REFEREE#2 CRITICISMS TO THE MANUSCRIPT:

1. *The lack of a detailed description of historical data on tsunamigenic sources (earthquakes) and tsunamis that affected the Malta coast. The Authors state that numerical modelling gives results that are in good agreement with historical data, but they should report historical run-up values or flooding of tsunamis to strength their results (e.g. Bertolaso et al., 2008 for the 1908 tsunami on the Malta coast, p.122).*

Authors reply. The paper has been improved with more informations concerning data and results of modelling for the Maltese archipelago.

Unfortunately, very poor direct information about tsunamis run-up heights or flooding are available in literature.

2. *The models used by the Authors to distinguish storm boulders from tsunami boulders are not appropriate.*

Authors reply. It is not fine to make a criticism to the approach without suggesting an alternative one. We selected equations accepted and commonly used in literature. Moreover the applied equations have been developed on the base of field evidences and not developed by a theoretical approach or developed in a flume with a lot of approximations due to the scale (see the note to Referee#1). We selected the equations that permit to detect and evaluate the possible type of process and mechanism for the detachment of the boulders and their movements starting from detectable data (their axis size and density, elevation and distance from coastline etc...); of course we considered them in relation to the local morphology. The results have been correlated and compared to the present wave climate.

In this paper we are most interested in arguing that extreme waves (especially generated by extreme storms that have a shorter return period and are very frequent in the Mediterranean Sea) can represent a real hazard for the low-lying coasts of Malta.

3. *The association of boulders with tsunamis just based on some dating and lacking of data on the extreme storm frequency.*

Authors reply. We strongly support the hypothesis of storm waves as the main responsible cause for these boulders, but we do not exclude the possibility of tsunamis.

Discussion and Conclusion chapters were enhanced in order to clarify that we attribute the deposition of these boulders mainly to storm waves (not only from the results of the hydrodynamic equations, because not necessarily these are suitable for the Maltese setting), but that we do not exclude tsunamis.

In the past, tsunamis have hit the coasts of Malta. According to the models provided by Tinti et al. (2005) and Bertolaso et al. (2008) the tsunami waves generated in the Sicily Channel or on the Malta Escarpment or in the Aegean Sea could reach Malta.

We are aware that in the first version of the paper these concepts were not clearly described, so we improved it.

TECHNICAL POINTS

4. *Page 3, line 9: "seismicity activity"? Seismic activity or better seismicity.*

Authors reply. We will use "seismicity" as the Reviewer suggested.

5. *Page 3, line 9: "related mainly to Malta Escarpment, the Sicily Channel Rift Zone and the Hellenic Arc". How the Authors can state that Malta was affected by tsunamis originated by these sources? Can they cite historical reports? Furthermore, do they know tsunamis originated in the Sicily Channel?*

Authors reply. The sentence has been rephrased. See at point 6.

6. *Page 3, lines 15-25: please rephrase statements, explaining better your results.*

Authors reply. The abstract has been re-arranged as follows:

Abstract

The accumulation of large boulders related to waves generated either by tsunamis or extreme storm events have been observed in different areas of the Mediterranean Sea. Along the NE and E low-lying rocky coasts of Malta five large boulder deposits have been surveyed, measured and mapped. These boulders have been detached and moved from the seafloor and lowest parts of the coast by the action of sea waves. In the Sicily-Malta channel, heavy storm are common and originate from the NE and NW winds. Conversely, few tsunamis are recorded in historical documents to have hit the Maltese archipelago.

We present a multi-disciplinary study, which aims to define the characteristics of these boulder accumulations, in order to assess the coastal geo-hazard implications triggered by the sheer ability of extreme waves to detach and move large rocky blocks inland.

The wave heights required to transport coastal boulders were calculated using various hydrodynamic equations. Particular attention was devoted to the quantification of the input parameters required in the workings of these equations, such as size, density and distance from the coast. Moreover, AMS ages were obtained from selected marine organisms encrusted on some of the boulders in various coastal sites. The combination of the results obtained by hydrodynamic equations, which provided values comparable with those observed and measured during the storms and the Radiocarbon datings suggests that the majority of the boulders has been detached and moved by intense storm waves. These boulders testify the existence of a real hazard for the coasts of Malta, as very high storm waves, which are frequent, are able to detach large blocks, whose volume can exceed 10 m^3,both from the coast edge and the sea bottom, and to transport them inland. Nevertheless, the occurrence of one or more tsunami events cannot be ruled out, since Radiocarbon datings of some marine organisms have revealed ages that can be related to historical known tsunamis, such as 963 AD, 1329 AD, 1693AD and 1743 AD.

7. *Page 4, lines 10-15: the tsunamis of Apulia and Sicily regard only these regions; please describe tsunamis that affected Malta Islands.*

Authors reply. In the "Introduction" chapter, the tsunamis that affected the Maltese Archipelago have been better distinct and described. This sentence has been added:

"In the Maltese Archipelago the attested tsunamis (Tinti et al., 2004) are the 1169 AD, 1693 AD, which was described by de Soldanis (1746), and the 1908 AD. The latter is well known to have affected the eastern coast of Malta and the southern coast of Gozo with a wave height comprised between 0.72 and 1.50 m (Guidoboni & Mariotti, 2008 and references therein). These events have been triggered by earthquakes occurred in eastern Sicily.

Moreover, according to the model provided by Tinti el al. (2005), a tsunami generated by an earthquake of Mw = 7.4, whose source is a fault placed offshore and parallel to the Malta Escarpment (the fault which is considered as one of the possible source for the 1693 earthquake), should hit the coasts of the Maltese

Archipelago with a wave height of 0.15-1 m, as well as a tsunami generated by an earthquake in the western Hellenic Arc (Mw = 8.3) but with higher wave heights (1-1.5 m)."

REF.:

Guidoboni E. & Mariotti D.: Il terremoto e il maremoto del 1908: effetti e parametri sismici. In: Bertolaso, G., Boschi, E., Guidoboni, E., Valensise G. (a cura di): Il terremoto e il maremoto del 28 dicembre 1908: analisi sismologica, impatto prospettive, INGV-DPC, Roma –Bologna 813 pp, 2008.

Pino N.A., Piatanesi A., Valensise G., Boschi E.: The 28 december 1908 messina straits earthquake (Mw 7.1): A great earthquake throughout a century of seismology. Seism. Res. Lett., 80(2), 243-259, 2008.

Tinti S., Armigliato A., Pagnoni G., Zaniboni F.: Scenarios of giant tsunamis of tectonic origin in the Mediterranean. ISET Journ. Earthq. Techn., 42(4), 171-188, 2005.

8. *Page 4, lines10-13: The 1908 earthquake-generated tsunami: : : destroying everything and determining tens of thousands of casualties". The 1908 tsunami caused about 1500 casualties (see Bertolaso et al., 2008).*

Authors reply. Ok. This information has been added.

9. *Page 4, line 15: The Stromboli tsunami did not destroy harbour structures and other facilities situated along the adjacent coasts of Calabria and Sicily, where did you find this information? Can a Stromboli tsunami influence the coast of Malta? Usually the tsunamis due to the Stromboli volcanic activity affect only Stromboli and sometimes the other Aeolian Islands (see Tinti et al., 2004).*

Authors reply. From Mastronuzzi et al., 2013: "More recently, a major instability event, deeply involving both the emerged and the submarine slope, occurred on the western flank of Stromboli volcano (Aeolian Islands, Italy), producing tsunami waves with a maximum run-up of over 10 m in the small coastal villages of Ficogrande and San Vincenzo."

Mastronuzzi, G., Brückner, H., De Martini, P.M., and Regnauld H.: Tsunami: from the open sea to the coastal zone and beyond. In: S. Mambretti (Ed), Tsunami: From Fundamentals to Damage Mitigation. WIT Press, Southampton, 1-36, 2013a.

From INGV (*http://roma2.rm.ingv.it/it/tematiche/33/tsunami/33/gli_tsunami_in_italia*): "Le onde, che hanno raggiunto gli 11 metri, hanno investito in pochissimi minuti le coste dell'isola di Stromboli causando la distruzione di molti manufatti costieri e il grave danneggiamento di qualche abitazione nella costa nord orientale. Lo tsunami si è propagato a tutte le Eolie ed ha raggiunto le coste nord della Sicilia, l'isola di Ustica e deboli effetti sono stati osservati nelle coste della Campania."

10. *Page 5, lines 21-23 "The aims of this paper are to identify the physical processes responsible for the accumulation of the boulders and to evaluate the vulnerability level of these Maltese coasts due to their exposure to such high-energy waves" These were the aims of the paper, but neither in the abstract nor in the conclusion I can read statistical data on the exposure to high-energy waves of the Malta coast.*

Authors reply. The sentence concerning the aims has been modified as follows:

"The aims of this paper are to identify the physical processes responsible for the accumulation of the boulders and to understand if they can be a potential geo-hazard for the low-lying rocky coasts of Malta".

11. *Page 6, lines 10-13 How do you define a high level of crustal seismicity? Please, show all the earthquake epicentres you describe in a map.*

Authors reply. A new figure was added in the Figure 1, with the location of the earthquakes occurred in the Mediterranean and Aegean Sea from 1900 to 2013 (font USGS: http://pubs.er.usgs.gov/publication/ofr20101083Q), the earthquakes felt on the island according to the historical chronicles (Galea, 2007) and the attested tsunamis on Malta according to De Soldanis (1746), Tinti et al. (2005), Galea (2007), Bertolaso et al. (2008).

12. *Page 6, lines 23-25 "Several earthquake-generated tsunamis struck the Ionian coast of south-eastern Sicily and the Maltese Archipelago in historical times such as in AD 1169, 1693 and 1908 (Tinti et al., 2004)". Please, report data for these tsunamis on the Maltese coast. Moreover, with respect to the tsunamis generated in the Hellenic Arc, the fact that "several tsunami crossed the Mediterranean Sea having been generated in the Hellenic arc area" does not mean that the Maltese Islands were attached.*

Authors reply. As mentioned before, in the point 7, the "Introduction" chapter has been improved with new data.

13. *Page 7, line 9 "wave-cut platforms which host boulders accumulations". wave-cut platforms, which host boulder accumulations*

Authors reply. The sentence has been modified following this suggestion.

14. *Page 7-8. Lines 25-30, and 1-10 The Maltese sedimentary succession: it is not clear why you reported this detailed description; it is not important according to the aims of the paper. On the other hand, what is important is the boulder formation.*

Authors reply. We have reduced the description of the sedimentary succession as follows:

"The Maltese sedimentary succession mainly consists of pelagic limestones, clayey terrains and marls (Pedley et al., 1976, 1978). As illustrated in Fig. 2, it includes four formations: 1) Lower Coralline Limestone Formation (LCL), consisting of late Oligocene (Brandano et al., 2009) bioclastic limestones; 2) Globigerina Limestone Formation (GLO), late Oligocene to middle Miocene in age (Baldassini et al., 2013; Baldassini and Di Stefano, 2015 and reference therein), consisting of pelagic marly limestones. It is subdivided, based on the occurrence of phosphoritic conglomerate beds (Baldassini and Di Stefano, 2015), into 3 Members; 3) Blue Clay Formation (BC), middle to late Miocene in age (Giannelli and Salvatorini, 1975; Hilgen et al., 2009), formed by silty marlstones; 4) Upper Coralline Limestone Formation (UCL), late Miocene in age (Giannelli and Salvatorini, 1975), consisting of shallow-water bioclastic limestone deposits."

15. *Page 8, lines 20-21. How did you decide the most representative boulders?*

Authors reply. The most representative boulders were chosen in term of size, shape, occurrence of marine encrustations and distance from the coastline. The sentence was enhanced.

16. *Page 8, lines 25-28. How did you select the equations to be used? None of your equations takes into account elevation, distance from the coastline and impacting wave height compared to the wave length and wave period. All the equations calculate the minimum tsunami and storm wave heights required to detach a boulder from the cliffedge.*

Authors reply. We selected equations that have been accepted and are commonly used in the literature. We choose the equations that permit to evaluate the type of mechanism for the detachment of the boulders. Parameters such as the distance from the coastline and elevation are crucial for example in the modelling of the wave penetration inland. We did not consider the distance and the elevation because the current position of each boulder not necessarily is the same of the moment of its deposition. As a matter of fact, we noticed, both from direct observations and from the witnesses of locals that some boulders moved after strong storms.

Moreover, as we wrote to the Reviewer#1, the aims of the proposed paper was not to calculate the velocity of the water flow but to estimate the height of the impacting wave in order to understand if:

1. it is likely that the wave was from a storm (in relation to those known) or from a tsunami;
2. it is likely that the waves (whatever their nature) have been able to exceed the height of the cliff and to scrape boulders acting from the bottom up (sub-aerial scenario).

17. *Page 9, line 15: "only the upper 50% has been averaged", of what?*

Authors reply. It is a recommendation by ISRM (1978) for the definition of HR value. We changed the sentence as follows:

"To avoid interferences due to the occurrence of discontinuities, fossils and weathering processes, we followed ISRM recommendations. We took at least 10 single impact readings for each block and averaged only the upper 50 % for the determination of boulder HR value, as suggested by ISRM (1978)".

18. *Page 9, lines 18-20. How did you determine the most probable setting (submerged, sub-aerial, etc.) prior to transportation? In addition, why did you carry out detailed submerged profiles of the four coastal sites by direct underwater surveys? Perhaps to see if the waves are amplified on the shoreline? Why do you report only two submerged profiles (fig. 3f and 6 f)?*

Authors reply. The most probable setting has been determined by means of biological analyses on the marine organisms and the underwater observations coupled with direct surveying on the deposited boulders.

We carried out submerged profiles in order to verify a correspondence between the submerged situation (fractures, rupture surfaces, detachment niches and holes) and the number and shape of the deposited boulders. As the Reviewer suggested, this underwater activity also provided data about the sea bottom slope and topography that, in turns, strongly can amplify the wave height. We added these explanations in the Material and Methods chapter and we added another submerged profile for Bugibba-Qawra site, explaining that the submerged topography is very similar also to Pembroke and Bahar Ic Caghaq sites.

19. *Page 19, line 24-26: "Bulk density of the boulders has been evaluated in: : :" Are they average values from Table 2? Why do you report them? In the equations, you used values for single boulders.*

Authors reply. The observation is correct. This sentence has been removed from the "Discussion" chapter.

20. *Page 20, lines 1-2: "the application: : : has highlighted the lack of correlation between density and volume values and the obtained results", but you consider them together and it is the weight of boulders, is not it? Have you some correlation with the weight of boulders?*

Authors reply. A column with the mass values of boulders has been added to Table 3. Moreover, a diagram that shows the correlation between mass and distance from the coastline for each boulder at each sites is here presented and could be added to the Figures (possible Figure 7). In the "Discussion" the following sentences that comment the diagram could be added:

"Considering that Ahrax Point case is not representative because of the poor number of data, 2 different distributions are observable:

1. Armier Bay and Zonqor: the distribution is regular (the lighter boulders are the more distant). This could be indicative of a storm event or of a "perfect tsunami", but the Radiocarbon datings performed at Armier Bay on different boulders are different. In this case, even if the diagram is typical of a storm, we suggest the combined action of storms (which are very frequent and severe) and one or more tsunamis. For Zonqor site, the hypothesis of extreme storms is confirmed by the hydrodynamic approach as well as by the Radiocarbon datings, the geomorphological and biological characteristics.
2. Bahar, Bugibba and Pembroke: the boulders are scattered and their distribution is caotic, indicating a caotic event or the succession of more events. However, such distribution of the boulders and such datings (post 1954 for Bugibba, 1672 ± 45 AD for Bahar and 1723 ± 40 AD for Pembroke) make to hypothesize the succession of more events (storm and storms, or storm and tsunami, or tsunami and tsunami).

But we have to keep in mind that only one datings for a boulder, as well as a tens of datings for all the considered boulders are not sufficient to discriminate a precise age, especially if considering the error margin."

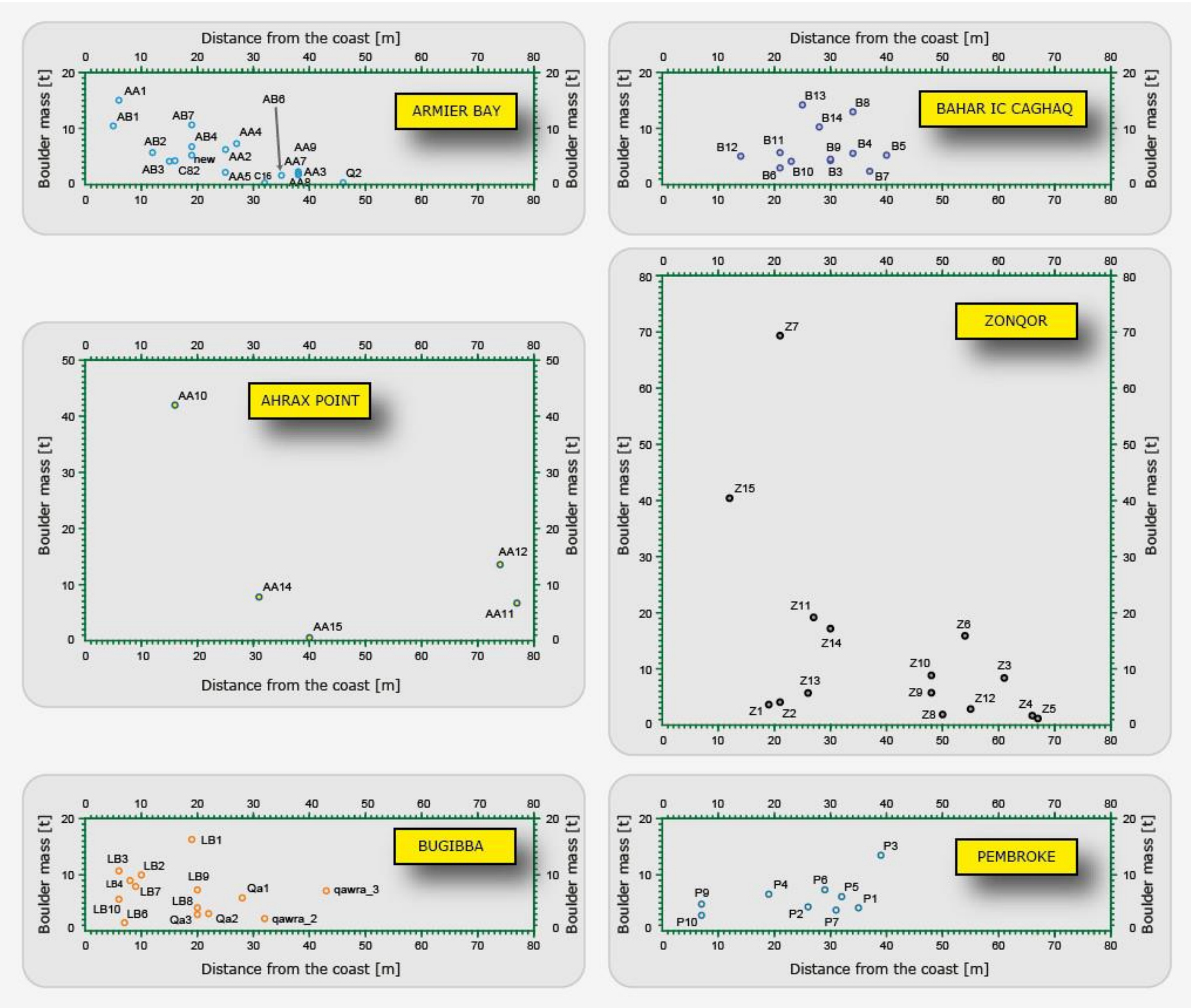

Figure 7

21. *Page 20, lines 16–17: please, show the significant wave heights in terms of their frequency in order to compare with the age of dated boulders.*

Authors reply. The lacking of these data has been commented also by the Reviewer#1. To improve the paper and the discussion, in the "Material and Methods" new data have been reported.

"Concerning the wave heights, the Environment and Planning Authority (Malta Maritime Authority, 2003; Malta Environment and Planning Authority, 2007) provided a statistic study in two different areas of Malta (close to Bahar ic Caghaq in the NE coast and close to Zonqor in the SE coast) from data measured during 2007, through which the inshore wave extremes have been estimated as 5,1-5,6 m and 5,3-5,9 m respectively for a return period of 50 years and as 5,28-5,8 m and 5,4-6,0 for a return period of 100 years at 20 m depth. A wave height of almost 7 m has been recorded on the 15th October 2007 during a very strong storm.

Moreover Drago et al. (2013) provided an analysis of the Maltese waves by taking into account wave data over a span of 5 years (2007-2011) measured by a buoy located 2 km offshore of the NW coast of Gozo. The highest wave was registered in January 2012: 7.46 m.

This value, associated with a wave period of 9 sec. (Drago et al., 2013) has been used to apply the Sunamura and Horikawa (1974) equation that permits to evaluate the wave height at breaking point (H_b) of a coastal area.

$$\frac{Hb}{H0} = (tan\beta)^{0.2} \ * \frac{H0}{L0}^{-0.25}$$

Where H_b is the breaking wave height, H_0 is the wave height in deep water, β is the slope of the sea bottom in the coastal area, L_0 the wave length in deep water ($L0 = \frac{gT^2}{2\pi}$; Sarpkaya and Isaacson, 1981).

The breaking wave height H_b has been evaluated in 6.6 m at Armier Bay, 9.38 m at Ahrax Point, 8.71 m at Bugibba, 7.063 m at Qawra Peninsula, 8 m at Bahar Ic-Cagaq, 10.18 m at Pembroke and 8.41 m at Zonqor.

REF.:

Drago A., Azzopardi J., Gauci A., Tarasova R., Bruschi A.: Assessing the offshore wave energy potential for the Maltese Islands. Sustainable Energy 2013: the ISE annual conference, Malta, 2013.

Sarpkaya, T., Isaacson, M., 1981. Mechanics of Wave Forces on Offshore Structures. Van Nostrand Reinhold Company Inc. 650 pp.

Sunamura, T., Horikawa, K., 1974. Two dimensional beach transformation due to waves. Proceedings 14th Coastal Engineering Conference. American Society of Civilian Engineers, pp. 920–938.

22. *Page 20, lines 17–20: "on the coast, the height can exceed 10 m since the superimposed effect of the sea bottom and coastline topographies can oversize the impacting waves". You can use the very nice underwater profiles shown in Fig. 3 and 6 to compute amplification factor.*

Authors reply. Unfortunately, at the moment, no bathymetric data are available to compute the local amplification. The breaking wave height has been estimated by means of Sunamura & Horikawa (1974) formula, which takes into account the maximum wave offshore and the slope of the sea bottom.

23. *Page 21, Line 3," gave back very interesting results". Please, rephrase this sentence see general comments*

Authors reply. The sentence has been modified as follows:

"Ten Radiocarbon datings were performed on marine organisms sampled from 10 representative boulders in all the sites. Moreover three dating provided by Biolchi et al. (2016) were re-calibrated (Table 4; Fig. 7). Amongst them, four samples support the hypothesis of recent strong storm events dated back to post 1954 AD".

24. *Page 21, lines 14-15: "The other radiocarbon datings seem to be related to events occurred in a span of time ranging from the 514_104 BC to the AD1723_40. They have been compared with historical events". Do you mean tsunamis? Why do you exclude the possibility that they can be storms?*

Authors reply. Yes, tsunamis.

We strongly support the hypothesis of storm waves as the main responsible cause for these boulders. We do not exclude the possibility of tsunami because the Radiocarbon datings, even if not enough, can arouse doubts.

The sentence was modified as follows:

"The other Radiocarbon datings seem to be related to events (extreme storms or tsunamis) occurred in a span of time ranging from the 514 ± 104 BC to the 1723 ± 40 AD. They have been compared with historical events (Papadopoulos et al., 2014; Tinti et al., 2004).Our results could be tentatively referred to some tsunami events that have occurred in the Mediterranean and the Aegean Sea (Table 4)."

Moreover, in the Conclusion chapter the following sentences strongly support the hypothesis of storm waves: "The occurrence of recent extreme storm waves are supported by the Radiocarbon datings performed on marine organisms. Such events are likely to increase in frequency and intensity due to climate change, whilst sea level rise, even a temporary one such as that brought about by storm surge, could shift coastal processes landward and impinge on the urban areas.

The possibility that one or more tsunami events may have affected these coasts cannot be ruled out, since Radiocarbon datings of some marine organisms encrusted on the boulders surfaces have revealed ages that can be related to historical known tsunamis".

25. *Page 22 lines 3-5: what event do Agius de Soldanis describe in his 1746 accounts? The 1693 or 1743 earthquake? Likely the 1693 because it occurred on 11 January, whereas the 1743 Ionian earthquake occurred on 20 February. Please specify in the text. Furthermore, the 1743 tsunami was observed only in Apulia, while at Malta there were only some damages (see Guidoboni et al., 2007-2013).*

Authors reply. The 1693 event; the information has been added in the text in order to make the description clearer.

26. *Please complete this reference: Baratta, M.: I terremoti d'Italia; saggio di storia geografia e bibliografia sismica italiana. Torino, [ristampa anastatica, A. Forni Ed., Sala Bolognese, 1980], 950 pp., 1901.*

Authors reply. Thanks to the Reviewer for this correction.

27. *In table 2 the boulder density is likely wrong add 1 before 670: QW1 LCL Qawra Peninsula 29 Jan 2015 15: 670 =1670*

Authors reply. This correction has been done.

28. *Fig. 1. Please, add epicentres of the tsunamigenic earthquakes.*

Authors reply. Figure 1 has been modified.

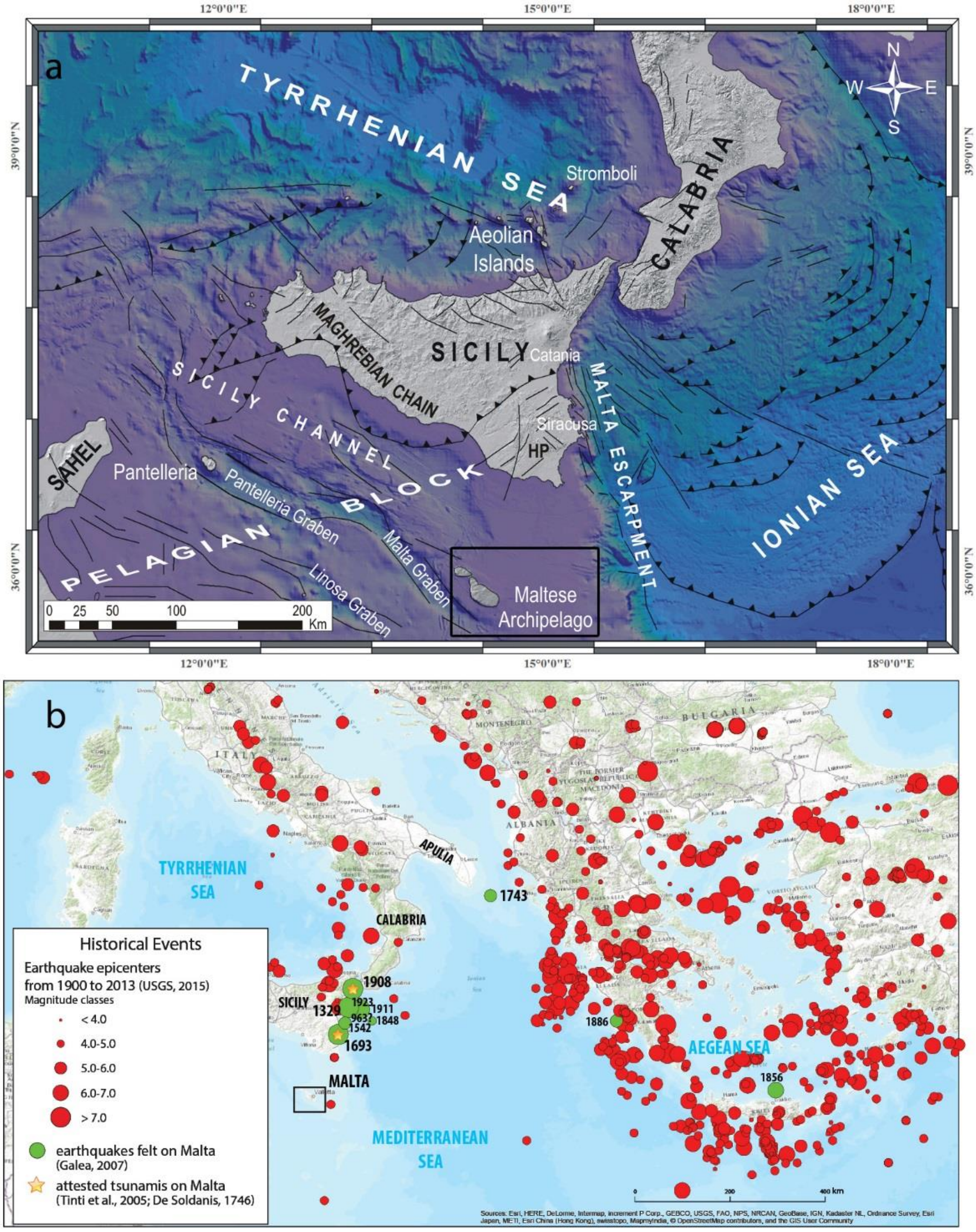

Figure 1

29. Fig. 3f. Increase, font dimension of the bathymetry; Fig. 6f. Increase, font dimension of the bathymetry.

Authors reply. The suggestions from the Reviewer have been added.

30. Fig 7. At Armier Bay-Ahrax, point elevation a.s.l. are missing.

Authors reply. The figure has been modified and will become Figure 8.

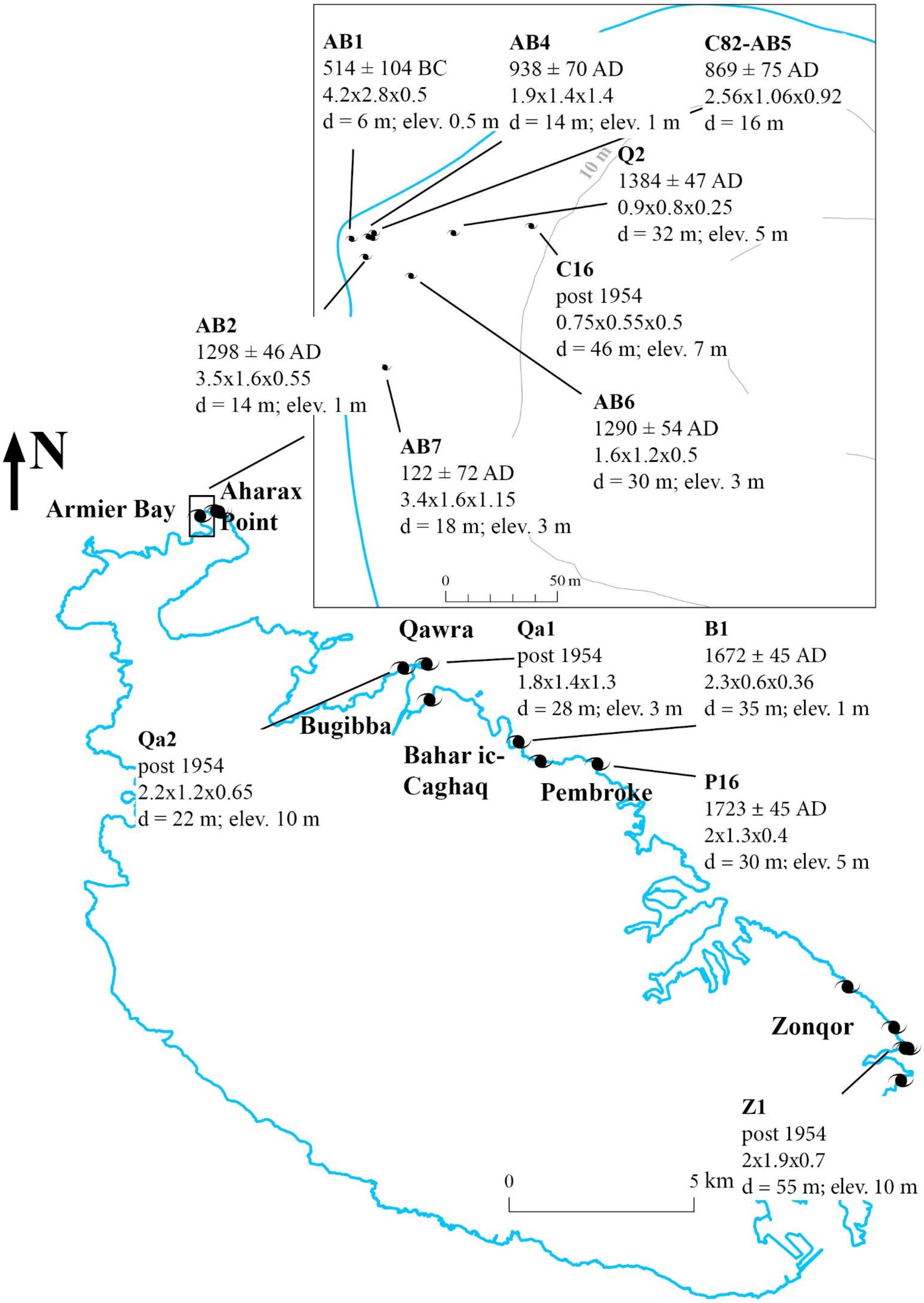
AB1
514 ± 104 BC
4.2x2.8x0.5
d = 6 m; elev. 0.5 m
AB4
938 ± 70 AD
1.9x1.4x1.4
d = 14 m; elev. 1 m
C82-AB5
869 ± 75 AD
2.56x1.06x0.92
d = 16 m
10 m
Q2
1384 ± 47 AD
0.9x0.8x0.25
d = 32 m; elev. 5 m
C16
post 1954
0.75x0.55x0.5
d = 46 m; elev. 7 m
AB2
1298 ± 46 AD
3.5x1.6x0.55
d = 14 m; elev. 1 m
AB6
1290 ± 54 AD
1.6x1.2x0.5
d = 30 m; elev. 3 m
AB7
122 ± 72 AD
3.4x1.6x1.15
d = 18 m; elev. 3 m
0
50 m
N
Armier Bay
Aharax Point
Qawra
Qa1
post 1954
1.8x1.4x1.3
d = 28 m; elev. 3 m
B1
1672 ± 45 AD
2.3x0.6x0.36
d = 35 m; elev. 1 m
Bugibba
Qa2
post 1954
2.2x1.2x0.65
d = 22 m; elev. 10 m
Bahar ic-Caghaq
Pembroke
P16
1723 ± 45 AD
2x1.3x0.4
d = 30 m; elev. 5 m
Zonqor
Z1
post 1954
2x1.9x0.7
d = 55 m; elev. 10 m
0
5 km

Figure 8