in 6 cores at about 70 cm depth, allowed us to correlate it with the 122 BC Etna tephra (Coltelli et al., 2000) (Fig. 3). Radiocarbon dating was performed on 2 shell specimens (Table 1); OPR-S11-43 has been collected just below the uppermost bioclastic layer while OPR-S1-9 constrains the age of the lowermost tsunami sand (D layer). Combining tephrostratigraphic and C14 data, that appear to be in good agreement, we may estimate an average sedimentation rate of 0.35-0.45 mm/yr for the past 4000 yrs. Moreover, we associate the two uppermost bioclastic deposits to the 1693 event and the 1169 tsunamis, respectively. The age of the lowermost tsunami layers, found at 90 and 160 cm depth, could be constrained in the time intervals 570-122 BC and 2100-1635 BC.

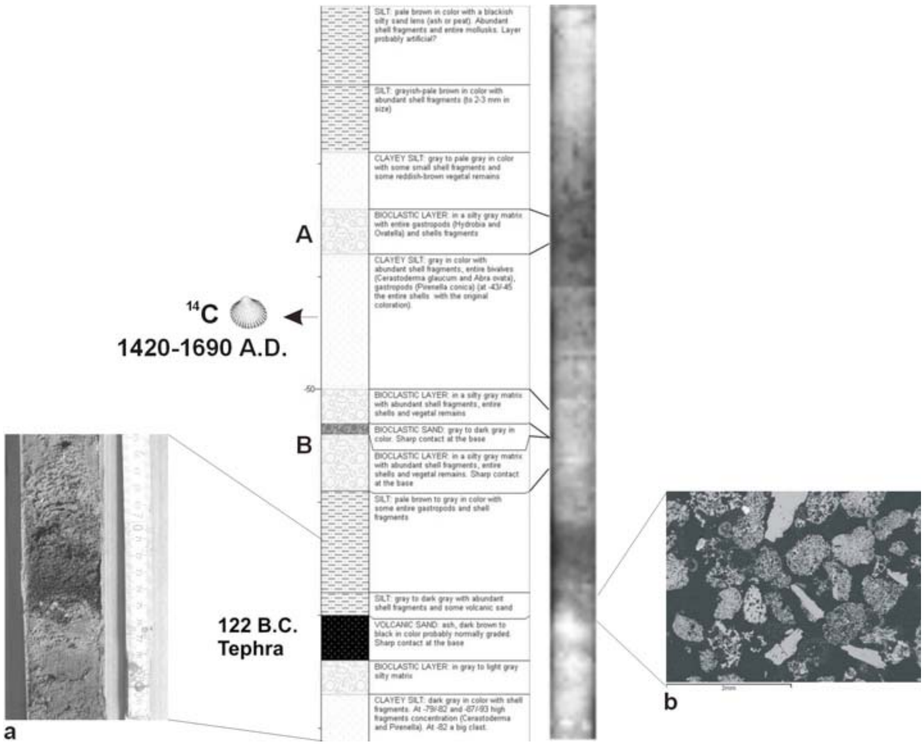

Fig. 3 - Priolo area: OPR-S11 log compared with X-Ray film (on the right), please note how the bioclastic and volcanic layers show up on the film; a) detail of the tephra layer; b) SEM picture of the tephra sample composed of micro-pumices, loose crystals of plagioclase and minor lava lithics.

Conclusions

Summarizing the results obtained in the Augusta Bay area, we were able to associate two tsunami deposits found at Priolo to the 1693 and 1169 earthquakes, and we collected interesting evidence for the occurrence of three paleoinundations occurred about 570-122 BC (Priolo), 1000-800 BC (Augusta) and 2100-1635 BC (Priolo). The identification and characterization of geological evidence of historical and paleo tsunamis (useful to obtain tsunami recurrence time, maximum inundation distance, elapsed time since the last tsunami event, etc) may have a significant relevance for Civil Protection applications being these data easily usable in the field of tsunami scenario and modeling, especially taking into consideration the fact that the Augusta and Priolo areas have an important role as main national industrial and military sites.

Acknowledgements.

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