Impact of geological processes and hazards on the Aegean civilisations in prehistorical and ancient time

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The Aegean region is known to be a site where geological and geodynamic processes are very active and evolve rapidly. It is also known that the time scale of most geological processes exceeds by ten to thousand and even million times man's life time. Nevertheless, the Aegean region is a place of continuous habitation during the last 35,000 yr, since the Paleolithic times, or even earlier.

Archaeological evidence and findings, ancient scripts from historical times and even myths of the Greek Mythology, provide, directly or indirectly, valuable information on the evolution of some of the geo-processes, as well as on the occurrence of catastrophic events and phenomena in the Antiquity and their impact on ancient civilizations. It is very common for geologists, working in the area, to relay upon ancient sources to verify or compare geological and geo-morphological data.

Thus, important maritime cities of the Antiquity were abandoned due to the seaward growing of the land in delta progradation areas or because of tectonically driven subsidence/uplift of the coastline. Others were totally or several times partially destroyed by earthquakes or tsunamis. Even the impact of the Holocene sea level rise may have been preserved as oral tradition between the successive prehistoric human generations and transformed into a myth in historical times.

The aim of this paper is to highlight and geologically explain some of the most typical cases of geo-processes, which affected in some way the development of ancient civilizations and to express the usefulness of the archaeological sources in the study of the Holocene Geology and vice versa. All localities mentioned in the text are shown in Fig. 1.

THE HOLOCENE SEA LEVEL RISE IN THE GREEK MYTHOLOGY

Two myths of the Greek Mythology may be related to the Holocene sea level rise. The first one is the Defkalion's flood, which may well be considered as a myth closely related to the Noah's flood, described in the Bible (see Lericollais *et al.* this volume). The second one is the Argonaut's expedition of Iason in the Black Sea and the pass through the Bosphorus strait.

Defkalion's flood: flooding of isolated basins, i.e. Gulf of Corinth

According to the myth of Defkalion's flood, Zeus was very angry because of the impiety and violent behavior of the people and decided to extinguish them by causing an enormous flood. Prometheus warned Defkalion and his wife Pyrra on the coming flood, and they constructed an Ark. During nine days and nine nights it was continuously raining, and the greatest part of the

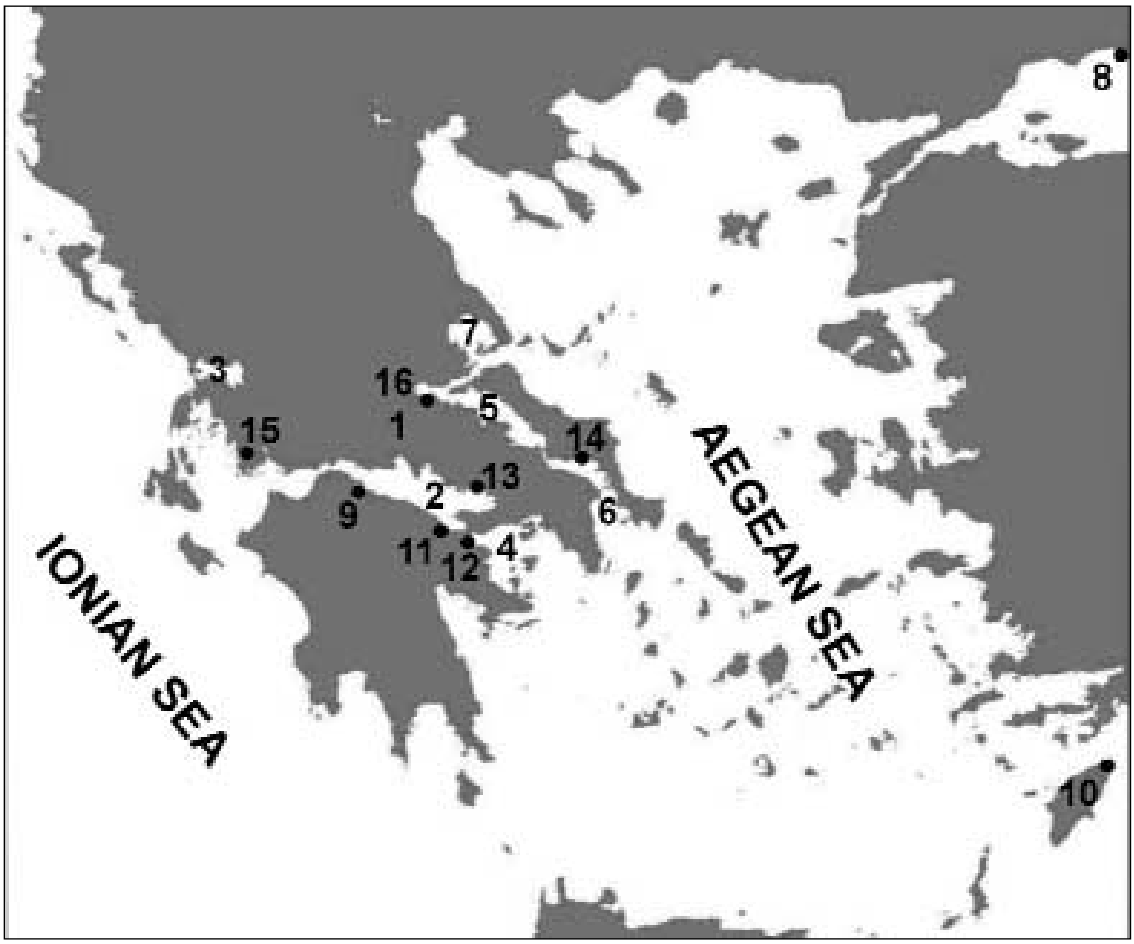

Fig. 1. Location map of the sites mentioned in the text. 1: Parnass Mt., 2: Gulf of Corinth, 3: Amvrakikos Gulf, 4: Saronic Gulf, 5: N. Evia Gulf, 6:S. Evia Gulf, 7: Pagasitikos Gulf, 8: Simpligadhes Petres / Bosphorus Strait, 9: Helike, 10: Rhodes island, 11: Lechaion, 12: Kechries, 13: Tifa, 14: Eretria, 15: Oiniadhes, 16: Thermopylae.

Hellenic region was flooded. Very few people survived the flood. Defkalion's Ark ("vessel") "docked" on the top of Parnass Mountain in Central Greece after the regression of the water. When did that happened?

It is known that the global Holocene rise of the sea level by 110-120 m started about 18,000 yr BP and proceeded at rates of 5-9 mm/yr. Higher rates of the sea level rise (25-37 mm/yr) may have occurred only during two short periods around 14,5 kyr and 11 kyr respectively (Bard *et al.* 1990). Nevertheless the above rates seem to be relatively slow in respect to the human lifetime. The available chronological data are very sporadic and do not allow a relatively precise definition of intermediate sea-level positions between the latest low-stand and the present high-stand in the Aegean region.

New data were obtained recently from the Gulf of Corinth where long piston coring in the basin of the Gulf of Corinth succeeded in penetrating the lacustrine sediments below the marine Holocene deposits at about 13-14 mbsf. AMS dating yielded ages of about 13,2 kyr BP for the establishment of marine conditions in the Gulf of Corinth (Lykousis *et al.*, in press). This age represents roughly the time that the Ionian Sea overflowed the Rion-Antirrion strait (62 m present day depth) and flew into the Gulf of Corinth lake.

High-resolution seismic data from the northern margin of the Gulf revealed the presence of continuously subsiding prodelta prograding sequences. The subsidence rate was estimated to 1 mm/yr. The topset-foreset transition of the last glacial prodelta deposits lies at about 105 m below the present sea-level (Fig. 2). Considering the subsidence rate and the relative position of the topeset-foreset transition in respect to the water level we may conclude that: i) the water level

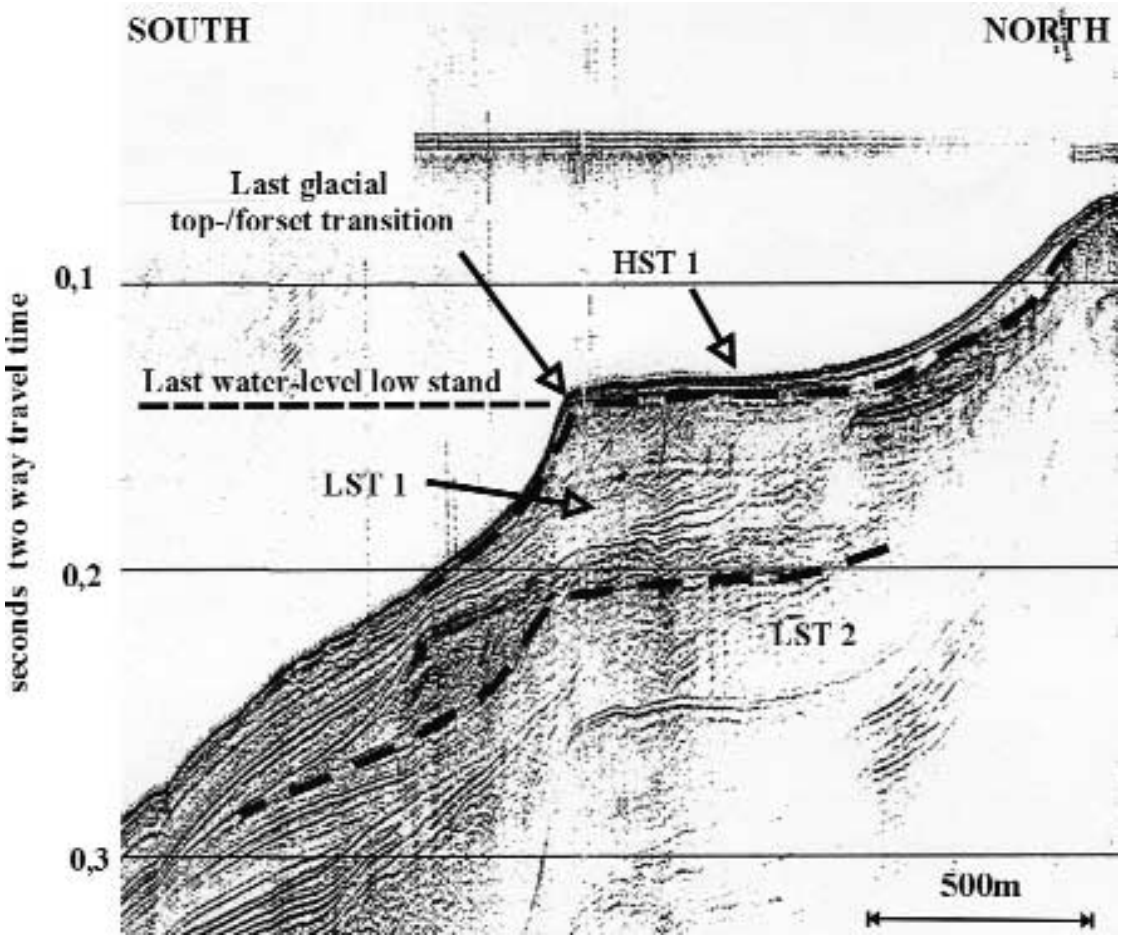

Fig. 2. Air gun single channel profile, Gulf of Corinth northern margin. The topset-foreset transition of the prodelta deposits (LST 1) of the last glacial maximum indicates the position of the water level in the Gulf at least 85 m below present sea level. HST 1: Holocene high system tracks; LST1: Last glacial low-stand system tracks. Oiniadhes, 16: Thermopylae.

in the Gulf of Corinth during the last glacial maximum was at least 85 m below the present sea level and ii) the Gulf of Corinth was a lake isolated from the open sea, with a lake level some 20-25m below the Rio-Antirio strait.

Single channel profiling in the area to the east of Rio-Antirio strait showed the existence of an erosional channel on the sea floor of the western Gulf of Corinth (Fig. 3). We interpret this channel as the result of the inflowing sea-water when entering into the former Corinth lake from the west. If this assumption is true, then the rise of the water level in the former Corinth lake from -85 to -60 m must have been very rapid and very impressive for the Paleolithic habitants of the surrounding lowlands. After that, and leaving out of consideration the local tectonic vertical movements, the rise of the water level should have slowed down, following the global sea level rise.

The same phenomenon must have taken place in all Gulfs, which are connected with the open sea (Aegean or Ionian) through shallow straits, like Amvrakikos Gulf, Western Saronic Gulf, Northern and Southern Evia Gulf, Pagasitikos Gulf, etc. The timing of the very rapid water level rise in each Gulf / former lake depends on the depth of each strait. It is thus quite possible, that the myth of Defkalion's flood roots on the initially very rapid rise of the water level of former, last glacial lakes which became marine Gulfs.

Argonaut expedition

One of the adventures that the crew of Argo had to overcome during the Argonaut expedition from Iolkos, in the Pagasitikos Gulf, to Colchis, in the Black Sea, was the pass through the Simpligadhes Petres. The Simpligadhes Petres used to be two huge rocky cliffs, located just

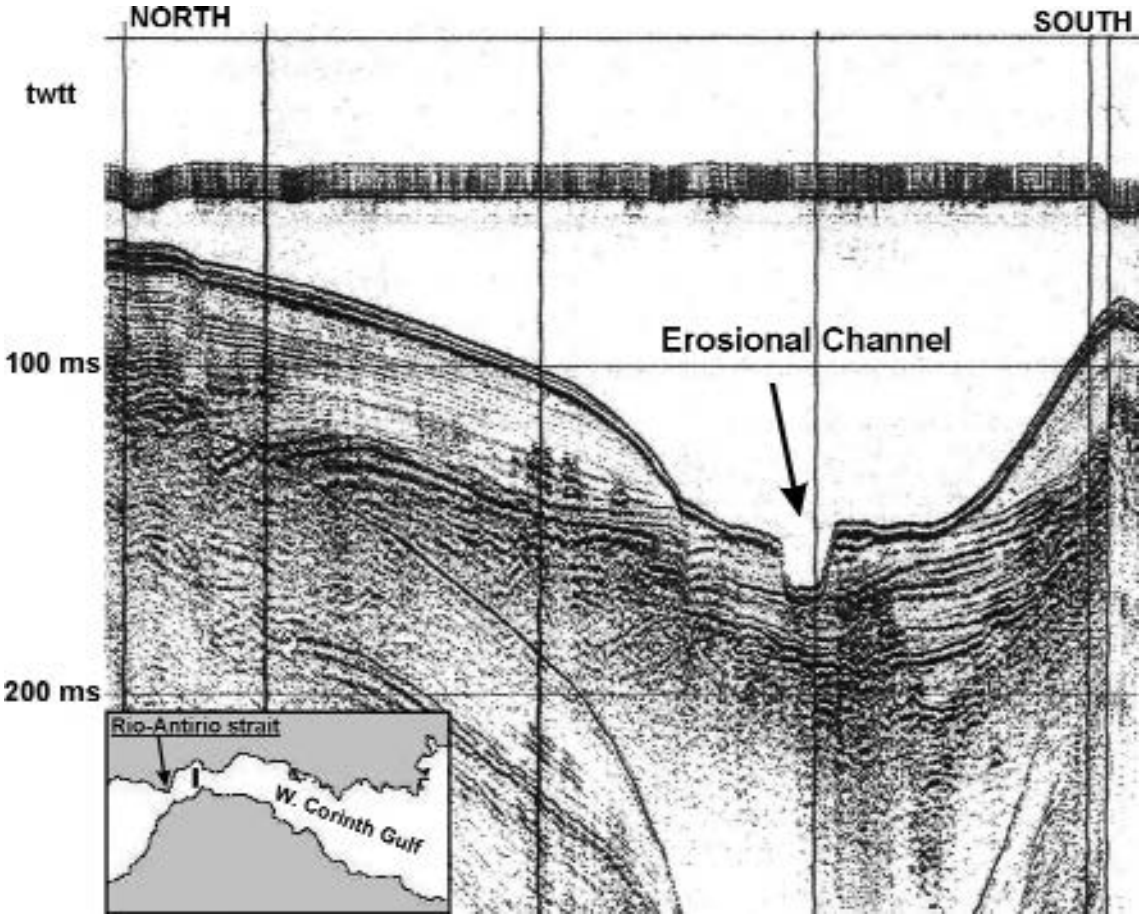

Fig. 3. Air gun single channel profile across the Gulf of Corinth showing the presence of the erosional channel east of Rio-Antirio strait.

before the entrance in the Black Sea. According to the myth, they were successively closing and opening. The soothsayer Phineas advised Iason to let a pigeon fly first through the rocks and if it would succeed, then they would succeed too. So it happened and Argo passed through the Simpligadhes Petres with minor damages at her stern. After that the Simpligadhes Petres remained open forever.

The retrogressive movement of the closing cliffs may refer to the relative rise of the water level in the Aegean Sea, the Sea of Marmara and the Black Sea, and the timing of overflowing the Bosphorus Strait, which is still debated (see Lericollais *et al.*, this volume).

EARTHQUAKE DISASTERS IN ANTIQUITY

Egeladhos was one of the Giants who took part in the fight against the Olympian Gods. Athena, who raised up from the head of Zeus, defeated him, let him fall down and then she threw the island of Sicily island upon him. Any time Egeladhos is moving, the earth is shaking and an earthquake happens. This is the way earthquakes are being explained in Greek Mythology. Earthquakes seriously affected most of the known civilization centers of the Greek Antiquity.

The devastation of ancient Helike (373 B.C.)

The soundest case is the devastation and sudden subsidence of Ancient Helike, the metropolis of the Ionic and Achaic Dodekapolis. It was located in the alluvial plain of Aigialia by the southern coast of the Gulf of Corinth. According to Pausanias and Strabo the ancient city was 7,2 km to the east of Aigion and 2,2 km from the coast, between the rivers Selinous and Kerynitis. A very strong earthquake completely destroyed the city in 373 B.C. The earthquake was followed by a tsunami, which drowned the ruins. The entire city and the surrounding lowland submerged

suddenly. Only the tops of the trees remained above the seawater level after the earthquake. The ruins of the city were visible on the seabed for many years after the earthquake and certainly until the second century AD, when Pausanias visited the area. Archaeological excavations, carried out on land during the past decades, have failed up to date to discover the ruins of the Ancient Helike.

Papazachos and Papazachos (1989) estimate magnitude Ms:7.0 for the earthquake of 373 BC, which devastated the ancient city. Such a strong earthquake may have caused extended liquefaction and subsequently subsidence of the alluvial plain. The strong seismic motion may have been triggered coastal sliding and failure as well as submarine landslides and the tsunami, which drowned the city. Fig. 4 shows the structure of the Gulf of Corinth basin off the delta plain of Aigialia, where the ancient city of Helike used to be. Extensive submarine sliding along the faulted slope of the basin is quite obvious.

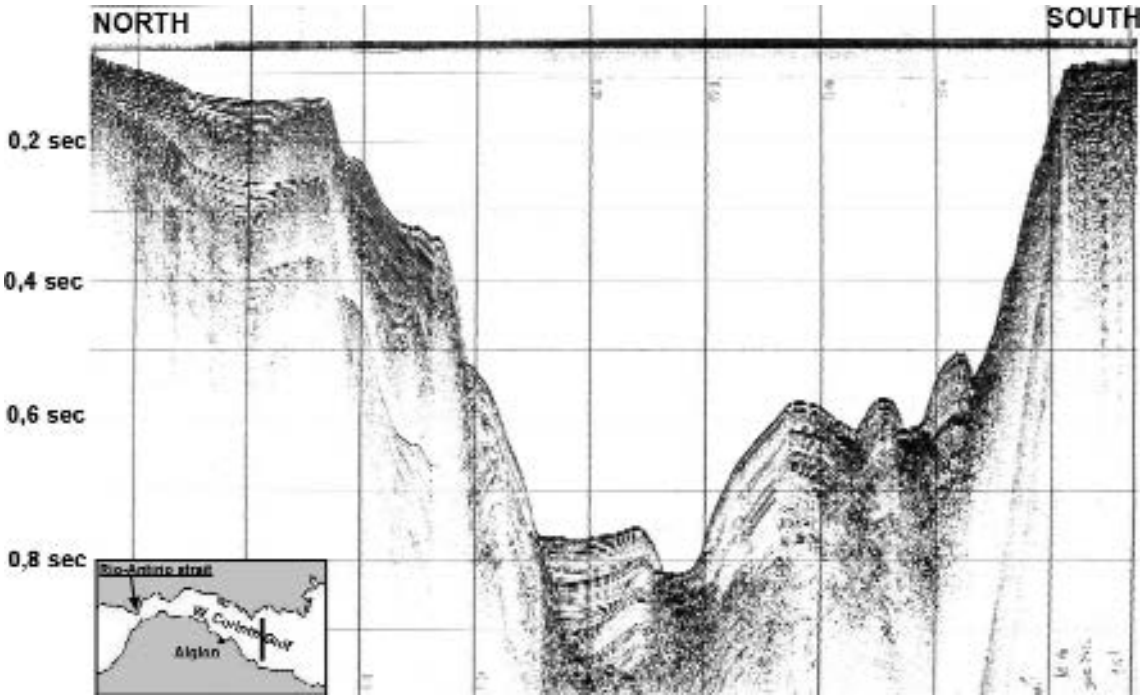

Fig. 4. Air gun single channel profile across the Gulf of Corinth showing extensive slumping off the assumed ancient Helike site.

Similar phenomena have occurred repeatedly since then in this area. Recently, the Ms: 6,5 Aigion earthquake in 1995 caused coastal sliding along several kilometers of the coastline and was followed six months later by a 2 m high tsunami. A 5 m high tsunami, the highest ever observed, hit the area after the 1817 earthquake (Papazachos and Papazachos, 1989). In 1873, December 26th, a Ms: 6.7 earthquake caused extensive liquefaction, while a 100-200 m wide coastal land stripe collapsed seaward, between Aigion and Diakofto. Schmidt (1875) reports that the vertical throw produced on the Helike fault was about 1 m. It is quite possible that Helike fault moved also during the 373 BC earthquake, although this is not proven yet.

Nevertheless, all known earthquakes recorded in the area since then caused phenomena, which are much weaker than the ones produced by the 373 B.C. earthquake. If the descriptions of Pausanias are precise, then the sudden submergence of Ancient Helike, which prior to the earthquake was 2.2 km away from the coastline, below the sea level, requires quite impressive subsidence of the alluvial plain, liquefaction and coastal failure (Lykousis *et al.*, 1997). Detailed geological mapping, high-resolution geophysical inspection and verification by drilling and radio-chronology, both on land and offshore, are needed to investigate the region. Since the ruins of the ancient city are still missing, the geological-geophysical survey will contribute significantly to the tectono-sedimentary and geomorphologic evolution of the alluvial-deltaic plain of Aigialia and to the search for Ancient Helike.

The demolition of the Colossus of Rhodes (227 B.C.)

The island of Rhodes has suffered strong earthquakes in recent times as well as in Antiquity. The 30 m high statue of the Sun, the famous Colossus of Rhodes, one of the seven wonders of Antiquity, was destroyed by an earthquake in 227 B.C. Pirazzoli *et al.* (1989) suggest that the earthquake, which destroyed Colossus, was also responsible for the sudden uplift of the coastline by 3.8 m.

VERTICAL TECTONICS

Vertical tectonics has affected most of the known coastal centers of the ancient world. Flemming *et al.* (1971) list over seventy coastal archaeological sites around the Peloponese and along the Turkish Aegean coastline which are vertically displaced by +3 m to –5 m relative to the present sea level. All along the coastline of the Aegean and Ionian Seas as well as in the Gulfs and on the islands one can find submerged or uplifted ruins of historic or prehistoric settlements. These vertical changes are local phenomena and cannot be simply interpreted with global sea level rise. Local tectonics and fault movements have to be carefully investigated site by site, to explain the vertical movements of the land relative to the sea level. A detailed listing of the known ancient coastal installations, initially located at the sea level, and indication of their present position relatively to the sea level would be a very important first step towards this direction, providing valuable information on the local vertical tectonics of the Aegean region.

A few examples are listed below to highlight the effect of vertical tectonics on the evolution of the ancient civilization centers.

Ancient Corinth: Lechaion vs. Kechries harbors

Ancient Corinth is reported to maintain two harbors on both sides of Isthmus. Lechaion was the one in the Gulf of Corinth, while Kechries was the harbor in the Saronic Gulf. The harbor installations of Lechaion were established in the 6th century B.C. and the port became very important during the 4th century B.C. at a time when Kechries used to be very important for the communication of the Corinthians to the east. The destiny of both ancient harbors was somehow different. Lechaion harborhas been silted up by sand and silt and is uplifted by several tens of centimeters. On the contrary the harbor installations of Kechries are now located about 1 m below sea level, obviously due to vertical tectonics.

Ancient Tifa

The northern margin of the Gulf of Corinth has undergone continuous subsidence during the last 250 kyr (Lykousis *et al.*, in press). The ancient city Tifa is located in the Gulf of Domvrena, a narrow gulf at the northern margin of Alkyonides Gulf, and is mentioned in the Argonaut Expedition. Tifys, who was coming from the city, was chosen to be the captain of Argo. The present location of the ruins of buildings and harbor installations below the sea level verifies the geologically observed subsidence of the area.

Ancient Eretria

Similarly to Ancient Tifa, a large part of the ancient city of Eretria, at the eastern coast of the Southern Evia Gulf now lies below the sea level. Kabouroglou (1989) suggests that ‘the sea level around Eretria has risen by at least 2 m since the 8th century BC’.

ANCIENT HARBORS AND DELTA PROGRADATION

Alluvial plains developed at the river deltas are common places for human settlements throughout history. At the same time, deltaic plains are sites of rapid seaward progradation of the land. Many important maritime cities of the Antiquity, settled initially on the coastline, were after some time abandoned, because of the rapid accumulation of the delta deposits.

Ancient Oiniades

The ancient city of Oiniadhes was settled before the 5th century B.C. on a hill in the Aheloos delta plain. Oiniadhes became a significant port of western Greece and took part in the Peloponesian War in the 5th century B.C. Impressive ancient shipyard installations at the foot of the hill indicate that the city was an important maritime center in the Ionian Sea. The city was

abandoned in the 1st century B.C. or slightly later. The present location of the ancient shipyard is within the delta plain of Aheloos river, about 5 km away from the sea.

An excellent description of the Ahellos delta plain as well as reconstruction of the delta progradation is provided by Vött *et al.* (this volume), based on drilling, paleo-environmental analyses and radio-chronology.

The Battle of Thermopylae (480 B.C.)

The Battle of Thermopylae in 480 B.C. is an example of exceptional bravery and self-sacrifice of Leonidas and his 300 soldiers from Sparta together with 700 soldiers from Thespies, who fought against 2 million soldiers of the Persian army under the leadership of Xerxis. In 480 B.C. Thermopylae used to be a narrow land stripe between the steep mountain slopes and the sea. The width of this land stripe was about 800 m and thus, it could be blocked by the 1000 Hellenic soldiers. In the 2,500 years following the Battle of Thermopylae, the narrow land stripe grew rapidly and is today 5 km wide. The area of Thermopylae is located on the southern shore of Maliakos Gulf, in the delta system of Sperchios river.

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