Title: Tsunamis in the Mediterranean Sea

Paolo Marco De Martini[1], Laura Graziani[1], Alessandra Maramai[1], Simone Orefice[2], Daniela Pantosti[1], Alessandra Smedile[1]

[1] Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy
[2] Autorità di Bacino Distrettuale dell'Appennino Centrale, Italy (Contractor)

Abstract

The Mediterranean area has been inhabited since long time and the development of human settlements along its coastlines allowed to "record" the occurrence of natural disasters as tsunamis in different coastal settings. Nowadays, the same coastal areas host large cities and critical infrastructures and the availability of historical and geological data on the tsunamis of the past, on their characteristics and effects can significantly contribute to the development of adequate mitigation measures, defense actions and better awareness of people living along the coastlines. The knowledge of past tsunamis is one of the keys to better forecast future events: our territory is a natural laboratory where past natural events can replicate in the future with with similar characteristics. All the coastlines may be considered as the geological and geomorphological archive of past inundations. In the Mediterranean area, valuable historical evidence of past tsunamis and several paleotsunami traces exist, these were recently well organized in homogeneous and coherent geographical databases; these represent the core of this manuscript. This type of information, recently improved and enriched, allows to increase the knowledge of tsunami histories of the Mediterranean sites most prone to tsunamis, providing information on the intensity and frequency of past events.

Keywords: Tsunami, Mediterranean Sea, Historical record, Paleotsunami deposit, Tsunami hazard, Euro-Mediterranean Tsunami Catalogue, Italian Tsunami Effects Database, Paleotsunami Deposits database

1 INTRODUCTION

Understanding natural phenomena, especially if they are rare such as tsunamis, requires a deep knowledge of what has happened in the past;this is fundamental to develop models to forecast future events and to assess the tsunami hazard. Moreover, the dissemination of information is a relevant factor in increasing awareness of people living in tsunami prone areas, especially where tsunamis are very rare and the memory of their occurrence can be lost.

A tsunami is a series of water waves with long wavelength and long period, generated in an ocean by a significant disturbance that displaces the water within a short period of time. Tsunamis are mainly associated with submarine earthquakes (more than 80% of the known tsunamis have seismic origin), but also to other triggering phenomena as submarine or coastal landslides and volcanic eruptions (for more information see Reference Module "Tsunami" by P. L.-F. Liu).

When a tsunami approaches the coastal area, it severely interacts with the shallow sea offshore, the coastline and onshore. In the Mediterranean region, the effects of this interactions on the natural and human environments are preserved and reported since the disastrous eruption and related tsunami of the Santorini volcano (Aegean Sea, Greece) occurred about 4000 yrs. BP. In fact, the tsunami waves not only devastated the Santorini Island but impacted along the shorelines of several islands nearby, up to the Crete Island in the Aegean Sea. The event was so catastrophic that it was assumed that it could have been the cause of the decadence of the Minoan civilization and several Greek Myths took inspiration from it (e.g. Atlantis). Based on the geographical distribution of historical reports and on the recognition of several paleotsunami deposits in different sites as far as the Ionian Sea of Sicily (southern Italy), the Santorini tsunami can be considered as the first known Mediterranean basin-wide event.

The Mediterranean area has been inhabited since long time and the presence of different morphological coastlines, rich in bays and low morphology as well as coastal lakes and fluvial plains, attracted the development of human settlements able to "record" the occurrence of natural disasters as tsunamis. Nowadays, the same coastal areas are clearly more developed with large cities and critical infrastructures and an event similar to that of Santorini would cause quite a bigger death toll and larger economic loss.

Active tectonics of the Mediterranean area is mainly driven by the present-day convergence between the Eurasian and African plates and its complexity is also related to the presence of different microplates. There is contemporary motion along different subduction zones (e.g. the western and eastern segments of the Hellenic Arc, the Calabrian Arc), as well as along large transform fault systems (e.g. offshore the Dead Sea Transform Fault in the Levantine Sea and the North Anatolian Fault Zone in the Eastern Aegean Sea and in the Marmara Sea), and along extensional fault systems (e.g. the Corinth Gulf of Central Greece and the Tyrrhenian Calabria and Messina Straits) and compressional fault system (e.g. the North Algerian margin and the Eastern Adriatic sea). The tsunamigenic potential of the active tectonic structures is clearly different and variable but, based on historical and instrumental data, there is a tsunami hazard increment moving from west to east when you consider the whole Mediterranean area. Moreover, it is worth mentioning that non-seismic potential tsunami sources, such as submarine landslides, are known in most of the Mediterranean basin and that also active volcanism (e.g. the Etna, Vesuvius and Phlegrean Fields coastal volcanoes and the Eolian islands in Italy or Nisyros-Yali and Santorini-Kolumbo volcanic islands in Greece) was responsible for significant tsunami events.

The detailed knowledge of the tsunamis occurred in the past is one of the keys to better forecast future events because the same event can occur again. In our territory tsunami occurred in the past and will also in the future, therefore all the coastlines may contain the geological and geomorphological archives of past inundations and provide insights on the events of the past as the historical reports. The availability of tsunamis historical and geological data , their characteristics and effects can also contribute to a better knowledge of the causative sources and to the development of adequate mitigation measures, defense actions and awareness of people living along the coastline.

Also, under the influence of the recent disastrous 2004 Indian Ocean Tsunami (IOT) and the 2011 Tohoku (Japan) tsunami effects, in the past years, a special effort has been done for the realization of catalogues making available the most complete and reliable sets of data on tsunami of the past. These data represent the first step for assessing the tsunami hazard of a region.

Nowadays, in the Mediterranean area we have an important tsunami historical record and several paleotsunami traces, these are well organized in homogeneous and coherent geographical databases, and represent the core of this manuscript. The increment of these types of data can allow the achievement of long tsunamigenic histories with information on the past tsunami intensity and frequency at different sites. Far to be complete in their present version, they will be updated regularly and represent a useful tool to define the limit of the areas known to have been inundated by past tsunamis, to verify coastal hazard assessments, as well as to test both probabilistic and deterministic inundation scenarios.

2 HISTORICAL TSUNAMIS

Historical tsunamis have been studied for many vulnerable coastlines of the world, including the Mediterranean region, and data published in tsunami catalogues or databases. Although the occurrence of tsunamis as a catastrophic natural phenomenon has been documented by historians since antiquity, data on tsunamis were concealed in catalogues of other natural phenomena like earthquakes, volcanoes and hurricanes, up to the first half of the 1900s. In the Mediterranean Basin the first information of a tsunami is the one related to the catastrophic eruption of the volcano Santorini (Aegean Sea, Greece), about 4000 years B.P. In ancient times natural catastrophes were attributed to divine punishment and very often the writers (usually clergymen or scholars of natural phenomena) report very emphasized and/or amplified descriptions to underline the divine chastisement for the wicked behavior of men. Nevertheless, both historians and scientists have gained experience in extrapolating useful information for scientific purposes from this kind of information.

Generally, historical sources allow us to reconstruct history, these can be original documents, pictures, books, or objects that conveys information about an event.

We can distinguish two main types of historical sources, primary and secondary, evaluated differently on the basis of their reliability. The former is composed by first hand documents, ranging from eyewitnesses accounts - which are considered the most reliable ones - to letters, diaries, chronicles, reports, religious and administrative documents, newspapers, maps which basically have the same high reliability (Figure 1). Historians work with primary sources to understand the past on its own terms, not through the modern-day lenses.

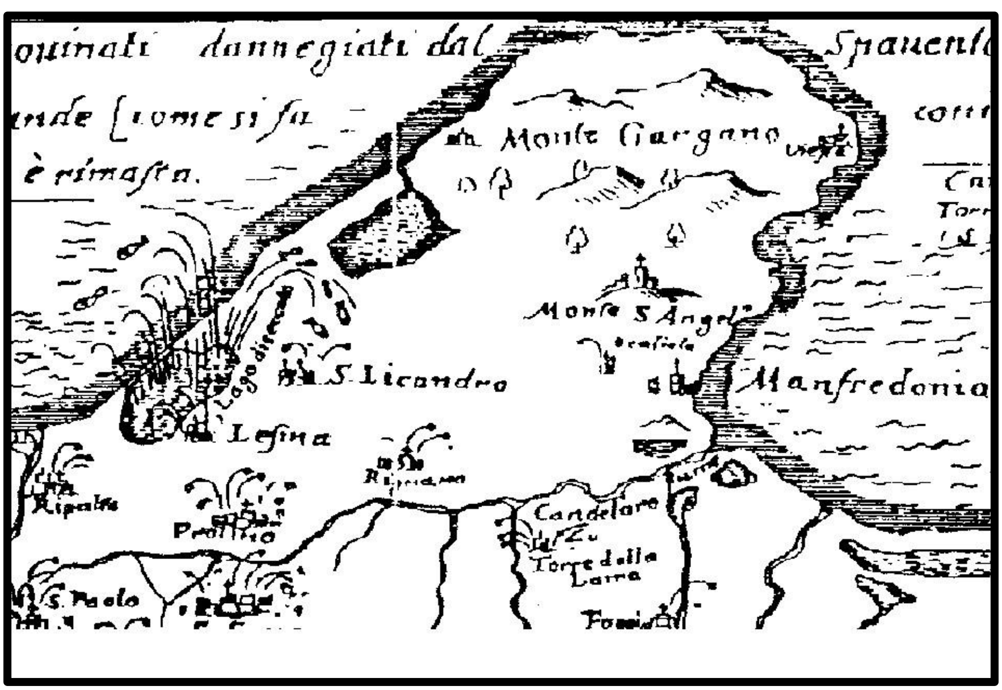


Figure 1 - An example of primary source: particular of the drawing from De Poardi (1627) describing some effects of the 1627 Apulian (Southern Italy) tsunami. During this event the Lesina lake remain dried for several hours and this can be also deduced from the draw, where fish are jumping out of the Lesina Lake.

A secondary source is a work that comments on the past: non-coeval documents, revisions, catalogues, recently written books and second-hand documents. In general, secondary sources are considered with a lower reliability level. Since most tsunamis are of seismic origin, historical documentary sources related to earthquakes are the main sources used in tsunami studies. On the contrary, it is more difficult to identify and find the bibliographical sources of tsunamis of non-seismic origin – tsunamis caused by volcanic eruptions or landslides.
All types of historical data suffer from relevant uncertainties, mainly related to the accuracy of the sources. Anyhow, when historical tsunami data are carefully analyzed in the light of reliable criteria, it is possible to obtain sensible and useful results. A tsunami database is a collection of both observational and instrumental data related to events occurred in a given geographical area. Data included in the database derive from a large variety of historical documentary sources, depending on the period of tsunami occurrence, the relevance of the event and the human presence in coastal areas. According to the quality of the available sources, data contained in a database can be more or less detailed and reliable. Instrumental data are more reliable and usable than observational ones but they are available, at best, only since the beginning of 1900s, with a range of a few decades of variability depending on different geographical areas. Instrumental networks for tsunami monitoring have been implemented only in the past few decades. On the contrary, due to their wide temporal coverage, historical records constitute a unique and valuable source of data for tsunamis, although with their limitations. The covered time range strongly varies from region to region, from a few hundreds of years in parts of the Pacific, southeast Asia, or Australia to thousands of years in the Mediterranean basin. Indeed, the Mediterranean Sea has always been the center of fervid activity and its coasts has been inhabited since very ancient times thus its history is well documented as well as the significant natural events occurred in the region.

3 THE EURO-MEDITERRANEAN HISTORICAL TSUNAMI CATALOGUE

A first fundamental step to reduce limitations of historical data is to carefully examine all the available sources attributing reliability to both documentary sources and data reported. This methodology has been pursued for the realization of the Euro-Mediterranean Tsunami Catalogue (available at http://roma2.rm.ingv.it/en/facilities/data_bases/52/euro-mediterranean_tsunami_catalogue, Maramai et al., 2014), at present the reference database for the Mediterranean basin (Figure 2). The Euro-Mediterranean Tsunami Catalogue, hereinafter EMTC, is the result of a critical review of all the existing regional catalogues available in literature for this area, each one having a different format and level of accuracy. EMTC includes tsunami occurred in the Mediterranean Basin and also events that took place in the neighboring seas, i.e. in the European coasts of the Atlantic Ocean, in the Sea of Marmara and in the Black Sea. As far as the Mediterranean Basin is concerned, three large regions have been identified in EMTC, corresponding respectively to the Eastern, Central and Western Mediterranean. For the EMTC realization the most relevant effort was the standardization of parameters and the quality of the data, by using unified criteria for data selection and cataloguing.

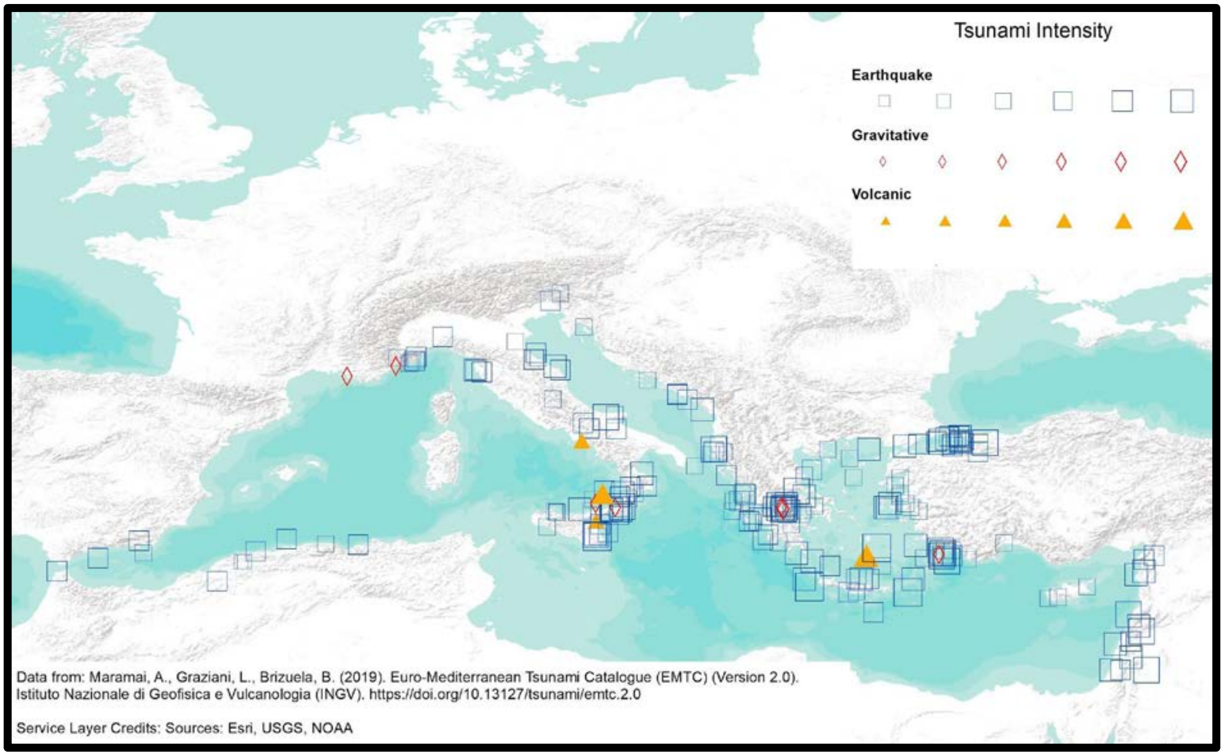


Figure 2 - Geographical distribution of the tsunamis occurred in the Mediterranean, taken from EMTC. In the map the tsunamigenic causes are reported with different symbols whose size is proportional to the intensity value.

The EMTC reports, for each tsunami, information on the main parameters of the event (date, region, subregion, reliability, tsunami intensity, run-up) and of the generating cause (i.e. geographical coordinates, earthquake magnitude, intensity, etc.) as well as detailed descriptions of the tsunami effects in the affected localities.
An example of a record of the EMTC containing the main parameters of an event is shown in Figure 3, while the complete dataset is shown in Table 1.

id	Year	Month	Day	hour	min	Reg	sub_Reg	short_description	lat	lon	macr_int	earth_mag	Rel	Cause
86	1693	1	11	13	30	M2	Eastern Sicily	Large sea withdrawal and flooding	37.140	15.013	11	7.32	4	ER

Figure 3 - Example of EMTC record for the 1693 Eastern Sicily tsunami. Id is the identification code of the event; Year, month, day, hour, min is the date of occurrence of the generating cause (earthquake in this example); Reg is the Mediterranean Region where the event occurred; sub_reg is the geographical subregion of occurrence; short description contains a short description of the event; lat and lon are the geographical coordinates of the generating cause; macr_int is the macroseismic intensity of the generating earthquake; earth_mag is the magnitude of the generating earthquake; Rel is the reliability of the tsunami; cause is the code attributed to the generating cause (ER means Earthquake Related). For readability reasons the empty table fields have not been shown.

Table 1 - List and description of all fields

Field Name	Description
EMTC_id	Identifier of the EMTC event
EMTC_Reliability	Reliability of the event.
EMTC_Cause	Cause of the tsunami.
EMTC_Year	Year of the EMTC event
EMTC_Month	Month of the EMTC event
EMTC_Day	Day of the EMTC event
EMTC_hour	Hour of the EMTC event
EMTC_minutes	Minutes of the EMTC event
EMTC_seconds	Seconds of the EMTC event
EMTC_source_reg	Geographical Region of the EMTC event
EMTC_source_sub	Geographical sub Region of the EMTC event
EMTC_short_desc	Short description of the EMTC event
EMTC_latitude	Latitude of the generating cause of the EMTC event
EMTC_longitude	Longitude of the generating cause of the EMTC event
EMTC_macr_int	Macroseismic intensity of the of the EMTC event (if seismic)
EMTC_earth_mag	Magnitude of the of the EMTC event (if seismic)

All events are fully referenced and supplemented by transcriptions of the used bibliographical sources. To equally rate the quality of the data, for each event a *reliability* value was used, assigned on the basis of the trustworthiness of the available data. According to EMTC, since 1630 B.C. to

2004, 224 tsunamis occurred in the Mediterranean Basin with a reliability ranging from 0 (very improbable tsunami) to 4 (definite tsunami). As expected, the majority of the events have seismic origin (86%), mainly triggered by submarine earthquakes and less frequently by earthquakes located in land (Figure 2). A small number of tsunamis were caused by gravitational phenomena induced by earthquakes (sub aerial or submarine landslides). Tsunamis caused by volcanic activity account for the 6%, for the most part caused by the Vesuvius and Aeolian islands volcanoes in the Central Mediterranean region. Few tsunamis (3%) are engendered by mass failures due to mere gravity load. Finally, the generating cause of the 5% of the tsunamis is unknown; in these cases, the reported description is typical of a tsunami but the generating mechanism has not been found yet. The Eastern Mediterranean, which includes the Greek Ionian and Aegean coasts, the coasts of Turkey and the Levantine coasts, is the region with the highest number of tsunamis (127 events). The Central Mediterranean, which includes the Italian coasts and the eastern Adriatic coast, counts 84 tsunamis while the Western region has the lowest number of events (13 tsunamis), mostly occurred in the Alboran Sea.More than 60% of the events included in EMTC have a high reliability value (3= "probable" and 4= "definite") which makes the Euro-Mediterranean Tsunami Catalogue an essential tool for the implementation of tsunami hazard and risk assessment.

On the basis of the available descriptions, for each event the maximum tsunami intensity value has been assigned, according to both the 6-degree Sieberg-Ambraseys scale (Ambraseys, 1962) and the Papadopoulos-Imamura 12-degree scale (Papadopoulos and Imamura 2001). Approximately the 65% of the tsunamis occurred in the Mediterranean have a Sieberg-Ambraseys intensity value ranging between 1 (very light) and 3 (rather strong) and therefore they produced slight damage to light structures at most. The 24% of the events has intensity value 4 (strong) and 5 (very strong).

The remaining 9 tsunamis have intensity 6 (disastrous) and caused destruction and many victims. Among these, it is worth mentioning the catastrophic tsunami that occurred in Crete in 365 A.C. for which many bibliographic sources are available having affected the whole Central Mediterranean with effects up to the coasts of Sicily. Another destructive event occurred in the Aegean Sea is the July 1956 tsunami where the wave height reached 25 m in the island of Amorgos. Also, Southern Italy, in particular Eastern Sicily, was hit in the past by two destructive tsunamis, the 1693 and the 1908 events, both triggered by strong earthquakes. The January 11, 1693 tsunami involved the eastern Sicily coast causing damage in some localities and many victims at Augusta where the first sea recession drained the harbor completely, causing severe damage to the ships, then the sea rose for about 15 m above its usual limit killing many people.

The December 28, 1908 tsunami is the strongest occurred in Italy. The generating earthquake took place in the Messina Strait causing a violent tsunami that hit both Sicilian and Calabrian coasts in less than ten minutes from the earthquake causing hundreds of victims and severe damage to villages and natural environment. The tsunami affected the whole Eastern Sicily coast, part of its Northern and Southern coasts, the Tyrrhenian Calabria coast and the island of Malta. The observed wave height generally diminished with the distance from the epicenter, but in the Messina Strait strong amplification effects were observed and the maximum measured runup heights exceeded 13 meters.

Detailed information on tsunami effects produced by these tsunamis along the Italian coasts are now included in the new Italian Tsunami Effects Database (Maramai et al., 2019, Figure 4). This is a first attempt to organize the available detailed information on the effects of historical tsunamis (e.g. run-up, inundation distance inland) and it represents a pilot project that should be extended to the whole Mediterranean basin.

The Italian Tsunami Effects Database (ITED) is an ancillary database compiled starting from the general descriptions reported in EMTC concerning tsunamis occurred in the Italian territory. Unlike EMTC, which focuses on the source of a tsunami, ITED centers on the tsunami effects observed along the Italian coasts, providing punctual and detailed information on how each place was affected by tsunamis effects over time. The information contained in ITED has been made available to the public through the display of a web application that allows the users to visualize the geo-referenced information on a map. ITED is accessible through https://tsunamiarchive.ingv.it/ited.1.0/.

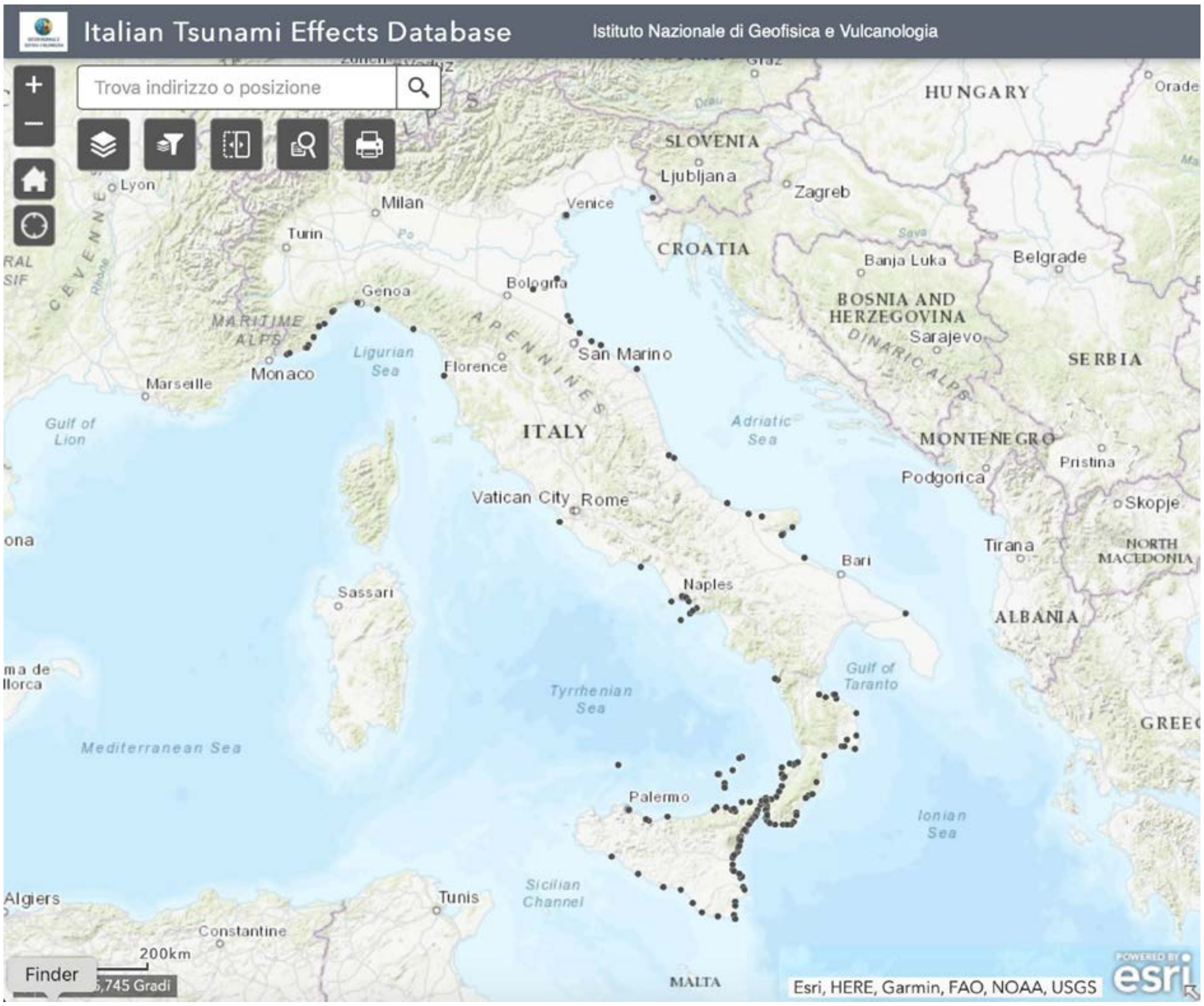


Figure 4: Geographical distribution of Italian places in which tsunami effects contained in ITED were observed.

ITED contains 300 observations of tsunami effects referred to 186 Italian places related to the 72 Italian tsunamis (Figure 4). The database provides also the tsunami-history for each locality, allowing the user to have a complete picture of how the site is prone to tsunami effects from an historical perspective.
An example of a record of the ITED containing info about one place in which the tsunami was observed is shown in Figure 5, while the complete dataset is shown in Table 2.

PlaceName	PlaceLat	PlaceLon	Prov	Comune	id	withd (m)	I_SA	I_PI	description
Taormina	**37.852**	**15.286**	ME	Taormina	86009	700	3	V	At Taormina the sea withdrew for about half a mile dragging some small boats (Boccone, 1697a).

Figure 5 - Example of an ITED record concerning a place where tsunami effects were observed for the 1693 Eastern Sicily tsunami. Place Name is the place where the effects were observed; PlaceLat and Place Lon are the coordinates of the place; Prov is the geographical administrative province; Comune is the Municipality of the place; Id is an identification code for the record; withd (m) is the observed withdrawal in meters; I-SA and I_PI are respectively the Sieberg Ambraseys and the Papadopoulos Imamura intensities of the tsunami at the place; description is a detailed description of the observed tsunami effects at the place with the related bibliographical reference. For readability reasons the empty table fields have not been shown.

Table 2 - List and description of all fields

Field Name	**Description**
PlaceID	Place identifier, from ASMI gazetteer
PlaceName	Place name
Sc	Place special case
PlaceLat	Place latitude
PlaceLon	Place longitude
Prov	Place province
Comune	Place municipality
ISTAT	Municipaly code assigned by Italian National Institute of Statistics
ITED_id	Identifier of the observation
ITED_Place	Reported observation place
ITED_inundation	Reported inundation (flag)
ITED_withdrawal	Reported withdrawal (flag)

ITED_SL_raise	Reported sea level raise (flag)
ITED_SL_low	Reported sea level lowering (flag)
ITED_Anom_SM	Reported anomalous sea movement (flag)
ITED_First_move	Reported first sea movement. Values: negative, positive, null
ITED_Lat	Latitude of the observation place
ITED_Long	Longitude of the observation place
ITED_ampl_m	Wave amplitude (meters)
ITED_Ob_WaHeigh	Observed wave height (meters)
ITED_Ob_runup_m	Observed runup (meters)
ITED_Ob_withd_m	Observed sea withdrawal (meters)
ITED_ob_inund_m	Observed sea inundation (meters)
ITED_ob_sea__ri	Observed sea rise (meters)
ITED_ob_sea_low	Observed sea lowering (meters)
ITED_Mean_perio	Mean wave period (minutes)
ITED_N_of_waves	Number of observed waves
ITED_description	Description of the observed effects
ITED_I_SA	Sieberg-Ambraseys tsunami intensity at the observation place
ITED_I_PI	Papadopoulos-Imamura tsunami intensity at the observation place

4 TSUNAMIS IN THE GEOLOGICAL RECORD

The tsunami waves produce a number of geological effects that are well observed and sizeable especially near the coast. The most common of these effects are related to inundation of the land with damping of marine deposits or to outgoing sediments flows (backwash waves) dispersing terrestrial and marine material in the offshore, breaking and transport of large boulders, change and modification of the setting of some portion of coast (e.g dune modification or washover fans). The propagation of tsunamis takes place over vast areas of the ocean from the deep sea to land, and the behavior of tsunamis varies intricately in response to bottom depth and coastal morphology. The possible variations in the sedimentary processes during this complex hydrodynamic event remain poorly understood, thus tsunamis can induce various types of sedimentation in submarine, lacustrine and continental environments. Generally, incoming tsunami waves (run-up phase) collect nearshore material from the local offshore and inland coastal substratum (erosional phase including both clastic and biogenic sedimentary particles ranging in size from sand to boulder), transport it landward (by pass phase with limited erosion and deposition) and damp it when the energy decreases (depositional phase). When the wave reaches its inundation limit, it may move seaward (backwash phase) and the suspended material still in the water column can be transported and deposited offshore (Figure 6). The repetition and waning of wave successions is quite complex and may result in the deposition of multiple tsunami layers or in the reworking of the just sedimented deposits due to the following backwash or run-up waves. Moreover, the impact of the waves with the coastal setting may change the beach profile/morphology (i.e. erosion of beach dunes, accumulation of washover fans, etc.) thus modifying the beach response to the following tsunami wave(s).

The tsunami-related geological effects are distinctive and can be seen as the tsunami fingerprints. In fact, their location, type, size and distribution are indicative of the characteristics of the tsunami in terms of its magnitude, timing and possibly source location and type (seismic, volcanic, mass movement - see Reference Module Tsunami by P. L.-F. Liu).

Under this light, the tsunami fingerprints represent a precious archive of information on past tsunamis that hit a portion of coastal area back in time to pre-historical times. The basis of the approach is the same of traditional paleoseismology: identification, characterization and dating of geologic effects of past tsunamis. Extending back in time the knowledge on the tsunamis that hit a region well behind the instrumental and historical times is a precious input for both deterministic and probabilistic hazard studies as we can figure out recurrent future scenarios for tsunami impact.

The first geological evidence for sediments deposited from prehistoric tsunamis (10 ka old sand sheets interbedded with marsh muds) was from North America (Atwater 1987) highlighting their potential for hazard mitigation. Since then, researchers worldwide investigated coastal areas looking for tsunami deposits related to large historical events (e.g., Chile 1960 and Lisbon 1755) or to huge well known pre-historical submarine collapses (Storegga landslide, North Sea).

The correlation of geological effects and tsunamis was further reinforced by the recent very large tsunamis that hit the Indian Ocean (IOT Tsunami) in 2004 and Japan in 2011 (Tohoku Tsunami) leading to major advances in tsunami sediment science.

4.1 IN SEARCH FOR PALEOTSUNAMI DEPOSITS

The first key question for the recovery of past-tsunami deposits is: where we do expect the tsunami deposit to have sedimented and preserved?

The best targets are low-energy environments such as coastal lakes, small lagoons, areas protected by coastal dunes, coastal marsh, as well as restricted bay or deep-sea floor in the offshore, where tsunami deposits may likely be trapped and do not experience important erosion and reworking (Figure 6A). Supplementary favorable geomorphic settings to look for tsunami deposit can be offered by rocky coast in case of boulder fields (Figure 6B) as well the continental shelf for the submarine deposition.

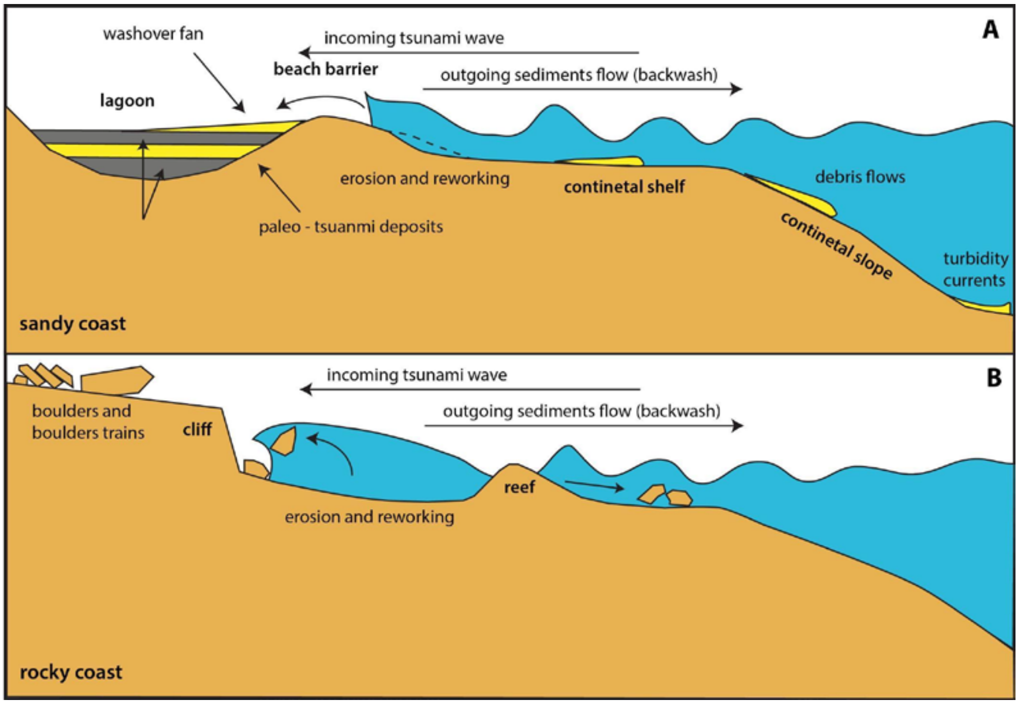


Figure 6 - Depositional environments in which deposits are formed associated with a tsunami (A) Tsunami landfall and deposits along sandy shores, and various types of backwash deposits; (B) Tsunami landfall at rocky coast (modified from Costa P.J.M. and Dawson S., 2015).

The second key question for the recovery of past-tsunami deposits is: what type of evidence researchers consider to identify and characterize a tsunami layer?

Tsunamis can disturb the prevailing steady state, and its high-energy sedimentation may be recorded as an obvious change in the sedimentary facies and environments. Tsunami can bring allochthonous material in the local depositional environment (e.g., concentration of marine organisms and plant within a continental stratigraphy).

Moreover, one of the caveats still under discussion in the scientific community is the distinction between tsunami and storm deposits (hurricane, typhoon, cyclones) that may be similar and occur in the same coastal setting. The best way to solve this ambiguity is linked to the possibility to search for tsunami deposits in low energy coastal sites at a distance from the present shoreline of at least 200 meters in order to exclude or to minimize the influence of the storms (Morton et al., 2007) along with a multiproxy approach.

The most common investigations may take advantage from the study of artificial cuts, hand and engine cores, exploratory trenches, natural exposures (Figure 7), which depend on the characteristics of the selected site.

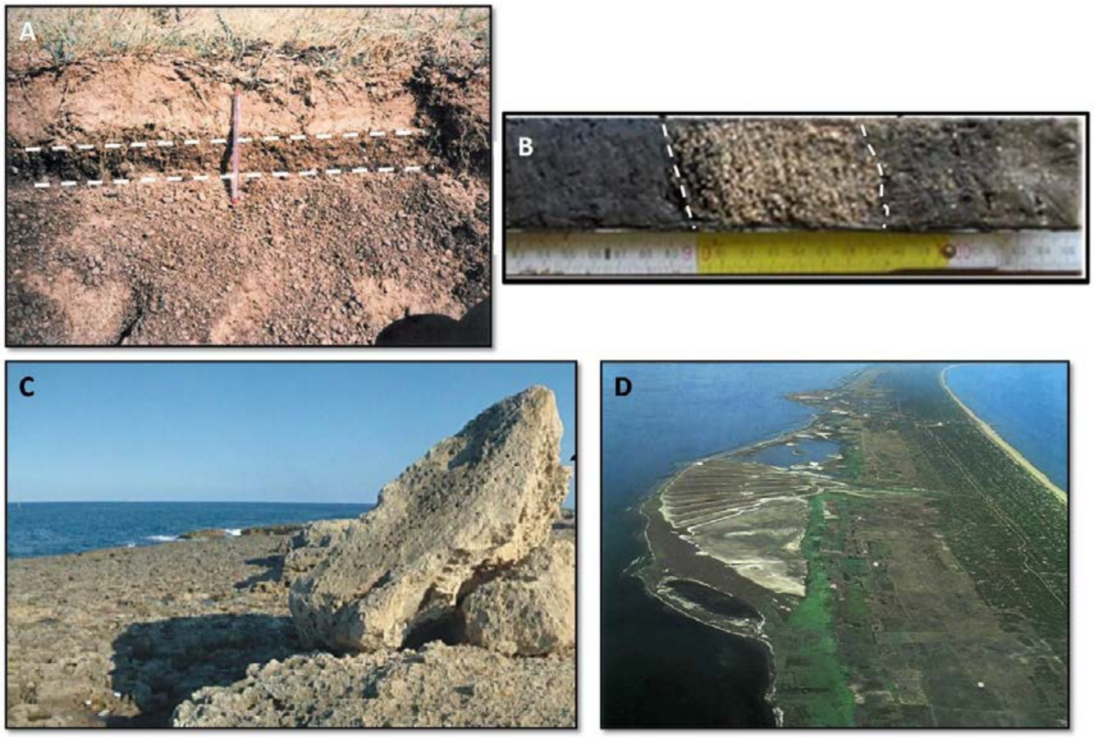


Figure 7 - Paleotsunami deposit evidence: (A) tsunami sediment in a trench wall, Didim, Turkey (modified from Papadopoulos et al, 2014); (B) paleo tsunami sediment layers in a core dug in eastern Sicily (modified from De Martini et al., 2010); (C) Boulders accumulation in the Ognina site, eastern Sicily (modified from Scicchitano et al., 2007); (D) Washover fan in the Lesina lake (modified from Gianfreda et al., 2001).

The most common and best studied tsunami related fingerprints are represented by fine grained deposits, secondarily followed by boulder(s) and geomorphic signatures. The 'proxy toolkit' for identifying tsunami fine sediments both inland and offshore can be summarized in the following four steps: (1) sediment lithology and stratigraphy; (2) grain size; (3) microfossils; and (4) physical and geochemical properties.

Tsunami sediments research (Figures 7A, 7B) start with a paleoenvironmental reconstruction based on a visual and laboratory analysis of the stratigraphical record to understand the lithology and the sedimentary structures (e.g. erosional vs transitional contacts, laminated vs massive deposits, rip-up clasts) that may be indicative of tsunami deposits. The grain size analyses are applied to further discriminate high energy layers that are potential tsunami deposits. In fact, most of tsunami sediments are characterized by a single sandy layer or by few sandy layers separated by mud laminations often with an erosive contact at the bottom and a thickness ranging from a few centimeters to a maximum of 20-30 cm (Tuttle et al., 2004; Morton et al., 2007). As for the fossil content, we known that tsunami sediments may present an important content of allochthonous organic matter and fossils. For example, in a coastal continental stratigraphy a tsunami deposits can be characterized by the presence of foraminifera, diatoms, fragments of corals and bivalves from offshore, contrasting with the surrounding fauna (Figure 8). Similarly, offshore tsunami deposits related to the back-wash waves may be characterized by the presence of allochthonous material and fauna such as continental and nearshore fauna and vegetation remains transported on the continental shelf. The recent developments in the characterization of the physical and geochemical properties of sediments provide further constraints on the nature of the samples. Among others we should mention, geochemical analyses and elements concentration (Smedile et al., 2019), heavy minerals analysis (Costa et al. 2018; Tyuleneva et la., 2018), measurements of anisotropy of magnetic susceptibility (AMS) (Vigliotti et al., 2019) and X-ray tomography (Falvard & Paris 2017).

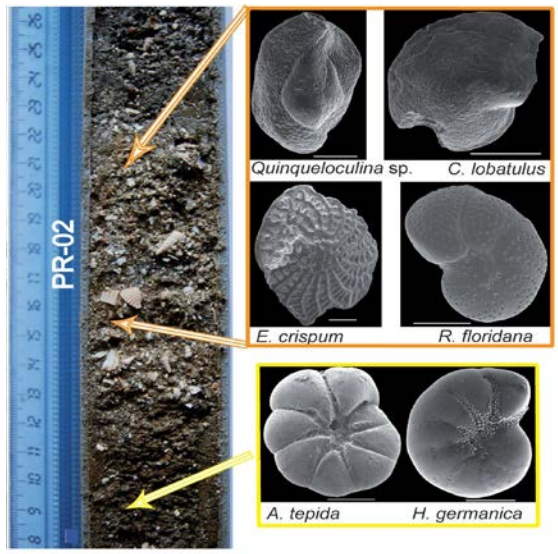


Figure 8 - Example of paleotsunami deposits found at the onland Priolo site, SE Sicily, Italy (modified from Smedile et al., 2012). On the left, picture of a bioclastic layer with sharp (probably erosional) basal contact (event PR-02 from the OPR-S11 core found at -0.60 m of depth), displaying a large amount of shell fragments and gastropods). FESEM images on the right (the scale bar below each picture represent 100 µm) show selected foraminifera collected within the high-energy layer (orange box) and above and below it (yellow box). The foraminifera in the yellow boxes are typical of lagoonal environments (*Ammonia tepida* (Cushman) and *Haynesina germanica* (Ehrenberg)), whereas those in orange boxes are typical of open marine environments (*Cibicidoides lobatulus* (Walker and Jacobs), *Elphidium crispum* (Linnaeus), *Quinqueloculina* sp. and *Rosalina floridana* (Cushman)).

Differently from loose sediments, tsunami deposits represented by large blocks are often located on rocky platforms or terraces characterized by a height above the sea level (Figures 6B and 7C). Blocks can be represented by megaboulders, isolated and sparse or arranged in fields or berms in the intertidal/littoral zone, accumulated along the rocky coasts and in protected areas of coral reefs. They reach several tons in weight and are detached from the near shore and deposited inland by the impact of extreme events as tsunami and storm waves. Discrimination of tsunami boulder deposits from storm deposits is still problematic even if some works suggest that tsunamis produce disorganized boulder deposits whereas, storms organize boulders along lines and clusters (e.g. Weiss 2012). Supplementing traditional ground-based methods and surveys can be implemented by digital and high-precision 3D methods, such as terrestrial laser scanner, DGPS, LiDAR or photogrammetry.

As previously mentioned, tsunami signatures may also be represented by geomorphological evidence. Strong tsunami can modify and change the coastal setting of a certain portion of coast as beaches or dunes ridges, generating for example washover fans structures (Figure 7D). For example, to identify past tsunami Goff et al. (2007) developed a method based on LIDAR data combined with ground surveys. They identified several tsunami-related geomorphological features as: (1) remnant sections of dune ridge separated by scoured areas; (2) hummocky topography or sand sheets that form landward from pedestals (hummocky topography is the old, weathered equivalent of sand sheets); (3) parabolic dune fields, which are remobilized sand sheets landward of pedestals; (4) low profile sequence due to post-tsunami feature indicative of changes to coastal sediment budget.

When a tsunami deposit is identified the estimation of the age is the last main element for its characterization. The age determination can be done directly on the tsunami deposits itself but also on the material just above and below the tsunami layer, in order to have a reliable time interval of occurrence. Among the main adopted dating methods, radioactive isotopes are commonly used for determining absolute ages; the most common is radiocarbon (C^{14}) that allows dating samples containing organic matter back in time up to about 50.000 yrs. For the most recent times (past 2-300 yrs.), for which radiocarbon is not efficient because of the atmospheric contamination from industrial revolution, Pb^{210} $^{\text{and}}$ Cs^{137} are also applied. Moreover, Optically Stimulated Luminescence (OSL) is used on Late Quaternary samples and it is able to determine the time of exposure to sunlight of sediments rich in quartz, while Thermo-Luminescence (TL) is frequently used especially in archeological studies to calculate the time elapsed since sample (pottery) was heated. Other techniques as micro- and macro- Paleontology as well as Palynology are often used to calculate at least the time interval of some samples. Moreover, the presence of volcanic deposits within the studied stratigraphy can add crucial information by applying tephra-chronological studies. Finally, the presence of archeological remains can be used as a precious input for chronological estimates.
Each of the above dating methods pertain to the availability of dating material as well as the timespan we are investigating.

5 THE PALEOTSUNAMI DEPOSITS DATABASE

Most of the data on paleotsunami deposits collected in the Mediterranean area were organized in a web-based database thanks to EU project ASTARTE (grant agreement n◦ 603839, Project ASTARTE - Assessment, Strategy and Risk Reduction for Tsunamis in Europe). The database on Paleotsunami deposits (De Martini et al., 2017) was implemented with the purpose to be the future information repository for tsunami research in Europe, integrating the existing official scientific reports and peer reviewed papers on these topics.
This geographic database is a relational database managed by ArcGIS for Desktop software by Esri Inc. The internet interactive map service is hosted by the ArcGIS Online portal (www.arcgis.com). The ASTARTE Paleotsunami Deposits database – NEAM region is now available online at the address http://arcg.is/1CWz0. Any interested user may access the online GIS resources through an Internet browser or specific apps that run on desktop machines, smartphones, or tablets and be able to use the analytical tools, key tasks, and workflows of the service. To date, a total of 151 sites and 220 tsunami evidence have been recorded within the

ASTARTE database for the whole North-East Atlantic and Mediterranean seas region. On the other hand, several paleotsunami sediment layers have been recognized specifically along the Mediterranean coasts as well as at shallow depth in the offshore and now they constitute the 66 sites and 120 events recorded in this database so far (Figure 9).
The spatial distribution of tsunami deposits together with the events age can help us to understand where, and potentially with which recurrence a future inundation could take place. Far to be complete in its present version it was supposed to be updated every year. The next version will most probably come out on spring 2020 with a particular attention to the East Mediterranean and northern African areas where the paucity of data is evident and a specific implementation with data from the archeological community (in progress). The Astarte Paleotsunami Deposits database – NEAM region hosts all the original data provided by the authors in order to make easier for any reader the reproducibility of the results (for instance, any lab's raw data used for the age constraints).

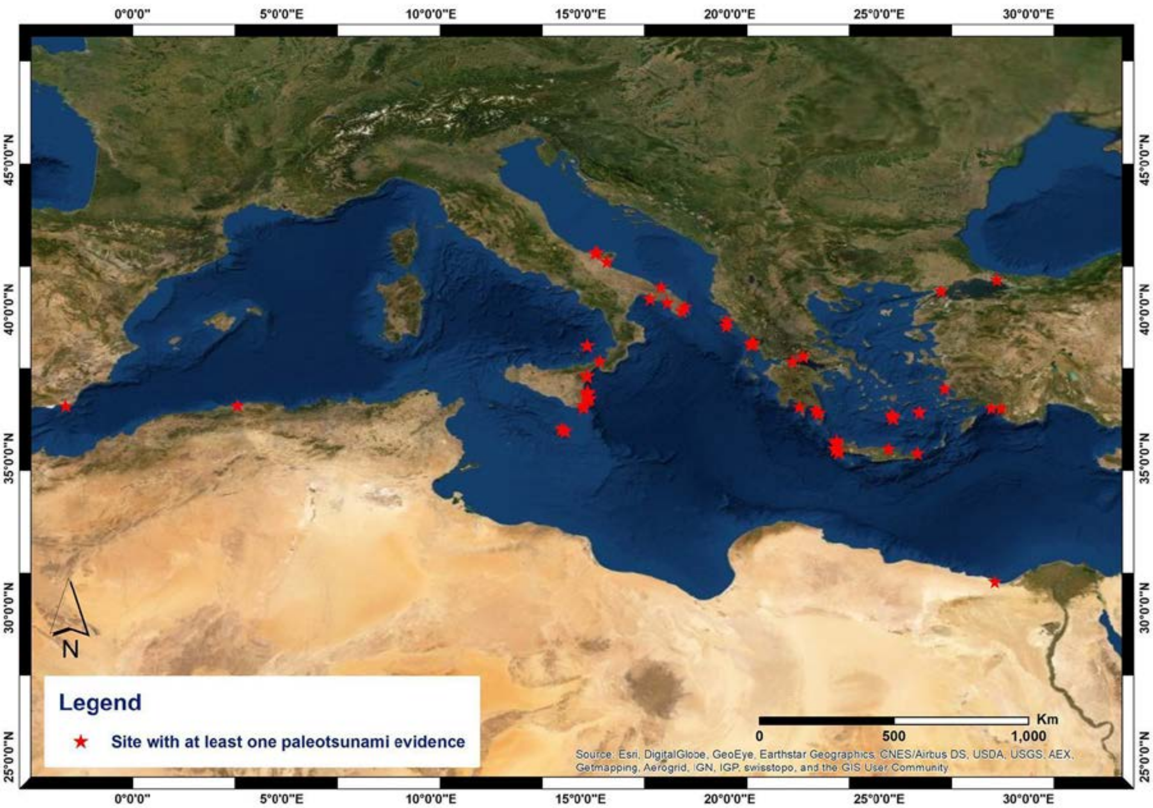


Figure 9 – Distribution of the 66 sites recorded in the Astarte Paleotsunami deposits database in the Mediterranean area, extraction from http://arcg.is/1CWz0; Presently, 45% of the sites are located in Greece, 38% Italy and 8% in Turkey.

5.1 THE DATABASE ARCHITECTURE

The database structure is characterized by the presence of two main tables: the *Site* table and the *Event* table. Each Site is related to one or more Event record (tsunami). At the same time, both the

Site table and the Event table are related to other tables, as shown in the database scheme represented below (Figure 10). Note the type of relationships between the two main tables (Site and Event) and the other tables (Reference, Compiler, Geomorphic setting, Type of site, Type of evidence, Type of analysis and Dating).

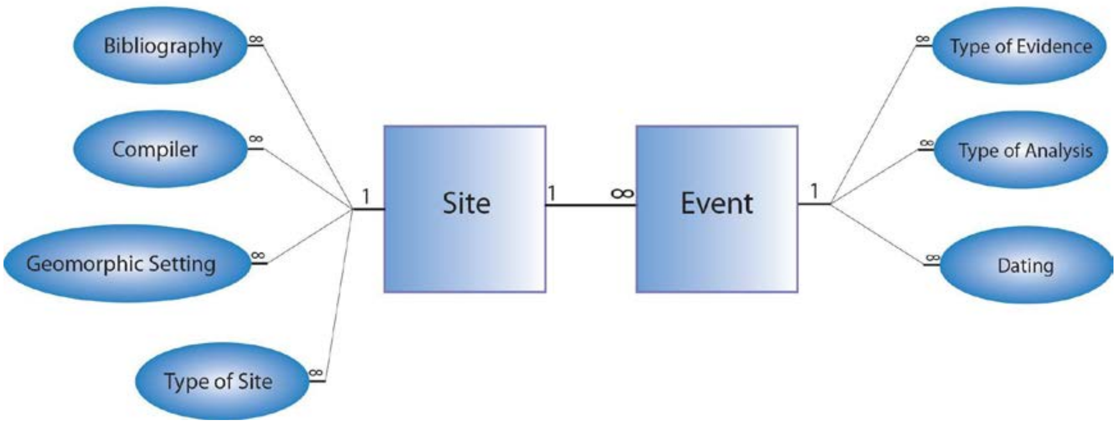


Figure 10 - The architecture of the database. Note the type of relationship between the two main tables (Site and Event) and the other tables (Reference, Compiler, Geomorphic setting, Type of site, Type of evidence, Type of analysis and Dating).

Site page

The site page is organized in one main table (Table 3) and in other four related tables (Compiler, Reference, Geomorphic setting and Type of Site). The Site table contains the following fields:

Table 3 - List and description of all fields contained in the Site Table.

Site	
Field Name	**Description**
Site name	Provide name quoted in literature or, if none, provide a reasonable name from a nearby locality
Year of investigation (from; to)	The age range of investigation of the site
Country	Country of the site location.

Region	Region of the site location.
Province	Province of the site location.
Site Geometry	Point if are reported results obtained from an individual point (e.g. a core), Area if are reported results from different observational points (e.g. several cores). When "Area" is selected the maximum extension of the area (radius in meters) is also reported.
Latitude	Provide Latitude in degrees expressed as a decimal fraction (i.e., 00.0000°); north is positive value.
Longitude	Provide Longitude in degrees expressed as a decimal fraction (i.e., 00.0000°); east is positive value.
Datum	Provide the kind of datum: ED50, ETRF89, Roma40 or WGS84
Elevation	Elevation in meters of the site above (positive value) or below (negative value) the present sea level.
Elevation type	GPS or Topographic map.
Distance	Maximum distance in meters of the site from the present shoreline.
Time all	Maximum age of the observed sequence (Yr BP).
Number of Events	The number of tsunami events recognized in the site.
Site description	The field provides a narrative on the site.
Site Notes	The field provides necessary data for the site description.
Related Data	
Compiler	Name, Surname, Affiliation, Acronym, Contact Email

References	Authors, Title, Publication, Volume, Issue, Pages, Year, Doi, Url, Abstract, Contact
Geomorphic Setting	Area protected by coastal dunes, Coastal lake, Coastal marsh, Estuary, Fluvial plain, etc, etc.
Type of Site	Artificial cut, Coast, Engine core, Exploratory trench, Hand core, Natural exposure, Other

Event page
As for the site description, the events information, is organized in one main table (Table 4), and in three other related tables (Type of evidence, Type of analysis, and Dating). The Event table contains the following fields:

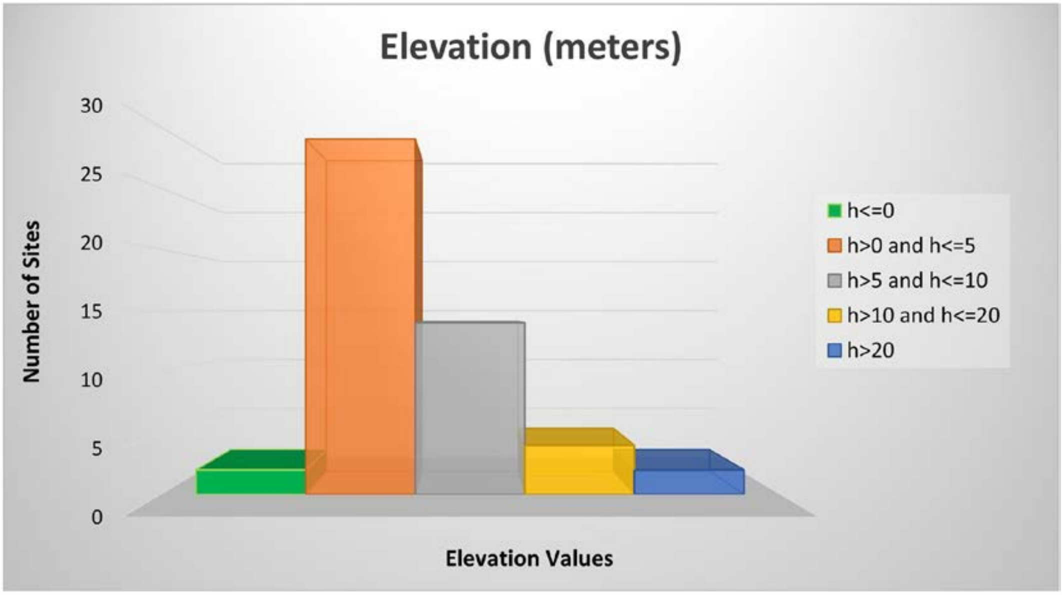
Table 4 - Fields and their relative description contained in the Event table.

Event	
Field Name	**Description**
Depth	The depth of the tsunami deposit in meters with respect to the present ground surface / sea bottom.
Thickness or dimension	The max value in meters of a tsunami layer or the max axis for blocks.
Evidence description	Free narrative on the process followed for the recognition of the tsunami deposit.
Lab Youngest Age (LYA)	Numeric value of the youngest laboratory age as yr BP (before present).
LYA standard deviation	Error of the laboratory radiocarbon age.
Youngest calendar age (Min and Max)	The youngest age as yr AD/BC (yr AD positive values and yr BC negative values). The field reports the dendrochronologically corrected age for Radiocarbon, historical/archaeological estimates.
Lab Oldest Age (LOA)	The numeric value of the oldest laboratory age as yr BP (before present).

LOA standard deviation	Error of the laboratory radiocarbon age.
Oldest calendar age (Min and Max)	The oldest age as yr AD/BC (yr AD positive values and yr BC negative values). The field reports the dendrochronologically corrected age for Radiocarbon, historical/archaeological estimates.
Preferred Age (Min and Max)	The minimum and maximum preferred ages for the tsunami (yr AD positive values and yr BC negative values).
Historical Age	Year of a potential tsunamigenic earthquake/landslide/eruption occurred within the interval of the time defined for the tsunami (yr AD positive values and yr BC negative values).
Event description	Short discussion about the type of dated materials (if marine, it's should be specify the Delta R), the position with respect to the tsunami deposit to be dated, pertinent problems and any information that is considered as relevant.
Event notes	This field reports necessary data for the event description.
Related Data	
Type of Evidence	Geomorphology, Sediment, Transported Blocks, Other
Type of Analysis	Environmental, Geochemical, Magnetic, Micromorphological, Paleontological, etc, etc.
Dating	Archaeological, Cs137, OSL, Paleontology, Palynology, Pb210, Radiocarbon, etc, etc.

5.2 THE MEDITERRANEAN REGION STATISTICS

ArcGIS Online provides several tools for spatial analysis and for performing basic descriptive statistics of features and their attributes. Analyses provided here are focused on the Mediterranean area only. The following histograms and pie diagrams (Figures 11, 12) show the statistics of the most significant fields of the Site and Event tables. The histograms shown in this paragraph, as well as the pie diagrams, were created using Microsoft Excel. ArcGIS online provided only the numerical statistic values, except for the median that was obtained from Microsoft Excel.
More information is available in the Appendix at the end of the manuscript.



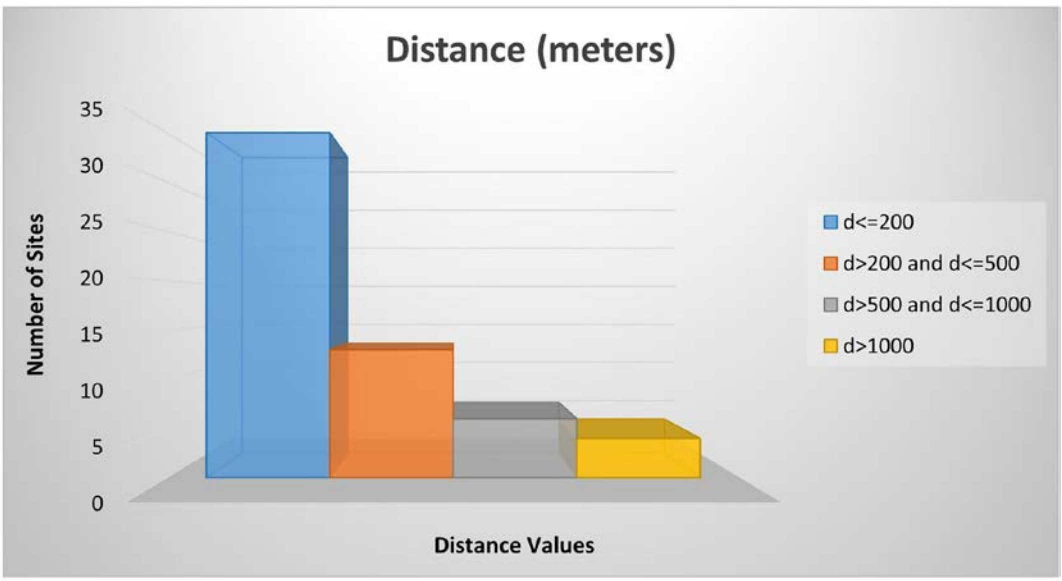


Figure 11 - The upper histogram shows the distribution of the sites in relation to their elevation above the sea level. All elevations are referred to the present sea-level and all the data are provided by the authors, not calculated or derived. The following parameters are intended to better represent the elevation value and the statistical values derived from the Elevation field: Total site: 66; Maximum value: 120 m; Minimum value: -72 m; Mean: 6.3 m; Median: 5 m; Standard dev.: 20; Sites without value: 15. The lower histogram shows the distribution of the sites in relation to their distance from the present shoreline. The following parameters are intended to better represent the elevation value and the statistical values derived from the distance field: Total site: 66; Maximum value: 2300 m; Minimum value: 20 m; Mean: 307 m; Median: 115 m; Standard dev.: 410.5; Sites without value: 8.

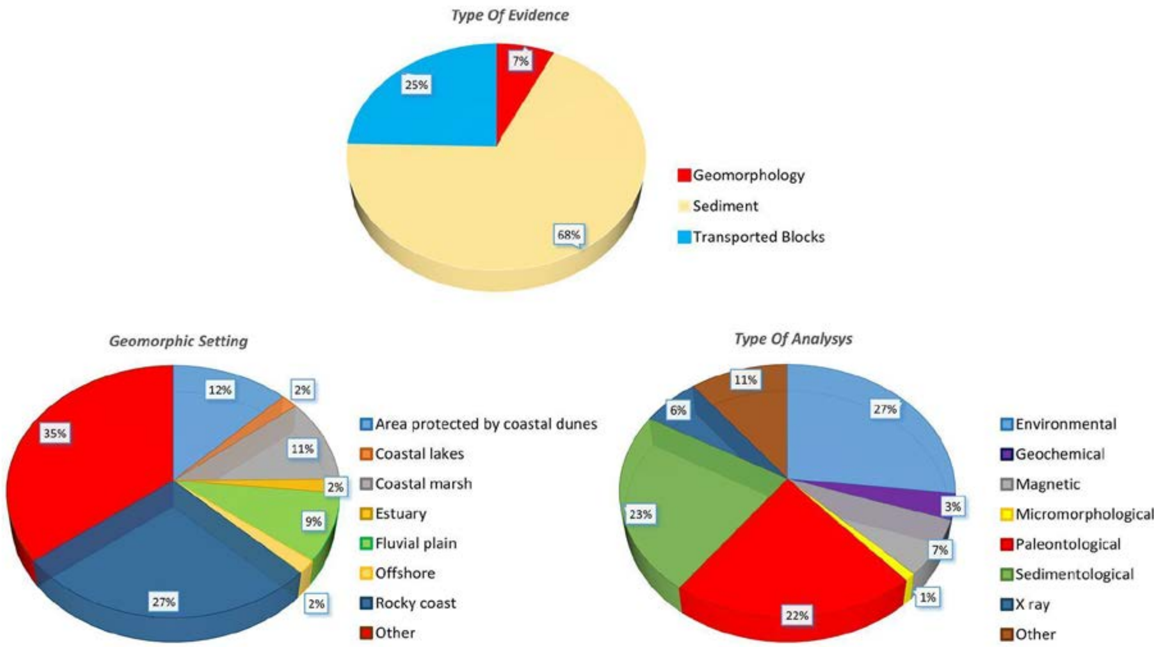


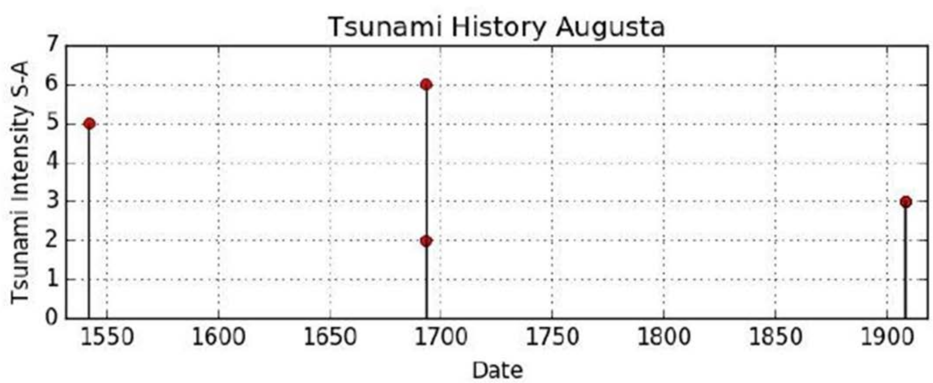
Figure 12 - The upper pie diagram shows the different typesof paleotsunami evidence present in all Mediterranean events recorded in the database. Tsunami sediments dominates with almost 70 % while the geomorphic imprint of a paleotsunami is not an easy task to achieve. The lower left pie diagram shows the geomorphological settings, divided according to their percentages, of all Mediterranean sites contained in the database. Note that each single site may have one or more geomorphic settings. It is possible to note that from a general point of view, the proposed settings fit well with those commonly investigated in the literature. The lower right pie diagram shows the distribution of the different approaches used to support the tsunami interpretation in all 120 events recorded in the database for the Mediterranean area. It is possible to see that only the environmental, sedimentological and paleontological analyses are commonly used.

6 DISCUSSION

Thanks to a long and deep critical review of the existing historical catalogues available in literature for the Mediterranean basin, it was created the Euro-Mediterranean Tsunami Catalogue, containing information on 242 tsunamis occurred since 1630 B.C. to 2004. Among them it is worth noting that 4% of the tsunamis has intensity 6 (disastrous) but also that 24% has intensity value 4 (strong) and 5 (very strong), thus suggesting that about 1/3 of the known Mediterranean historical tsunamis had significant impact on the natural and human environments. A further step towards a more detailed local hazard assessment has been started by collecting at site information on tsunami effects. Up to now this was completed, only along the Italian coasts: the new Italian Tsunami Effects Database contains 300 observations of tsunami effects referred to 186 Italian places related to 72 Italian tsunamis. Tsunami-history for each locality can be performed on this database thus allowing any user to see the complete picture of a single site in order to better estimate how a coastal place is prone to tsunamis.
As for the Paleotsunami database, the collected and analyzed data for the Mediterranean area can be summarized as follow: the Paleotsunami Deposits geodatabase contains 66 sites and 120

geological evidence of tsunamis in the Mediterranean area; the tsunami deposits are characterized by a predominance of fine sediment layers (68%), followed by transported blocks (25%) and geomorphological signatures (7%); 11 % of sites exceeds the value of 10 meters in elevation a.s.l., while the inundation distance of 17% of the sites overcomes 500 meters inland. Moreover, most of tsunami deposits are grouped in a time range between 2000 BP and the present day.

Below we show two examples of historical and paleotsunami data integration and specifically at the Augusta Bay (eastern Sicily, Italy) and at Stromboli Volcano (Aeolian Islands, Italy) where the availability of a large number of data may stimulate interesting considerations and possible implications for the local tsunami hazard assessment.
Figure 13 shows the historical tsunamis that severely hit this site; these occurred in 1542, 1693 and 1908. The 1693 tsunami, was given intensity 6 according to Sieberg-Ambraseys scale, the inundation distance recorded is about 700 m and the run-up is close to 2 m, this latter value was again reached at this site by the 1908 tsunami waves.



Date	Observation Points	Intensity (S-A)	Short Description
10-12-1542	Augusta	5	The city of Augusta was almost submerged by the sea and many people drowned (CFTI5 quoting Lacisio (1543) and Anonimous (1542)
6-1-1693	Augusta	2	In the harbor of Augusta, anomalous movement of the sea (Campis, 1980).
11-1-1693	Augusta	6	At Augusta the first sea recession drained the harbor completely, causing severe damage to the ships. During the following inundation, the sea submerged the district close to the port as far as the S. Domenico monastery (Acquaviva, 1693, Boccone, 1697a, b, c, Mongitore, 1743, Anonymous, 1693d, Burgos, 1693, Muglielgini, 1695) and killed many of the people that were camping near the pier (Anonymous, 1693e). The sea rose for about 15 m above its usual limit (Mongitore, 1743).
28-12-1908	Augusta-Salina Regina	3	At Augusta the first sea movement was positive and about 20 min after the shock the water invaded the beach with many waves, the first one being the biggest. The water flooded more than 700 m inland carrying many boats and causing severe damage to the Regina saltpan. Measured runup: Salina Regina 1.85 m (Platania, 1909b, Baratta, 1910)
28-12-1908	Augusta-Salina Mulinello	3	At Augusta the first sea movement was positive and about 20 min after the shock the water invaded the beach with many waves, the first one being the biggest. Measured runup: Salina del Mulinello 0.60 m (Platania, 1909b).
28-12-1908	Augusta- Bridge	3	At Augusta the first sea movement was positive and about 20 min after the shock the water invaded the beach with many waves, the first one being the biggest. Measured runup: countryside bridge 2 m (Platania, 1909b). Outside the harbor the sea penetrated in land for about 15 m. (Baratta, 1910)

Figure 13 - Historical tsunamis at Augusta (Sicily).

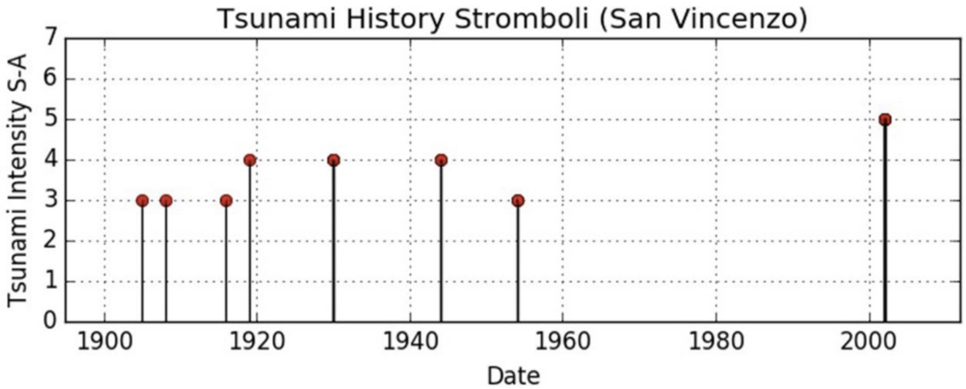
The Paleotsunami deposits database provides extra information on the tsunami history of the Augusta Bay by taking into consideration all the work done at this site both inland and offshore.

The geological record is composed of 13 different tsunami with inundation distance of at least 530 m inland and a run-up value of about 5 m a.s.l.. The main historical events recognized in the geological record coincide with those occurred in the last millennium (1908, 1693, 1542, 1169, 365 A.D.) but also the disastrous event of Santorini Island (Greece) dated back to about 3600 yrs. B.P.. Note that seven more tsunamis, whose age range does not match any historical tsunami documentation, were identified and characterized.

The two datasets integrate very well. For example, the comparison and integration of the databases, show that the two different datasets suggest a similar inundation distance (700 vs 530 m), run-up height (2 vs 5m) and tsunami frequency (recurrence interval of 200 vs 300 yrs.) even if the number of events and the time window investigated is different for the two archives.

This highlights the high potential for tsunami hazard evaluations based on the tsunami history that represents a strong tool to verify the reliability of inundation models and scenarios.

Figure 14 shows the eight tsunamis that hit the coasts of Stromboli volcanic island since 1900. The lack of documentation regarding tsunami effects occurred before that date does not allow us to attribute this high frequency of occurrence of tsunamis as related to particular periods. The geological record available in the literature for this island suggests that there were three tsunami inundations between 1300 and 1500, characterized by inundation distance of about 250 m and run-up height of 6 m a.s.l. and possibly an older tsunami hit the Stromboli volcano about 5000 yrs. B.P. with run-up values from 15 to 120 m a.s.l. These were probably the largest that left geological signatures. The integration of the two datasets can thus provide a complete picture of the tsunami history.



Date	Observation Points	Intensity (S-A)	Short Description
8-9-1905	Stromboli	3	At Stromboli the sea was violently agitated for about 1 hour (Rizzo, 1907).
28-12-1908	Stromboli	3	About 1 min after the shock the tsunami was observed: the first sea movement was positive with a max inundation of less than 10 m. No damage reported (Platania, 1909b, Baratta, 1910).
3-7-1916	Stromboli-Piscità	3	According to Ponte (1921) "...the inhabitants of Piscità" soon after the explosion observed a sudden sea retreat and then violently the water invaded almost completely the beach. The first wave penetrated by about 20 m on the beach and heaps of seaweeds were carried on land. The sea behavior, according to the inhabitants, was only noted on the northern beach of the island (Spiaggia Lunga), while at San Vincenzo, on the northeastern coast, the sea behavior was as usual". According to Maramai et al. (2005b), at Stromboli, in the S.Bartolo village, the sea level rose by about 10 m (Cavasino, 1935). Similar descriptions are reported on July 4 and 5 in the following newspapers: Il Corriere di Napoli (1916), La Gazzetta del Popolo (1916) and La Tribuna (1916).
22-5-1919	Stromboli-Punta Labronzo	4	More or less contemporary to the explosion, a tsunami occurred along the coast of the island of Stromboli. An eyewitness reports a sea retreat of about 200 m at Punta Labronzo, contemporary to the eruption, shortly after the explosion the sea water flooded the beach all around for about two minutes, carrying all the ships by more than 300 m in the neighbouring fields (Platania, 1922, Oddone, 1923). Maramai et al. (2005b) quotes some newspaper accounts: "La Nazione" reports that a few minutes after the beginning of the eruption a huge water wave was produced and the tsunami lasted for more than ten minutes. The "Osservatore Romano" describes some damage to many fishing boats that were thrown on the beach at a distance larger than 150 m. The same description of the local impact is replicated in other newspapers namely Il Messaggero (1919), Il Corriere della Sera (1919), Il Mattino (1919) and Il Giornale di Sicilia (1919).
11-9-1930	Stromboli- Piscità	4	This tsunami is the only one known to have caused fatalities among the events of the Aeolian Islands. Maramai et al. (2005b) quotes some newspaper accounts that report that at San Vincenzo the sea water rose for more than 2.5 m moving towards the beach, dragging and killing an old fisherman that was on the beach.
11-9-1930	Stromboli-Sopra Lena	4	This tsunami is the only one known to have caused fatalities among the events of the Aeolian Islands. Maramai et al. (2005b) quotes some newspaper accounts that report that at San Vincenzo the sea water rose for more than 2.5 m moving towards the beach, dragging and killing an old fisherman that was on the beach.
20-8-1944	Stromboli-Forgia Vecchia	4	According to Maramai, (2005b), a stream of lava entered the sea at Sciara del Fuoco, producing huge waves that nearly caused the shipwreck of a boat. A hot avalanche at the Forgia Vecchia reached the beach were big waves were noted (Ponte, 1948).
20-8-1944	Stromboli-Punta Lena	4	At Punta Lena the sea penetrated 300 m in land destroying one house. A lot of fish found on the beach (Cavallaro, 1957, Barberi et al., 1993).
2-2-1954	Stromboli-Scari	3	At Scari the salt warehouse was damaged by the wave (Maramai et al., 2005b).
2-2-1954	Stromboli-Forgia Vecchia	3	Between Forgia Vecchia and Punta dell'Omo sea withdrew for about 10 m leaving some boats stranded. Then two or three waves (the second bigger than the others) invaded the beach carrying some boats in land (Maramai et al., 2005b) Tsunami delay times after the explosion are reported by Imbo (1965): Ginostra (Stromboli) 10 min, Panarea 25 min, Lipari 60 min, Sicilian coast 90 min. The above delay times are inconsistent with tsunami travel times.
30-12-2000	Stromboli-Scari	5	Scari is the place where the maximum horizontal inundation has been measured (146 m). Due to the relevant width of the beach and also to the increasing distance from the tsunami source region, here the tsunami impact was less disastrous than in the other hamlets. Relevant damage was suffered by buildings on the northern sector of the beach (warehouses, boats depots and small huts). Particularly impressive were the erosion produced by the tsunami on the house foundations and the possible formation of erosional scarps. Maximum runup 5.6 m. (Tinti et al., 2006a).
30-12-2000	Stromboli-La Petrazza	5	At La Petrazza the tsunami caused erosive phenomena associated with small landslides of the steep near shore escarpments. The runup values range from 1.5 up to 6 m. (Tinti et al., 2006a).
30-12-2000	Stromboli-Ficogrande	5	It has been ascertained that within a few minutes the water invaded Ficogrande beach. At Ficogrande the damage produced by the tsunami was very severe. Some small buildings were completely destroyed; a lot of walls were knocked down. A large amount of sand was deposited in courtyards, terraces and inside the houses. Heavy objects (i.e. lava blocks, boats, scooters, etc.) were transported by the wave. Maximum measured runup 9.5 m. (Tinti et al., 2006a).
30-12-2000	Stromboli-Piscità	5	At Piscita the buildings located near the shore were seriously damaged. Typical effects of the tsunami impact were low brick walls and balustrades pulled down, door and window frames unhinged, windowpanes broken, sand deposited inside the houses and along the inner narrow streets, shrubs flattened, small boats and other objects moved inshore. Maximum runups 6.910.7 m. (Tinti et al., 2006a).
30-12-2000	Stromboli-Punta Lena	5	At Punta Lena (indicated also as Sopra Lena) party walls, gates, doors and windows were pulled down or destroyed. Railings and iron fences were bent. Pebbles thrown shoreward by the waves remained stuck inside the slots of several windows. Small pebbles were also found over the roof of a building at the height of about 7 m. Heavy objects (gas cylinders, household appliances, etc.) dragged by the wave. Furniture inside several houses was untidily heaped or even ejected outside due to strong whirlpools. Maximum runups between 2.97.7 m. (Tinti et al., 2006a).
30-12-2000	Stromboli-Spiaggia Longa	5	In the beach called Spiaggia Longa (northeastern coast) the highest value of runup (10.90 m) was measured (Tinti et al., 2006a, Maramai et al., 2005a)

Figure 14 - the tsunami history of Stromboli (Aeolian Islands).

The two examples shown above testify how the availability of data from both historical sources and geological research may provide a clearer and richer knowledge of the tsunami inundations occurred in the past at the sites. This advancement (different approaches, more data, more detail) translates into a better tsunami hazard assessment at the local scale. More in detail, a possible application of these parameters could be placed in tsunami simulations in order to have a minimum constraint to be inserted into the inundation models. This kind of data represent a benchmark to make a comparison between the historical/geological data (heights and distances) and modeled inundations (from tsunami simulations).

Appendix

The statistical analysis applied to elevation and distance fields can be summarized as follow: the height of sites above the sea level (Figure 11, upper panel) may be considered as a minimum run up value. This value is assumed to be "minimum" since the Holocene sea level was never higher than today (Fleming et al., 1998) and researchers may easily miss the paleotsunami evidence left farther inland because of the erosional processes acting on the surface. On the basis of the heights histogram it is possible to approximate that 60% of the sites are below 5 m a.s.l. and that 11% of the sites are elevated above 10 m a.s.l.. This classification reflects the site coastal settings. In fact, most sites are located in coastal areas that, due to their geomorphological setting (coastal marsh, lakes, fluvial plain, estuaries and back dune environment) can hardly overcome 10 m a.s.l..
The distance of the sites compared to the present coastline (Figure 11, lower panel) represents the maximum distance where the tsunami deposit was found. This value can be interpreted as the minimum inundation distance reached by the tsunami wave. Moreover, modern events showed that a tsunami wave can reach sites located even farer inland but without leaving a "signature" that can be preserved for a long time (e.g. the 2011 Tohoku tsunami in the Sendai plain, Japan; Szczuciński et al., 2012). It is possible to generalize that just over half of the sites have a distance from the present shoreline <= 200 meters that may represents the storms inundation limit (Morton et al., 2007) while 17% of the sites have distances greater than 500 meters. Thus, even at long distances from the present shoreline (more than 500 m) there are sites able to preserve "traces" of the tsunami inundation.

From a general point of view, we can assert that all sites, where the tsunami evidence is characterized by boulder accumulations, have a distance from the present shoreline of maximum 100 meters (with few exceptions), as the wave energy was not sufficient to carry away large blocks for longer distances. Differently, all sites where sediment tsunami layers were detected and recognized present a variable distance from the present shoreline, even exceeding the kilometer. For example, vary flat coastal morphologies (low elevations above the present sea level) can be inundated for several hundred meters. As an example, the coastal lowland of Pantano Morghella site, (Sicily, southern Italy) shows a maximum inundation distance of 1200 meters from the present coastline (Gerardi et al., 2012).

The statistical analysis applied to geomorphic setting, type of evidence and type of analyses fields can be summarized as follow: the coastal geomorphic setting of sites (Figure 12, lower left panel) may be divided in three categories: the first one includes all coastal settings characterized by a low energy sedimentation (e.g. coastal marsh, coastal lake). The second category covers those coastal settings characterized by estuary and by fluvial plain where the sedimentation environment could have been affected by continental high energy events due to the presence of paleo and actual fluvial systems. Most of fluvial plain settings, recorded in the database, are characterized by abandoned plains where fluvial processes did not affect the sedimentation in recent time, favoring the preservation of tsunami sediment layers. The third and last category includes all site settled on rocky coasts.

In the event table the most considerable field to analyze is the type of evidence (Figure 12, upper panel). It provides the kind of geological evidence left by the tsunami wave onshore and offshore. 68 % of the type of evidence is represented by fine sediment, 25 % by transported blocks and only 7% by geomorphological signatures. This reflects the geomorphic setting noticed in the sites. In fact, a fine sediment deposit can be clearly recorded and preserved in a stratigraphic sequence of a coastal lake, coastal marsh, estuary or fluvial plain. Differently, transported blocks can only be observed along rocky coasts (that represent 25% of geomorphic setting) like marine terraces gentle sloping toward the sea. Finally, it is possible to note that geomorphological evidence of paleotsunami are very rare (only 7%). This could be attributed to the difficult of preservation and recognition of morphological signatures left by a prehistorical/historical tsunami, especially because coastal geomorphological processes are able to erase old geomorphological tsunami signatures. For example, a coast under erosion will very hardly preserve geomorphological record of past tsunamis while a prograding coast has a good chance to preserve the geomorphological tsunami signatures (Goff et al., 2007).

Querying the database, allows also to deduce the main approaches adopted in order to identify and characterize a tsunami deposit (Figure 12, lower right panel). From the analysis shown in pie diagram it emerges that environmental considerations together with paleontological and sedimentological analyses are the most used approaches.

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