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Paper to be presented at UNESCO-IGCP-659 session

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

3 Alina Polonia¹, Alberto Armigliato², Luca Gasperini¹, Giulia Giorgetti¹, Gianluca
4 Pagnoni², Stefano Tinti², and Filippo Zaniboni²

5 ¹ Institute of Marine Sciences, National Research Council, 40129 Bologna, Italy

6 ² Department of Physics and Astronomy, Alma Mater Studiorum – University of Bologna,
7 40127 Bologna, Italy
8 alina.polonia@cnr.it
9

10 **Abstract.** The Calabrian and Hellenic subduction systems accommodate Africa
11 Eurasia plate convergence in the Mediterranean Sea and are site of large earth-
12 quakes in the forearc region facing the northern African coasts. Some of the his-
13 torical earthquakes were associated with the generation of tsunami waves af-
14 fecting the entire Mediterranean basin. We investigated the submarine effects of
15 the AD 365 Crete earthquake on the sedimentary record through the integrated
16 analysis of geophysical data, turbidite deposits, and tsunami modeling.
17 Seismic reflection images show that some turbidite beds are thick and marked
18 by acoustic transparent layers at their top. Radiometric dating of the most recent
19 of such megabeds, the Homogenite/Augias turbidite (HAT), provide evidence
20 for synchronous basin-wide sedimentation during a catastrophic event which
21 occurred in the time window AD 364–415, consistent with the AD 365 Mw =
22 8.3–8.5 Crete earthquake/tsunamis. The HAT (up to 25 m thick) contains com-
23 ponents from different sources, implying remobilization of material from areas
24 very far from the epicenter. Utilizing the expanded stratigraphy of the HAT,
25 and the heterogeneity of the sediment sources of the Mediterranean margins, we
26 reconstructed the relative contribution of the Italian, Malta and Africa margins
27 to the turbidite deposition. Our sedimentological reconstructions combined with
28 tsunami modelling suggest that the tsunami following the Crete earthquake pro-
29 duced giant turbidity currents along a front over 2000 km long, from northern
30 Africa to Italy. Our cores suggest that during the last 15,000 yrs only two simi-
31 lar turbidites have been deposited in the deep basins, pointing to a large recur-
32 rence time of such extreme sedimentary events.
33

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

36 **1 Introduction**

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

57 **2 Materials and Methods**

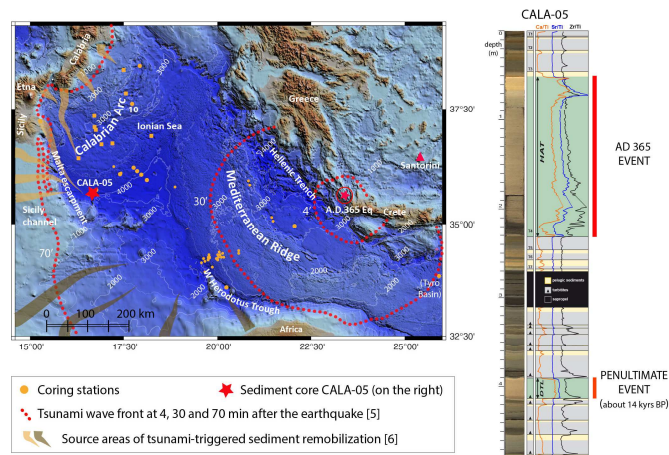
58 Our high-resolution study combines the interpretation of seismic reflection profiles,
59 multibeam data and the analyses of sediment cores. Cores were collected with a 1.2 t
60 gravity corer and a 2.3 t piston corer. The cores were analyzed through a multi-proxy
61 approach involving X-ray images,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

65 **3 Results**

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

72 Radiometric ages obtained from pelagic sediments deposited after the cata-
73 strophic event suggest that all the turbidites collected in different physiographic set-
74 tings were deposited synchronously in the time window AD 364–415. Sedimentology
75 and geochemistry of the cores identified different turbidite units whose composition

76 widely varies as confirmed by geochemical analyses. Further micropaleontological
 77 and mineralogical analyses suggest that the sediment sources are compatible with
 78 Greece, the Malta escarpment, Southern Italy, and Africa.



79
 80 **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
 81 geochemical elements. Modified from [6]
 82
 83

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

92 4 Discussion

93 The HAT was triggered by an event taking place in the time window AD 364-
 94 415 which was capable of initiating simultaneously sediment transport in widely separated
 95 sedimentary basins. The lithology, structure and regional occurrence of the megabed place the triggering mechanism within narrow constraints: it affected every
 96 basin of the Central Mediterranean and its provenance varied in different parts of the
 97 basin margins. The only historical earthquake potentially capable of generating such
 98 devastating effects from Greece to the African margins during the given time interval,
 99 is the exceptionally strong Crete 365 AD earthquake.
 100

101 The M=8.3-8.5 AD 365 Crete earthquake [5] occurred on a major reverse
 102 fault, dipping beneath Crete. Seismic shaking from this earthquake, although excep-
 103 tional, was probably unable to triggering mass movements 700 km from the epicenter,
 104 in flat and stable areas of the Sicily Channel and Africa continental shelves. The areal

105 extent of the megabed as shown by our radiometric dating supports the hypothesis
106 that it was the tsunami following the Crete earthquake that triggered giant turbidity
107 currents (Fig. 1). The 365 AD Crete tsunami wave caused local reworking during its
108 transit towards West. When the tsunami hit the shallow continental shelves of Italy
109 and Africa triggered gigantic turbidity flows that transported shallow water detritus to
110 the deep basins along a front from Calabria to Africa. The magnitude of the parent
111 earthquake and the extent of the ensuing tsunami impact make this event comparable,
112 at least as a first approximation, to more recent giant subduction-zone earthquake-
113 generated tsunamis (2004 Sumatra and 2011 Tohoku-Oki), whose effects as regards
114 sediment mobilization can then be used as terms of comparison for our investigations.

115 **5 Conclusions**

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

126 The synchronous deposition of the HAT over an area larger than 150,000
127 km² implies an exceptional event triggering catastrophic failure of submarine slopes
128 in the Mediterranean Sea basins including the African coasts.

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