ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
Εθνικόν και Καποδιστριακόν Πανεπιστήμιον Αθηνών
ΙΔΡΥΘΕΝ ΤΟ 1837

Interinstitutional Postgraduate Programme
"Oceanography and Management
of the Marine Environment"

Visualizing the Corinth Gulf: A Comprehensive Narration of Marine and Coastal Interactions

Effrosyni Zafeirakopoulou

Athens, 2024

ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
Εθνικόν και Καποδιστριακόν Πανεπιστήμιον Αθηνών
ΙΔΡΥΘΕΝ ΤΟ 1837

Interinstitutional Postgraduate Programme
"Oceanography and Management
of the Marine Environment"

Visualizing the Corinth Gulf: A Comprehensive Narration of Marine and Coastal Interactions

Effrosyni Zafeirakopoulou

Examining Committee:

Paraskevi Nomikou, Professor NKUA (Supervisor)

Serafeim Poulos, Professor NKUA

Varvara Antoniou, Laboratory Teaching Staff NKUA

Athens, 2024

Abstract

Corinth Gulf (Greece) is a small, long, semi-enclosed and significantly deep gulf, formed between Central Greece and Peloponnese. It's one of Europe's most active seismic areas, characterized by an intense topographic relief with steep slopes and many submarine canyons. Being a part of Natura 2000 site areas, Corinth Gulf foster an unusually high biodiversity and productivity of marine habitats due to its high depths in combination with the particular geomorphological, oceanographical and environmental conditions. In an effort to combine the aforementioned features with the coastal anthropogenic environment and provide a clearer understanding of how the tectonic dynamics of the Corinth Gulf interact with marine processes, biodiversity, and human activities, a Story Map was created. Story map is an interactive tool used for science and spatial data communication, information and dissemination. A web-based application using story mapping technology is presented here to highlight places of interest around Corinth Gulf. A tailored story map that combines thematic webmaps and scenes (3D webmaps) generated through a Geographic Information System (GIS) having a great impact on web-based visual presentations with narrative text and multimedia content was created to highlight the Marine and Coastal Interactions Corinth Gulf.

Keywords: *GIS Story Map, Corinth Gulf, Seafloor geomorphology, Geohazards, Natura 2000*

Περίληψη

Ο Κορινθιακός (Ελλάδα) είναι ένας μικρός, μακρύς, ημίκλειστος και ιδιαίτερα βαθύς κόλπος, που σχηματίζεται μεταξύ της Στερεάς Ελλάδας και της Πελοποννήσου. Είναι μια από τις πιο ενεργές σεισμικά περιοχές της Ευρώπης, που χαρακτηρίζεται από έντονο τοπογραφικό ανάγλυφο με απότομες πλαγιές και πολλά υποθαλάσσια φαράγγια. Όντας μέρος των περιοχών Natura 2000, ο Κορινθιακός Κόλπος ευνοεί την ανάπτυξη μιας ασυνήθιστα υψηλής βιοποικιλότητας και παραγωγικότητας θαλάσσιων οικοτόπων λόγω του μεγάλου βάθους του σε συνδυασμό με τις ιδιαίτερες γεωμορφολογικές, ωκεανογραφικές και περιβαλλοντικές συνθήκες. Σε μια προσπάθεια να συνδυαστούν τα προαναφερθέντα χαρακτηριστικά με το παράκτιο ανθρωπογενές περιβάλλον και να γίνει πιο κατανοητός ο τρόπος με τον οποίο η γεωδυναμική του Κορινθιακού Κόλπου αλληλεπιδρά με τις θαλάσσιες διαδικασίες, τη βιοποικιλότητα και τις ανθρωπογενείς δραστηριότητες, δημιουργήθηκε ένα Story Map. Το Story Map (αφηγηματικός χάρτης) είναι ένα διαδραστικό εργαλείο που χρησιμοποιείται για την επικοινωνία, την ενημέρωση και τη διάδοση της επιστήμης και των χωρικών δεδομένων. Μια διαδικτυακή εφαρμογή που χρησιμοποιεί την τεχνολογία των αφηγηματικών χαρτών παρουσιάζεται εδώ για να τονίσει σημεία ενδιαφέροντος γύρω από τον Κορινθιακό Κόλπο. Ένας ειδικά σχεδιασμένος αφηγηματικός χάρτης που συνδυάζει θεματικούς χάρτες και σκηνές (3D webmaps) που δημιουργούνται μέσω ενός Συστήματος Γεωγραφικών Πληροφοριών (GIS) που έχουν μεγάλη επίδραση σε οπτικές παρουσιάσεις μέσω web με αφηγηματικό κείμενο και περιεχόμενο πολυμέσων, δημιουργήθηκε για να τονίσει τις θαλάσσιες και παράκτιες αλληλεπιδράσεις του Κορινθιακού Κόλπου.

Λέξεις κλειδιά: *GIS Story Map, Κορινθιακός Κόλπος, Γεωμορφολογία θαλάσσιου πυθμένα, Γεωκίνδυνοι, Natura 2000*

Acknowledgements

I would like to express my sincere gratitude to my supervisor, Prof. Paraskevi Nomikou, for her unwavering support, guidance, and patience throughout my research. I'm also thankful to Dr. Varvara Antoniou and Prof. Serafim Poulos for their contribution and help with their expertise and time. Lastly, I express my sincere appreciation to my family and friends for their understanding and encouragement throughout this journey.

Table of Contents

Table of Figures

1. Introduction

Recent improvements in Geographic Information Systems (GIS) technologies can provide new opportunities for immersive and wide engaging public audiences with complex multivariate datasets. Story Maps can provide support for scientific storytelling in a compelling and straightforward way (Antoniou, et al., 2019) using multi-media assets (e.g. photos, videos, 3D representations) and narrative text for visualizing spatial data effectively. Thereby, Story Maps can be used in order to disseminate and understand scientific findings to broader non-technical audiences (Janicki et al., 2016; Wright et al., 2014).

In this thesis geodiversity (geological formations, major active faults, sea level changes) and biodiversity (unique flora and fauna), cultural and recreation areas environment on both shorelines of the Corinth Gulf, are presented through a narrative map, as it is now included in Natura 2000 site areas.

In order to meet the challenge of creating the Story Map of Corinth Gulf, different types of datasets have been compiled (geological, topographical, historical, etc. data together with geospatial data from open-source portals). Moreover, multiple field trips have taken place for data collection, such as photos and videos for each site of interest to enrich the existing knowledge.

The Story Map of Corinth Gulf (https://arcg.is/0abn9K0) has been created in the ArcGIS platform, although other free software is also available (e.g. StoryMapJS, Google Earth Outreach). The selection was based on the fact that all available data as well as the necessary tools and apps, exist into the same platform without the need to use different software to achieve the same result and without the need for programming.

Thus, all the available vector and grid spatial data, along with descriptive data, was first collected, homogenized and organized into a geodatabase via ArcGIS Pro v.2.4 software. Moreover, the geodatabase also contained the necessary feature layers to be used during field work for data collection.

Geodatabase was then uploaded in ArcGIS online platform and the available information layers were used to create a webmap.

To ensure the accuracy of the geographic location of the sites and to collect real time data, a web application, available in ArcGIS Online, was created using the aforementioned webmap and Collector for ArcGIS, an application both compatible for Android and iOS devices, which gives the opportunity, to collect and update spatial and descriptive data through mobile devices (tablets or smartphones). Accordingly, during field work, points that correspond to sites of interest were collected using the map or the GPS signal, while descriptive text and photos completed the fields available in the attribute table of the corresponding layer as attachments.

After having gathered and processed all the data for the area, the creation of the Story Map followed. In terms of visual output, the new story map approach called ArcGIS StoryMaps has been implemented to present the available information as it offers a user-friendly interface with a responsive design and advanced features. Furthermore, due to the large variety of information the guided linear narration through immersive scrolling is more effective for the users.

In the Story Map created for Corinth Gulf, web maps, narrative texts, images, tables, multimedia content and scenes, which correspond to 3D presentation of data, were used. Additionally, 3D animations using the available spatial data were created, while Instant Apps were embedded into the main application. The thematic maps which are presented in the application, were created directly in ArcGIS Online, based on the collected data, fieldwork and literature review, depicting the most important and unique points. In every web map, the individual parameters for each of the information layers, e.g. its symbol, the appearance or not of pop-up menus, reference scale, etc., have been determined (DiBiase et al. 1992; Newman et al. 2010). Due to the great amount of information the Sidecar layout immersive tool was used in order to enhance user's experience.

2. Study Area

2.1. Physico-Geographical Information

2.1.1. Geographic location

Corinth Gulf is a small, long, semi-enclosed and very deep gulf, formed between Central Greece and Peloponnese, starting from the Ionian Sea to the west and ending up to the Isthmus of Corinth to the east (Figure 1).

It is divided into two subdivisions, Patraikos and Corinth gulf, with the Rio-Antirrio ferry and the homonymous bridge to be their boundary. In the medieval times, the gulf was known as Lepanto Bay from the name of Nafpaktos and has been described as a miniature of the Mediterranean.

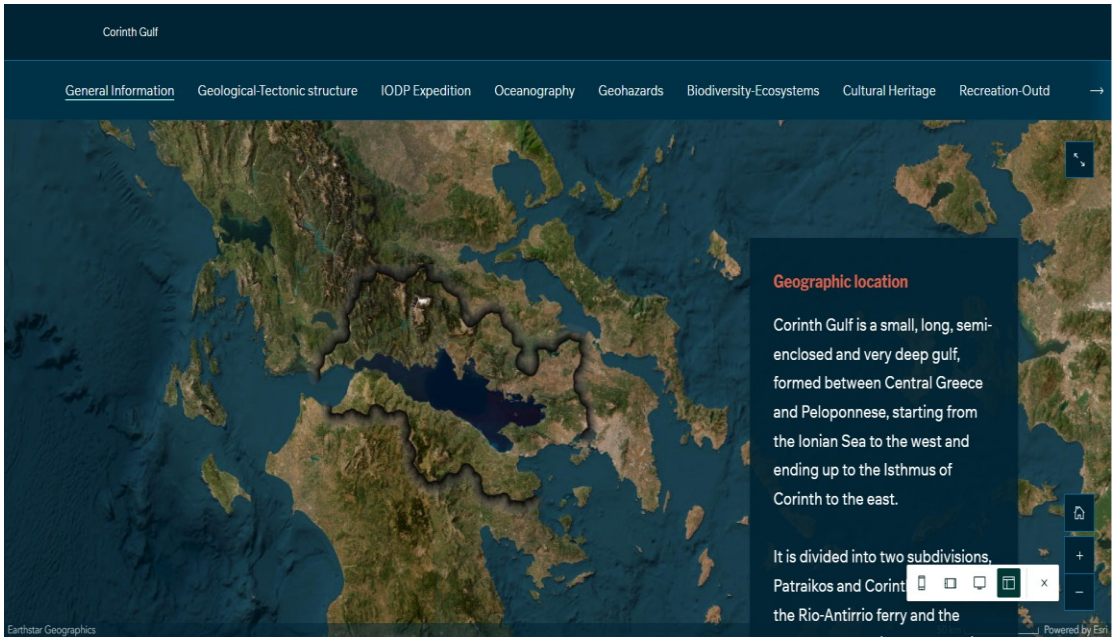


Figure 1 Screenshots showing the boundary of the area.

2.1.2. Morphology

Corinth Gulf is an elongated basin of 105km length with a WNW-ESE direction and 10-15km width, separating the Peloponnese from Central Greece. The central part of the gulf is characterized by a flat area of 800-870m with a length of 40km and a width of 9km to the west up to 12km to the east (Figure 3). Its southern part is characterized by the existence of many submarine canyons in the NE-SW direction, while its northern part is mild up to 400m and then with steep slopes up to 800m. Of the total of 2336 square kilometers of its surface, 23% is deeper than 100m, while 38% has 400-800m depth (Figure 2).

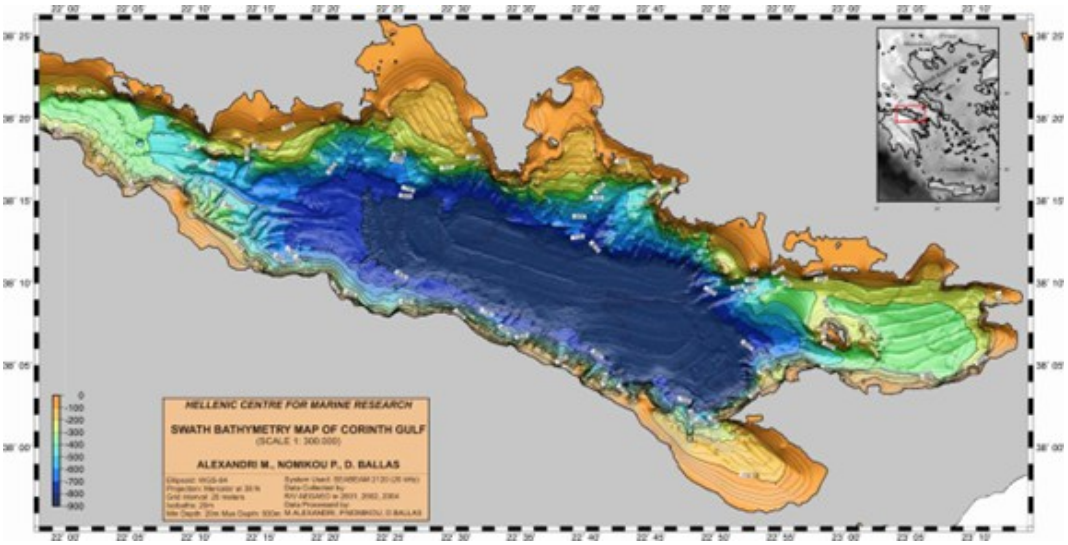


Figure 2 Multibeam bathymetric map of the Corinth Gulf having 20m isobaths (Nomikou et al, 2011)

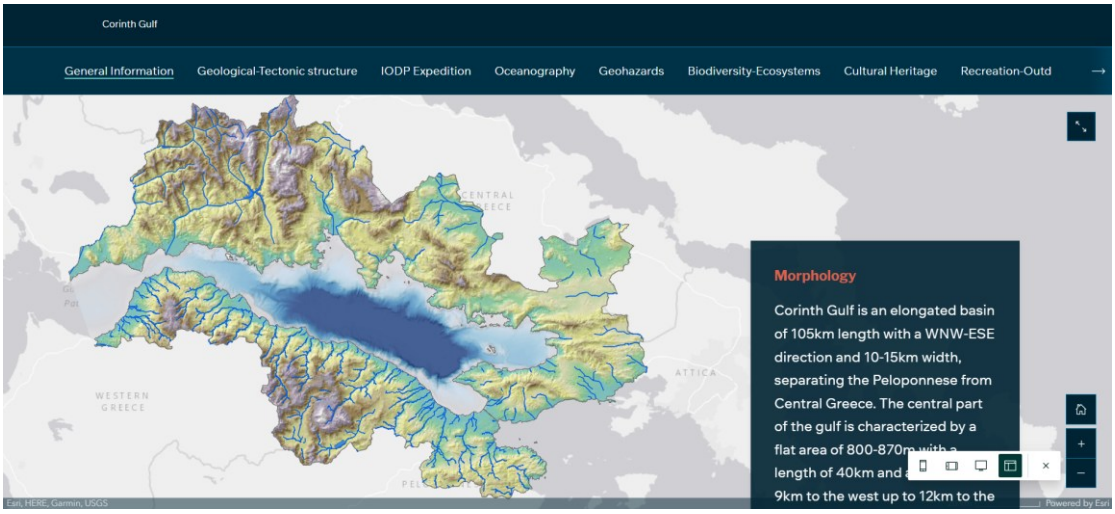


Figure 3 Screenshots showing the onshore-offshore morphology of the area.

2.1.3. Administrative structure

Corinth Gulf is surrounded by four Districts, six Prefectures (Aetoloakarnania, Fokida in the north, Boeotia in the northeast, Attica in the east, Corinth in the southeast and Achaia in the southwest), and fifteen Municipalities, fourteen of which are part of the Protection and Development Association of Corinth Gulf "Arion" and they are the Municipalities of Patras, Aigialeia, Xylokastro - Evrostini, Sikyon, Velo-Vocha, Corinth, Loutraki - Agioi Theodoroi, Mandra - Eidyllia, Levadia, Distomou - Arachova - Antikyra, Delphi, Doris, and Nafpaktia (Figure 4).

Figure 4 Screenshot showing the administrative structure of the area.

2.1.4. Anthropogenic Environment

The total population living in the Municipalities that border Corinth Gulf is approximately 584.000 (2017) citizens. The six largest are the Municipality of Patra, which is also the most populous, Corinth, Aigialeia, Thebes, Megara, and Levadia, while the Municipality with the fewest citizens is the Municipality of Distomo - Arachova – Antikyra (Figure 5).

In the wider area, various anthropogenic activities take place, such as touristic, industrial, urban, fishing, etc.

Aquaculture: Areas of existing marine aquaculture development are located in the prefectures of Achaia, Corinth, Boeotia (Antikyra, Vourlia), Aetoloakarnania and Fokida (Eratini, Galaxidi), as well as in West Attica, where among others the species of sea bream are bred, sea bass, sharp snout sea bream, dentex, and red porgy.

Mineral resources: In the Prefectures of Fokida, Fthiotida, Attica, and Boeotia there are mining mines, as well as main aluminum production facilities with the geological deposits to be the most important in Europe.

Wind Turbines: In the area of Mandra is located a proprietary factory which produces small wind turbines. At the Panachaikos mountain, there are two wind parks, nine in Boeotia and one in Fokida.

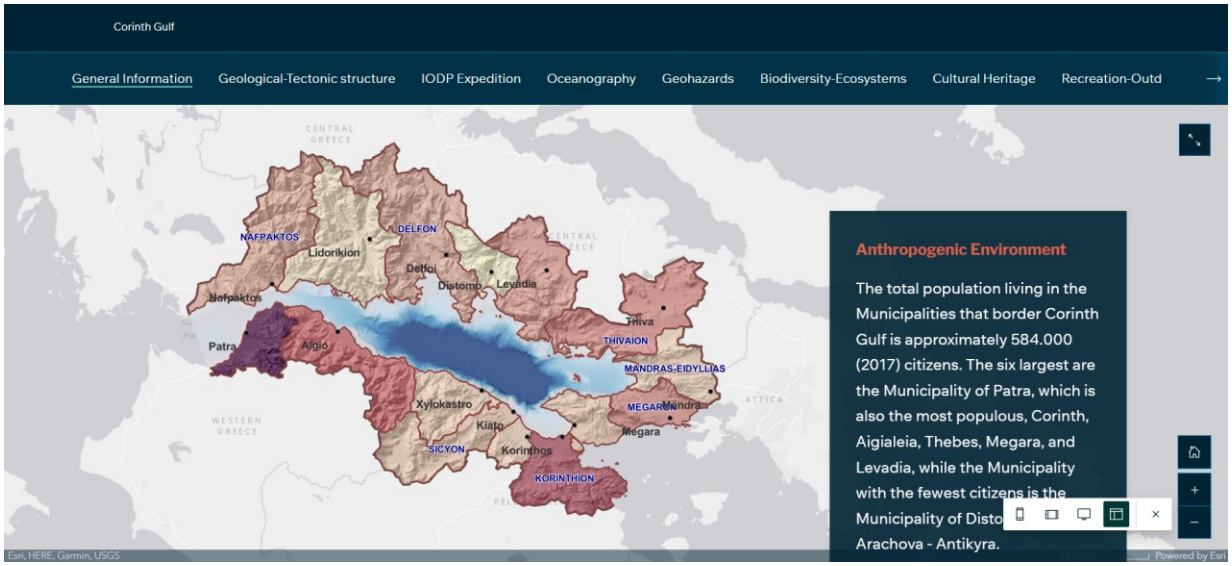


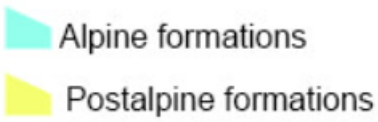
Figure 5 Screenshot presenting the municipalities of the area.

2.2. Geological - Tectonic structure

Corinth Gulf is an elongated basin of 105km length with a WNW-ESE direction and a width of 10-15km, separating the Peloponnese from Central Greece.

This basin is a tectonic half-graben to an asymmetric graben with a strong differentiation of its two sides. Thus, in the North Peloponnese, there is a large tectonic uplift, which has raised the first post alpine sediments of the gulf at an altitude of 1200-1400m. These sediments consist mainly of sandstone-conglomerate formations, which are coherent and create an intense topographic relief. Their age is very young, ranging from the Upper Pliocene (3,6-2,58Ma) to the Lower-Middle Pleistocene (0.78 million years).

The impressive appearances of Pleistocene conglomerates have been recorded on the first geological map of the Peloponnese since 1892, by Alfred Philippson. In contrast to the south side of the Corinth Gulf, the north side along the coast of Central Greece consists of alpine rocks mainly of Mesozoic - Lower Cenozoic (Figure 7).



This asymmetry was analyzed by I. Mariolakos (1976) who introduced a new term, "the tectonic dipole". That is the different tectonic movement on both sides of the gulf with an intense uplift of the Northern Peloponnese and subsidence or relatively stable position of Central Greece. This structure was associated with the corresponding similar tectonic structure observed in the Sperchios River, between North Central Greece in the rising Oeta and the Othrios subsidence.

The reason for the creation of the Corinth Gulf half-graben is not clear if we approach it as a purely neotectonic structure, because the geological structure of its two sides is very different, as is comes from the sequence of alpine tectonic nappe.

Thus, in Central Greece we meet the Parnassos Unit, which is absent from the North Peloponnese, while neither the Tripoli Unit exists under Pindos nor the underlying Unit of Arna (Phyllite-Quartzite) which occurs at Feneos. Significant differences are also observed to the east in the inner sections of Boeotia and Eastern Greece (Figure 6).

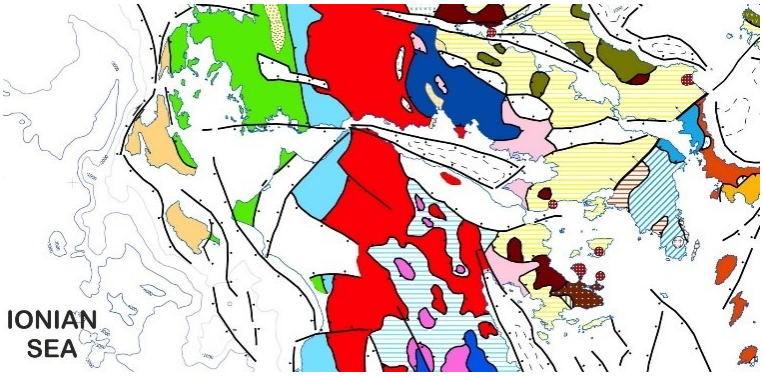


Figure 6 Part of the geotectonic map of Greece (Papanikolaou 2015) covering both sides of the Corinth Gulf. Geological units: Pindos (red), Parnassos (blue), West Thessalia-Boeotia (pink), Tripoli (blue striped), Arna-phyllitic (purple), Ypopelagoniki (yellow striped), Gavrovo (light blue), Ionia (green). The white color includes the post alpine deposits of the Neogene-Quaternary formations.

The above features exclude a mere fracture - displacement of the alpine layers by the neotectonic deformation but indicate old movements within the Tithios paleogeographic area during the Mesozoic with transform faults that defined some units, such as Parnassos (Aubouin & Bercourt, 1975, Papanikolaou, 2015). Therefore, the Corinth Gulf is the result of the reactivation of the old transform fault under the recent geodynamic framework of the Greek arc.

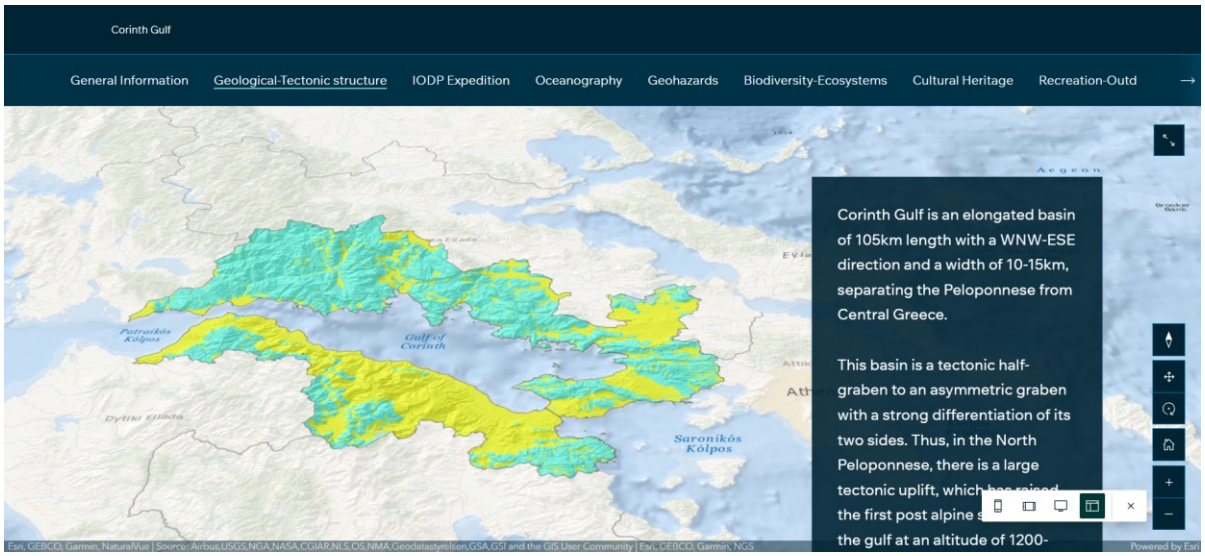


Figure 7 Screenshot showing the three-dimensional distribution of alpine and post-alpine formations of the area.

The peculiarity of the Corinth Gulf, from a tectonic point of view, is that it is a transverse structure as to the Hellenic Arc, contrary to the usual parallel structures which develop in orogenic arcs. This particular structure, along with some of its sub-parallels, is due to the differential deformation caused by the movement of the Aegean plate in relation to the Eurasian at the north and Anatolian plate at east within the Central Hellenic Shear Zone (Papanikolaou & Royden, 2007) (Figure 8).

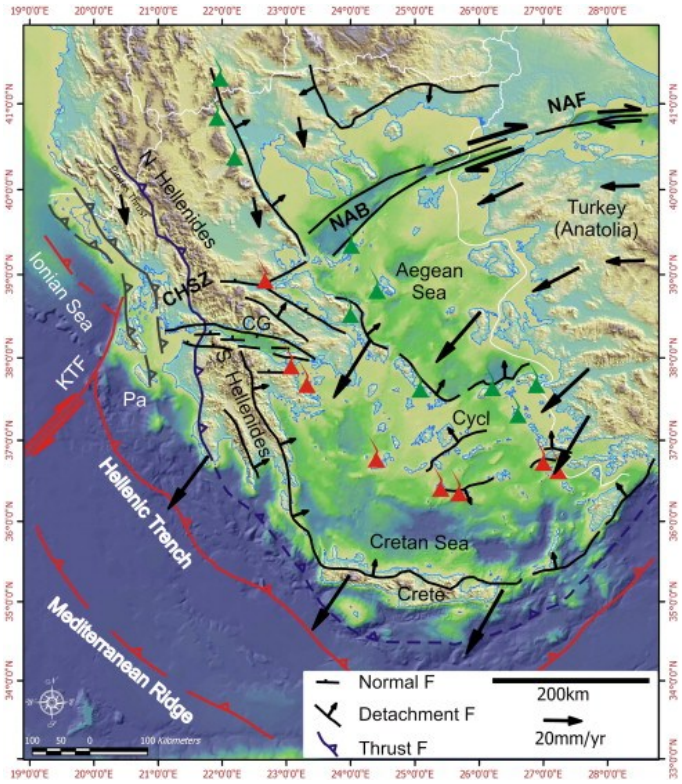


Figure 8 Geodynamic map of Greece with horizontal GPS movements as to stable Africa, which shows the parallel and transverse structures of the Hellenic arc (Papanikolaou & Royden, 2007, Vassilakis, Royden and Papanikolaou, 2011).

To this case, the Aegean plate, which McKenzie distinguished in 1970, 1972, move 40-50mm/year towards Libya, and the Eurasian plate south, with only 10-12mm/year. Therefore, a tensile regime is created, with the main result being the opening of the North Aegean trench between Halkidiki and the Northern Sporades. At the same time, the Anatolian plate moves 20mm/year to the west, lagging along the coast of western Asia Minor, where the other shear zone of Western Anatolia develops. On either side of the Corinth Gulf, there are significant

changes in annual extension rate (GPS) from 12 to 20mm/year (Briole et al., 2000; Bernard et al., 2006).

The rapid uplift of northern Peloponnese can be studied by analyzing/dating the Middle-Upper Pleistocene marine terraces, amounting to eleven southern of Kiato and are observed from the present coast to altitudes of up to 750m (Armijo et al, 1996) (Figure 9). The cause of the marine terraces' creation is the climate change in conjunction with the continuous tectonic uplift of the Northern Peloponnese. Thus, between two periods of low sea level over approximately 100.000 years with glacial climate, the coast has risen by about 100m. Therefore, the new marine terrace of the next hot period will be 100m lower than the previous one.

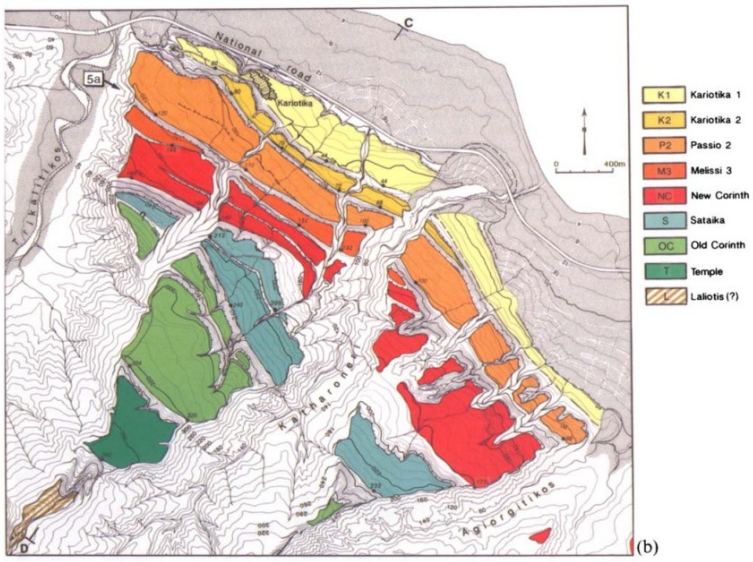


Figure 9 Marine terraces in the North Peloponnese (Armijo et al, 1996).

The timing of the opening of the present-day Corinth Gulf is not accurate but is generally estimated in the Upper Pliocene (3,6Ma). This is the oldest age of the clastic deposits of Northern Peloponnese, characterized by a special type of geometry that occur in the active margins of the basins by distinguishing the horizontal layers in the coastal zone, the primary inclined layers in the continental slope and the horizontal layers at the bottom of the basin (topset, foreset, bottomset beds).

This tectonostratigraphic model was proposed by Ori (1989) and applied to the Neotectonic Map of Corinth by Papanikolaou et al. (1995). Thus, the successive stratigraphic

phases do not overlap the older ones but are laterally deposited in the ongoing active tectonic margin.

To this case, an important role plays the major normal marginal faults, with WSW-ENE direction, which border the different geodynamic-environmental units and at the same time constitute the main seismic sources of the gulf. The entire recent transverse structure of the last 3.5Ma overlaps in the central part of the gulf an older parallel structure of NNW-SSE direction, characterized by normal low-inclination faults that border molasse-type sedimentary basins.

The low-inclination faults have been described both in the Peloponnese (Papanikolaou & Royden, 2007) and in the southern Central Greece at the Galaxidi-Itea region, where they have been dated to the Lower-Middle Miocene (23-13Ma) (Papanikolaou et al, 2009, Gouliotis 2014). Therefore, in the central sector of the present-day Corinth basin, there is an underlying clastic sequence of several hundred meters thickness of Miocene molassic sediments.

The evolution of the Corinth Gulf is characterized by the migration of tectonic activity from south to north. Thus, the first marginal faults, which are currently seismically inactive, are encountered at the mountainous flanks of the palaeo-gulf at altitudes of 1.200 to 1.400m. In contrast, the rifts that occur today along the gulf coasts are younger and border an elevated zone of the bottom of the palaeo-gulf. This gradual elevation is revealed by the marine terraces of the Middle-Upper Pleistocene (the last 0.774Ma). Therefore, the entire zone of the post alpine sediments of Northern Peloponnese has been incorporated in the rest of the Peloponnese for at least 650.000 years.

On the contrary, the present gulf is under continuous subsidence with a constant depth of central area at 800m. The fans and coastal cones formed at the outlets of the canyons of the Northern Peloponnese constitute the modern deposits of the coastal zone, while at the slope between 100 and 800m depth are deposited the modern inclined layers of sandstone-conglomerates. In the flat zone of the bottom of the basin are deposited marl-type and pelite-type clayey sediments with intercalations of sandstones and coarser clastic sediments, mainly in host zones of submarine landslides derived from the steep slopes of the Northern Peloponnese continental slope.

The alteration of the dynamic equilibrium due to intense erosion, development of canyons in coastal fan deposits and deltaic prism formations along the shores, where large marginal faults occur, such as the Psathopyrgos fault (Figure 10).

Figure 10 The Psathopyrgos Fault that borders the coastal zone and leaves the elevated fault block with the alpine formations and the canyons to the south, while to the north it forms successive fans in the shallow waters (Papanikolaou 2015).

The underwater structure shows the asymmetry of the gulf with the large active faults in the south and only smaller reverse faults to the north (Nixon et al., 2016, Taylor et al., 2011, Bell et al., 2009), which are correlated with terrestrial fault traces (Ford et al. 2007, 2013, Skourtsos and Kranis 2009) (Figure 11).

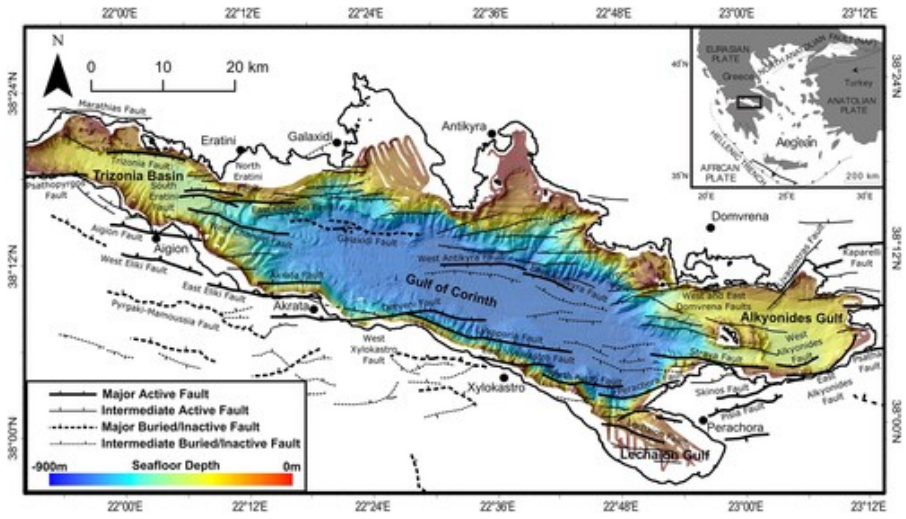


Figure 11 Structural map of the Corinth Rift with the major marginal faults (active and inactive). The bathymetry was obtained through multibeam mapping systems (Nomikou et al., 2011). Offshore faults by Nixon et al., 2016, Taylor et al. 2011, Bell et al., 2009. Onshore faults by Fold et al., 2007, 2013 and Skourtsos and Kranis 2009.

2.3. IODP Expedition

The International Ocean Discovery Program (IODP) is an international marine research collaboration that explores Earth's history and dynamics using ocean-going research platforms to recover data recorded in seafloor sediments and rocks and to monitor subseafloor environments.

The primary objective of IODP Expedition 381 was to retrieve a record of early continental rifting and basin evolution from the Corinth rift, central Greece. The expedition themes are the following:

- High-resolution fault slip and rift evolution history,
- Surface processes in active rifts,
- High-resolution late Quaternary Eastern Mediterranean paleo-climate and paleoenvironment of a developing rift basin, and
- Geohazard assessment in an active rift.

In order to be achieved these objectives three sites had been chosen for drilling, coring and logging in the Gulf of Corinth (Figure 12), which collectively yielded 1645 m of recovered core over a 1905 m cored interval. These cores provide:

1. A long rift history (Sites M0078 and M0080),
2. A high-resolution record of the most recent phase of rifting (Site M0079),
3. The spatial variation of rift evolution (comparison of sites in the central and eastern rift).

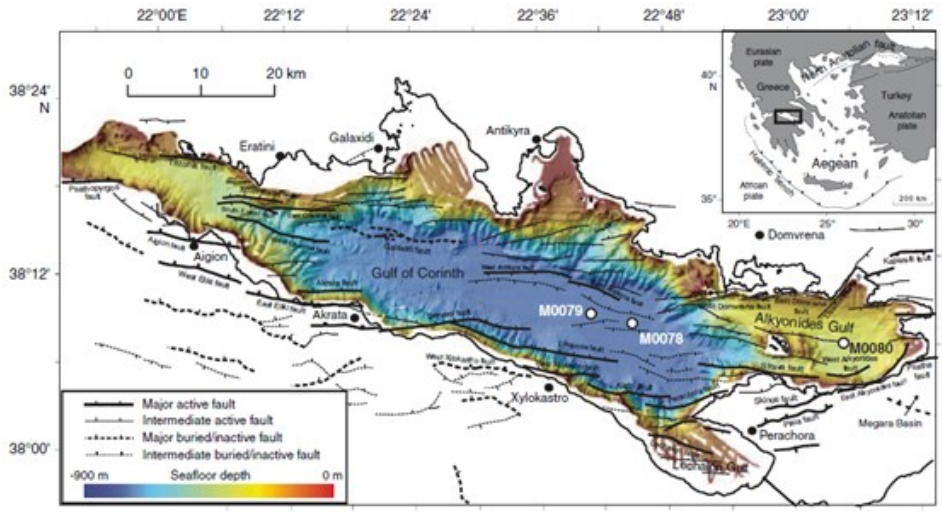


Figure 12 Corinth rift with Expedition 381 drill sites. The bathymetry was obtained through multibeam mapping systems (Nomikou et al., 2011). Offshore faults by Nixon et al., 2016, Taylor et al. 2011, Bell et al., 2009. Onshore faults by Fold et al., 2007, 2013 and Skourtsos and Kranis 2009.

IODP Expedition 381 drilled and cored the most recent ~1–2 Ma of syn-rift sediments to a depth of 705 meters below seafloor (mbsf). This is the longest and highest resolution record of its kind in a young extensional basin at the point of connection to the global oceans, and it provides the first constraints on the age of the full rift sequence, syn-rift stratigraphy, rates and timings of rift tectonic processes, sediment fluxes and basin environmental conditions (McNeill et al. 2019).

- **Site M0078** is located in the central Gulf of Corinth on a fault-bounded horst block with the aim of recovering a long, condensed record of synrift sedimentation. Two holes (M0078A and M0078B) were drilled at water depths of 859.5 and 864.0 meters below sea level (mbsl), respectively. Hole M0078A was drilled and cored to 610.43 mbsf. Hole M0078B was drilled and cored to 55.85 mbsf (Figure 13).
- **Site M0079** is located in the central Gulf of Corinth with the aim of drilling a complete and expanded stratigraphic section of the most recent rift phase and the uppermost section of sediments from the penultimate phase to provide a high-resolution temporal record. Hole M0079A (water depth of 857.1 mbsl) was drilled and cored to 704.9 mbsf (Figure 13).

- **Site M0080** is located in the Alkyonides Gulf with the aim of testing spatial variation in rift evolution history and to sample earlier phases of rifting. Hole M0080A (water depth of 348.8 mbsl) was drilled and cored to 534.1 mbsf (Figure 13).

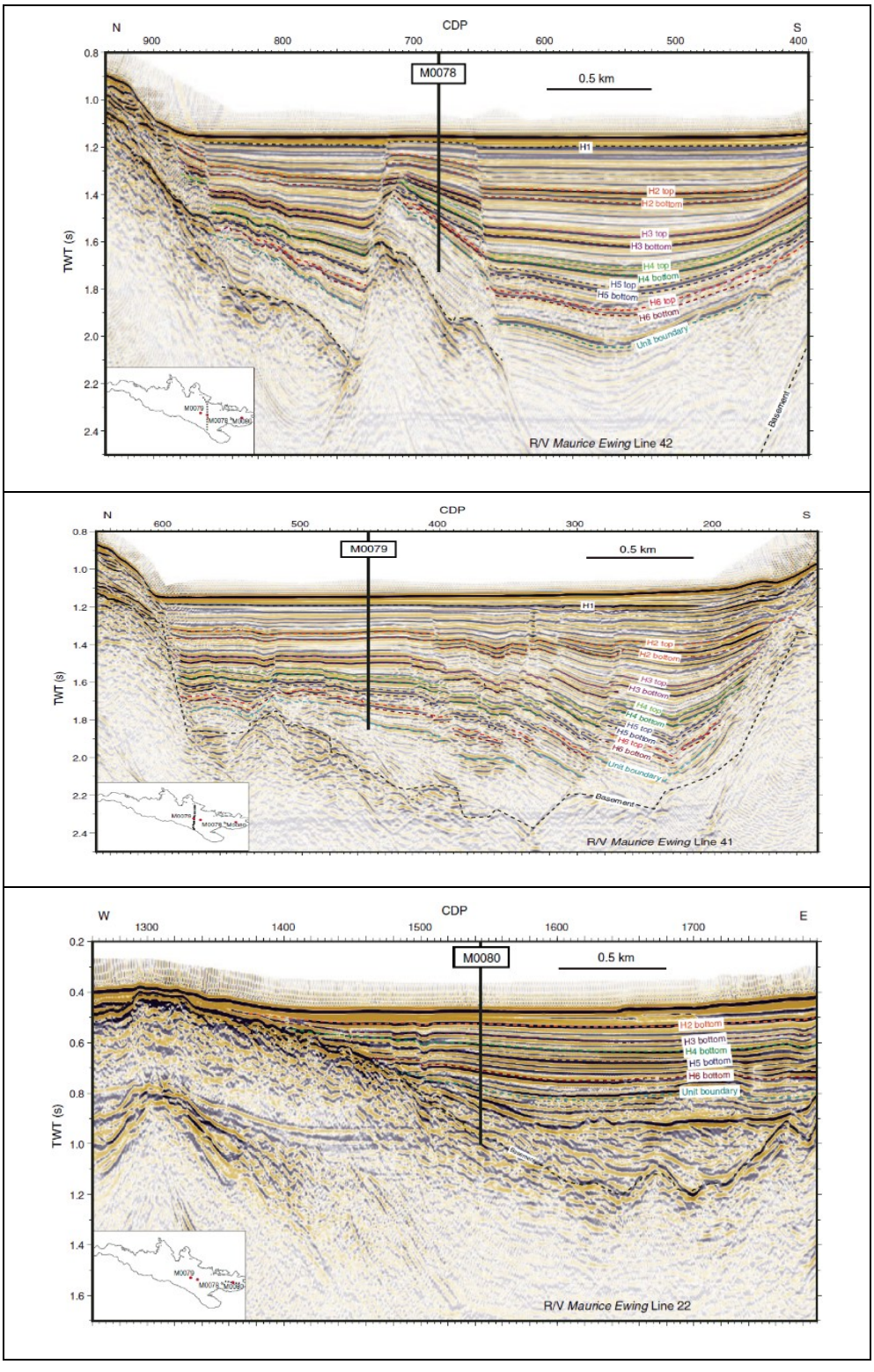


Figure 13 Site M0078, M0079, M0080 shown with Maurice Ewing Line 42, 41, 22 respectively (Taylor et al., 2011) and interpretations from Nixon et al. (2016) (colored dotted lines and text). Inset: Seismic line and drill site locations. (McNeill et al. 2019)

The three deep boreholes confirmed the tectonic structure and identification of the lithostratigraphic horizons, especially in the upper part of the stratigraphic sequence.

This segment corresponds to the Middle Pleistocene - today, including the last 630.000 years. It is characteristic that the stratigraphic sequence comprises about eleven phase alternations from semi-pelagic marine deposits to closed-sea-lake clastic deposits (Figure 14). This phenomenon is due to climate change which, except the marine terraces already mentioned, has significant impact on the paleogeography of the gulf because of the small depth at the Rio-Antirrio Strait (today is about 80-82m), as during the glacial periods of low sea level at a depth of about 125m the connection with the Gulf of Patras is cut off. Therefore, we can observe the climate changes of the last 630.000 years from the stratigraphic analysis of the drill cores.

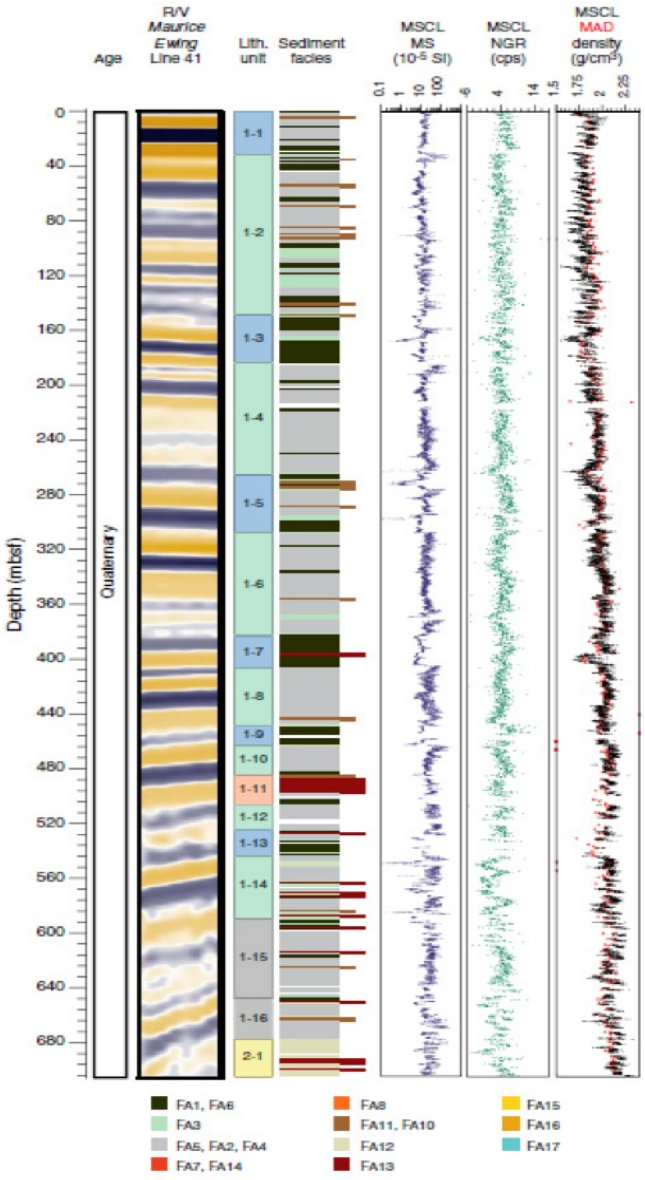


*Figure 14 Lithostratigraphic units from the drill at MOO79 site, 700m depth and sediment facies that show a continuous alternation of facies between closed basin-lake and open sea (*McNeill et al. 2019*).*

Rift Evolution

Initially, the Gulf of Corinth depression began to form when the first faults, ~5 Ma, vertically ruptured the mountain ranges. During this phase, the Peloponnese separated from Central Greece and began to move away towards the south (Figure 15). The sediments of the initial depression, the so-called "Proto-Corinthian Gulf", are today found in the N. Peloponnese, from the area of Corinth and Nemea to Xylokastro, Kalavryta and Aigio. During Phase 1 (Pliocene), the initial basinal deposition (from onshore preserved sediments) was continental, varying from alluvial fans in the west to lacustrine in the east.

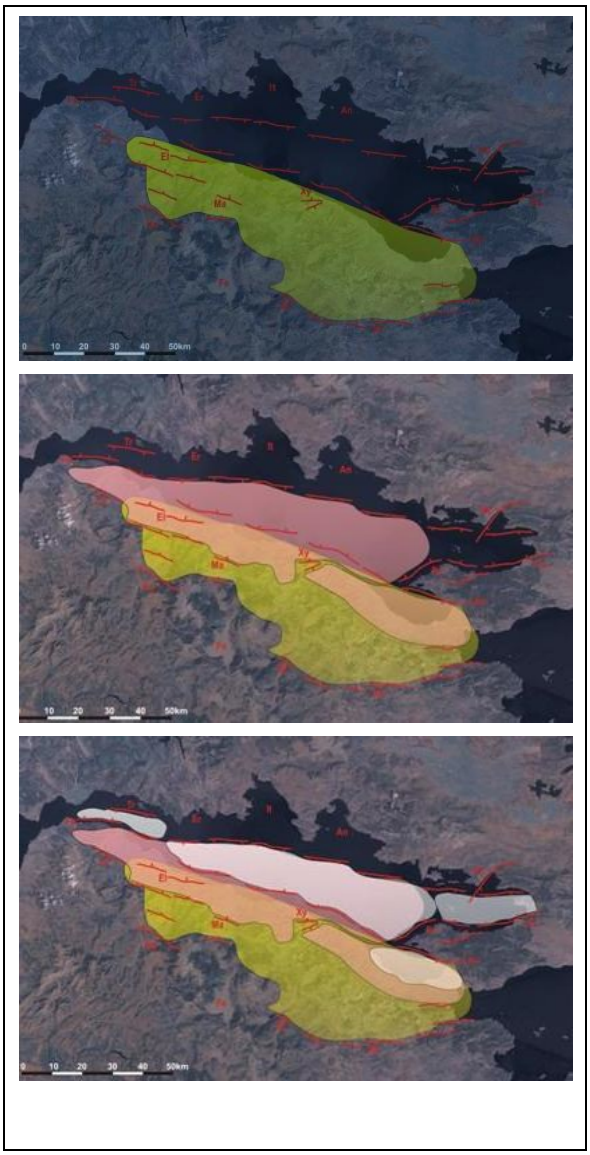


Figure 15 The 3 phases of the rift evolution of the Corinth Gulf (McNeil et al., 2019)

The Phase 1–2 transition appears to have occurred at different times along the rift (e.g., ~2.2 Ma in eastern rift, ~3.0 Ma in the central rift [Leeder et al., 2008, 2012], and ~1.8 Ma in the western rift [Ford et al., 2013]). During Phase 2, the rift was controlled by both south- and north-dipping faults (Bell et al., 2009; Ford et al., 2013, 2016; Nixon et al., 2016). The first faults, which were located further south, were no longer active and new faults were observed north of them. The new faults in the areas of Perachora, Xylokastro and Aigio radically changed the morphology of the Proto-Corinthian Gulf area. The areas south of the new faults began to rise, while the areas north of them began to sink.

At the onset of Phase 3 (~0.5–0.8 Ma), fault activity again stepped northward and propagated westward, establishing the dominant N-dipping rift fault system along the southern boundary and development of fan deltas along the western part of the southern Gulf margin. The transition from Phase 2 to 3 may mark the onset of repeated connection to the open ocean, although earlier marine incursions are recognised onshore. The new faults are those that continue to be active to this day and have created the deep basin of the Corinthian Gulf, the Gulf of Alkionides and the Western Corinthian Gulf.

2.4. Oceanography

In the Corinth Gulf, two sea masses can be distinguished (Anderson and Carmack, 1973). The first is a surface layer (0-200 m) where temperature and salinity vary seasonally with depth, while at depths greater than 200 m they remain constant with depth. Between these two layers (125-175 m) an intermediate layer is distinguished which presents maximum salinity and temperature values. These differences are due to the outflow of water from the Ionian Sea through the Rio Antirrio.

The circulation of the waters is mainly affected by the wind regime. Due to the orography, the most frequent winds have a direction of SW/W and NE/E and are related to deep water upwelling phenomena (e.g. in the Bay of Nafpaktos). In general, the surface circulation of the waters of the Corinthian Gulf is characterized as weakly cyclonic, while at depths greater than 125 m it is characterized as weakly anticyclonic.

The optical transmittance of light ranges between 80% and 95%. The total amount of terrestrial material in suspension, for the total volume of the Corinth Gulf, is about 300·10 3 t, i.e. proportional to the annual inflow of terrestrial sediments, of which >85% is concentrated during the wet season. Sediment supply is mainly along the coasts of the northern Peloponnese, where the hydrographic network is particularly developed in contrast to that of Central Greece.

In the central part of the Gulf of Corinth at great depths, the existence of sand-clay-silt was observed. The main process of sediment transport is gravitational mass movements due to intense seismic activity in the area and changes in gradient of the slopes due to intensive sedimentation.

The physicochemical characteristics of the Corinth Gulf at 5m and 50m depth in both June 1999 and January 2000 are presented in an interactive slider (Figure 16, 17). User can swipe left and right to compare the maps.

Seawater properties in June 1999

At a depth of 5 m, τhe lowest temperatures are recorded NE of the Corinth Gulf and in the central part of the coast of the northern Peloponnese. The salinity diagram shows the effect of the less salty waters entering the Corinth Gulf. Moving SW, salinity increases with a maximum value on the NE coast of the Peloponnese, probably due to the fresh water of the

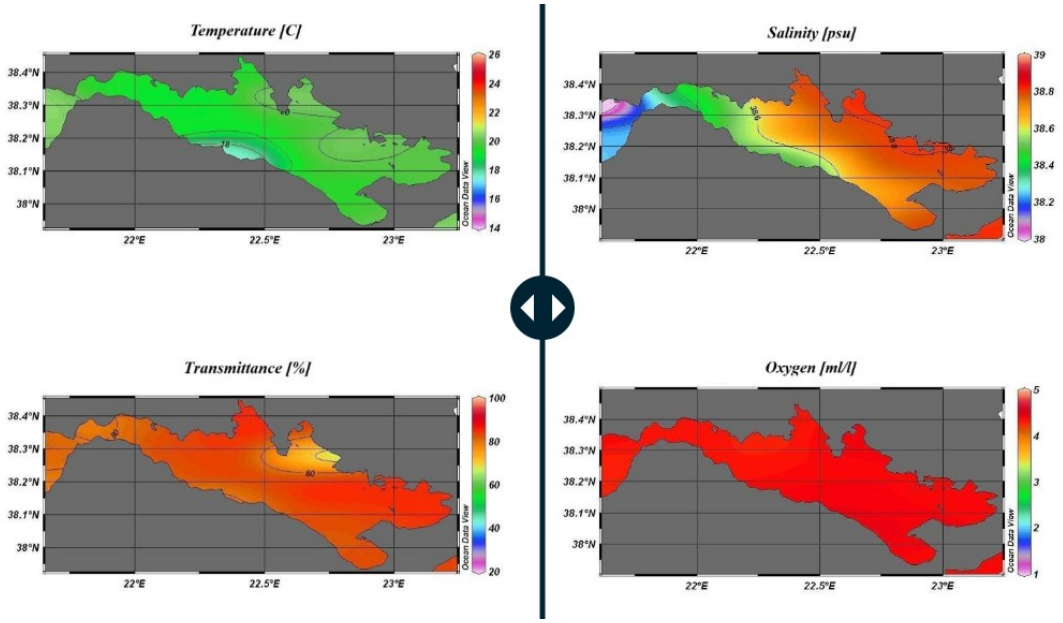


Figure 16 Physicochemical characteristics of the Corinth Gulf at a depth of 5 m in June 1999 (left) and January 2000 (right).

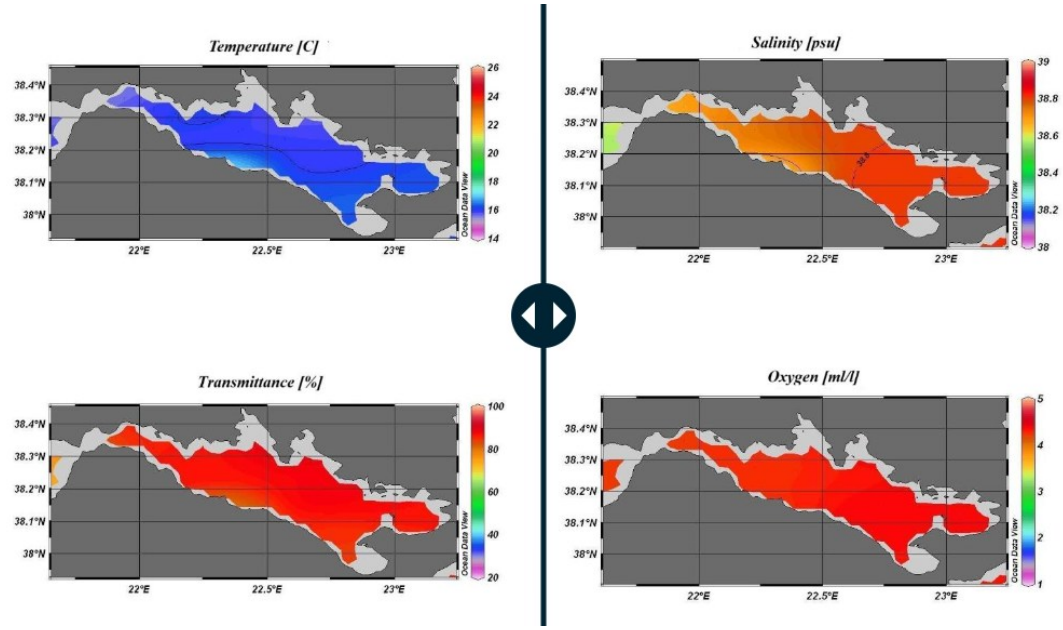


Figure 17 Physicochemical characteristics of the Corinth Gulf at a depth of 50 m in June 1999 (left) and January 2000 (right).

rivers flowing in the surface layers and preventing the saltier waters from rising to the surface. As for the oxygen content, the waters show a gradual increase from north to south with the

highest content occurring in the central part of the coast of northern Peloponnese, indicating greater mixing with surface waters.

At a depth of 50 m, the temperature appears to increase in the northern, central and northeastern part of the Corinth Gulf, while it decreases near the bay of Nafpaktos and on the central coasts of the northern Peloponnese. Salinity shows a slight increase from north to south. The waters are clear, while their difference with the less clear waters of the Patraikos is clearly visible. The oxygen content has the same gradual increase from north to south as at a depth of 5 m.

Seawater properties in January 2000

At a depth of 5 m, the entry of colder waters is clearly visible, affecting a large area and dividing the Corinth Gulf into two sub-regions, its central and northeastern part, and the western one. The salinity, which is very low due to the influence of the waters from the rivers of the Peloponnese and Mornos respectively, is also affected, forming again a diagonal (NW-SE) division of the Gulf. Similarly, the light transmittance with the less clear waters of the Patraikos entering the Gulf, mainly affecting its western end. The oxygen content throughout the area is quite high and does not present particular differences.

At a depth of 50m, the entry of waters from the Ionian Sea affects the Corinth Gulf but to a lesser extent. Salinity increases from west to east, again following a diagonal distribution. The waters in the west are the least saline due to the supply of fresh water from the rivers of both the Peloponnese and the Central Greece and the entry of less saline waters from the Gulf of Patras. As with the temperature, the eastern area of the Gulf seems not to be affected by the waters entering the Gulf and presents a quit high salinity. The transmittance is quite high, while the difference in color between the waters and the Gulf of Patras is visible. The oxygen, like in the surface layers, does not present visible differences and is quite high.

The tidal levels are small <20 cm, although the tidal induced currents at the strait of Rio-Antirio could exceed the 1 m/s. The overall circulation of the Gulf is cyclonic (anticlockwise) while upwelling events have been reported along the northern margin of the Gulf (Sperelaki and Poulos, 2009).

3. Geohazards

At the Corinth Gulf area, it is possible geohazards to be expressed caused by the geodynamics of the area, the seismicity and the peculiar relief that they create.

3.1. Earthquakes

The wider area of the Corinth Gulf constitutes a seismic laboratory for Greece, as it exhibits strong seismic activity and high seismicity. Historical and modern, instrumentally recorded, seismicity confirms that the Hellenic Arc and especially the Corinth trench is one of the most active seismic regions in the world (Ambraseys & Jackson 1990, 1997; Papazachos & Papazachou 1989, 1997; Papadopoulos 2000) (Figure 18).

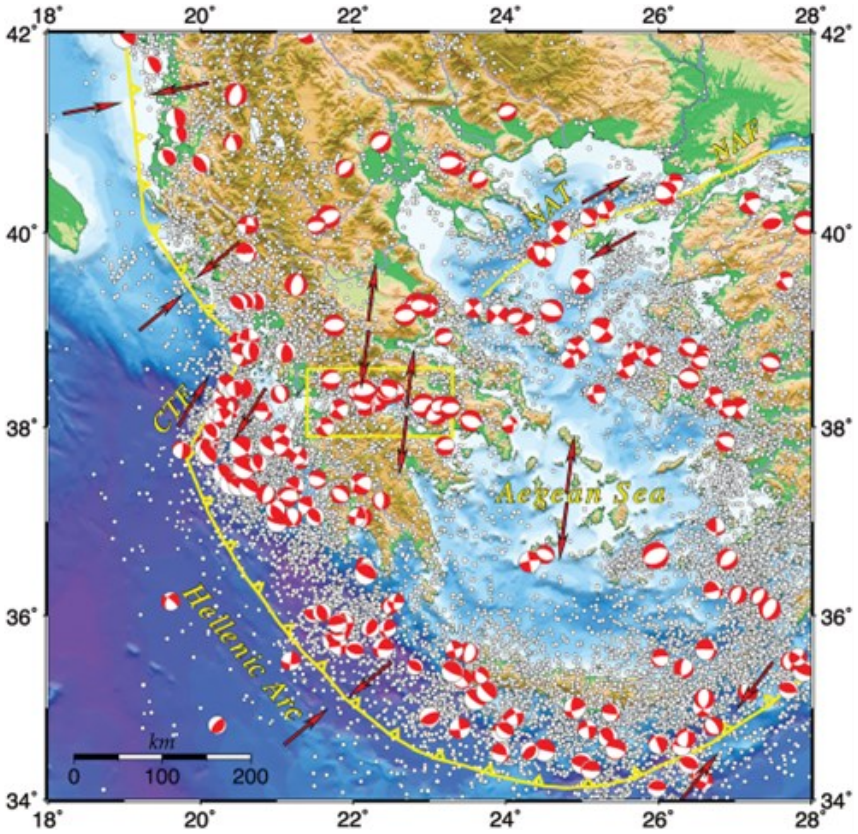


Figure 18 Main structures, spatial distribution of the earthquakes with M ≥ 4 since 1964 and available focal mechanisms during the last five decades in the region of Greece and Aegean Sea. The arrows indicate the different kinematics (contractional, strike-slip, and extensional) that dominate in the region. The study area is shown by a yellow rectangle. CTF: Cephalonia Transform Fault, NAT: North Aegean Trough, NAF: North Anatolian Fault.

Strong earthquakes in the area have resulted in the loss of many human lives or even the destruction of entire cities. Most of the seismic events are related to a shallow, northward seismic zone. Seismic events are more concentrated in the areas between Aigio and Akrata and between Corinth and Alkionides. This concentration coincides spatially with the western (Aigio-Akrata region) and eastern margin (Alkionides bay) of the Corinth trench.

During the last 150 years strong earthquakes bigger than Ms = 6.0 and small focal depth have been recorded, not exceeding 15km with a recurrence of approximately 25-30 years (Figure 19). Geological studies have revealed many main active faults that have spectacular surface appearances, making populated cities such as Corinth and Athens vulnerable to seismic hazard (Papadopoulos et al., 2000).

Figure 19 Tectonic map of the study area showing surface traces of the major fault segments of the area. Stars depict the epicenters of the earthquakes of magnitude exceeding 6.0 between 1700-2011 (Papazachos and Papazachou, 2003).

The maximum potential of the faults (length not exceeding 15-20km) encountered in the area can cause an earthquake of magnitude M = 6.8, which is the maximum magnitude observed and has affected the area seven times (373 and 279 BC, 996, 1580, 1756, 1769 and 1870) (Balkanotis, 2008).

The Alkionides earthquakes in 1981 (Collier et al., 1998) triggered old neotectonic faults of E-W direction that co-shape the Megara area along with older NW-SE faults that formed the Megara basin (Meriolakos Basin. & Papanikolaou 1981).

The following control panel shows the seismicity of the last 10 years (2008-2018) of the wider area (Figure 20). User can configure the information displayed through the selection criteria.

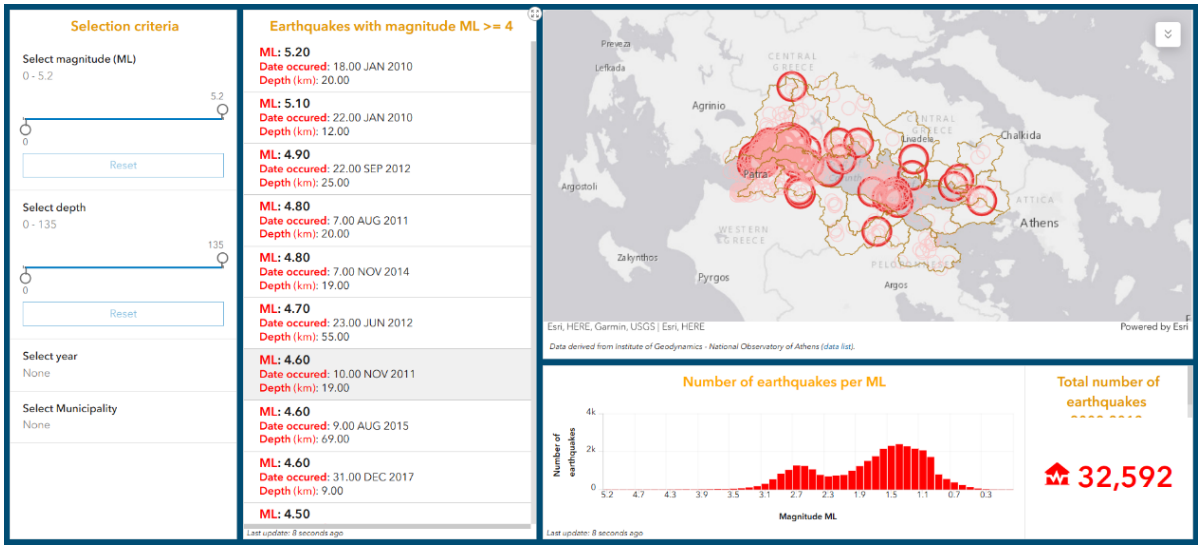


Figure 20 Screenshot of the dashboard where the high seismicity of the area is presented.

3.2. Tsunami

On the coast of Greece, a significant number of tsunami events have been observed, from antiquity to the recent past, many of which were significantly catastrophic. Most of them were due to seismic events with a magnitude of 5.2R to 8.3R.

Throughout the country the main cause of tsunamis is seismic activity (Figure 21), which either results in seabed displacements along the fault triggered by the earthquake, or triggers submarine landslides (Galanopoulos et al. 1966; Papadopoulos, 2003).

Most of the tsunamis that occurred in Corinth Gulf are due to seismic vibrations of low focal depth. However, four cases have been recorded due to coastal landslides caused by seismic vibrations and detected in the years 1794, 1861, 1965 and 1984. According to historical sources, the cause of the tsunami outbreak in 373 BC was similar and eradicated the coastal town of Eliki. The tsunamis that occurred in 1888, 1963 and 1996 were due to submarine landslides, the first of which was caused by seismic activity, while the others were non-seismic (Papadopoulos, 2003). The steep coastal morphology, as well as the presence of loose alluvial sediments along the continental shelf, favor the development of submarine landslides.

The pre-existing evidence of submarine mounds interruptions on the eastern side of the Corinth Gulf, which have occurred during the last 3.000 years, indicates the possibility of a tsunami with a maximum wave height of 1.04 - 4.04m and a maximum wavelength of 4.52 - 6.25km (Stefatos et al., 2006).

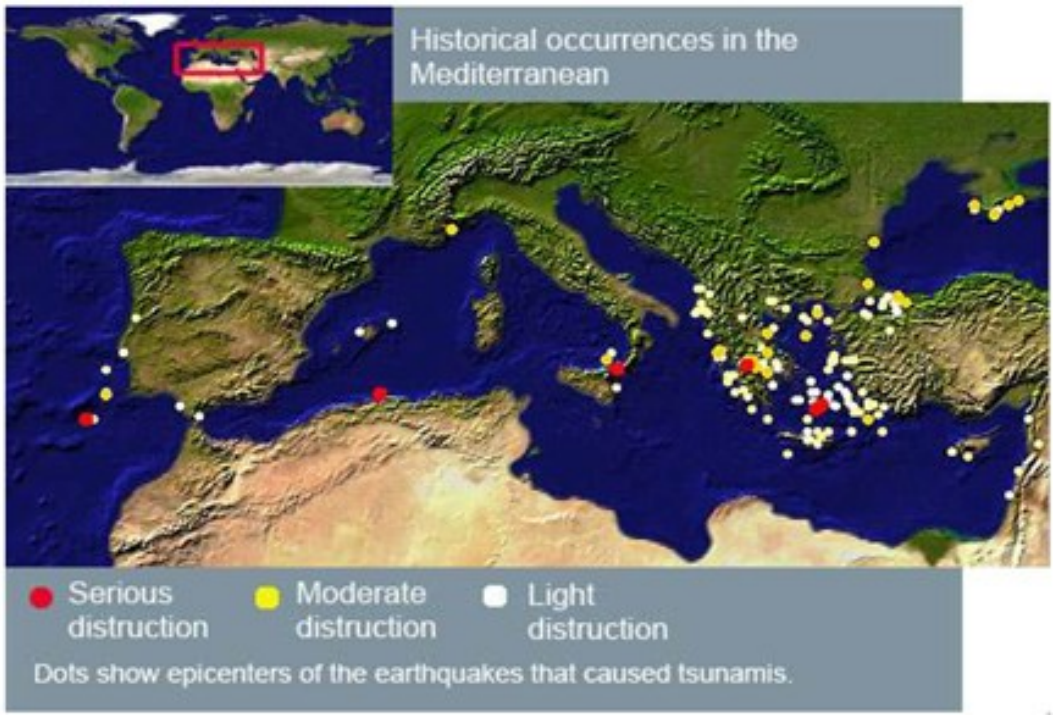


Figure 21 Map of earthquake epicenters that caused tsunamis in the Mediterranean region (www.tsunami-alerm-system.com)

3.3. Landslides

Intense seismic activity in the wider area of the Corinth Gulf is often associated with the occurrence of falls, depressions and land fractures. These phenomena, as well as the subsidence-liquidation of the coastal zone (during earthquakes or non-seismic), are a natural process, which results in a long-term negative balance of sediment in the coastal zone, resulting in either episodic or gradual recession and erosion of the coast.

These processes are located mainly in the southern Corinth Gulf due to the combination of deltaic fields (high sediment discharge), high seismicity and active faults in the coastal zone, where steep slopes are created, as well as additional instability of predeltaic deposits.

The distribution of landslides is in accordance with the main WNW-ESE direction of normal faults (onshore and submarine), whereas at a regional scale they are related to faults/trenches (Figure 22). The spatial distribution of 218 landslides in the Corinth region, from 1995 to 2005, indicates that in some areas the risk is significantly high, with more than 6 landslides per 5 square kilometers (Koukis et al, 2009).

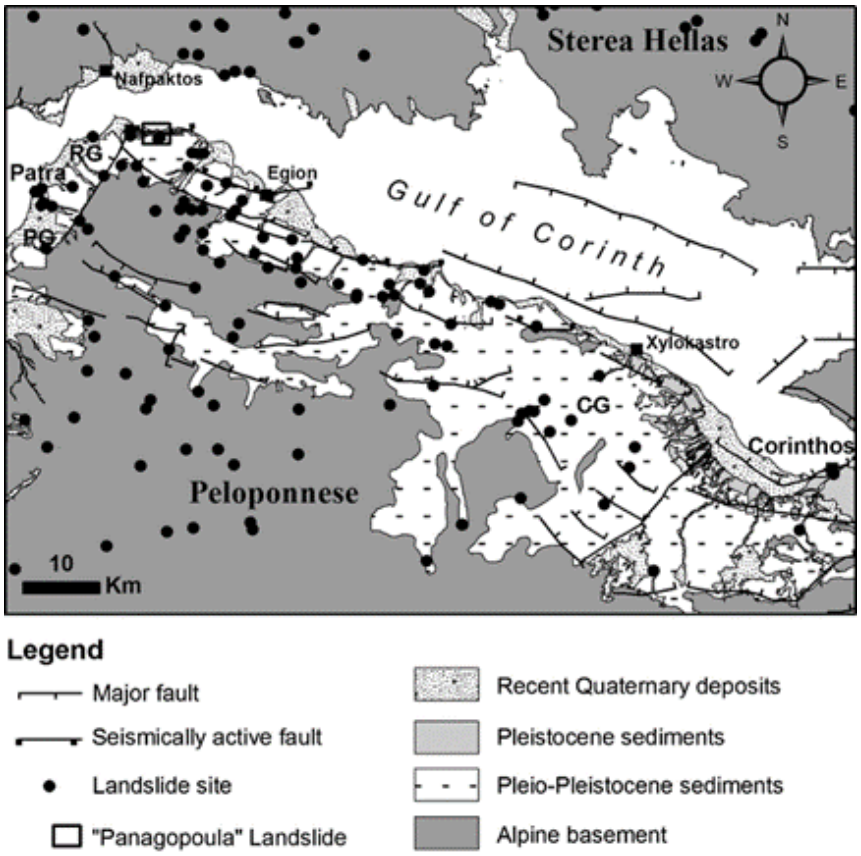


Figure 22 Simplified engineering geological map of Corinth Gulf also showing the distribution of recorded landslides that caused financial damage between 1950 and 2005 (Koukis et al, 2009).

3.4. Floods

In the wider area of the Corinth Gulf may occur, due to its morphology, flooding phenomena in the areas recorded in the context of the Preliminary Flood Risk Assessment (Ministry Of Energy And Climate Change- Special Secretariat For Water, 2012) as follows:

North Peloponnese: High zone of r. Asopos, Low zone of Stymfalia lake basin, Low zone of Feneos artificial lake basin, Low current zone of N. Peloponnese coast from Kiato to Corinth, Low zone of r. Selinounta, Plain zone of Pirou- Piniou-Glafkos watershed.

Central Greece: Delta r. Mornos – Coastal zone of Nafpaktia, delta r. Evinos, Low r. Acheloos zone and lakeside area of Mesolongi lagoon, lakeside areas of Trichonis, Lysimachia, Ozeros, Amvrakia, Low zone upper reaches of Boeoticos Kifisos, Low zone of medium-lower reaches of Boeotian Kifisos - Lakes Yliki-Paralimni-low zone of Schimatari-Dilesi area, the Lower zone of upper reaches of r. Asopos and upper reaches of r. Alargino.

3.5. Forest fires

Many areas around the Corinth Gulf face fire problems. Regarding the Peloponnese side, the distribution of burned areas over the total area of each Prefecture shows that Corinth is the most affected one in the whole Peloponnese Region since all its burnt areas for the period 1983-2005 corresponds to 22.4% of the area of the Prefecture (Tsangari et al., 2010).

As for Central Greece, the distribution of burned areas over the total area of each Prefecture shows that Attica is the most affected prefecture in this District since all of its burnt areas for the period 1983-2005 corresponds to 26.25% of the area of the Prefecture (Tsangari et al., 2010). Consequently, the areas of Megarea and Mandra-Eidyllia are the ones facing the biggest fire problem, followed by the Boeotia area but with a much lower rate.

3.6. Coastal erosion

The Corinth Gulf coastline is in widespread erosion at a percentage of more than 65%, while its southern coast is in full recession, which has already been identified since 2004 with the implementation of the EUROSION program (2004).

The causes of the Corinth Gulf's erosion are its geodynamic framework, with its main characteristic being the intense seismicity and various human interferences, either indirectly by the suspension of river sediments, by dams or extensive sand extraction (at least in the previous decades), or direct interventions on the coastline, with civil engineering projects, such as road retaining walls, construction of fishing shelters, as well as residential expansion near the coastline (Valaouris et al., 2014; Tsokos et al., 2018).

A typical example of coastal erosion, due to geological reasons, is the coastal landslides in Eratini and Derveni associated with the seismicity of the area (Photos by S. Poulos) (Figure 23).

Figure 23 (A) Extensive erosion in the area of Eratini, following the subsidence of about 1m (onshore) after the earthquake of 1993 that plunged a marine zone >40m, (B) Residential expansion and general erosion due to disturbance of the sedimentation equilibrium in the Xylokastro area, (C) In the Mornos Delta region (in its abandoned east part after its diversion), subsidence of about 1m due to the compaction of deltaic sediments, by their own weight.

4. Biodiversity-Ecosystems

The following protected areas are found in the wider area around the Corinth Gulf. (http://natura2000.eea.europa.eu/) (Figure 24):

Κωδικός	Κατηγορία	Ονομασία	Έκταση (ha)
GR2320003	πΤΚΣ, ΤΚΣ, ΕΖΔ	Φαράγγι Βουραϊκού	2.200,44
GR2320004	πΤΚΣ, ΤΚΣ, ΕΖΔ	Αισθητικό Δάσος Καλαβρύτων	2.473,59
GR2320005	πΤΚΣ, ΤΚΣ, ΕΖΔ	Όρη Μπάρμπας, Κλωκός και Φαράγγι Σελινούντα	6.116,87
GR2320006	ΕΖΔ-ΖΕΠ	Αλυκή Αιγίου	31,98
GR2320007	πΤΚΣ, ΤΚΣ, ΕΖ	Όρος Παναχαϊκό	12.721,46
GR2320010	ΖΕΠ	Όρη Μπάρμπας, Κλωκός και Φαράγγι Σελινούντα	15.716,40
GR2320013	ΖΕΠ	Όρος Χελμός (Αροάνια) – Φαράγγι Βουραϊκού και Περιοχή Καλαβρύτων	32.215,40
GR2410002	ΖΕΠ	Όρος Παρνασσός	34.414,33
GR2450001	πΤΚΣ, ΤΚΣ, ΕΖΔ	Βαρδούσια Όρη	19.320,78
GR2450002	πΤΚΣ, ΤΚΣ, ΕΖΔ	Όρος Γκιώνα	2.668,63
GR2450005	πΤΚΣ, ΤΚΣ, ΕΖΔ	Νοτιοανατολικός Παρνασσός, Εθνικός Δρυμός Παρνασσού, Δάσος Τιθορέας	18.633,99
GR2450007	ΖΕΠ	Κορυφές όρους Γκιώνα, Χαράδρα Ρέκα, Λαζόρεμα και Βαθειά Λάκα	10.563,91
GR2450008	ΖΕΠ	Βαρδούσια Όρη	25.014,24
GR2450009	ΖΕΠ	Ευρύτερη περιοχή Γαλαξιδίου	12.210,90
GR2530001	πΤΚΣ, ΤΚΣ, ΕΖΔ	Κορυφές Όρους Κυλλήνη (Ζήρεια) & Χαράδρα Φλαμπουρίτσα	23.276,42
GR2530002	πΤΚΣ, ΤΚΣ, ΕΖΔ, ΖΕΠ	Λίμνη Στυμφαλία	1.283,57
GR2530003	ΕΖΔ	Ακροκόρινθος	589,79
GR2530005	ΕΖΔ	Όρη Γεράνεια	6836,55
GR2530006	ΖΕΠ	Όρος Ζήρεια (Κυλλήνη)	20.309,77
GR2530007	πΤΚΣ	Κορινθιακός Κόλπος	236354

πΤΚΣ: προτεινόμενος Τόπος Κοινοτικής Σημασίας
ΤΚΣ: Τόπος Κοινοτικής Σημασίας
ΕΖΔ: Ειδική Ζώνη Διατήρησης
ΖΕΠ: Ζώνη Ειδικής Προστασίας

In the Corinth Gulf, in particular, has been detected habitats as well as genus and species that can be found at the following link: http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=GR2530007.

Furthermore, in the wider area, visitors meet the "Helmos - Vouraikos" geopark 4 belonging to the UNESCO Network of European Geoparks and the World Geoparks Network (https://goo.gl/F4Tyoo), as well as the Parnassus National Park.

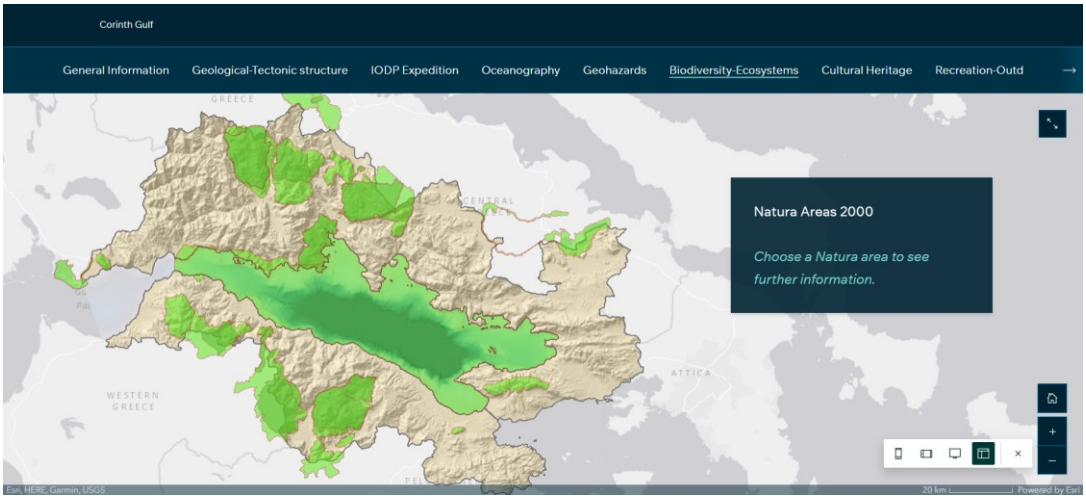


Figure 24 Screenshot of the spatial distribution of the Natura Areas 2000.

The wider area is grouped phytosociologically, in terms of vegetation, in evergreen broadleaves (Mediterranean habitats) and riparian vegetation (Emmanuel, 2008). The evergreen broadleaves consist mainly of shrubs, which dominate all the mountain slopes. These are Mediterranean habitats, but also "faces" of vegetable sums, created either by degradation or reforestation. **Cumaea** (Pistacia lentiscus) (Figure 25), **Wild olive** (Olea oleaster) and **Kermes** (Quercus coccifera and Juniperus phoenicea) are typical examples.

Figure 25 Cumaea (Pistacia lentiscus) (source: Wikimedia Commons 07/03/2019) (By H. Zell - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=44185980)

The riparian formations grow on the banks of streams, with representative species of **osier** (Vitex agnus - castus), **oleander** (Nerium oleander), **plane tree** (Platanus orientalis) (Figure 26), **alder** (Alnus glutinosa) and **reed** (Arudo douax).

Figure 26 Plane tree (Platanus orientalis) (source: Wikimedia Commons 07/03/2019) (By Elisabetha55 - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=59442440)

The most typical terrestrial and marine fauna species found in the wider area are (Emmanuel, 2008):

Mammals

Hare (Lepus sp.), **Wild rabbit** (Oryctolagus cuniculus), **Fox** (Vulpes), **Weasel** (Mustela nivalis), **Ferret** (Martes foina), **Squirrel** (Sciurus vulgaris), **Hedgehog** (Erinaceus concolor), **Wolf** (Canis lupus), **Roe** (Capreolus capreolus) and **Wild boar** (Sus scrofa) (Figure 27).

Figure 27 Wild boar (Sus scrofa) (source: Pixabay 07/03/2019) (https://cdn.pixabay.com/photo/2016/05/01/03/44/warthog-1364424_1280.jpg)

Birds

Partridge (Alectoris graeca), **Pheasant** (Phasianus eolchicus), **Quail** (Coturnix coturnix), **Merle** (Turdus merula), **Thrush** (Turdus spp), **Rock Sparrow** (Petronia petronia), **Starling** (Stunus vulgaris), **Swallow** (Hirundio Rustica), **Goldfinch** (Carduelis cerduelis), **Bird of prey** (hawks and eagles) with the endangered **Lesser Kestrel** (Falco tinnunculus), **Woodcock** (Scolopax rusticola), **Ringdove** (Columba Palumpus), **Mallard–greenhead duck** (Anas platyrhynchos) (Figure 28), **Robin** (Erithacus rubecula), and **Nightingale** (Luscinia megarhynchos).

Figure 28 Mallard–greenhead duck (nas platyrhynchos) (source: Wikimedia Commons 07/03/2019) (By I, Acarpentier, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=3115907)

Marine biodiversity

The high depths of the Corinth Gulf exceeding 900m, in combination with the particular geomorphological, oceanographic and environmental conditions, foster unusually high biodiversity and productivity of marine habitats.

At the part of Central Greece, the seabed is mainly rocky, while the good visibility of the waters allows the development of abundant marine flora and fauna. From the Peloponnese side the seabed is mainly sandy and muddy, so mainly migratory or seasonal fish populations are observed. The two main surface currents recorded in the middle of the Corinth Gulf are related to the transport of planktonic organisms, but also to the presence of species such as tuna, swordfish, and bonito (Archipelago, Marine Protection Institute).

Typical examples of the flora of the Corinth Gulf are the Posidonia meadows, the red algae coral reefs and the Gorgonian (yellow, red & pink) (Figure 29).

Figure 29 Red Gorgonian (Paramuricea clavata) (source: Wikimedia Commons 07/03/2019) (By Parent Géry - Own work, CC0, https://commons.wikimedia.org/w/index.php?curid=12203256)

Pandora (Pagellus erythrinus), **Pike** (Sphyraena sphyraena) (Figure 30), **Saddled seabream** (Oblada melanura), **Large-eye dentex** (Dentex macrophthalmus), **Red Mullet** (Mullus barbatus), **Round sardinella** (Sardinella aurita), **Pompano** (Trachinotus ovatus),

Salema porgy (Sarpa salpa), **Surmullet** (Mullus surmuletus), **Dentex** (dentex dentex), **Pinna** (Pinna nobilis), **Date shell** (Lithophaga lithophaga), and **Octopus** (Octopus vulgaris) are typical species of marine fauna found in the Corinth Gulf.

Figure 30 Pike (Sphyraena sphyraena) (source: Othonas Vlassopoulos)

Despite its relatively small extent, Corinth Gulf supports significant populations of **marine mammals**, either sailing in the gulf waters or living permanently in them (Archipelago, Marine Protection Institute). Typical species are the **Common bottlenose dolphin** (Tursiops truncatus), **Striped dolphin** (Stenella coeruleoalba), **Common dolphin** (Delphinus delphis) (Figure 31), **Risso's dolphin** (Grampus griseus), **Fin whale** (Balaenoptera physalus), and **Loggerhead sea turtle** (Caretta Caretta) (Figure 32).

Figure 31 Common dolphin (Delphinus delphis) (By Jessica Redfern (according to photo caption) - Source: http://swfsc.nmfs.noaa.gov/PRD/CruiseInformation/CSCAPE/VisitTheCruise/PostingFolder/Photos-Leg7/Mammals/index.html, Public Domain, https://commons.wikimedia.org/w/index.php?curid=524618)

Figure 32 Loggerhead sea turtle (Caretta Caretta) (By Strobilomyces - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=719666)

Consequently, there are following representative photos of the marine biodiversity of the Corinth Gulf by Giorgos Toumpaniaris (Figure 33).

Figure 33 Marine biodiversity of the Corinth Gulf (Source: Giorgos Toumpaniaris)

5. Cultural Heritage

From prehistoric times to the present day, the continuous habitation of the wider Corinth Gulf region has provided important archaeological sites of global importance and cultural heritage sites, as well as sports facilities and cultural sites.

5.1. Archaeological Sites – Museums

Greece is a vast archaeological site, as the Greek territory has been inhabited since prehistoric times. The great archaeological sites of Greece, which have been recognized as the birthplace of mankind, attract hundreds of thousands of visitors from all around the world every year, who come to admire the dawning of the western civilization and experience the power and vitality of these sites.

Along the Corinth Gulf, visitors can encounter a wealth of archaeological sites (Figure 34), most notably Delphi, considered by the ancient world to be the center of the earth, the center of the universe, and since 1987 has been designated a UNESCO World Heritage Site.

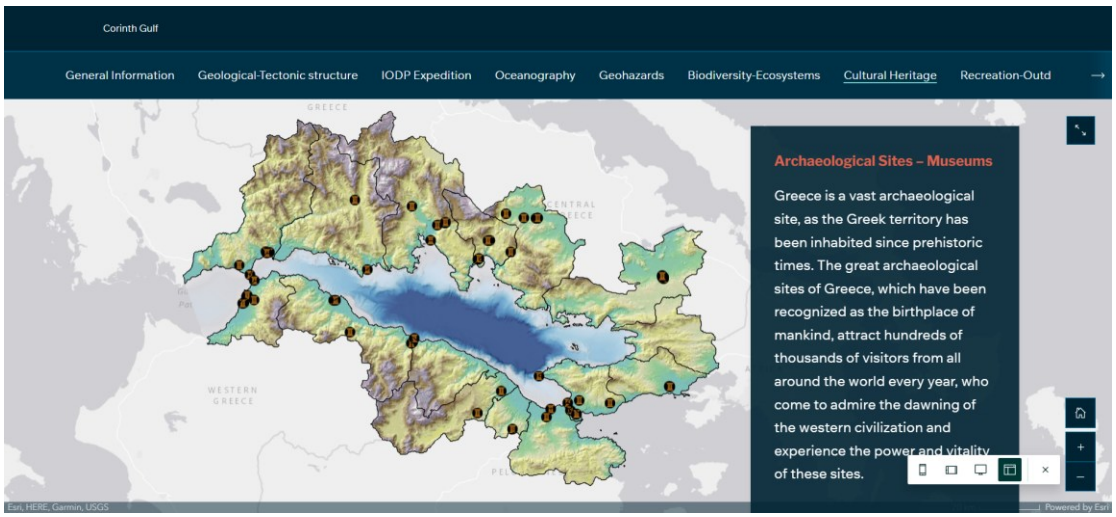


Figure 34 Screenshot showing the spatial distribution of the Archaeological Sites – Museums

Except images and texts extracted from the official websites http://listedmonuments.culture.gr/search_declarations.php and http://odysseus.culture.gr/, additional photographic material and text were provided by the Ephorate of Antiquities of

Achaia. Points of archaeological interest in the coastal zone of Corinth were also indicated by the Ephorate of Antiquities of Corinth.

5.2. Cultural Heritage Monuments

The term "Cultural Heritage" refers to monuments, groups of buildings and sites of historical, aesthetic, archaeological, scientific, ethnological or anthropological value. Greece, thanks to its geographical location, has been a crossroad of civilizations that have left their mark on the architecture of monuments and settlements, on the craftsmanship, on everyday life, on dietary habits and on all forms of folk art.

Throughout the peripheral districts of the Corinth Gulf, visitors have the opportunity to visit cultural heritage sites, such as folklore museums and collections that bring them close to the culture and traditions of the area and give a vivid picture of the ancient times (Figure 35).

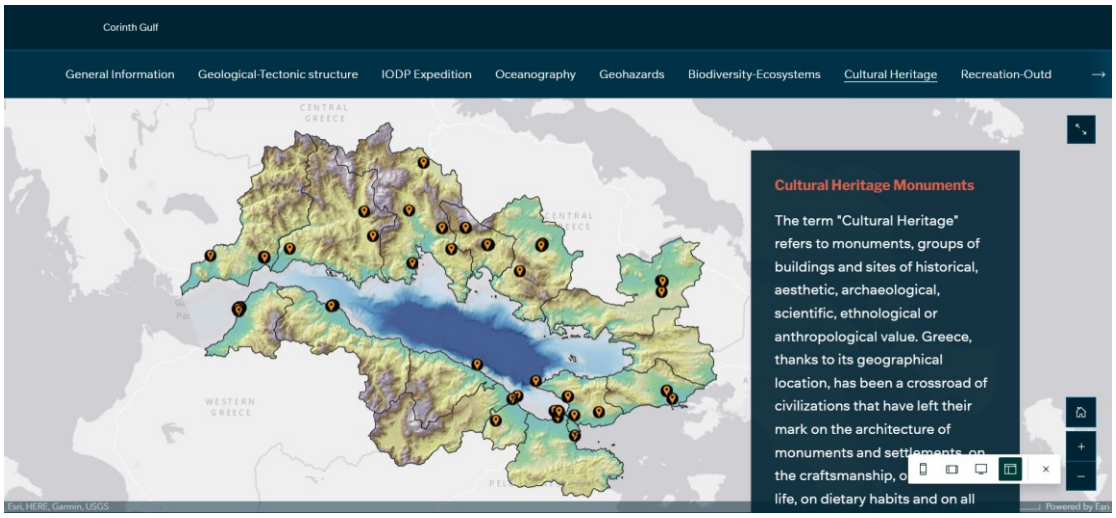


Figure 35 Screenshot showing the spatial distribution of the cultural heritage museum

5.3. Sports facilities

The harmonious balancing of the psychosomatic and spiritual nature of man is directly linked to sports, which is a sample of culture for society and generally reflects its standard of living.

In all the Municipalities around the Corinth Gulf, there are sports facilities of all kinds (soccer fields, basketball courts, swimming pools, etc.) that promote the team and individual sports for both children and adults, while there are local teams (football, basketball, etc.) participating in the amateur championship (Figure 36).

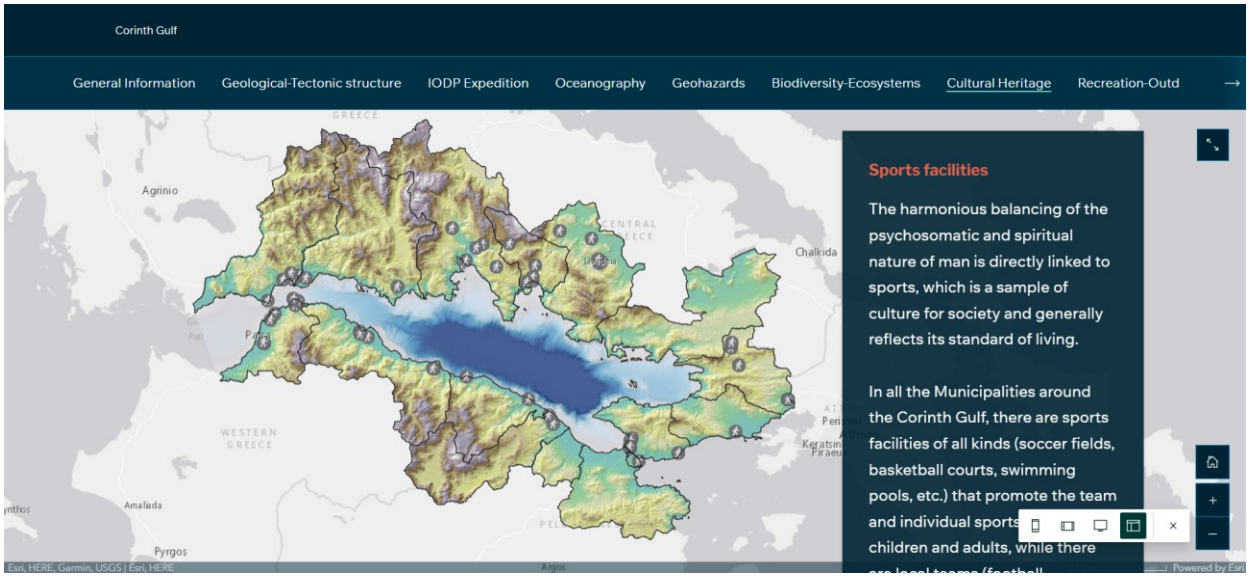


Figure 36 Screenshot showing the spatial distribution of the sport facilities.

6. Recreation and Outdoor facilities

Except for cultural heritage that attracts visitors in and out of Greece, in the wider area of the Corinth Gulf rise recreation and outdoor facilities related to the marine environment, the natural landscape, and the religious tradition.

6.1. Fishing Shelters

The destination of maritime tourism is, by definition, the high seas and relates to all the activities carried out there. It is a very popular way of entertainment and holidays as it is extremely interesting and offers unique emotions.

The Corinth Gulf region is ideal for such excursions. Its diverse coastal zone offers a great number of seaside destinations, while isolated areas are ideal for sailing boats and open sea routes for exploration, fishing, swimming in virgin beaches, romantic evenings in isolated bays and unforgettable moments.

For this reason, modern fishing shelters and marinas are in operation and meet the safety needs of both existing local and seasonal pleasure boats and serve professional and amateur fishermen (Figure 37). Most of them have a place for docking of many other boats, with priority criteria defined by the local authorities. In addition, almost all of them have sloping ramps and can be used by citizens as they will not interfere with the proper operation of fishing shelters.

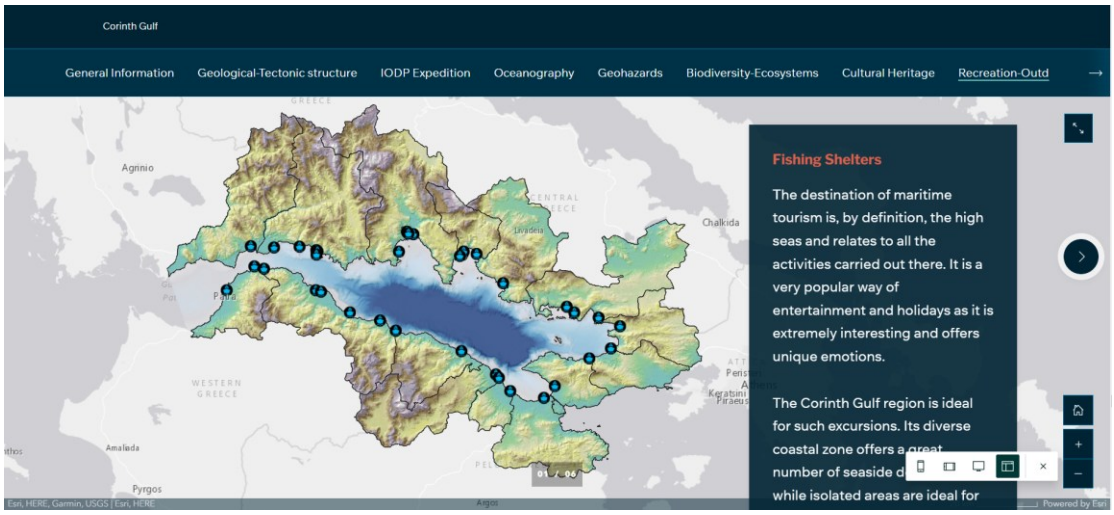


Figure 37 Screenshot showing the spatial distribution of the fishing shelters.

6.2. Diving centers

Diving is undoubtedly one of the most exciting recreational activities as it offers not only experience but also physical activity, knowledge and mental health. It is a highly qualitative type of tourism as it mainly attracts high-educated and high-income people traveling to explore the seabed.

The special geomorphological, marine and environmental conditions in the region give unusually high biodiversity and productivity to marine habitats. This makes Corinth Gulf an extremely popular diving destination.

Many specialized diving schools are active in the Municipalities bordering Corinth Gulf, and there are dozens of diving spots available for a range of diving activities that cover the entire spectrum, from the early stages of offshore divers to technical diving at depths reaching 100m (Figure 38).

The following diving clubs are also active in the wider area:

- Corinthian Diving Association (www.facebook.com/Συλλογος-Δυτων-Κορινθιας-771117232947118/)
- Loutraki Dive Club (www.facebook.com/pg/Loutraki.Dive.Club/posts/)
- Krissaios, Free and Independent Divers Association of Fokida Prefecture (krissaiosdive.blogspot.com).

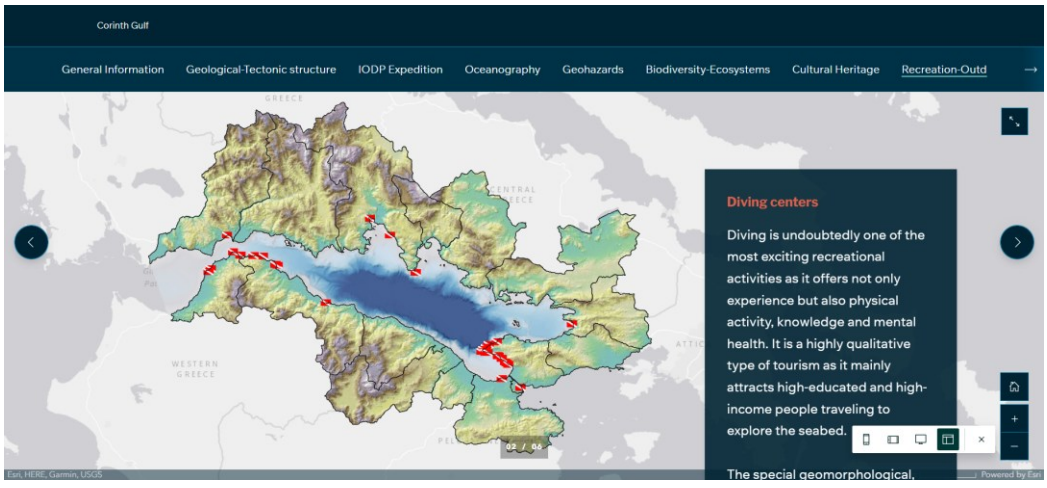


Figure 38 Screenshot showing the spatial distribution of the diving centers.

According to padi.com and scubahellas.gr, some of the main diving sites are Kalogria, Nestos (Shipwreck), Drepano Achaia, Stones of Achaia, Tsolis, Tsimentadiko (Shipwreck), Diakopto, Itea Gulf, Agios Minas, Makrinikolas, Psatha, Mylokopi, Sterna, Deep Blue, Lighthouse Heraion, Poseidon Hotel, Andros (Shipwreck), Mushroom, Limenarchis, Plevra, Vouliagmeni lake, Skala, Chapel, Atlas, Pappas.

6.3. Bathing waters

Ensuring the best quality of coastline and bathing waters is priority for our country over time and is regularly monitored in the framework of the "Country Bathing Water Quality Monitoring Program" (Special Secretariat of Water) for the quality parameters grouped into two categories a) Microbiological (coliform bacterium & Enterococcus) and b) Visually Monitored (tar residues, glasses, plastics, rubber or other waste) (www.bathingwaterprofiles.gr).

By applying the criteria of National and Community legislation in force, Greece has shown very good results, with bathing water quality being ranked among the 2-3 best in Europe.

The map (Figure 39) shows some of the bathing waters found in the Corinth Gulf.

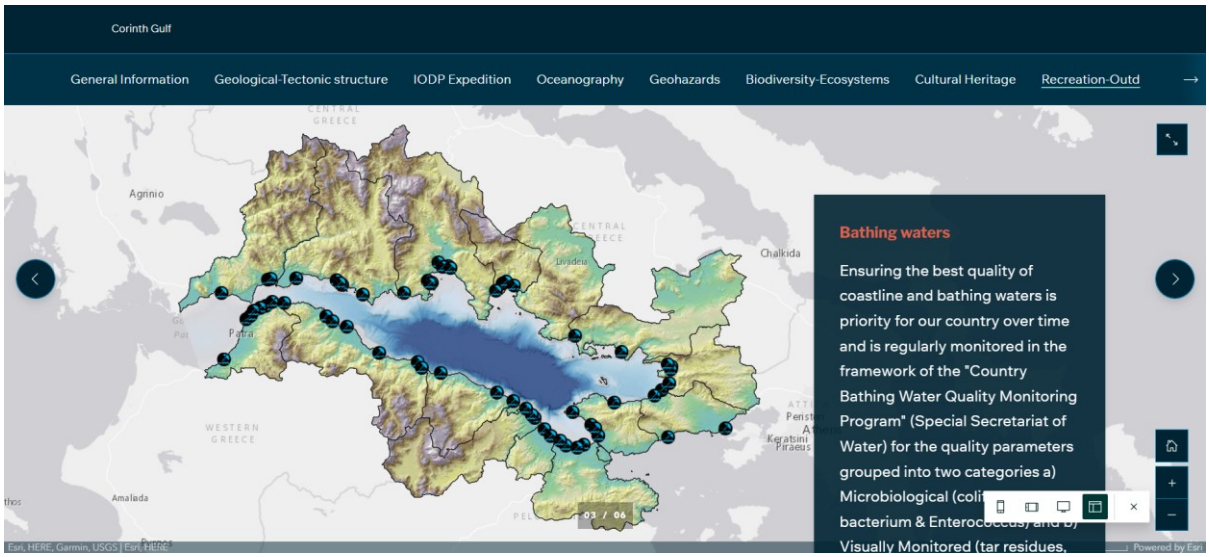


Figure 39 Screenshot showing the spatial distribution of the bathing waters.

6.4. Walking paths

In addition to hiking network through areas of remarkable aesthetic, environmental and cultural value, hiking tourism is at the same time an activity that contributes to recreation, well-being, and health. Some criteria for choosing a destination are easy to access, the existence of signposting, accommodation opportunities, parallel activities, adequate information, etc.

Greece meets the key features to support the development of hiking tourism thanks to its impressive terrain and its unique landscapes, ideal for hiking and walks, that offer moments of relaxation and contact with nature. In recent years, with funding from various agencies (Municipalities, mountaineering clubs, individuals, etc.) large sections of old trails have been maintained, revived and signaled throughout Greece, creating a wide network of approximately 3.500km.

In the northern part of the Corinth Gulf, of particular interest are the lush massifs of Parnassus and Giona, the hydrographic network between them and the Mornos lake, where a variety of mapped paths can be visited. Correspondingly, in its southern part, on the Peloponnese side, there are typical national trails in the municipalities of Patra and Aigialia, as well as trails in Mount Kyllini (Ziria) (Figure 40).

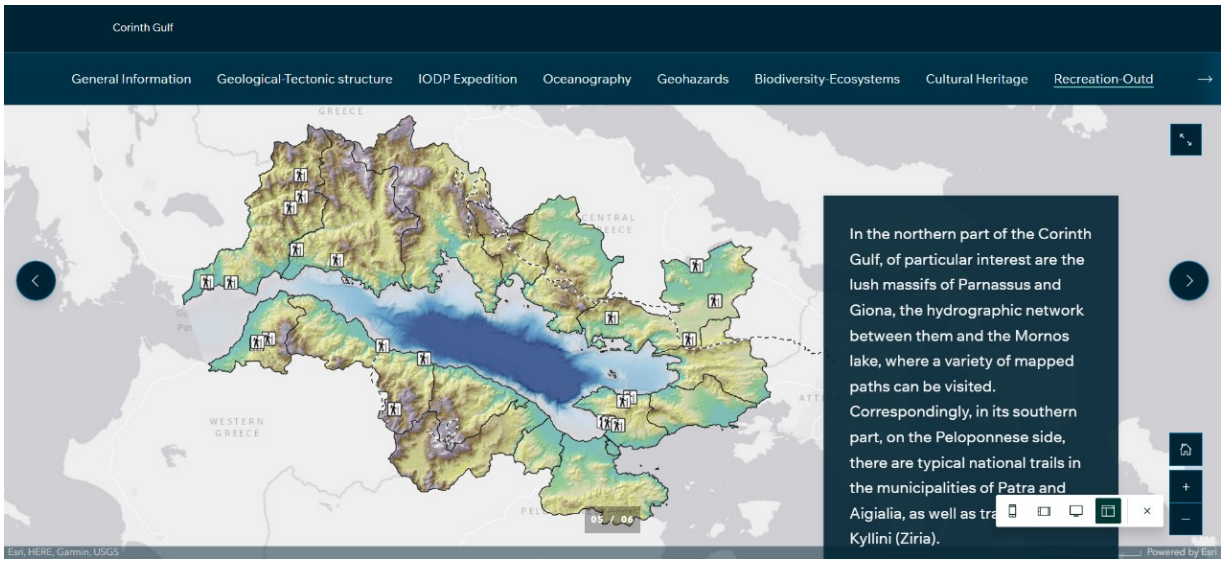


Figure 40 Screenshot showing the spatial distribution of the walking paths.

7. Synopsis and Conclusions

In the demonstrated application the aim was to highlight the marine and coastal interactions of the Corinth Gulf. Using Story Maps, a relatively new geographical approach, and having open-source code, provide many possibilities, due to the simplicity of use, both from the aspect of the developer and the end-user. It allows integration of new functions combining many scientific fields, in a way that scientific knowledge is received and comprehended by a broader audience. Furthermore, it is responsive, and it can also be as interactive as the developer wishes.

Moreover, this can be an interactive way for showcasing geological, geomorphological and cultural contents of any significant area, especially places which can be characterized as geotopes or protected areas worldwide.

Finally, as Corinth Gulf portrays a Natura 2000 area, this application serves as an effective tool for providing a quick access of all useful data. It not only aids in the dissemination of scientific knowledge but also serves as a powerful resource to attract attention, raise awareness, and inspire people to visit and explore the area. Through this, the application has the potential to drive public interest, encouraging both education and eco-tourism in this significant region.

Bibliography

Ambraseys N.N. and Jackson J., 1990. Seismicity and associated strain of central Greece between 1980 and 1988. Geophys. J. Int., 101, 663-708.

Ambraseys N.N. and Jackson J., 1997. Seismicity and strain in the Gulf of Corinth (Greece) since 1694. J. of Earthquake Eng., 1, 433-474.

Armijo R. et al., 1996. Quaternary evolution of the Corinth Rift and its implications for the Late Cenozoic evolution of the Aegean. Geophys. J. Int., 126(1), 11-53.

Aubouin, J., and Dercourt, J., 1975. Les transversales dinariques dérivent-elles de paléofailles transformantes? C. R. Acad. Sci. Paris, Sér. D, p. 347–350.

Backert N., et al., 2010. Architecture and sedimentology of the Kerinitis Gilbert-type fan delta, Corinth Rift, Greece.

Valkaniotis S., et al., 2008. Active tectonics and seismic hazard of the wider area of Corinth Gulf. Bulletin of the Hellenic Geological Society, vol. XXXVI, 2008. (in Greek)

Bell R.E., et al., 2009. Fault architecture, basin structure and evolution of the Gulf of Corinth Rift, central Greece, Basin Research, 21, 824-855.

Bernard P., et al., 2006. Seismicity, deformation and seismic hazard in the western rift of Corinth: new insights from the Corinth Rift Laboratory (CRL). Tectonophysics, 426(1–2), 7-30.

Briole P., et al., 2000. Active deformation of the Corinth rift, Greece: esults from repeated Global Positioning System surveys between 1990 and 1995. J. Geophys. Res., 105, 25605-25625.

Brooks M. and Ferentinos G., 1984. Tectonics and sedimentation in the Gulf of Corinth and Zakynthos and Kefallinia channels, western Greece, Tectonophysics, 101, 25-54.

Clarke P.J., et al., 1998. Crustal strain in central Greece from repeated GPS measurements in the interval 1989-1997. Geophys. J. Int., 135, 195-214.

Collier R.E.L. and Dart C.J., 1991. Neogene to Quaternary rifting, sedimentation and uplift in the Corinth basin, Greece. J. Geol. Soc. London, 148, 1049-1065.

Collier R., et al., 1998. Paleoseismicity ofthe 1981 Corinth earthquake fault: seismic contribution to extensional strain in central Greece and implications for seismic hazard. J. Geophys. Res., 103 (B12), 30,001–30,019.

Console R., et al., 2013. Renewal models and coseismic stress transfer in the Corinth Gulf, Greece, fault system, J. Geophys. Res. Solid Earth, 118, 3655– 3673.

Doutsos T. and Piper D.J.W., 1990. Listric faulting, sedimentation and morphological evolution of the Quaternary eastern Corinth rift, Greece. First stages of continental rifting. Geological Society of America Bulletin, 102, 812-829.

Doutsos T. and Poulimenos G., 1992. Geometry and kinematics of active faults and their seismotectonic significance in the western Corinth–Patras rift (Greece). J. Struct. Geol., 14, 689–699.

Doutsos T., et al., 1988. The Corinth-Patras rift as the initial stage of continental fragmentation behind an active island arc (Greece). Basin Research, 1, 177-190.

Emmanouil, G.G., 2008. Marine environment and environmental pressures: The case study of the NW Corinth Gulf. Department of Marine Sciences, University of the Aegean, Mytilene, 14-26. (in Greek)

Ford M., et al., 2007. Stratigraphic architecture, sedimentology and structure of the Vouraikos Gilbert-type fan delta, Gulf of Corinth, Greece. In Nichols, G., Paola, C., and Williams, E. (Eds.). Sedimentary Processes, Environments and Basins: A Tribute to Peter Friend. Jarvis, I. (Series Ed.). Special Publication of the International Association of Sedimentologists, 38:44–90.

Ford M., et al., 2013. Tectono-sedimentary evolution of thewestern Corinth rift (Central Greece). Basin Research, 25, 3–25.

Ford M., et al., 2016. Rift migration and lateral propagation: evolution of normal faults and sediment-routing systems of the western Corinth rift (Greece). In Childs, C., Holdsworth, R.E., Jackson, C.A.-L., Manzocchi, T., Walsh, J.J., and Yielding, G. (Eds.), The Geometry and Growth of Normal Faults. Geological Society Special Publication, 439, 131–168.

Frydas D. 1989. Biostratigraphische Untersuchungen Aus Dem Neogen Der Nw-UndWpeloponnes, Griechenland. N. Jb. Geol.Palont.Mon, 1, 321-344.

Galanopoulos A., Delimpassis N. and Komninakis P., 1966. Sea wave from a landslide without seismic excitation. Ann. Geol.; Pays Hellen., 16, 93-110. (in Greek)

Gawthorpe R.L., et al., 2017. Tectono-sedimentary evolution of the Plio-Pleistocene Corinth rift, Greece. Basin Research (2017) 1–32.

Gouliotis L., 2014. The tectonic structure of Mount Giona and its hydrogeological applications. National and Kapodistrian University of Athens (p.451). (in Greek)

Heezen B.C., et al., 1966. The Gulf of Corinth floor. Deep Sea Research and Oceanographic Abstracts, 13(3), 381-411.

Hemelsdaël R., et al., 2017. Interaction of an antecedent fluvial system with early normal fault growth: implications for syn-rift stratigraphy, western Corinth rift (Greece).

Higgs B., 1988. Synsedimentary structural controls on basin deformation in the Gulf of Corinth Greece. Basin Research 1, 155-165.

Kontopoulos N. and Doutsos T., 1985. Sedimentology and tectonics of the Antirion area (Western Greece). Bull. Geol. Soc. Italy, 1, 479-489.

Koukis G., Sabatakakis N., Ferentinou M., et al., 2009. Landslide phenomena related to major fault tectonics: rift zone of Corinth Gulf, Greece. Bull Eng Geol Environ 68: 215.

Leeder M.R., et al., 2012. A “Great Deepening”: Chronology of rift climax, Corinth Rift, Greece. Geology, 40(11), 999-1002.

Leeder M.R., et al., 2008. Late-Pliocene timing of Corinth (Greece) rift-margin fault migration. Earth and Planetary Science Letters, 274, 132-141.

Mariolakos, I., 1976 Thoughts and Views on Certain Problems of Geological and Tectonic Structure of the Peloponnese. Ann. Geol. PaysHellen., 27, 215-313. (in Greek)

Mariolakos I. & Papanikolaou D., 1981. The Neogene Basins of the Aegean Arc from the paleogeographic and the geodynamic point of view. Proc. int. Symp. Hellenic Arc and Trench, Athens 1981: 383-399.

McKenzie, D.P., 1970. Plate tectonics of the Mediterranean region. Nature, 226: 239-243.

McKenzie, D., 1972. Active tectonics of the Mediterranean region. Geophys. J.R. Astron. Sot., 30:1099185.

McNeill, L.C., Shillington, D.J., Carter, G.D.O., and the Expedition 381 Participants, 2019. Corinth Active Rift Development. Proceedings of the International Ocean Discovery Program, 381: College Station, TX (International Ocean Discovery Program) 10.14379/iodp.proc.381.101.2019.

Moretti I., et al., 2003. The Gulf of Corinth: an active half graben?. J. Geodyn., 36, 323-340.

Nixon C.W., et al., 2016. Rapid spatiotemporal variations in rift structure during development of the Corinth Rift, central Greece. Tectonics, 35(5), 1225-1248.

Nomikou P., et al., 2011. Swath bathymetry and morphological slope analysis of the Corinth Gulf. 2nd INQUA-IGCP-567 International Workshop on Active Tectonics, Earthquake Geology, Archaeology and Engineering, Corinth, Greece (2011).

Ori G.G., 1989. Geologic history of the extensional basin of the Gulf of Corinth (Miocene–Pleistocene), Greece. Geology, 17, 918–921.

Papadopoulos G., et al., 2000. Foreshock activity as a precusror of strong earthquakes in Corinthos Gulf, Central Greece. Physics and Chemistry of the Earth, 25, 239–245.

Papadopoulos G.A., 2003. Tsunami Hazard in the Eastern Mediterranean: strong earthquakes and tsunamis in the Corinth Gulf, Central Greece, Natural Hazards, 29, 437–464.

Papanikolaou, D.J. and Royden, L.H., 2007. Disruption of the Hellenic arc: Late Miocene extensional detachment faults and steep Pliocene-Quaternary normal faults—Or what happened at Corinth?. Tectonics 26.

Papanikolaou D. and associates 1995. NEOTECTONIC MAP OF GREECE: SHEET "CORINTH" 1 : 100,000. (in Greek)

Papanikolaou D., Gouliotis L., Triantaphyllou M., 2009. The Itea-Amfissa detachment: a pre-Corinth rift Miocene extensional structure in central Greece. Geological Society, London, Special Publications. 2009;311:293-310.

Papanikolaou D., 2015. Geology of Greece. Patakis Publications, p.448. (in Greek)

Papanikolaou D. & Lozios S., 2015. Tectonic Geology, Publications: Da Vinci, p.480. (in Greek)

Papazachos B. and Papazachou C., 1997. Earthquakes in Greece, Ziti Publications, 304.

Papazachos B. and Papazachou C., 1989. Earthquakes in Greece, Ziti Publications, 244.

Papazachos B.C. and Papazachou C., 2003. The Earthquakes of Greece, pp. 317, Ziti Publ, Thessaloniki, Greece.

Pavlides S., 1993. Active faulting in multi-fractured seismogenic areas: examples from Greece. Zeitschrift für Geomorphologie N.F. 94, 57–72.

Philippson A., Mitteilungen, P., 1890. Ethnographische Karte des Peloponnes (ethnographic map of the Peloponnese).

Poulimenos G., 1991. Tectonic and sedimentary analysis of the western part of the Corinth rift. Phd Thesis, University of Patras, 1-298.

Rohais S., et al., 2007. Stratigraphic architecture of the Plio–Pleistocene infill of the Corinth Rift: implications for its structural evolution. Tectonophysics, 440(1–4), 5–28.

Roberts G.P. and Koukouvelas I.K., 1996. Structural and seismological segmentation of the Gulf of Corinth fault system: implication for models of fault growth. Annali di Geophysica, 39, 619–646.

Sachpazi M., et al., 2003. Rift structure, evolution, and earthquakes in the Gulf of Corinth, from reflection seismic images. Earth and Planetary Science Letters, 216(3), 243–257.

Sakellariou D. and Lykousis V., 2007. Spatial and temporal evolution of the neotectonic deformation in the Gulf of Corinth. [presented at the Geological Society of Greece Symposium in honor of Prof. I. Mariolakos, Athens, Greece, 7 December 2007].

Skourtsos E. and Kranis H., 2009. Structure and evolution of the western Corinth Rift, through new field data from the northern Peloponnesus. In Ring, U., and Wernicke, B. (Eds.), Extending a Continent: Architecture, Rheology and Heat Budget. Geological Society Special Publication, 321(1), 119–138.

Sperelaki M. and Poulos S.E., 2009. Investigation of the hydrological balance of the Gulf of Corinth. Proceedings of the 9th Panhellenic Symposium of Oceanography & Fisheries 5/2009 – vol. I, pp. 479-483. (in Greek)

Stefatos A., Charalambakis M., Papatheodorou G. & Ferentinos G., 2006. Tsunamigenic sources in an active European half-graben (Gulf of Corinth, Central Greece). Marine Geology, 232: 35–47.

Taylor B., et al., 2011. The structures, stratigraphy and evolution of the Gulf of Corinth rift, Greece. Geoph. J. Int., 185(3):1189–1219.

Tsangari K., Karetsos G. & Proutsos, N., 2010. Forest Fires of the Peloponnese (1983-2005). WWF-Hellas Publishing. Independent publication. (in Greek)

Tsangari K., Karetsos, G. & Proutsos, N., 2010. Forest Fires of Central Greece (1983-2005). WWF-Hellas Publishing. Independent publication. (in Greek)

Tsokos A., Kotsi E., Petrakis S., Vassilakis E., 2018. Combining series of multi-source high spatial resolution remote sensing datasets for the detection of shoreline displacement rates and the effectiveness of coastal zone protection measures. J Coast Conserv, 22: 431.

Valaouris A., Poulos S., Petrakis S., Alexandrakis G., Vassilakis E., Ghionis G., 2014. Processes affecting recent and future evolution of the Xylokastro beach zone (semi-enclosed Gulf of Corinth, Greece). Global NEST J 16:773–786.

Vassilakis, E., Royden, L. and Papanikolaou, D., 2011. Kinematic links between subduction along the Hellenic Trench and extension in the Gulf of Corinth, Greece. A multidisciplinary analysis. Earth and Plan. Sc. Let., 303 (1-2), 108-120.

Ministry of Environment, Water and Sanitation, 2012. Implementation of Directive 2007/60/EC - Preliminary assessment of flood risks. 128p. (in Greek)