REFEREE#1 COMMENTS

1. *Since the behavior of water after wave-breaking is very complicated, simple formula such as u2 = dgH (where u: fluid velocity; h: gravity acceleration; H: wave height; d(tsunami) = 4; d(swell) = 1) cannot be used. The d(tsunami) value can range between 0.5–4.0, and d(tsunami) = 4 corresponds to the maximum value, as shown by Matsutomi and Okamoto (2010). Importantly, the wave-height ratio of the tsunami to storm, which can transport the boulders, is not constantly 4.0. Thus, the estimation of the wave heights of tsunamis based on the flow velocity is associated with large uncertainty. The estimation of wave heights of the storms also is associated with uncertainty. The author should check the results of calculations and discuss the uncertainty associated with the wave heights of storms and tsunamis, which could have moved the boulders. Matsutomi, H. and K. Okamoto, Inundation flow velocity of tsunami on land, Island Arc 19, 443–457, 2010.*

**Authors reply**. The relationship between tsunami waves and storm surges cannot be always simplified in a ratio of 1/4 and surely, from a theoretical point of view, it varies from 0.5 to 4 as shown by Matsutomi and Okamoto (2010) with simulations in a flume; the method suggested by the reviewer was developed in the flume and in the laboratory with some forcing that do not take into account the reality of the rocky coasts. The resulting approximations lead the authors to believe that the suggested model cannot be simply applied to the proposed case study, derived by field surveys.

First, what has been developed in the flume cannot be applied directly to reality since: I – the geometry of the coastline, bathymetry and topography; II – the variety of the type of rocky coast (gently sloping rocky coast vs. cliffs); III – the presence of a roughness coefficient; IV – the absence of evidence of water line on the coast or around of boulder scattered inland. Such setting would require an approach which considers numerous buffers of "small amplitude" according to the local geomorphological features.

Moreover, the proposed model was tested on geometric solids of "simple shape" that do not correspond to the morphological characteristics of the boulder studied in Malta (for example, the surfaces are smooth and oppose less resistance to water flow; the roughness of the surfaces of the boulder - very irregular – makes them easier to be moved (if equal in size and weights with respect to the body from Matsutomi and Okamoto; 2010).

Finally, it should be not forget that the model proposed by Matsutomi and Okamoto (2010) largely differs in scenario from the surveyed ones. In fact, the shapes on which the model has been developed are placed on a slightly inclined surfaces emerged and are surrounded by the water flow along four surfaces.

On the contrary the studied boulders are in two / three well characterized scenarios: Scenario A - submerged (so affected by the flow on six surfaces if considered simply rectangular); Scenario B - joint bounded on the edge of the rocky coast (and therefore affected by the flow on one surface, the frontal one); Scenario C - at the top of a cliff (therefore interested by the impact along one surface, which is the lower one).

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 (Scenario C).

We thank for the suggestions, but we prefer to not adopt in this paper the suggested approach and to make reference, maybe, in another one with appropriate aims.

2. *Lines 16–21 at page 5986: The author should indicate the period (start and end times) of the wave data. Moreover, please show the significant wave heights in terms of their 50-year (and 100-year if possible) probabilities for this region. The wave height for the 50-year probability will be higher*

*than the recorded maximum one (5–5.5 m; line 17 at page 5996). These data will be useful when discussing the magnitude and frequency of extremely high waves in this region and the source of the boulder movement.*

**Authors reply**. The lacking of these data has been commented also by the Reviewer#2. 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.

3. *The author compares the 14C dating of the boulder with historical tsunamis in this region and estimates that the movements of some boulders correspond to historical tsunamis. However, the source areas that the author estimated are mainly distributed in eastern Sicily. In this case, it is unknown whether the tsunami arrived in the Maltese Archipelago. The author should discuss whether the tsunami heights estimated from the previous source fault model are consistent with the estimated runup height from the elevation of boulders and fluid-dynamics equation. The tsunami height at the boulder locations should be evaluated not only with the fluid-dynamics equation, but also with the elevations of the boulders. Moreover, the runup height is generally higher than the elevation of a boulder. The runup height distribution in the Maltese Archipelago should be discussed in a manner that includes these factors.*

**Authors reply**. We strongly support the hypothesis of storm waves as the main responsible agent for the displacement of 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.
As suggested by the Reviewer, Figure 1 was improved by means of a new picture that shows the epicenters of earthquakes in the Mediterranean Sea (see Figure below).
In the past, tsunamis are known to hit the coasts of Malta.
In order to clarify it, this sentence has been added in the "Introduction":

"In the Maltese Archipelago the attested tsunamis (Tinti et al., 2004) are the 1169 AD, 1693 AD, which was described also by de Soldanis (1746), and the 1908 AD. The latter is well known to have affected the eastern coast of Malta (Pino et a., 2008) 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.

4. *Regarding the possibility whether the boulders were transported by tsunamis or storm waves: As estimated from the photographs of the boulders in each area, the boulders are distributed within the backshore area, where storm waves are known to have attacked frequently in the past (Figs. 3–6). This suggests that the boulders can be re-transported by storm waves after the tsunamis. Since the occurrence of large storm waves is more frequent than the occurrence of tsunamis, it is possible that the boulders will be transported by storm waves in general. The author should show that the boulders that were transported by the tsunami were in a stable position after the tsunami or explain that they have been re-transported by storm waves on the terrace.*

**Authors reply**. A tsunami is able to locate boulders in unstable position (for example the spectacular case of Japan, where fishing boats are on the roof of buildings in unstable equilibrium). During a tsunami, boulders are landed over the coast and fall down without any adjustment.
A storm event, being characterized by many waves that affects the coast on the same point, can arrange its deposit.
But now we are not able to establish if the current position of the boulders is the same one of the moment in which they have been deposited. There is the real possibility that storm waves have moved them again and again. For example, at Armier Bay site, the "most ancient" boulder (according to the serpulid Radiocarbon age) is currently the closest to the shoreline and it is overlapping on other boulders. More recent boulders (according to the Radiocarbon dating of marine organisms) are instead more distant. It is therefore possible that this boulder arrived on the coast because of an ancient tsunami event and later it has been moved by other waves to its current position.

5. *To show that the boulders were transported by the tsunami, the author should show that the boulders were located at a position (elevation and distance from the shore) where the storm waves could not reach or could not move the boulder. However, all boulders were distributed within 55 m from the shore (Fig. 7). Moreover, the boulder Z1, which was the farthest among the boulders, was transported by storm waves. Since other boulders were distributed near the shore and their elevation was lower than boulder Z1, they could have been transported by storm waves.*

**Authors reply**. We apologize for this, but in the first version of the paper, there were some mistakes in the Table concerning Zonqor boulder: the dimension of Z1 are 2 x 1.7 x 0.7m; its volume is 2.39 and its weight 3.64 tonns. The distance from the coastline is 19 and not 55 (see Table below; this is the new version of the Table 3, in which a column with the "mass" has been added).

| SITE | BOUL_ DER | ax a (m) | ax b (m) | ax c (m) | volume ($m^3$) | density ($g/cm^3$) | mass (t) | Nandasena tsunami (m) | Nandasena storm (m) | Pignatelli tsunami (m) | Pignatelli storm (m) | Engel tsunami (m) | Engel storm (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AHARAX POINT ARMIER BAY** | AA1 | 4.1 | 2.4 | 1.1 | 10.82 | 1.39 | 15.02 | 1.18 | 4.71 | 1.11 | 4.46 | 0.80 | 3.21 |
| | AA2 | 2.8 | 1.2 | 1.1 | 3.70 | 1.70 | 6.28 | 2.18 | 8.71 | 2.06 | 8.24 | 0.49 | 1.97 |
| | AA3 | 1.8 | 0.8 | 0.8 | 1.15 | 1.70 | 1.96 | 1.58 | 6.34 | 1.50 | 5.99 | 0.33 | 1.31 |
| | AA4 | 3 | 2.2 | 0.65 | 4.29 | 1.70 | 7.29 | 1.29 | 5.15 | 1.22 | 4.87 | 0.90 | 3.61 |
| | AA5 | 2.25 | 1.9 | 0.3 | 1.28 | 1.70 | 2.18 | 0.59 | 2.38 | 0.56 | 2.25 | 0.78 | 3.11 |
| | AA7 | 1.7 | 1 | 0.8 | 1.36 | 1.70 | 2.31 | 1.58 | 6.34 | 1.50 | 5.99 | 0.41 | 1.64 |
| | AA8 | 2 | 1 | 0.5 | 1.00 | 1.70 | 1.70 | 0.99 | 3.96 | 0.94 | 3.75 | 0.41 | 1.64 |
| | AA9 | 2 | 1.2 | 0.45 | 1.08 | 1.62 | 1.75 | 0.78 | 3.13 | 0.74 | 2.96 | 0.47 | 1.87 |
| | AA10 | 9.5 | 2 | 1.3 | 24.70 | 1.7 | 41.99 | 2.61 | 9.70 | 2.43 | 9.74 | 0,82 | 3,28 |
| | AA11 | 3 | 1,5 | 0,9 | 4,05 | 1,66 | 6.72 | 2,46 | 6,32 | 1,59 | 6,35 | 0,60 | 2,40 |
| | AA12 | 2,6 | 1,7 | 1,5 | 6,63 | 2,047 | 13.57 | 3,94 | 16,91 | 4,24 | 16,97 | 0,84 | 3,36 |
| | AA14 | 2,9 | 1,8 | 0,9 | 4,70 | 1,66 | 7.80 | 2,46 | 6,32 | 1,59 | 6,35 | 0,72 | 2,88 |
| | AA15 | 1,1 | 1 | 0,3 | 0,33 | 1,7 | 0.56 | 2,61 | 2,24 | 0,56 | 2,25 | 0,41 | 1,64 |
| | **AB1** | **4.2** | **2.8** | **0.5** | **5.88** | **1.78** | 10.45 | **1.10** | **4.41** | **1.04** | **4.17** | **1.20** | **4.80** |
| | **AB2** | **3.5** | **1.6** | **0.55** | **3.08** | **1.85** | 5.70 | **1.33** | **5.32** | **1.26** | **5.03** | **0.71** | **2.85** |
| | AB3 | 2 | 1.6 | 0.8 | 2.56 | 1.62 | 4.14 | 1.39 | 5.57 | 1.32 | 5.27 | 0.62 | 2.50 |
| | **AB4** | **1.9** | **1.4** | **1.4** | **3.72** | **1.81** | 6.76 | **3.24** | **12.95** | **3.06** | **12.24** | **0.61** | **2.45** |
| | **AB6** | **1.6** | **1.2** | **0.5** | **0.96** | **1.70** | 1.63 | **0.99** | **3.96** | **0.94** | **3.75** | **0.49** | **1.97** |
| | **AB7** | **3.4** | **1.6** | **1.15** | **6.26** | **1.70** | 10.64 | **2.28** | **9.11** | **2.15** | **8.61** | **0.66** | **2.62** |
| | **C16** | **0.9** | **0.8** | **0.25** | **0.18** | **1.80** | 0.32 | **0.57** | **2.27** | **0.54** | **2.15** | **0.35** | **1.39** |
| | **C82/AB5** | **2.56** | **1.06** | **0.92** | **2.50** | **1.70** | 4.24 | **1.82** | **7.29** | **1.72** | **6.89** | **0.43** | **1.74** |
| | new | 2.39 | 1.69 | 0.82 | 3.31 | 1.58 | 5.22 | 1.33 | 5.31 | 1.26 | 5.02 | 0.64 | 2.57 |
| | **Q2** | **0.75** | **0.55** | **0.5** | **0.21** | **1.70** | 0.35 | **0.99** | **3.96** | **0.94** | **3.75** | **0.23** | **0.90** |
| BAHAR IC CAGHAQ | **B1** | **2.3** | **1.85** | **0.6** | **2.55** | **1.70** | 4.34 | **1.14** | **4.55** | **1.12** | **4.49** | **0.76** | **3.03** |
| | B2 | 4.35 | 3.65 | 0.4 | 6.35 | 1.80 | 11.43 | 0.87 | 3.48 | 0.86 | 3.44 | 1.58 | 6.33 |
| | B3 | 2.4 | 1.8 | 0.55 | 2.38 | 1.80 | 4.28 | 1.20 | 4.78 | 1.18 | 4.73 | 0.78 | 3.12 |
| | B4 | 2.6 | 1.7 | 0.7 | 3.09 | 1.80 | 5.57 | 1.52 | 6.09 | 1.50 | 6.01 | 0.74 | 2.95 |
| | B5 | 2.15 | 1.93 | 0.7 | 2.90 | 1.80 | 5.23 | 1.52 | 6.09 | 1.50 | 6.01 | 0.84 | 3.35 |
| | B6 | 2 | 1.5 | 0.55 | 1.65 | 1.80 | 2.97 | 1.20 | 4.78 | 1.18 | 4.73 | 0.65 | 2.60 |
| | B7 | 2.3 | 1.6 | 0.36 | 1.32 | 1.80 | 2.38 | 0.78 | 3.13 | 0.77 | 3.09 | 0.69 | 2.78 |
| | B8 | 3 | 2.4 | 1 | 7.20 | 1.80 | 12.96 | 2.17 | 8.70 | 2.15 | 8.59 | 1.04 | 4.17 |
| | B9 | 3.3 | 1.65 | 0.6 | 3.27 | 1.39 | 4.53 | 0.66 | 2.62 | 0.61 | 2.43 | 0.55 | 2.21 |
| | B10 | 3.1 | 1.6 | 0.6 | 2.98 | 1.39 | 4.13 | 0.66 | 2.62 | 0.61 | 2.43 | 0.54 | 2.14 |
| | B11 | 3.3 | 1.8 | 0.69 | 4.10 | 1.39 | 5.69 | 0.75 | 3.01 | 0.70 | 2.80 | 0.60 | 2.41 |
| | B12 | 3.1 | 2.35 | 0.5 | 3.64 | 1.39 | 5.06 | 0.55 | 2.18 | 0.51 | 2.03 | 0.79 | 3.15 |
| | B13 | 4.3 | 3.4 | 0.7 | 10.23 | 1.39 | 14.20 | 0.76 | 3.06 | 0.71 | 2.84 | 1.14 | 4.55 |
| | B14 | 3.2 | 2.1 | 1.1 | 7.39 | 1.39 | 10.26 | 1.20 | 4.81 | 1.11 | 4.46 | 0.70 | 2.81 |
| B | LB1 | 4 | 2 | 1.2 | 9.60 | 1.70 | 16.32 | 2.44 | 9.78 | 2.25 | 8.99 | 0.82 | 3.28 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UGIBBA & QAWRA | LB2 | 2.9 | 1.65 | 1.05 | 5.02 | 1.98 | 9.97 | 3.03 | 12.13 | 2.79 | 11.15 | 0.79 | 3.16 |
| | LB3 | 2.6 | 1.8 | 1.1 | 5.15 | 2.08 | 10.69 | 3.54 | 14.17 | 3.20 | 12.81 | 0.90 | 3.60 |
| | LB4 | 3.3 | 2.8 | 0.6 | 5.54 | 1.62 | 8.97 | 1.09 | 4.37 | 0.99 | 3.95 | 1.09 | 4.37 |
| | LB6 | 2.016 | 1.12 | 0.35 | 0.79 | 1.85 | 1.46 | 0.89 | 3.54 | 0.80 | 3.20 | 0.50 | 2.00 |
| | LB7 | 1.984 | 1.8 | 1.1 | 3.93 | 2.02 | 7.92 | 3.34 | 13.35 | 3.02 | 12.07 | 0.87 | 3.50 |
| | LB8 | 1.739 | 1.6 | 0.85 | 2.37 | 1.74 | 4.11 | 1.86 | 7.45 | 1.68 | 6.73 | 0.67 | 2.68 |
| | LB9 | 2.5 | 2.15 | 0.8 | 4.30 | 1.70 | 7.31 | 1.63 | 6.52 | 1.50 | 5.99 | 0.88 | 3.52 |
| | LB10 | 2.4 | 2.3 | 0.5 | 2.76 | 2.05 | 5.65 | 1.50 | 5.98 | 1.41 | 5.66 | 1.13 | 4.54 |
| | **Qa1** | **1.8** | **1.4** | **1.3** | **3.28** | **1.80** | 5.90 | **2.95** | **11.81** | **2.79** | **11.17** | **0.61** | **2.43** |
| | **Qa2** | **2.2** | **1.2** | **0.65** | **1.72** | **1.80** | 3.09 | **1.54** | **6.18** | **1.40** | **5.58** | **0.52** | **2.08** |
| | Qa3 | 1.5 | 1.5 | 0.7 | 1.58 | 1.85 | 2.91 | 1.77 | 7.08 | 1.60 | 6.40 | 0.67 | 2.68 |
| | qawra_2 | 2 | 1.05 | 0.6 | 1.26 | 1.74 | 2.19 | 1.24 | 4.97 | 1.19 | 4.75 | 0.44 | 1.76 |
| | qawra_3 | 2.3 | 1.5 | 1.1 | 3.80 | 1.88 | 7.15 | 2.74 | 10.95 | 2.62 | 10.47 | 0.68 | 2.72 |
| PEMBROKE | **P16** | **2** | **1.3** | **0.4** | **1.04** | **1.80** | 1.87 | **0.90** | **3.60** | **0.86** | **3.44** | **0.56** | **2.26** |
| | P1 | 2.55 | 1.2 | 0.6 | 1.84 | 2.24 | 4.12 | 2.18 | 8.72 | 2.02 | 8.09 | 0.65 | 2.60 |
| | P2 | 2 | 1.5 | 0.65 | 1.95 | 2.20 | 4.29 | 2.28 | 9.11 | 2.11 | 8.45 | 0.80 | 3.18 |
| | P3 | 2.85 | 2.7 | 0.8 | 6.16 | 2.19 | 13.48 | 2.78 | 11.11 | 2.58 | 10.31 | 1.43 | 5.70 |
| | P4 | 2.5 | 1.8 | 0.7 | 3.15 | 2.08 | 6.54 | 2.20 | 8.79 | 2.04 | 8.15 | 0.90 | 3.60 |
| | P5 | 2.8 | 1.5 | 0.7 | 2.94 | 2.08 | 6.11 | 2.20 | 8.79 | 2.04 | 8.15 | 0.75 | 3.00 |
| | P6 | 2.4 | 2.1 | 0.7 | 3.53 | 2.08 | 7.33 | 2.20 | 8.79 | 2.04 | 8.15 | 1.05 | 4.21 |
| | P7 | 2.55 | 1.4 | 0.5 | 1.79 | 2.08 | 3.71 | 1.52 | 6.09 | 1.46 | 5.82 | 0.70 | 2.80 |
| | P9 | 2.55 | 1.5 | 0.6 | 2.30 | 2.08 | 4.77 | 1.83 | 7.31 | 1.75 | 6.99 | 0.75 | 3.00 |
| | P10 | 2.55 | 1.5 | 0.35 | 1.34 | 2.08 | 2.78 | 1.07 | 4.26 | 1.02 | 4.08 | 0.75 | 3.00 |
| ZONQOR | **Z1** | **2** | **1.7** | **0.7** | **2.38** | **1.53** | 3.64 | **1.08** | **4.32** | **0.99** | **3.94** | **0.63** | **2.51** |
| | Z2 | 2.3 | 1.3 | 0.8 | 2.39 | 1.70 | 4.07 | 1.64 | 6.57 | 1.50 | 5.99 | 0.53 | 2.13 |
| | Z3 | 2.8 | 2.2 | 0.8 | 4.93 | 1.70 | 8.38 | 1.57 | 6.27 | 1.50 | 5.99 | 0.90 | 3.61 |
| | Z4 | 2 | 1.2 | 0.4 | 0.96 | 1.74 | 1.67 | 0.83 | 3.32 | 0.79 | 3.17 | 0.50 | 2.01 |
| | Z5 | 2.3 | 0.7 | 0.5 | 0.81 | 1.74 | 1.40 | 1.04 | 4.14 | 0.99 | 3.96 | 0.29 | 1.17 |
| | Z6 | 4.35 | 3 | 0.7 | 9.14 | 1.74 | 15.89 | 1.49 | 5.98 | 1.39 | 5.54 | 1.26 | 5.03 |
| | Z7 | 8.5 | 4 | 1.2 | 40.80 | 1.70 | 69.36 | 2.42 | 9.69 | 2.25 | 8.99 | 1.64 | 6.56 |
| | Z8 | 3 | 1.1 | 0.3 | 0.99 | 1.88 | 1.87 | 0.76 | 3.05 | 0.71 | 2.86 | 0.50 | 2.00 |
| | Z9 | 2.5 | 1.2 | 1.1 | 3.30 | 1.74 | 5.74 | 2.33 | 9.30 | 2.18 | 8.71 | 0.50 | 2.01 |
| | Z10 | 3.3 | 2.2 | 0.7 | 5.08 | 1.74 | 8.84 | 1.48 | 5.92 | 1.39 | 5.54 | 0.92 | 3.69 |
| | Z11 | 3.5 | 2.1 | 1.5 | 11.03 | 1.74 | 19.17 | 3.17 | 12.68 | 2.97 | 11.88 | 0.88 | 3.52 |
| | Z12 | 2.2 | 1.45 | 0.6 | 1.91 | 1.49 | 2.84 | 0.83 | 3.31 | 0.77 | 3.07 | 0.52 | 2.08 |
| | Z13 | 2.8 | 1.1 | 1 | 3.08 | 1.85 | 5.70 | 2.46 | 9.85 | 2.29 | 9.14 | 0.49 | 1.96 |
| | Z14 | 4.6 | 2.1 | 1 | 9.66 | 1.78 | 17.17 | 2.25 | 8.99 | 2.08 | 8.34 | 0.90 | 3.60 |
| | Z15 | 5.7 | 2.7 | 1.5 | 23.09 | 1.75 | 40.44 | 3.32 | 13.27 | 3.02 | 12.10 | 1.14 | 4.56 |

Anyway, we must observe that tsunamis can show a lower wave height than a storm, but their energy is higher, because the water mass involved is higher. The position of Z1 and other more distant boulders (such as Z12, Z5, Z4, see Table below) can be explained by the energy of a storm coming from NW or SE, where the maximum fetches of the Mediterranean Sea are observed.

But what we are discussing is that probably the main reason for these boulders (especially at Zonqor, southeastern coast) lying out of the sea are the very frequent and strong storm waves.

Today we can observe very recent boulders with fresh algae on their surface and very fresh damage tracks on the coast. Moreover also the local people told us that these large boulders move during the storms. The horizontal bedding, the poor geomechanical properties of the local rocks and the low-lying coast, as well as the strong wind and waves with NE and NW direction and the position of the archipelago in the middle of the Mediterranean Sea surely favor the detachment and the transport of large boulder, even at large distance and at high elevations.

As a matter of fact, the hydrodynamic equations seem to confirm for the majority of boulders a storm origin.

Otherwise some marine encrustations provided ages that are very ancient and comparable with historical known tsunami events and also to those observed in Eastern Sicily by Scicchitano et al. (2007, 2012) or in Apulia by Mastronuzzi et al. (2007).

As the Reviewer highlighted, a storm has a shorter return period than a tsunami (for example, for a return period of 50 years a wave of 5-5,9 m is estimated and for a return period of 100 years a wave of 5,3-6,0 m) and this is the reason why it must be considered as a more concrete hazard for the coast of Malta.

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).

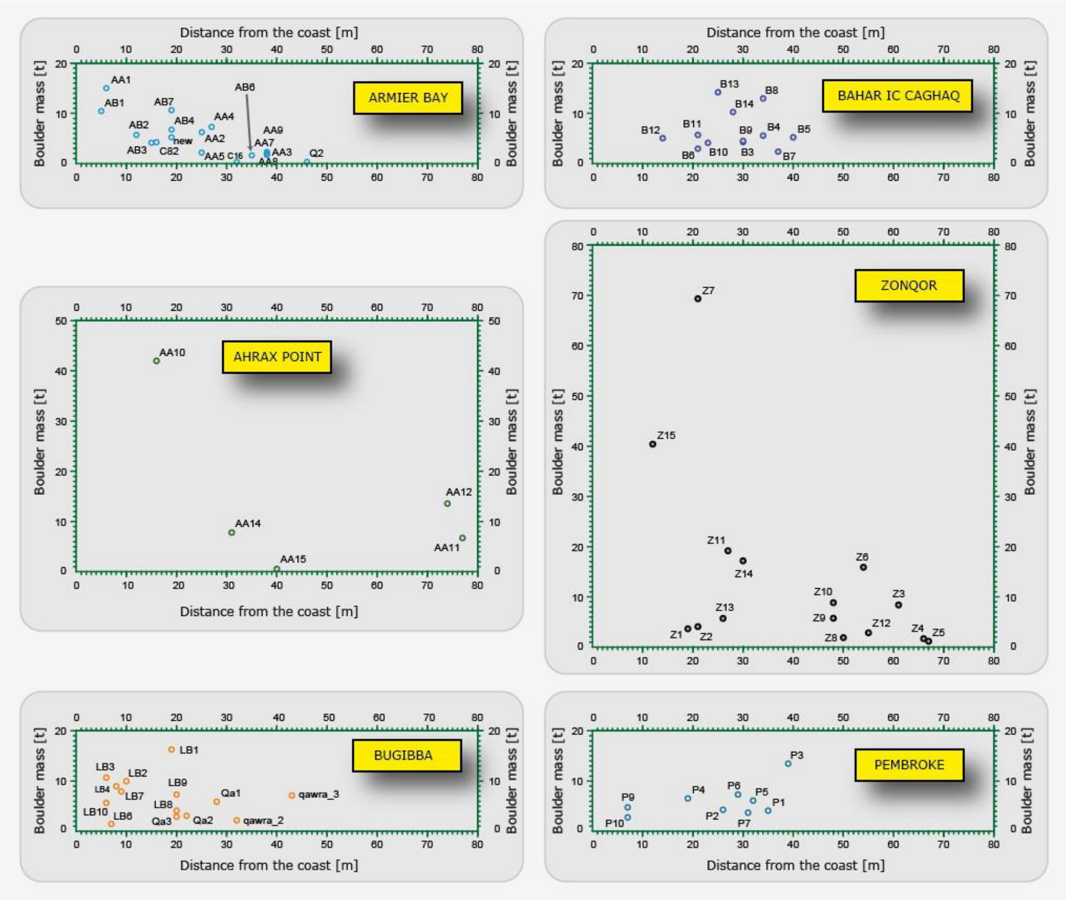


*Figure 7*

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."

6. *Discussion, lines 24–27 at page 5995: The author provides the densities of limestone distributed in the area in lines 24–27. However, relations between boulder density, boulder volume, and the obtained results are discussed in the next paragraph. The information denoted in lines 24–27 is not used until the next paragraph. The relation between the information in lines 24–27 and the discussion in the next paragraph is not clear. The author should correct this portion of the text.*

**Authors reply**. The observation is correct. These values were in fact not useful for the discussion.

MINOR COMMENTS

7. *Abstract: An overview of the results has not been given in the abstract (lines 22–25 at page 5979). The author should denote these results briefly and state that most boulders were transported by storm waves, while some boulders were transported by tsunamis.*

**Authors reply**. The Abstract was modified 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.

8. *Introduction, lines 9–12 and lines 23–25 at page 5982: Please plot the epicentre of the events whose epicenters were estimated in Fig. 1. Moreover, please show the tsunami heights (if possible, tsunami heights in the Maltese Archipelago) for these events.*

**Authors reply**. Figure 1 has been improved. We took inspiration from the USGS website, where we found the epicentres of earthquakes for the Mediterranean Sea from 1900 to 2013 (http://pubs.er.usgs.gov/publication/ofr20101083Q). Moreover 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) have been added.

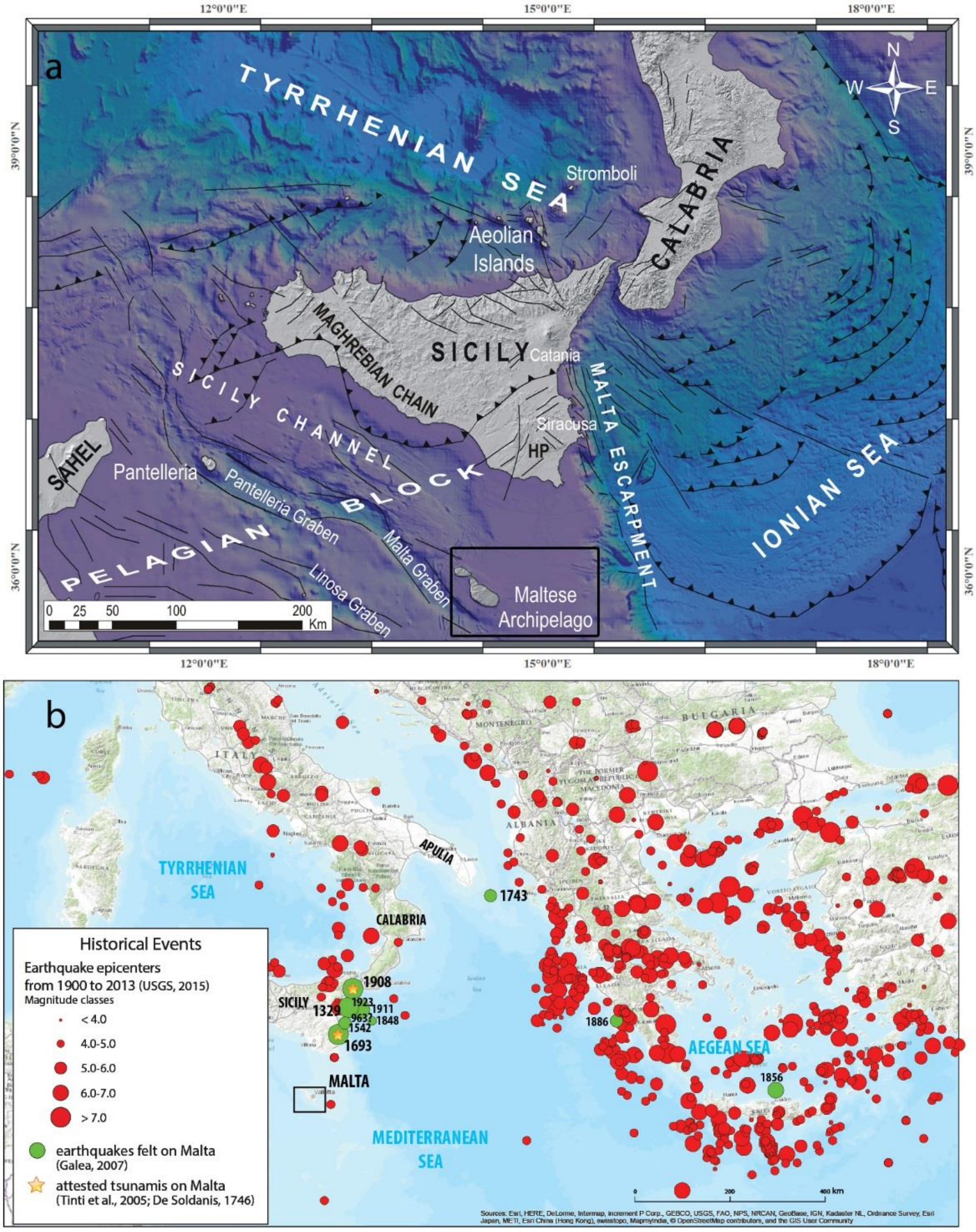


*Figure 1*

9. *Line 15 at page 5987: The word "N300W" should be changed to "N30W" or "300degrees."*

**Authors reply**. Thanks to the Reviewer for this suggestion.

10. *and 5. Lines 13–14 at page 5988, lines 3–4 at page 5990, line 3 and lines 27–29 at page 5992, and lines 24–25 at page 5994: Please show the results for the hydrodynamic equations. 5. Lines 10–11 at page 5990, lines 12–13 at page 5991, lines 27–29 at page 5992, and lines 24–25 at page 5994: Please describe the results for the 14C dating.*

**Authors reply**. For each site a new sentence that comments the results of the hydrodynamic equations and of the datings has been added.

**Armier Bay**. The results of the application of the hydrodynamic equations are listed in Table 3, whereas Radiocarbon datings are listed in Table 4. According to the equations of Nandasena et al. (2011) and Pignatelli et al. (2009), only four boulders seem to require storm waves with heights that exceed the local values, being comprised between more than 7 and about 13 m. Conversely, with the Engel and May (2012) approach, the wave heights are decisively lower (1.7 – 2.5 m). Instead, the tsunami wave heights are comparable with those observed during the 1908 event (Guidoboni & Mariotti, 2008) or obtained by Tinti et al. (2005). All other values obtained with the hydrodynamic equations are compatible with the Maltese storm waves (2.27-6.34 m for Nandasena et al., 2011; 2.15-5.99 m for Pignatelli et al., 2009; 1.31-4.80 m for Engel and May, 2012). Concerning the Radiocarbon datings, among the highest values obtained, boulders AB4, AB7 and AB5 provided ages that are possibly comparable with historical tsunami events: 938±70 (AB4), 869±75 (AB5) and 122±72 (AB7). The other boulders, such as AB1 (514±104 BC), AB2 (1298±46), AB6 (1290±54) and Q2 (1384±47), despite their very ancient age and comparable with historical events, seem not to require extraordinary waves. Conversely, for the C16 boulder, the Radiocarbon dating confirms a storm origin.

**Ahrax Point**. Moving eastwards, toward Ahrax Point, tens of boulders have been deposited at relatively higher elevations. They actually represent the boulder site with the highest elevation point across the island of Malta. Some of them are scattered and isolated (Fig. 3e). Conversely, the major part are gathered and arranged forming something like a storm-berm, which is aligned in the NW direction, at a distance from the coast varying from 10 to 40 m. Their maximum elevation is about 20 m. Locally, the boulders are imbricated toward NE.
At this site, the boulders do not have any marine encrustations and seem to have been detached from the top of the nearby cliff, which is deeply eroded and indented. A detachment scarp located at an elevation of 10 m a.s.l., seems to indicate a sub-aerial process-driven scenario. It is possible that these blocks correspond to cliff top storm deposits (CTSD), very similar to those characterised by some small karst pools including sand with marine shells, described by Hall et al. (2006). ). As a matter of fact, the underwater surveying did not reveal scarps, holes or fractured rocky outcrops.
Unlike the hypothesis proposed by Mottershead et al. (2014), we suggest an extreme storm wave. higher than 10 m. Waves in shallow water increase their height, so th elevation of such extreme storm waves could be increased near the coast up to 10 m. Their height was amplified by the topography of the sea bottom.

**Bugibba**. According to the results coming from the hydrodynamic equations of Nandasena et al. (2011) and Pignatelli et al. (2009) (Table 3), within the 10 measured blocks, 4 of them have required waves higher than 8.7 m to be detached from the coast edge or from the sea bottom. On the contrary, according to Engel and May (2012) equation, the values are lower (2 - 4,5 m). Among these, the serpulid sampled from boulder Qa2 has been dated back to post 1954 (Table 4), confirming a storm origin.

**Qawra**. The results coming from the hydrodynamic equations of Nandasena et al. (2011) and Pignatelli et al. (2009) (Table 3) show that 3 of the 4 considered boulders require waves that exceed 7 m. On the contrary, according to Engel and May (2012) equation, the values are lower (1.7 – 2.7 m). Among these, the serpulid sampled from boulder Qa1 has been dated back to post 1954 (Table 4). A debated origin is proposed also because only one AMS age is not enough.

**Baharic-Caghaq**. The application of the hydrodynamic equations (Table 3) provided among the 14 considered boulders, only one that required a wave higher than 8 m according to Nandasena et al. (2011) and Pignatelli et al. (2009), while for Engel and May (2012), the result is completely different: 4,17 m. Anyway the values are comparable to the Maltese wave regime. The dated vermetid crust on boulder B1, 1672 ± 45 AD (Table 4), could be related to two different historical tsunami events occurred in the closed Eastern Sicily: 1693 and 1743. However, the storm wave height obtained by means of the hydrodynamic equations for this boulder are not so excessive, as they are lower than 5 m. A debated origin is proposed also because only one AMS age is not enough.

**Pembroke**. Concerning the hydrodynamic equations (Table 3), within the 10 measured boulders, the results show that 1 of them required waves higher than 10 m to be detached from the coast edge according to Nandasena et al. (2011) and Pignatelli et al. (2009). However, according to Engel and May (2012), all values are lower, being comprised between 2,6 and 5,7 m. The dated organism from boulder P16 gave back an age of 1723±40 AD, but the hydrodynamic approach seems to refer to ordinary storm waves.

**Zonqor**. According to the results coming from the hydrodynamic equations (Table 3), within the 15 measured blocks, 6 of them have required waves higher than 8.4 m to be detached from the coast edge of from the sea bottom. The boulder Z1, that provided a $^{14}C$ dating of post 1954 AD (Table 4), should have been affected by a storm wave of 3.94 m according to Pignatelli et al. (2009) or 4.32 m according to Nandasena et al. (2011) or 2.51 according to Engel and May (2012) approaches.

11. *Fig. 1: Please surround the Maltese Archipelago with the rectangular region that is shown in Fig. 2 to clarify the location of the Maltese Archipelago.*

**Authors reply**. Thanks to the Reviewer for this suggestion.

12. *Fig. 7: The elevations of the boulders (AB1–AB5, C16, C85, and Q2) in Armier Bay are not plotted in this figure. Please insert the corresponding elevation values in this figure.*

**Authors reply**. The figure has been modified as suggested.

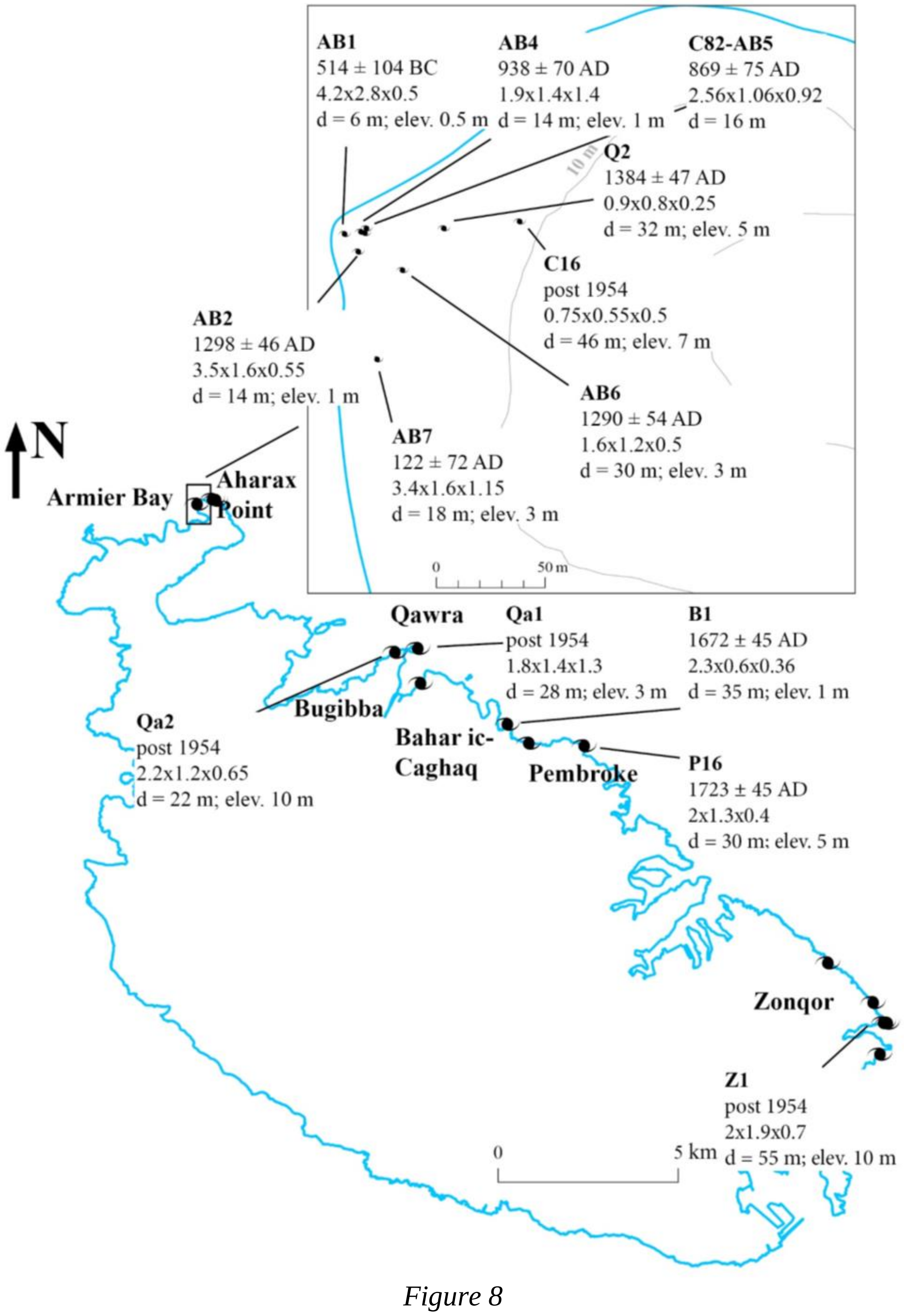
AB1
514 ± 104 BC
4.2x2.8x0.5
d = 6 m; elev. 0.5 m
AB4
938 ± 70 AD
1.9x1.4x1.4
d = 14 m; elev. 1 m
C82-AB5
869 ± 75 AD
2.56x1.06x0.92
d = 16 m
10 m
Q2
1384 ± 47 AD
0.9x0.8x0.25
d = 32 m; elev. 5 m
C16
post 1954
0.75x0.55x0.5
d = 46 m; elev. 7 m
AB2
1298 ± 46 AD
3.5x1.6x0.55
d = 14 m; elev. 1 m
AB6
1290 ± 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*