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Aegean Earthquakes, Tsunamis and the Kykladic Frying Pans.

1. Introduction

Primarily due to plate tectonics, the Aegean region is one of the places on earth most prone to seismic phenomena. The small Aegean tectonic plate, carrying Crete, most of the Aegean sea and of the Greek mainland as well as western Turkey, is limited towards the south by a round border, the so called Hellenic Arc or Trench. (**Fig. 1**). From there, or somewhat more to the south, the large African plate is plunging under the Aegean plate, advancing about 30 mm a year at a downward angle of about 30 degrees. Due to the semicircular form of the southern border, the subduction process creates something like the walls of a funnel under the Aegean plate.[1] At a depth of 100-200 km the downshifted masses of the African plate are molten and, being specifically lighter than the surrounding upper earth mantle, tend to buoy up and break through the earth crust. That creates the parallel arc of tertiary to recent (Santorini) volcanic activity (black triangles).

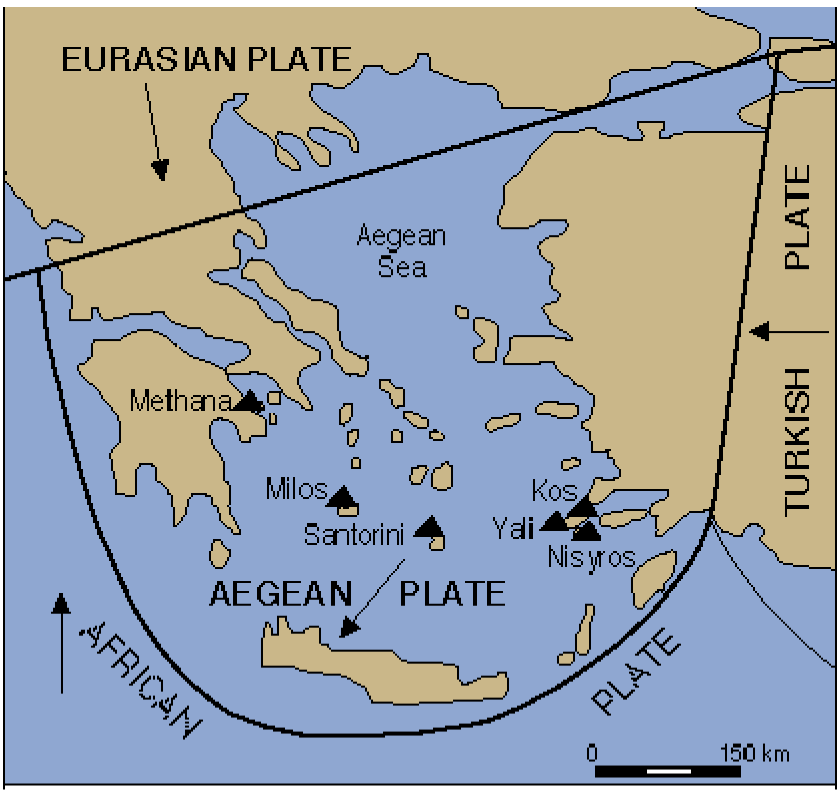

Fig. 1: Hellenic Arc and volcanic arc. [2]

This is the scene for the Aegean earthquake creation. Some earthquakes are followed by tsunamis; and perhaps also the Kykladic Frying Pans have a role in that play.

[1] **Knapmeyer,M.**: Abbildung seismischer Diskontinuitäten in der südlichen Ägäis mit migrierten Receiver Functions. Berichte des Instituts für Geophysik der Ruhr-Universität Bochum, Reihe A Nr. 55

[2] http://volcano.oregonstate.edu, mended

2. Earthquakes

The upper side of the down-plunging African Plate is marked by earthquakes, the foci of which - proceeding from the Hellenic Arc towards the middle of the Aegean Plate - also get deeper until to about 200 km. At that depth the melting process makes the plate soft and excludes the generation of slip friction and stress. So, north of the volcanic arc no deep-centred earthquakes are found. This does not exclude the occurrence of shallow-centred earthquakes within the solid earth crust, i.e. at depths of about 10 - 20 km, due to the general seismic stress of the region, generated by the tectonic situation. Tsunamis are mainly generated by shallow-centred quakes.

In fact, the average occurrence rate of - fortunately mostly rather small and regional - earthquakes in the Aegean region is about 3-5 per month[3], but per century there are also 4-5 larger and sometimes catastrophic events.[4] The highest measured Richter earthquake magnitudes were about 7.5 . Historical sources and archaeological studies suggest, that early seaquakes centred south of Crete may have been much larger, perhaps of magnitude 8 and more, as also experienced in comparable tectonic settings in other parts of the world.[5]

3. Tsunamis

Contrary to the common surface sea waves, the wave movement of a tsunami comprises the whole water column until to the ground of the sea. In that way enormous volumes of water are set to movement. On the open sea, the surface phenomena of such waves are not very conspicuous, but when such a wave hits land, it may tower up to 10-20 or more meters, and – depending on the flat or steep rise of the land from the sea – may inundate large areas.

Japan generally rises rather steep from the sea. This situation increases the height of the land falling wave, but exposes only the immediate costal region. Japanese fishermen therefore, now and then, experienced the fate that, coming home without having observed something special in the open sea, they found their home harbour flooded and smashed. They coined the notion tsunami (harbour-wave) for that phenomenon.

This Japanese word was transferred to the Aegean region, when the Minoan-time explosion of the Thera volcano was discussed and compared to the 1883 volcanic Krakatoa catastrophe in Indonesia. At the latter event, most of the damage to goods and life was done by a tsunami and, as the Thera event must have been four to ten(?) times bigger than Krakatoa, an as much bigger Aegean tsunami was inferred.

Not the word, but the phenomenon was well known in the Aegean sea since old times, and several catastrophic tsunamis are reported by classic Authors:

479 BC Potidaia Herodot tells us that, when the town of Potideia was besieged by the Persians, a tsunami ("very big ebb and flood") hit. It first started with the wave trough and exposed large areas of the sea ground before the town. Trying to exploit this fortunate situation, the Persian soldiers made haste to invade the town from this side. They were drowned by

[3] Catalogue of Earthquakes, UNESCO, Skopje 1974
[4] European-Mediterranean Seismological Centre. http://www.emsc-csem.org
[5] USGS, US Geological Service, Tectonic Summary of Greece

the inrushing wave crest. Herodot regards this tsunami to be the revenge of Poseidon for the Persians' disgrace of his temple.

426 BC Euboian Gulf Reported by Thucydides. The main consideration given to his report is, that he - for the first time - clearly ascribes the tsunami to a releasing earthquake. As also Strabo handles of a very severe earthquake disaster and tsunami in this region, both reports are often mixed up to one event. Actually there seem to have been two events, from which Strabo's was the more severe.[6]

4?? BC dto. (Strabo)

372 BC Helike This town was evidently fully submerged as result of an earthquake and a tsunami (Heracleides)

330 BC Sporades

227 BC Rhodos

365 AD Alexandria This tsunami, which reportedly washed over the whole Egyptian (?) town of Alexandria must have been excited by one of the presumed very large seaquakes south of Crete.

As triggers of tsunamis, Wikipedia(de) mainly states earthquakes (86%), for the remaining part volcanic events and slumping of land- or subaquatious masses down the coastal slope. On global average, only 1% of the earthquakes generate measurable tsunamis.

For the Aegean sea, about eight tsunamis per century have to be expected[7]. Related to the 3-5 (mainly small) earthquakes per month, this is – despite of the large share of sea in the area - considerably less than the global average. Maybe the smaller quakes are more frequently regarded and registered here than in other parts of the world.

Several thousand years ago at the beginning of the bronze age, the seismic and tsunami activity there might have been somewhat larger, because the end of the last ice age rapidly increased the sea level by 100 to 150 meters, effecting a blow to the geotectonic balance of the region. **Fig. 2** gives an impression of the last phase of the sea level increase, relative to the thousand years of "Kykladic Frying Pans" presence among the archaeological findings.

The last tsunami with considerable destructive power in the Aegean region happened 1956 AD and was the consequence of a seaquake south of the island of **Amorgos.** This event will be more closely represented in the following section.

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[6] **Papaioannou I., Papadopoulos G.A., Pavlides S.:** The Earthquake in N. Evoikos Gulf revisited: Amalgamation of two different strong earthquake events? Bulletin of the Geological Society of Greece 2004, pp.1477-1481

[7] **Soloviev S.L. et al**.: Tsunamis in the Mediterranean Sea 2000 BC – 2000 AD. Kluwer Academic Publishers 2000, ISBN 0-7923-6548-8

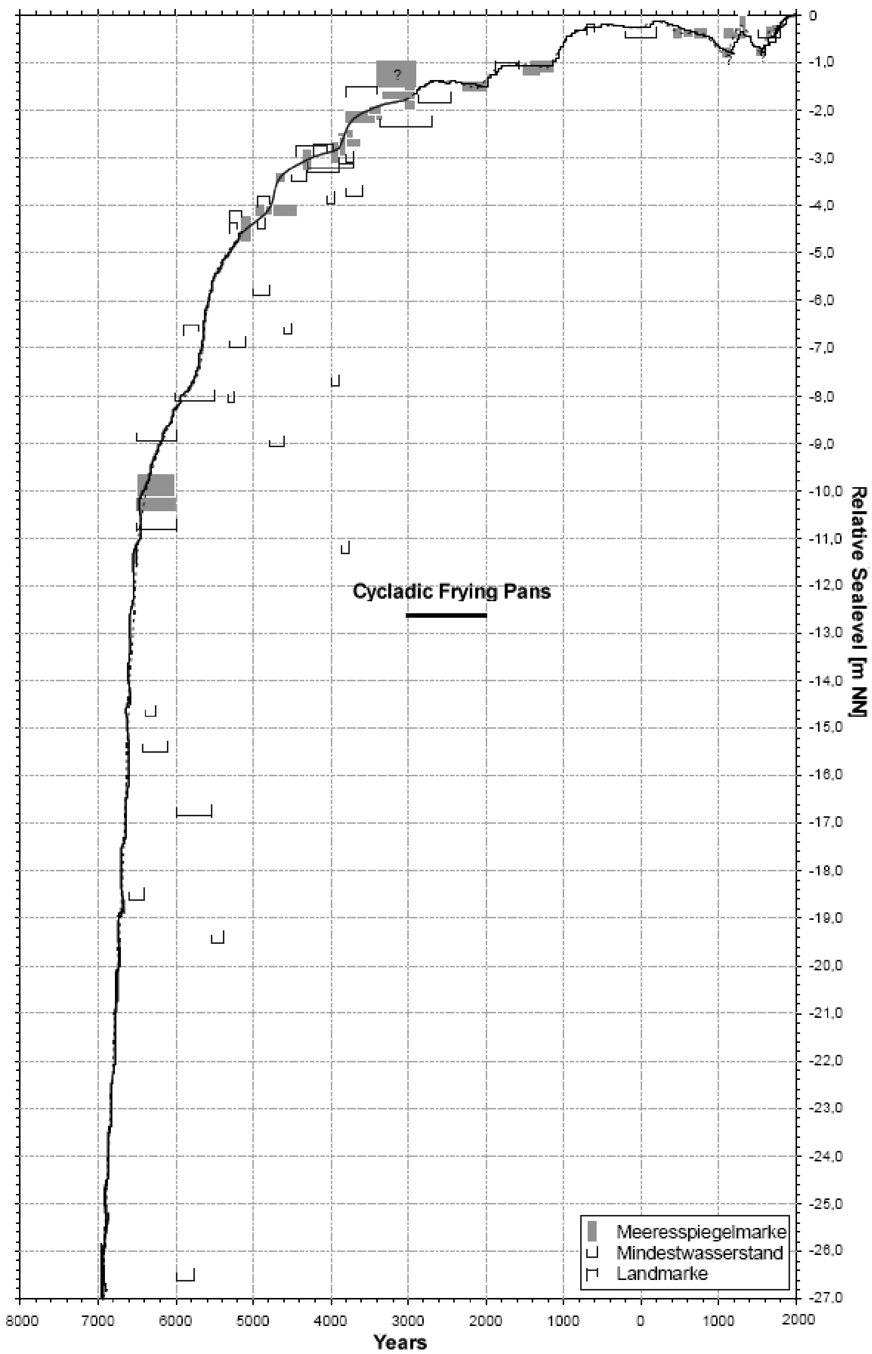

Fig. 2: Sea level increment after the last Ice Age [8]

4. The 1956 Amorgos seismic event.

The Earthquake hit at 5h 11 min and 38 s local time on July 9th 1956 with an epicentre ca. 20 km south of the island Amorgos (**Fig. 3**) and a Mercalli-Intensity of VIII-IX. It was 13 min later followed up by an aftershock of Magnitude 6.5, the epicentre of which shifted 50 km south-west to the vicinities of the island Thera, further by a series of minor afterquakes. The damage done by the earthquake itself was practically restricted to the islands Amorgos, Astipalaia and Thera which encircle the epicentre in 20 – 60 km distance. The damage to Thera might mainly have been done by the aftershock.

[8] from Jakobsen et al.: Postglazialer Meeresspiegelanstieg in der südwestlichen Ostsee. Proceedings of the 22nd annual conference in Warnemünde, Germany, 2004. mended.

The earthquake generated a tsunami which swept over the southern Aegean Sea and - by area and scale - did considerably more damage. Among many swamped townships, harbours and land, smashed boats and drowned cattle, there were 3 casualties on Kalymnos island. **Fig.3** shows the isoseists of the Amorgos earthquake in Mercalli scale[9]. The Mercalli intensities are a scale of macroseismic phenomena, e.g.:

-VII : Very strong, general alarm, cracking of walls.

-VI : Strong, trees sway, some damage from overturning and falling objects.

-V : Rather strong, sleepers awakened and bells ring..

Richter describes the seismic energy by a logarithmic scale with the base 10 (correlation see Fig.4) .

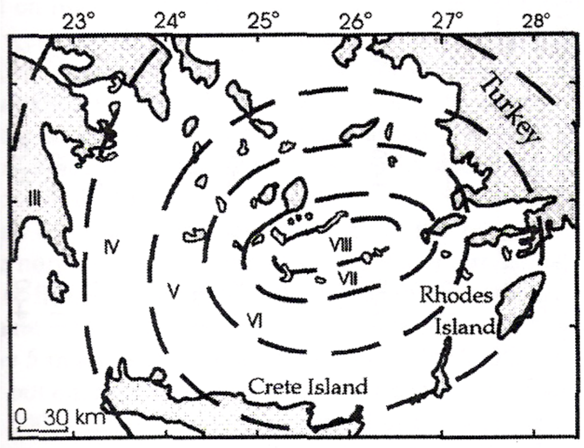

Fig 3: (Mercalli)- Isoseists of the 1959 Earthquake

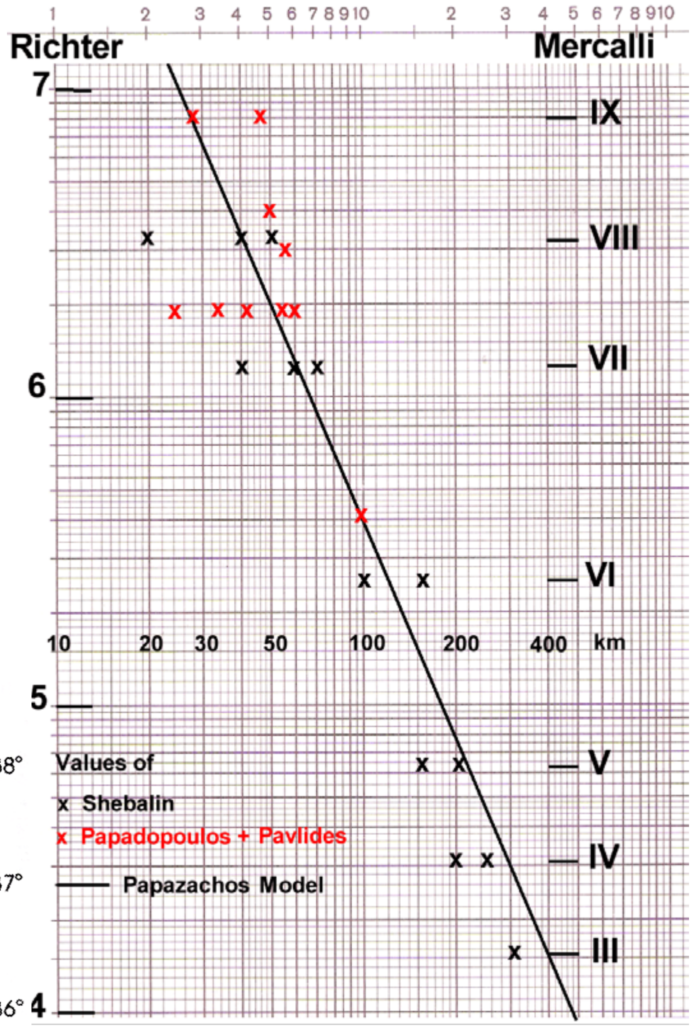

Fig. 4 : Earthquake Magnitudes related to distance from Epicentre

Fig. 4 from different sources[10] collects the attenuation of earthquake waves with distance from the epicentre. The black line in the doubly-logarithmic diagram marking an attenuation power of –2,41 corresponds to model calculations with parameters derived from earthquakes hitting Greece in the period of 1902-1980[11]. It fits relatively well to the 1956 values, of course with a high scatter. The spread of the Shebalin values originates from the ellipticity of the isoseists in Fig. 3.

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[9] **Shebalin, N.V.** :Atlas of isoseismal Maps. Part III of the catalogue of earthquakes of the Balkan region. UN-ESCO, Skopje 1974

[10] **Papadopoulos, G. A, Pavlides, S.B.**: The large 1956 earthquake in the South Aegean: Makroseismic field configuration, faulting, and neotectonics of Amorgos Island. Earth and Planetary Science Letters113. Elsevier 1992

[11] **Papazachos B.C. et al.**: Atlas of isoseismal maps for earthquakes in Greece. Publ. Geophys. Lab. Univ. Thessaloniki 4, 1982

As for the released tsunami, **Fig. 5** sums up the report of Ambraseys[12] and data of the National Geophysical Data Center[13] in a map of the southern Aegeis. The numbers show in red the height of the tide (flood, wave crest), in green the depth of the ebb (trough) of the tsunami. At most places the ebb was first; this is marked by a green "-". Otherwise a red "+" marks the flood coming in first. All values are given in meters.

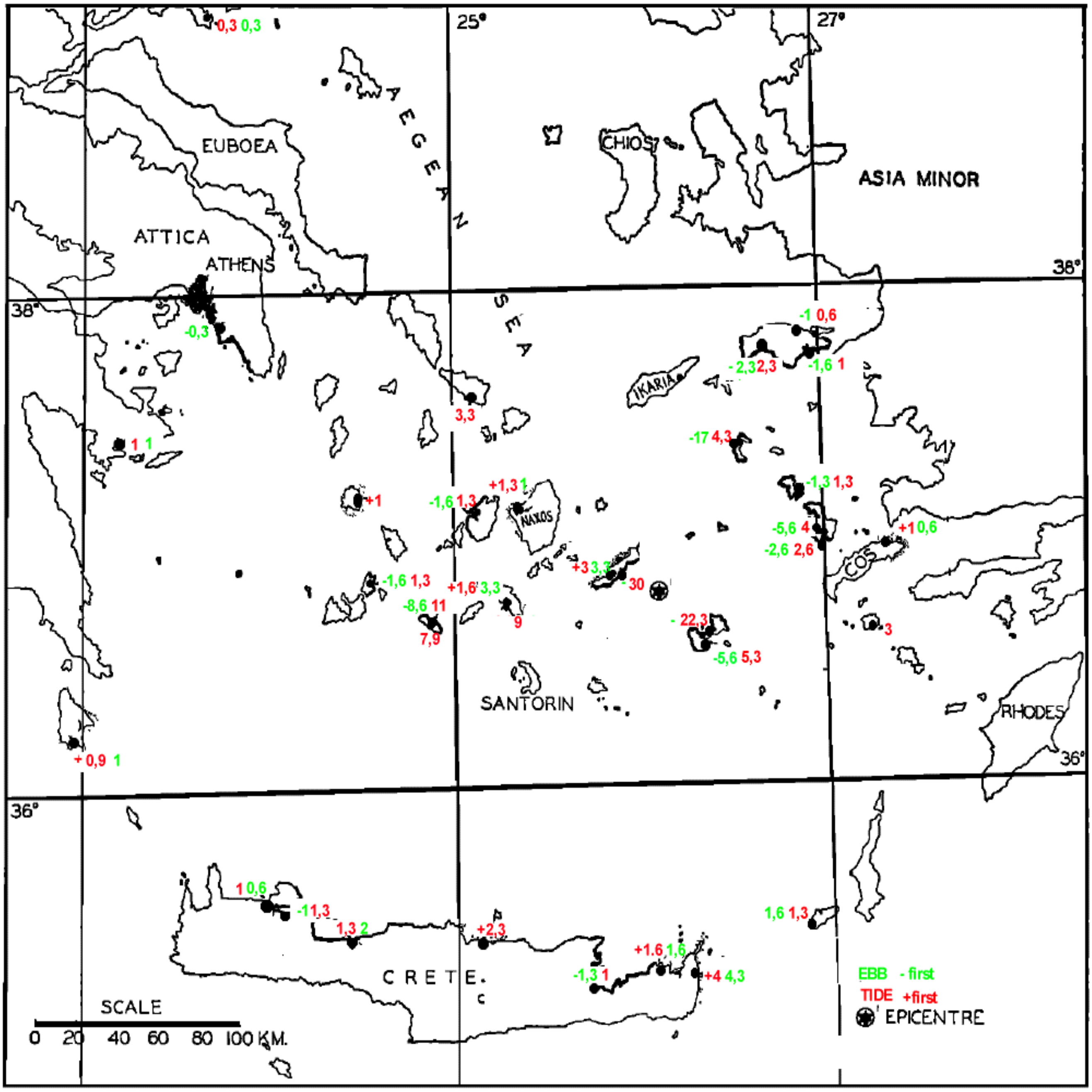

Fig. 5 : Altitude of ebb and tide of the 1959 tsunami at different locations

The most spectacular fact regarding the force of the Tsunami was that at 180 km (!) distance from the epicentre, it swept away the 300 m wide sandy beach **(Fig.6)** connecting the south end of Rhodos to the small island Prasonisos, down to 10 m below sea level[12]

[12] **Ambraseys, N.N.**: The Seismic Sea Wave of July 9, 1956, in the Greek Archipelago. JGR 65 No4, 1960
[13] http://www.ngdc.noaa.gov

Fig. 6 : South end of Rhodos (above) with beach connecting over to Prasonios island (lower left).[14]

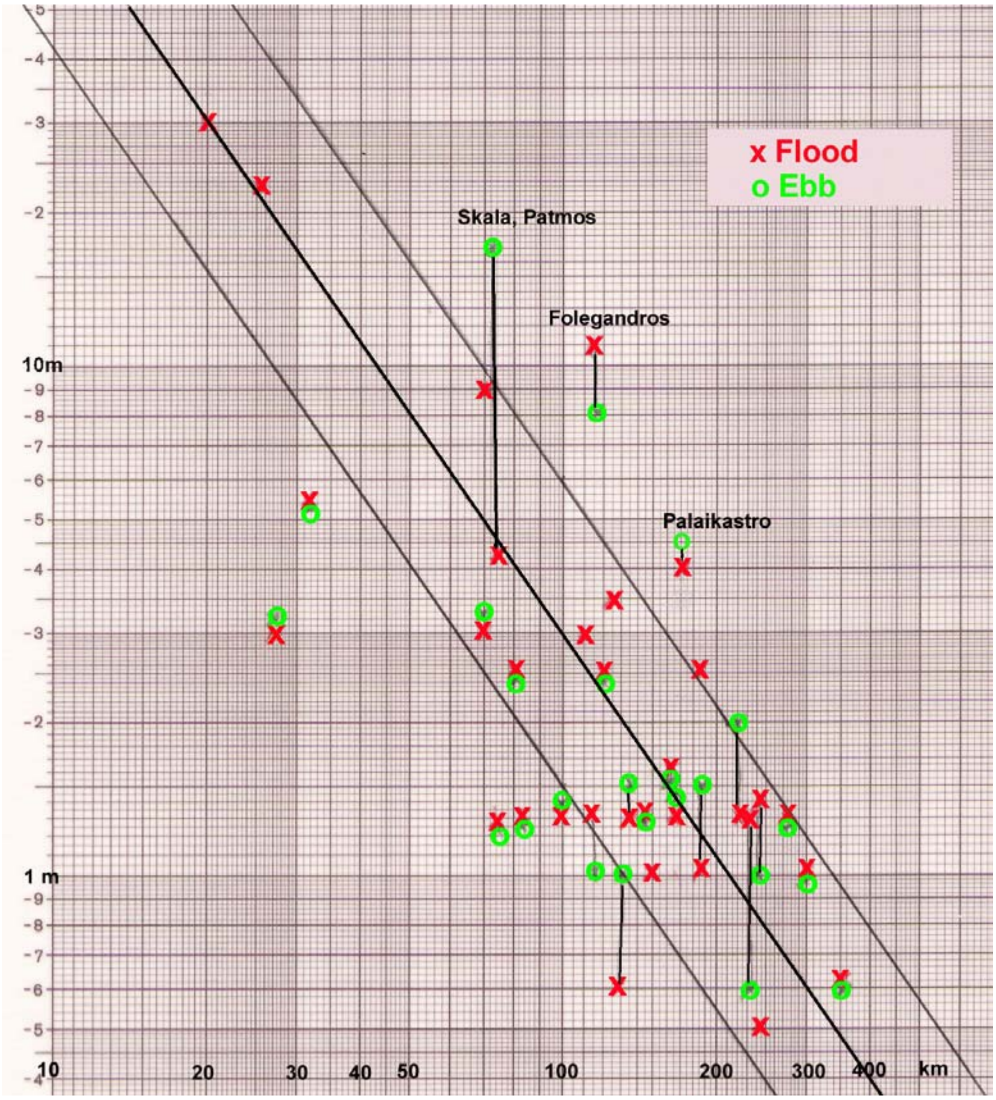

Fig.7 : Size of tsunami flood and ebb altitudes (of fig. 5) against distance from epicentre

[14] from Google Earth

In order to see the attenuation of the tsunami amplitude with distance **Fig. 7** shows this relation on a doubly logarithmic scale. This allows to derive the power of the attenuation from the median line of the values (black line). In the present case the power was –1,4306.

Anyhow, the scatter - mainly in the range of the factor ±2 (soft parallel lines) - is considerable. Whereas the values below the lines can easily be considered as taken from protected sites, the extremely deviating high values of Patmos, Folegandros and Paleikastro would deserve special consideration. In most cases ebb and flood are of the same height. Where they differ, the two values of one location have been connected by a black line. Impressive is the situation at Patmos, where an immense ebb was followed up by a conservative flood. **Tab. 1** collects data relevant to these three sites, which are the distance from the epicentre, the arrival time after the quake and the size of the tsunami as well as the size of the quake felt at the three locations.

Site	Distance	Arrival Time	Flood	Ebb	Richter	Mercalli
Patmos	72 km	24 min	4,3 m	- 17 m first	5,9	VII -
Folegandros	115 km	38 min	11 m	- 8,6 m first	5,4	VI
Palaikastro	170 km	56 min	4 m first	- 4,5 m	5	V - VI

Tab.1: Tsunami and earthquake data at three locations (1959)

5. Kykladic Frying Pans

These Objects - humorously named by their sight - are not too seldom found in Early Bronze excavations on the Aegean islands, but also on the mainlands on both sides of the sea, often in sepulchral settings. Their interpretation is difficult and ambiguous;

"" some of the more common theories include:

- plates
- cooking utensil (i.e. an actual frying pan)
- mirrors
- drums
- a specifically religious or ritualistic object
- libation vessel

although some of these theories are not widely accepted. The plate interpretation is fairly neutral, as a plate could be anything from a decorative object to a religious one. It is unlikely that they are actual cooking utensils, as there is no signs of food or fire, and as previously stated, they are usually found in burial contexts. That they were mirrors is a much more interesting interpretation: ceramics are quite obviously non-reflective, but it has been suggested that filled with water or oil, they could function as a mirror. The drum theory is fairly unlikely as one would expect a drum to have holes around the edges so that the hide could be stretched across it. Furthermore, with many of the handles found on these objects, it would be very hard for the drummer to hold the artifact in the style suggested. The weakness of the religious/ritualistic explanation is that it is the old standby of archaeologists to explain anything that is not obvious. However given that they are found in a burial context, even if they did have a mundane every day purpose, the ones we find most likely ***did*** have a deeper symbolic meaning. "" [15]

Fig. 8 : Rear side of a typical Kykladic Frying Pan from Syros.[16]

Fig. 2 shows a typical Kykladic Frying Pan from Syros with its cross section (left) and the design of the rear side. Papers regarding the Pans[17] usually concentrate on the different ship forms found in the rear decoration , the form of the legs or handles below, the vagina on many of the specimens, the border ornaments and whether the spiralling waves of the depicted sea are drawn or impressed by punches. The best and perhaps only comprehensive interpretation of the whole setting is found in Zietschmann (1935)[18], who writes: "You have to interpret these Pans…as idols. There are the legs and the vulva and the round is the body [of the goddess] !"[19]

The author wants to introduce another interpretation, which starts from replacing the word "body" in Zietschmann's remark by the more adequate word "womb". The goddess (say Gaia) bears in her womb a piece of the sea, depicted by waves, ships and fishes. Giving birth, she would generate a tsunami. This interpretation unambiguously puts the rear side – and with it the whole instrument – into the context "earthquakes and tsunamis" detailed above.

Frying Pans belong to Early Cycladic about 3000 – 2000 **BC,** which is 5000 – 4000 years ago. 5000 years is not a long time in geologic setting, so the seismic situation elucidated above can more or less also be assumed for the time of Early Bronze. Somewhere, there may have been some meters elevation or depression of the land in between, some fluctuations of

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[15] cited from Wikipedia (en)
[16] after **E. Alram**
[17] see **Coleman J E**: "Frying Pans" of the early bronce age Aegean. American Journal of Archaeology 89 (1985)
[18] **Zietschmann, W.** , Kykladenpfannen, Archäologischer Anzeiger 1935, pp. 652-668
[19] " Man muss diese Pfannen …als Idole deuten. Vorhanden sind die Beine und die Scham und die Rundung ist der Leib [der Göttin] !"

the sea-level, but no big (km-size) horizontal displacements. Especially, the situation of the Aegean Tectonic Plate with its general seismic performance was not altered. The Ice-Age was over and the present-day sea level was almost established (**see Fig. 2**), but there could still have been some residual strain in balancing the additional water column. So we might expect, that the early Aegean inhabitants experienced an earthquake and tsunami frequency somewhat elevated against the present day situation.

The "Kykladic" Frying Pans are not only found on the Cyclades. They have a much wider distribution over the Aegean islands and are even found on Crete and on both neighbouring mainlands[20]. Tsunamis are not present on firm land, earthquakes are. Indeed, the rear side decorations with the "sea-in-womb" are mainly found on the islands, with a concentration on Syros. The mainland Frying Pans - but also some specimens on the islands - show astral and general designs in their rear ornament, up to no ornament at all, also often no vagina (**Fig. 9**).

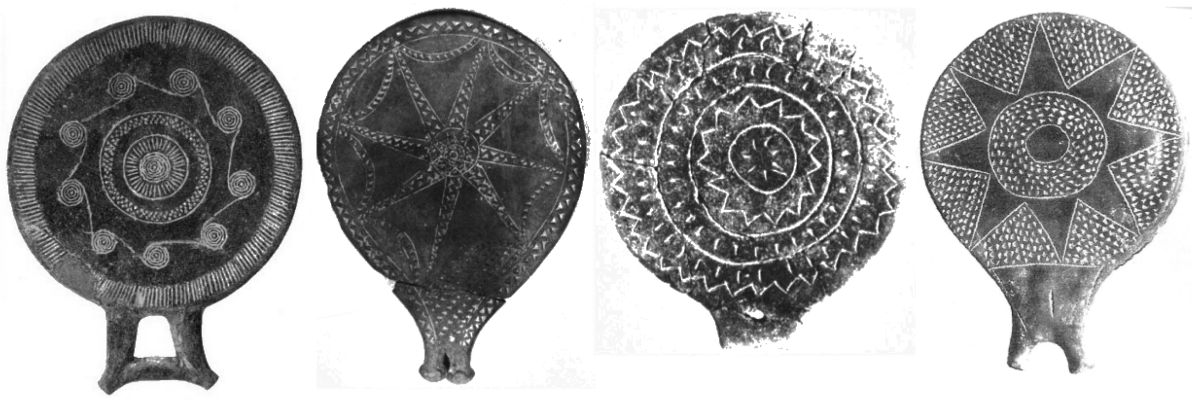

Fig. 9 :Rear side of Pans from Attica, early Syros (?), Crete and ?

The recent work of J. Rambach[21] has further shown a historic development of the pans' rear ornamentation. In fact, the "sea-in-womb" decoration is late and mainly belonging to Early Cycladic II B (2400-2200 BC), whereas the start of Frying Pans (ca. 3100 BC) is with astral and some sea-design but without a vagina and stumpy legs. If we want to stay in the scene, then we have to assume that the pans were first related to earthquakes only, and were then later - and especially on the islands - related to tsunamis.

Stronger earthquakes are a detrimental and fearful experience to people. They are sent by the Gods and the only thing one can do, is to reconcile the Gods. This is done by sacrifice[22] or libation. So turn over the Frying Pan, the rear side down, put it to the ground and fill it with - say - wine or olive oil. If an earthquake hits, the liquid will spill over, the Gods get an immediate - so to speak automatic - libation and after a while will stop shaking the Earth and make the quake less "dis-astrous".

Transferring this procedure to tsunamis requires an at least a basic idea of their correlation to earthquakes (2000 years before Thucydides ?!). An earthquake, where the gods' wrath was immediately mitigated by libation would not beget a tsunami ??. Maybe, but as the old people up to the Romans were always trying to foretell the future (= the will of the gods) from all phenomena, why not from the overspill (= libation) of the Pans?

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[20] **Coleman J E**: "Frying Pans" of the early bronce age Aegean. American Journal of Archaeology 89 (1985)

[21] **Rambach, J.:** Kykladen I, Grab und Siedlungsbefunde, Bonn 2000

dto.: Kykladen II, Frühbronzezeitliche Beigabensitten auf den Kykladen, Bonn 200

[22] **Sakellarakis G. u E.** : Archanes, Ekdotiki Athenon ISBN 9602132345

The author, supposing that the early Aegeans were not only pious but also able to learn, suspects a further coincidence: The waves of an earthquake spread by ca. 5 km/s, tsunami waves (at 200-300m sea depth) by only 0,05 km/s. So for each kilometer distance from the epicentre, a possible tsunami arrives about 20 seconds later than the quake; at 100 km distance 2000 seconds, or half an hour later. This is time gained to probably survive. Could the Pans within their about thousand years of application have given enough experience to the applicants, that they had adapted the function of an earthquake-meter and (on the Islands) a tsunami warning instrument?

In order to achieve this, the conditions to be fulfilled are:

- With distance from the epicenter, earthquake waves (energy) in general attenuate faster than tsunami waves (amplitude). The Pans' earthquake measuring sensitivity had to be sufficient to indicate earthquakes with epicentre distances apt to send dangerous tsunamis to the given location.

  Looking back to **Tab. 1,** a Mercalli V to VII shaking at about 100 km distance from the epicenter would indeed satisfy this requirement.

- The size of a tsunami is strongly effected and potentially increased by local coast forms. So the direction of the epicentre of the quake and of the possibly incoming tsunami might be decisive. Optimally, the characteristics of the Pans' overspill would give clues, e.g. on the size and direction of the quake, and would allow a more real appraisal of the danger.

  Such features could experimentally be analysed by an earthquake simulator.

Fig.10: Reproduced Kykladic Pan

For a small pre-experiment in that direction, the oscillation-modes of a filled “Kykladic Pan”[23] were examined. Libations using wine or olive-oil could be envisioned, therefore both liquids were tested. When filled with water (wine) the basic frequency of the liquid level in a Pan of the size of **Fig. 8** is about 1 Hertz, but there are also further (ca. harmonic) modes.. When filled with olive oil, the basic frequency is a bit smaller (ca. 0,8 Hz) and the swing is very much – almost aperiodic - damped, higher modes were not marked. These oscillation features – especially that of the oil filling – interestingly are not far from those of the old mechanical earthquakerecorders.

[23] The reproduction of a Pan of the Fig.8 dimensions has to be thanked to Prof. Dr. K.W. Wagner, Duisburg.

6. Conclusion

As cited above (p.8), there are different incoherent interpretations as for the use of the Kykladic Pans. The interpretation proposed here would in fact integrate the "specifically religious or ritualistic object" and the "libation vessel" together with a more mundane, publicly important and possibly life saving task. Whether this "Kykladic Instrument" was indeed capable to do more than the glas ball of a fortune-teller, requires further research.