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The AD 365 Crete earthquake/tsunami submarine impact in the Mediterranean region

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Abstract. The Calabrian and Hellenic subduction systems accommodate Africa Eurasia plate convergence in the Mediterranean Sea and are site of large earthquakes in the forearc region facing the northern African coasts. Some of the historical earthquakes were associated with the generation of tsunami waves affecting the entire Mediterranean basin. We investigated the submarine effects of the AD 365 Crete earthquake on the sedimentary record through the integrated analysis of geophysical data, turbidite deposits, and tsunami modeling.

Seismic reflection images show that some turbidite beds are thick and marked by acoustic transparent layers at their top. Radiometric dating of the most recent of such megabeds, the Homogenite/Augias turbidite (HAT), provide evidence for synchronous basin-wide sedimentation during a catastrophic event which occurred in the time window AD 364–415, consistent with the AD 365 Mw = 8.3–8.5 Crete earthquake/tsunamis. The HAT (up to 25 m thick) contains components from different sources, implying remobilization of material from areas very far from the epicenter. Utilizing the expanded stratigraphy of the HAT, and the heterogeneity of the sediment sources of the Mediterranean margins, we reconstructed the relative contribution of the Italian, Malta and Africa margins to the turbidite deposition. Our sedimentological reconstructions combined with tsunami modelling suggest that the tsunami following the Crete earthquake produced giant turbidity currents along a front over 2000 km long, from northern Africa to Italy. Our cores suggest that during the last 15,000 yrs only two similar turbidites have been deposited in the deep basins, pointing to a large recurrence time of such extreme sedimentary events.

Keywords: AD 365 Crete earthquake, tsunami, slope failures, seismo-turbidite, tsunami modeling.

1 Introduction

Extreme submarine geo-hazards, such as strong earthquakes and tsunamis, have repeatedly affected the Mediterranean regions. A record of these past events can be provided by large-volume turbidites in the marine sedimentary record as the result of catastrophic failure of submarine slopes. The central Mediterranean Sea is located between the Calabrian and Hellenic subduction systems that were struck repeatedly by strong tsunamigenic earthquakes [1]. During the late Quaternary turbidite deposition dominates in the deep basins, where earthquake-triggered mass flows deposits represent more than 90% of the total sedimentation during historical times [2,3]. Some of the turbidites are up to 20 m thick and marked by the acoustic transparency of the upper mud layer in the seismic sections. The most recent of these mega-beds, the Homogenite/Augias turbidite (HAT) is observed over a wide area of the Central and Eastern Mediterranean Sea. The original hypothesis attributed the HAT to the 3500 yr BP Minoan eruption of Santorini and related tsunamis [4]. However, the turbidite composition and structure, as well as radiometric dating and age modeling, revealed that it was not triggered by the Santorini event but by the later AD 365 Crete earthquake/tsunami [3,5]. We present the analysis of seven sediment cores containing the complete record of the HAT in different physiographic and oceanographic settings including basins offshore Africa. Sedimentology was integrated by tsunami modelling to verify the possible role of tsunami propagation and impact on the coastal regions in the destabilization of continental slopes.

2 Materials and Methods

Our high-resolution study combines the interpretation of seismic reflection profiles, multibeam data and the analyses of sediment cores. Cores were collected with a 1.2 t gravity corer and a 2.3 t piston corer. The cores were analyzed through a multi-proxy approach involving X-ray images, texture, geochemistry, organic matter, micropaleontology and mineralogical analyses. Results of radiometric dating obtained from pelagic sediments interbedded between re-sedimented deposits were used to define an age model and a chronological framework.

3 Results

Seismic reflection profiles show that the megabed is present in many different basins of the Central-Eastern Mediterranean Sea. These range from the 4,000 m deep abyssal plain to shallower slope basins, including the Calabrian Arc and the Mediterranean Ridge, the Tyro Basin SE of Crete and the Western Herodotus trough offshore Cyrenaica (Fig.1). The thickness of the turbidite varies between 0.1 to more than 25 m in the different basins.

Radiometric ages obtained from pelagic sediments deposited after the catastrophic event suggest that all the turbidites collected in different physiographic settings were deposited synchronously in the time window AD 364–415. Sedimentology and geochemistry of the cores identified different turbidite units whose composition widely varies as confirmed by geochemical analyses. Further micropaleontological and mineralogical analyses suggest that the sediment sources are compatible with Greece, the Malta escarpment, Southern Italy, and Africa.

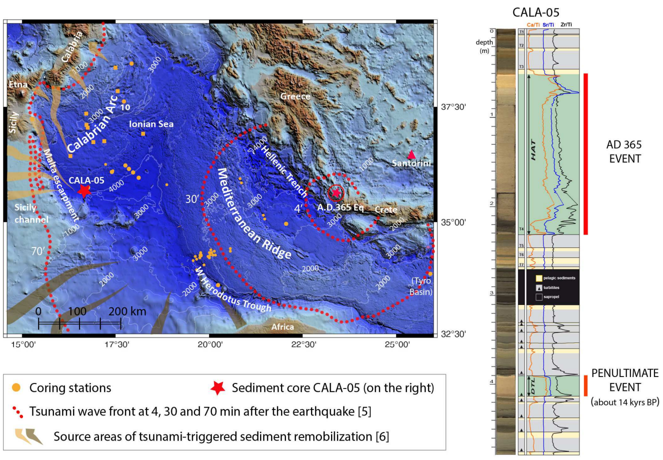

Fig. 1. a) Shaded relief map of topography/bathymetry of the central and eastern Mediterranean Sea. b) Photograph of sediment core CALA-05 with sedimentary facies and major XRF geochemical elements. Modified from [6]

Tsunami modelling allows verifying a possible correlation between tsunami propagation and the generation of turbidity currents. Starting from some reasonable hypothesis for the parent fault of the 365 earthquake [5], numerical simulations of the tsunami propagation help deduce the main paths of tsunami energy focussing, and quantifying the spatial distribution of the extreme particle velocities. The latter can be used to estimate the shear stresses induced by the tsunami on the ocean bottom and along the coastal regions, providing a rough estimation of the destabilisation and transport power of the tsunami waves and currents.

4 Discussion

The HAT was triggered by an event taking place in the time window AD 364-415 which was capable of initiating simultaneously sediment transport in widely separated sedimentary basins. The lithology, structure and regional occurrence of the megabed place the triggering mechanism within narrow constraints: it affected every basin of the Central Mediterranean and its provenance varied in different parts of the basin margins. The only historical earthquake potentially capable of generating such devastating effects from Greece to the African margins during the given time interval, is the exceptionally strong Crete 365 AD earthquake.

The M=8.3-8.5 AD 365 Crete earthquake [5] occurred on a major reverse fault, dipping beneath Crete. Seismic shaking from this earthquake, although exceptional, was probably unable to triggering mass movements 700 km from the epicenter, in flat and stable areas of the Sicily Channel and Africa continental shelves. The areal extent of the megabed as shown by our radiometric dating supports the hypothesis that it was the tsunami following the Crete earthquake that triggered giant turbidity currents (Fig. 1). The 365 AD Crete tsunami wave caused local reworking during its transit towards West. When the tsunami hit the shallow continental shelves of Italy and Africa triggered gigantic turbidity flows that transported shallow water detritus to the deep basins along a front from Calabria to Africa. The magnitude of the parent earthquake and the extent of the ensuing tsunami impact make this event comparable, at least as a first approximation, to more recent giant subduction-zone earthquake-generated tsunamis (2004 Sumatra and 2011 Tohoku-Oki), whose effects as regards sediment mobilization can then be used as terms of comparison for our investigations.

5 Conclusions

The earthquake and tsunami of 21 July 365 AD have stimulated discussions between historians, archaeologists and geophysicists mainly because historical records are not always concordant in chronology and extent of reported damages. However, an unusual event with magnitude > 8.5 was proposed [7] with a tsunami spread across the Mediterranean Sea [5,8]. The detailed sedimentological and chronostratigraphic analysis of deep-sea cores allow to reconstruct sedimentary processes that generated the deposit. Our results suggest that the HAT deposition was related to multiple turbidity currents triggered by the tsunami waves hitting the continental shelves of Italy, Malta and Africa along the continental margins for more than 2000 km.

The synchronous deposition of the HAT over an area larger than 150,000 km^2 implies an exceptional event triggering catastrophic failure of submarine slopes in the Mediterranean Sea basins including the African coasts.

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