Proc. of the Intl. Conf. on Advances In Management, Economics And Social Science– MES 2014.

ISBN: 978-1-63248-023-1 doi: 10.15224/ 978-1-63248-023-1-58

# Tsunami Waves in the Hellenic Area

## The Malian Gulf Situation

Deligeorgiou Georgios, Postgraduate Student and Stefou Theodoros, PhD Candidate
Harokopion University
Eleftheriou Venizelou 70, Kallithea, Athens, Greece

**Abstract - Marine Gravity Waves (tsunamis) are a secondary geodynamic phenomenon caused mainly after large undersea earthquakes and characterized by a series of huge, gigantic waves. However, this phenomenon may also be caused by a number of other causes such as a volcanic eruption, an undersea landslide, even a nuclear weapon testing explosion and extraterrestrial causes (meteorites or asteroids). Due to the low appearance frequency, the risk of a potential disaster a tsunami can cause is often underestimated.**

**The aim of this paper is the study of tsunami waves in Greece and particularly in Maliakos (or Malian) Gulf. The study of tsunamis allows a better understanding of their importance as natural phenomena and the effects that they can cause at the coastal zone. The results of the research show that the area has been hit by a forceful tsunami at least once in the past, according to historical data and analyses of samples from the area, and due to the seismicity of the entire Hellenic area, the appearance of a new catastrophic tsunami cannot be excluded in the future.**

***Key words: Maliakos (Malian) Gulf, Fthiotida, Seismic Sea Waves, Marine Gravity Waves***

## I. INTRODUCTION

On hearing of the word tsunami many people are terrorized considering it as an extreme, destructive phenomenon. Etymologically, the word tsunami (津 波) comes from the Japanese words tsu (津), which means harbor and nami, which means wave (波). This term was adopted in 1963 but did not respond at all at what a tsunami really is. Many scientists called the phenomenon as tidal waves, but this is also incorrect, because on the one hand it confines it on the sea surface and on the other it has nothing to do with the phenomenon of the tides [1].

So, tsunami waves are secondary geodynamic phenomena caused mainly after large undersea earthquakes and are characterized by a series of huge, gigantic waves. However, this phenomenon may be caused by a number of other causes as well, such as a volcanic eruption, an undersea landslide, even a nuclear explosion and extraterrestrial causes (meteorites or asteroids).

Nevertheless, each undersea earthquake does not create a tsunami. Necessary conditions for that to occur are the focal depth to be less than 50 km and the size of the earthquake's magnitude greater than 6.5 degrees on the Richter scale. Still, the creation of a tsunami depends on the nature and magnitude of the shift of the overlying water above the earthquake's focus [1].

The main feature of marine gravity waves is that they are not perceived in the open sea, where their height barely reaches one meter. Instead, as they approach the shore where the water's depth is reduced, their height becomes greater and can reach up to 40 meters. Also, their speed is high, depending on the depth of the water and can reach up to 1000 km/h. The energy of marine gravity waves is typically equal to the 1/10 of the energy of the earthquake that caused them. Scientists have proposed various scales for measuring and classifying tsunami magnitudes. The determination of the scales is usually based on measurements of the height of sea waves. There are also tensions scales based on the results of the waves (I, II, III, IV, V and VI) [2].

## II. DAMAGE CAUSED BY TIDAL WAVES

### A. *World Wide Insidents*

This phenomenon has been observed and recorded since ancient times. Specifically, the first historically documented tsunami struck the coast of Syria in 2000 BC. The highest ever marine gravity wave was recorded in Alaska in 1958 and was caused by landslides in a closed bay after an earthquake. The height of the waves on the upstream bank was estimated at 158 meters, while on the rest of the bay's coastline it exceeded 100 meters [3].

The most destructive tsunami occurred on December 26th, 2004 in Indonesia after a powerful earthquake measuring a magnitude of 9.3 degrees Richter, resulting in the death of about 250,000 people and creating incalculable damages. The most recent and remarkable was the one that struck northeastern Japan on 20th March 2011, after an earthquake measuring 9 degrees on the Richter scale in the Pacific Ocean, also causing unprecedented human casualties and damages, including a nuclear incident.

From the continuous study and observation of the phenomena it has been estimated that 90% of total worldwide marine gravity waves are generated in the Pacific Ocean, in the so-called "ring of fire", with an average of 2 events each year [1].

### B. *Insidents in Greece*

Greece is on the verge of convergence of the African and Eurasian lithospheric plates and therefore displays strong tectonic surges "Figure 1". From ancient times until today many devastating tsunamis after strong earthquakes have hit the islands and mainland of Greece "Table 1".

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The mythological flood of Deucalion was interpreted by many researchers as a tsunami that hit the shores of prehistoric Greece. The interesting in this theory is that the Bible describes Noah's flood happening at about the same time. Also at about the same time the great eruption of Thera (Santorini) took place, which by many was the cause of the destruction of the Minoan civilization.

TABLE I. MAJOR TSUNAMIS IN THE HELLENIC AREA [4]

| AREA | LARGEST IMPACT AREA | MAGNITUDE | DATE |
|---|---|---|---|
| North Aegean Trench | Potidea | III | 479 BC |
| Malian Gulf | Skarfia | V | 426 BC |
| Western Gulf of Corinth | Eliki | VI | 373 BC |
| Northern Crete | Voulismeni | VI | 8th November 447 |
| Malian Gulf | Malian Gulf | IV | 551 |
| Gulf of Corinth | Gulf of Corinth | V | June 1402 |
| Santorini | Santorini | V+ | 7th October 1850 |
| Amorgos | Amorgos | V | 9th July 56 |

The oldest historically verified tsunami in Greece was the one that destroyed the Persian fleet in Potidaia (Chalkidiki) in 479 BC. From then and on there are several recorded tsunamis on the Greek shores. Most important were on 365 AD at the southwest coast of Crete (earthquake's magnitude 8.3 Richter, which is the largest that has occurred in the Greek area) and on 1303 AD on the east coast of Rhodes, result of an earthquake of 8 Richter. However, the observed gravity sea waves in the Greek seas do not exhibit the hazardous properties of those in the Pacific Ocean [2].

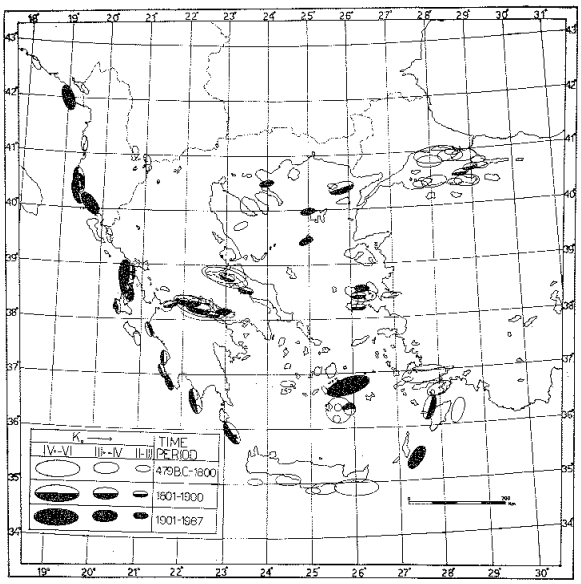


Figure 1. Possible Areas in Greece that can give Tsunamis ([2], pp 117)

According to statistical analysis a marine gravity wave size III appears every seven years in Greece, a size IV every 40 years, a size V every 200 years, and a size VI every 1200 years [2]. The most affected areas are the Dodecanese, the Cyclades, Chios, the Corinthian Gulf, the western coast of the country and Maliakos Gulf.

## III. THE AREA OF MALIAKOS (MALIAN) GULF

Maliakos is a Gulf in the Aegean region of Fthiotida, in the eastern Central Greece. It was named after the ancient tribe of Malians who lived on its shores. The city of Lamia is 8.5 km in a straight line from the proximal point of the Gulf's coast. It stretches east to west at 15 to 22 kilometers, depending on the establishment of its outer limits. The accurate definition places the limits at the capes of Chiliomili (southeast) and Karavofanara (northeast). In this case its aperture is 2,8 km and infiltration 15 km.

There are several bays created inside the gulf, such as Agia Triada (south coast) and Stylida. The only river that flows into the gulf is Sperheios and due to the continued accumulation of its deposits for tens of thousands of years the bay has shrunk over the centuries and is very shallow, with a maximum depth of 27 m. Thus, the ancient narrow passage of Thermopylae, that at the time of the famous battle was defined by mount Kallidromos and the Malian gulf, has now become a broad coastal plain (Figure 2).

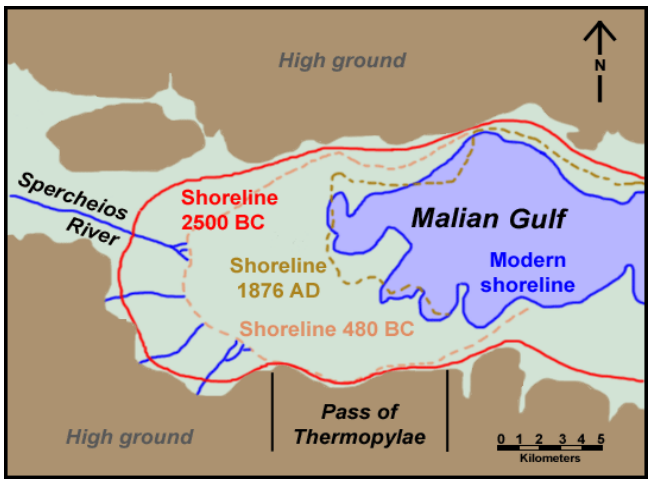


Figure 2. Shoreline shift from antiquity to today ([9], pp96)

The only port in the area is that of Stylida, which serves the city of Lamia. To the east of the bay is the northernmost point of the island of Euboea, cape Lihada. Agia Triada is the only coastal settlement on the south coast of Maliakos, if we consider the Chiliomili as the limit of the gulf. On the north coast we have, from west to east, Agia Marina, Stilida, Melissia, Petarades and the Panorama.

## IV. THE EARTHQUAKE AND TSUNAMI OF 426 BC

During the autumn of the fifth year of the Peloponnesian War (427 BC) and the next summer, there were too many earthquakes in Attica, Boeotia and Euboea. Orchomenos (Boeotia) according to Thucydides was the area that was hit

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especially hard. The frequency of earthquakes in the autumn of 427 BC is well documented by historians for a specific reason: earthquakes discouraged Spartans to invade Attica because of their superstition. Indeed, the Spartan king Agis had reached the Isthmus of Corinth in the summer of 426 BC, in preparation of his army's invasion. But the repeating seismic activity, which continued during the following autumn, was then considered a bad omen. As a result, the operation was abandoned [5].

Thucydides describes in detail the seismic events of 427-426 BC and according to his testimony, no great destruction in mainland Greece was ever recorded until that time. He also states that such an event had never happened during his life [5]. We can conclude that the seismic activity of those two years from 427 to 426 BC, was frequent, but not strenuous. This view is supported by the fact that the earthquake of 426 BC was not strong enough to ultimately prevent the Spartans, who as mentioned before were superstitious, to expand military operations in Heraclea, the area near the focal point.

It seems that apart from earthquakes near Orchomenus, a number of independent vibrations occurred in the sea area between Euboea and the mainland during the spring and summer of 426 BC. Those earthquakes altered the alluvial shores of Evia and the coast of the Maliakos Gulf. These facts show earthquakes of a quite significant magnitude. According to Strabo [6], much of the islands Lihades (Lichadonisia) and Cape Kynaio in northwestern Euboea had precipitated "Figure 3". A strip of land that once formed a peninsula was then forming a new island, Atalanti (Talantonisi) [7]. In Evia, the soil in the area of Rovies declined and the coastline proceeded to the inland after the quake. As a result of the earthquake, the hot springs of Thermopylae and Aedipsos ceased to flow for three days. Then the normal flow began again, but the sources of Aedipsos reappeared in a different location. In general, springs and rivers ran dry for several days and River Sperheios changed its bed [8].

On the mainland, the cities of Echinos and Heraclea were severely damaged and the cities Falara (Stylida), Lamia and Larissa were completely destroyed. In Skarfia, 2500 people lost their lives when the city was destroyed, with some areas sinking into the ground. Cities Alopis, Kynos and Opous were also severely damaged. In Elatia , the city wall collapsed.

In Evia, the sea walls collapsed along with seven hundred houses, while the settlement Rovies was destroyed. There were similar losses in Atalanti and the town of Skopelos, where the earthquake also demolished a part of the walls, the town hall, and a few houses. As a result of the quake, the sea in Rovies retrieved from the shoreline and later, "returned huffy and engulfed part of the settlement, inundating several times. Although the sea finally retreated, part of the coast remained permanently submerged" [5]. The waves, according to Strabo, flooded the coast three times [6].

The valleys near Skarfia, Thronio and Thermopylae were flooded and many villages were destroyed [5]. In Atalanti there was a similar flood. The waves there dragged triremes and washed them up onto the shore. The sea receded in Skopelos too, but there was no submersion. There were many changes in the coastline on the northeastern coast of Euboea: after the earthquake, it was found that in Kynaio, Rovies and in Lihades the sea marched to the inland and the coast retreated, so that "many places were now at sea while before they were ashore" [5].

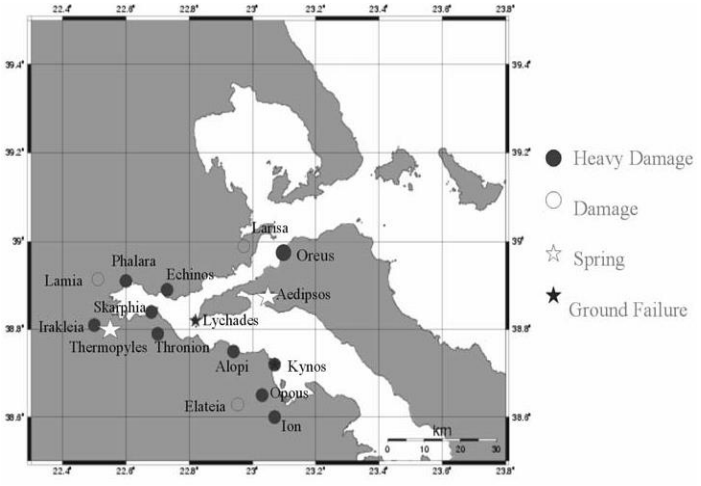


Figure 3. Damaged Area According to Strabo [10]

The configuration of the coast, the river flows and the characteristics of the neighboring valleys were then completely changed, fact that makes extremely difficult to assess the topography of the area in 426 BC. The area of Maliakos Gulf seems to have changed significantly. Inside the gulf three or four miles (4,8 - 6,5 km) of new land have been created and shaped by the gradual accumulation of deposits of the river, so that the bay is much smaller and many cities are no longer near the sea. The river Sperheios has changed significantly its course and has been joined by other rivers which at the time of the earthquake emptied at the sea separately, but now have become its tributaries [8].

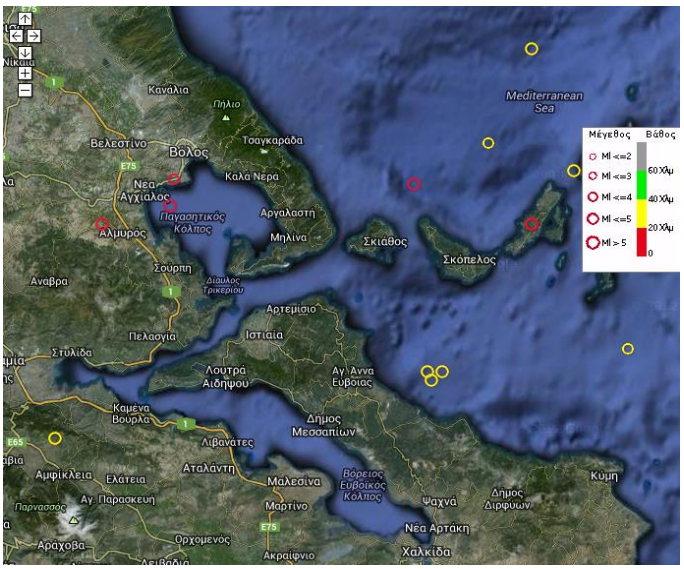


Figure 4. Map of seismic activity within 150 km East from the city of Lamia, showing events greater than 5 degrees in Richter scale and focal depth less than 60 km, occurring from 1/6/1964 until today.([11], elaborated)

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The tsunami of 426 BC seems to be a strictly local phenomenon, manifested in Maliakos and Evian gulf and not extended beyond Skopelos and the east coast of Evia. From the available data, the cause of the tsunami appeared to be the movement of a piece of the earth's crust along a fault in the epicenter of the Evian Gulf, and not a series of underwater landslides. As a result of this movement, part of the Evian coast declined permanently, with a consequent promotion of shoreline to the inside. Unlike the mainland coast and more especially Maliakos gulf, where any permanent land subsidence could easily be attributed to the deposition of silt from the river, the coast of Evia is and to a greater extent was less alluvial. Thus, any permanent settling of rocky coast on Lihades and Kynaio, to an extent that has been observed and reported in ancient texts, must be linked to earthquakes.

Apart from the above there is another historically documented tsunami on 551 AD for which there is no data on casualties or damages.

## V. WHAT IS HAPPENING TODAY

Today no one can claim that the area of the Maliakos Gulf is fortified against a possible tsunami. There are several villages near the sea, which have a large population, especially during the summer months “Figure 5”. Two of the main occupations of population near the coastal areas allover Greece is fishing and tourism. From south to north we find the following seaside or near the shore municipalities and settlements: Asproneri , Kamena Vourla , Kainourgio, Agia Ekaterini, Neo Thronio, Agios Seraphim, Skarfia, Molos, Agia Triada, Thermopylae, Anthili, Panorama, Karavomilos, Achinos, Skamada, Platanias, Paradise, Couvelas, Drepano, Ftilia, Raches , Fournoi, Achladi. Not all of them are located within the Gulf, but they certainly are in a tsunami influence zone. Large facilities in the area are the satellite ground observatory station, the port of Stylida, which is defenseless in such a disaster, and of course, the city of Lamia, which requires a fairly significant wave height to receive a major blow.


Figure 5. The Area of Malian Gulf

Houses and public utility projects that have been built according to the new Hellenic Seismic Code 2000, will probably survive a marine gravity wave of a magnitude up to V, with the proviso that the surrounding soil will last too. However, older constructions particularly in the regions mentioned above may exhibit extended damages.

Along the coast of the Malian Gulf runs the New National Road from Athens to Thessaloniki, which in the lowlands of Fthiotida is an important measure of protection, since it is on embankment height of three meters approximately. However, there are many bridges for transportation and communication so it is not an impervious barrier. On the one hand it can decrease the momentum of a tsunami, but it cannot completely halt its progress.

## VI. CONCLUSION

Marine gravity waves can affect any coastal area. It is a phenomenon that follows immediately or within a few minutes or hours, undersea earthquakes or submarine landslides. Because of the low frequency of the phenomenon, the extend of the disaster that may be caused is often underestimated.

Through continuous study cases both globally and locally from various geoscientists, it is possible to determine accurately the hazard and vulnerability of each area which was affected or may be affected by a tsunami of any size.

Unfortunately, for the region of the Maliakos Gulf there are few and insufficient studies and surveys for the past tsunamis, nor are predictions and models for the effects of tidal waves on the area and how to enable the local community to protect itself in the possibility of such a disaster.

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