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Morphotectonic control on drainage network evolution in the Perachora Peninsula, Greece

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ABSTRACT

In tectonically active areas drainage systems are often influenced by the type, geometry, and recent activity of regional and local faults. In the Perachora peninsula, eastern Gulf of Corinth (Greece), most drainage networks are influenced by neotectonic processes and eustasy. Two major east–west trending fluvial systems (Perachora and Pissia) in the southwestern part of the peninsula are affected by faults of similar orientation. Detailed geomorphological mapping was performed focusing on knickpoints, gorges, planation and depositional surfaces, alluvial fans and talus cones. Longitudinal river profiles and hypsometric curves of their basins were constructed utilizing GIS technology.

The two drainage systems exhibit opposite network asymmetries. The Pissia network is well developed south of the main channel while the Perachora extends to the north. The analysis of the longitudinal profiles of the main stream channels denotes that they exhibit different evolutionary trends. The Pissia stream has a "transverse" drainage crossing the active Loutraki fault, while the Perachora stream has a "parallel" evolution as it has the same orientation as the Loutraki fault. The drainage system of Pissia is much older than the Perachora as a large part of the latter was underwater in Late Pleistocene times.

The combination of eustacy and vertical tectonic movements has led to the development of four marine terraces corresponding to previous high sea-level stands during Oxygen Isotope Stages (OIS) 5e, 7e, 9c and 11c. Following the analysis of the longitudinal profiles and the hypsometric curves two depositional surfaces were verified at Perachora village. The first surface at 280–360 m and the second one between 120 and 160 m are probably related to marine terraces 11c and 7e respectively.

The development of the present drainage systems of Perachora and Pissia in the Late Quaternary depends mostly on the fault tectonism of the two main offshore fault systems of Xylokastro and Loutraki resulting in the uplift of marine terraces to heights of more than 300 m, but also due to the inland faults (Pissia and Alepochori) which created depositional surfaces and knickpoints. Sea-level changes have played a secondary role in the development of the drainage systems.

1. Introduction

The landscape of Greece reflects in many ways its recent tectonism and high seismicity. The Gulf of Corinth, a 130 km long, WNW–ESE trending structure, is one of the most active tectonic areas of continental Greece (Fig. 1a). Its overall form comprises an asymmetric half-graben with uplifted southern coasts and submerged northern ones, a characteristic example of neotectonic processes whose resulting landforms have become the object of various studies (Vita-Finzi and King, 1985; Armijo et al., 1996). The configuration of the Gulf of Corinth is controlled by a series of main normal faults that bound the high relief along the southern coast and extend towards the east into the sea, having an overall WNW–ESE to E–W strike and a dip to the north. On the northern side, there are smaller antithetic normal faults dipping south. The eastern end of the Gulf of Corinth, the Perachora Peninsula, is more complex. There, the main active normal faults strike E–W to ENE–WSW and dip north-northwest, like the main faults of the southern coast of the gulf, but there are also main faults with a WNW–ESE strike that dip to the south-southwest (Fig. 1b).

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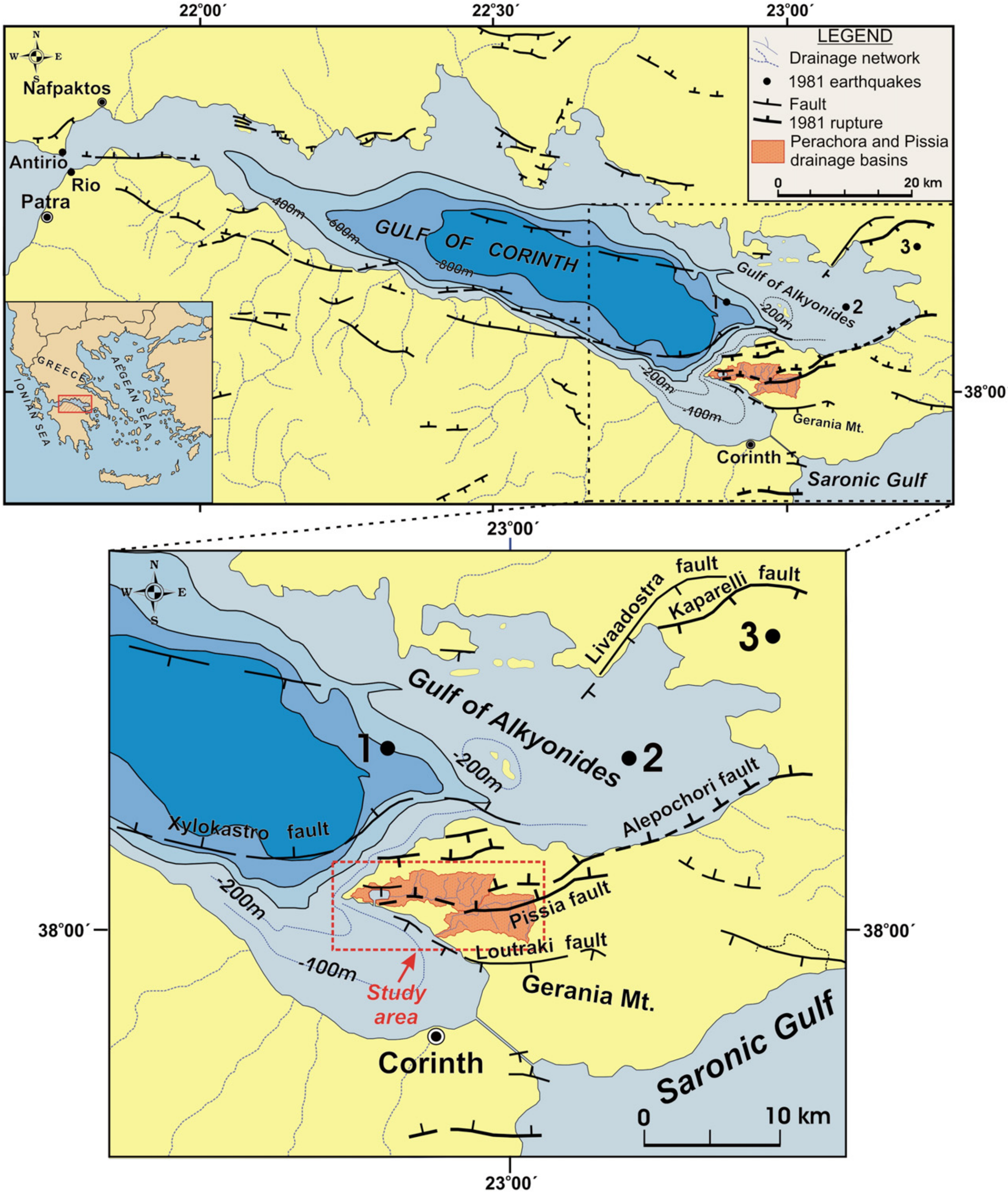

Fig. 1. a. Location map of the study area in the Gulf of Corinth showing the main faults. b. Main tectonic features and characteristics of the sea bottom morphology of the Gulf of Corinth. The main faults are plotted after Armijo et al. (1996) and the three main shocks of the 1981 earthquake sequence are after Taymaz et al. (1991). Discontinuous rectangle depicts the study area.

In such tectonically active areas, drainage systems are often influenced by the type, geometry, and recent activity of the faults. (Schumm, 1986; Leeder et al., 1991; Eliet and Gawthorpe, 1995; Burbank and Anderson, 2001). In the Perachora Peninsula, most drainage networks are influenced by neotectonic processes. Two major fluvial systems (Perachora and Pissia) were studied in detail in the southwestern part of the Perachora Peninsula, on which the complexity of the tectonic regime of the broader area has left its imprints.

In order to examine the influence of tectonism on drainage networks as well as to draw conclusions about the Quaternary palaeogeographic evolution of the area detailed geomorphological mapping was performed focusing on knick points, gorges, planation surfaces, alluvial fans, talus cones and slope changes. In addition, in an attempt to extract geomorphological characteristics with quantitative measurements, the main channel longitudinal profiles and hypsometric curves of the drainage basins were constructed, using

Geographical Information Systems (GIS) and Digital Terrain Models (DTM) technology. This DTM was created from topographic maps at a scale of 1:50 000 for the high relief areas of the basin, and from topographic diagrams at a scale of 1:5 000 for the lowland areas in the central part of the basin, both obtained from the Hellenic Military Geographical Service. The cell size of the grid was 15 m and the software used for this analysis was MapInfo v6.0 and Vertical Mapper v3.1. From elevation data the hypsometric curves for the Perachora and Pissia basins was computed, in order to describe the distribution of elevations across an area of land (Strahler, 1952; Mayer, 1990; Keller and Pinter, 2002). This curve is created by plotting the proportion of total basin height (h/H = relative height) against the total basin area (a/A = relative area). The useful attribute of the hypsometric curve is that it is independent of differences in basin size and relief. In addition, hypsometric curve analysis is very sensitive to discontinued evolution of the topography. This is especially true for Perachora basin, which is located in the center of a peninsula with very high tectonic influence.

2. Tectonic and geologic setting of the area

The broader area of the Perachora Peninsula is affected by intense tectonism. It exhibits a rectangular shape due to the existence of the offshore faults of Xylokastro and Loutraki. The peninsula itself is also affected by inland faults, like that of lake Vouliagmeni ("sunken" in Greek) which is a tectonic depression. Of the two drainage systems examined the Perachora empties into Vouliagmeni Lake and Pissia into Agrilio bay. The faults of Pissia and Alepochori and the western end of Xylokastro fault, have an ENE–WSW strike dipping to the NNW. The Loutraki, Kaparelli and Livadostra faults have a WNW–ESE strike and dip to the SSW (Fig. 1b). This region is tectonically very complex as it is influenced by positive or negative land movements depending on the reactivation of the faults. Specifically, the activation of the faults of Xylokastro and Loutraki extending offshore along the NW and the SW shores of the Gulf of Corinth respectively may cause the emergence of land, while the re-activation of the Pissia fault located north of Mount Gerania may cause land subsidence. However, the dominant long term vertical movement of the area is uplift. The Holocene re-activation of these faults is verified by the presence of a fresh scarp at their bases, exceeding several meters at some places (Fig. 2). The two main east–west trending fluvial systems of Perachora and Pissia located in the southern part of the peninsula are influenced by these faults.

The alpine basement of the Perachora Peninsula belongs to the Boeotian zone (Geological map of IGME, Perachora sheet, 1984). (Fig. 3). The older formations outcropping in the study area are Triassic–Lower Jurassic grey, thick-bedded to massive limestones, overlain by Upper Jurassic composite volcano-sedimentary series consisting of mainly basic rocks and including sandstones and rhyolites with calcarenite lenses, and Lower Cretaceous Boeotian flysch, a periodic series mainly of radiolarites and intercalations of red pelites, marly limestones and sandstones. On top of it lies the Maestrichtian flysch, a rhythmic series consisting of sandstone and calcarenite–rudite intercalations. The basement is overlain by Upper Pliocene marine deposits composed mainly of conglomerates, marls and sandstones. The Pleistocene deposits are abundant in the area. From Cape Heraeon area to Agrilio Bay, Upper Pleistocene marine deposits of coastal facies, consisting of conglomerates, sandstones, marls and calcarenites are found, reaching a height of 28 m (Mitzopoulos, 1933; Marcopoulou-Diakantoni, 1983). Vita-Finzi and King (1985) assigned an age of 31820 to 36180 yr BP, while Vita-Finzi (1993) and Dia et al. (1997) dated them as Tyrrhenian at 134±3 kyr and 128±3 kyr by U/Th series respectively, corresponding to the interglacial stage 5e (Aharon and Chappell, 1986; Chappell and Shackleton, 1986). In the Makrygoas area, southeast of Lake Vouliagmeni, marine deposits were observed capping hills whose elevations reach 100 m; according to the geological map of IGME their age is Tyrrhenian. Morewood and Roberts (1999) ascribe the higher levels of these surfaces to older interglacials, 7e and 9c, sea-level highstands. Leeder et al. (2005) recognized two terraces at elevations of 25–30 m and 55 m and correlated them to 5e and 7e interglacial sea level stands respectively. The terrestrial deposits consist of consolidated cones and talus material. The Holocene deposits are composed of talus, scree, colluvial, fluvio-torrential and coastal sediments.

Based on the raised marine deposits of the study area, it becomes evident that the prevailing tectonic movement is positive (emergence) during the Late Pleistocene and Holocene periods.

3. Seismicity of the area

Concerning the seismicity of the area, its high activity is proven from archaeological evidence and historical reports as well as from instrumental seismicity demonstrating that the broader area of Perachora Peninsula has suffered the consequences of many catastrophic earthquakes since ancient times, in relation to the active

Fig. 2. The Pissia fault plane. The reactivation of the 1981 earthquake with a throw of about 1 m is seen at the bottom of the fault scarp.

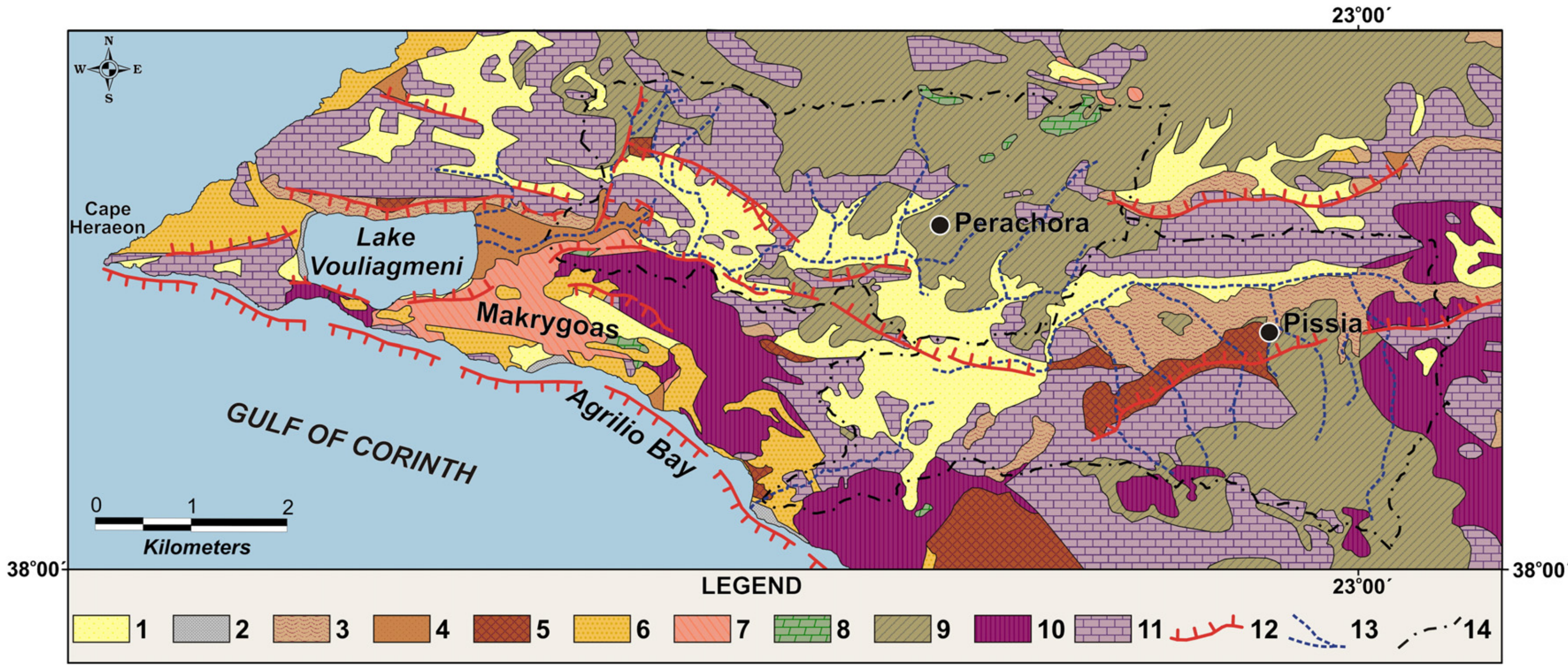

Fig. 3. Simplified geological map of Perachora Peninsula (based on IGME, 1984). Legend: 1: alluvial deposits (Holocene), 2: coastal sandy deposits (Holocene), 3: scree slopes (Holocene), 4: talus cones (Holocene), 5: consolidated scree (Pleistocene), 6: marine deposits (mainly conglomerates, sandstones, marls, calcarenites) (Plio–Pleistocene), 7: Boeotian zone flysch (Maestrichtian–Palaeocene), 8: limestones (Cenomanian–Maestrichtian), 9: Boeotian flysch (Up. Malm–L. Cretaceous), 10: Composite volcanosedimentary series (basic rocks, radiolarites, sericitized sandstones, phylites, calcarenite lenses and limestones), 11: limestones (Triassic–Middle Jurassic), 12: normal fault, 13: drainage network, 14: watershed.

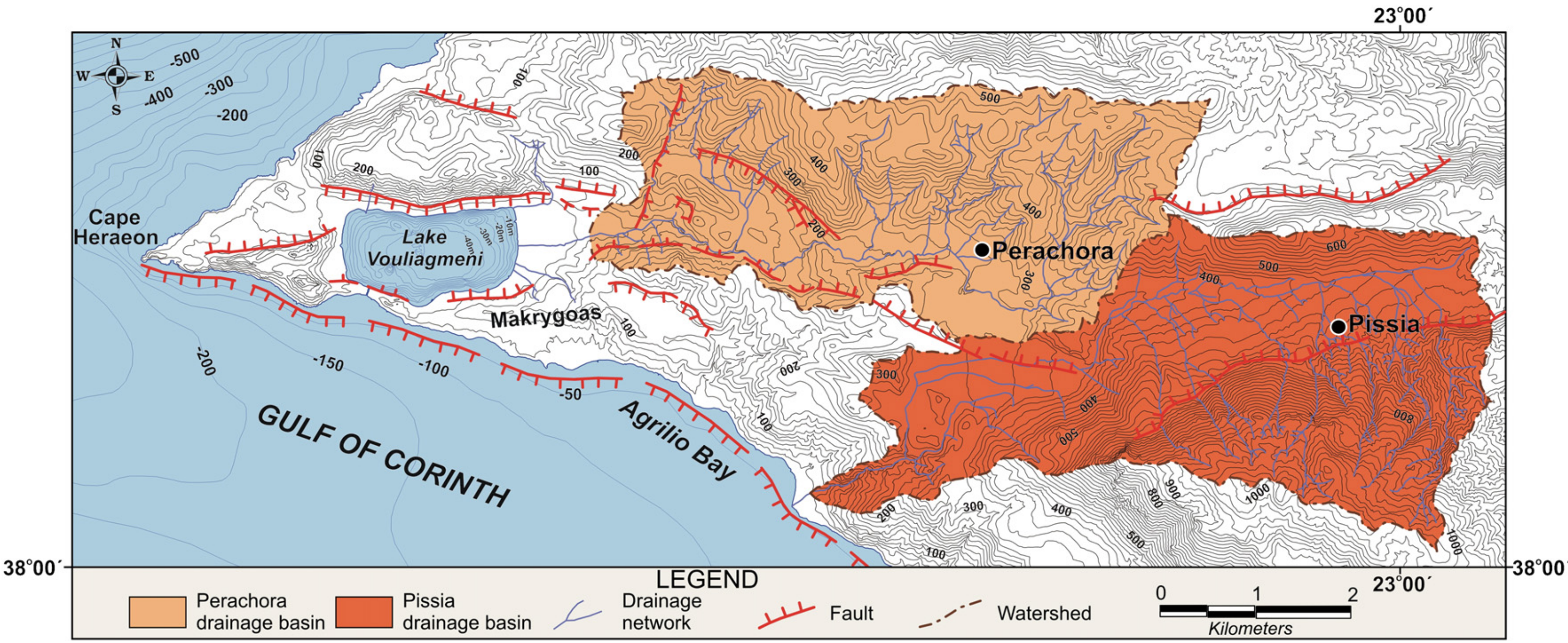

Fig. 4. The drainage systems of Perachora and Pissia. The main faults are also depicted.

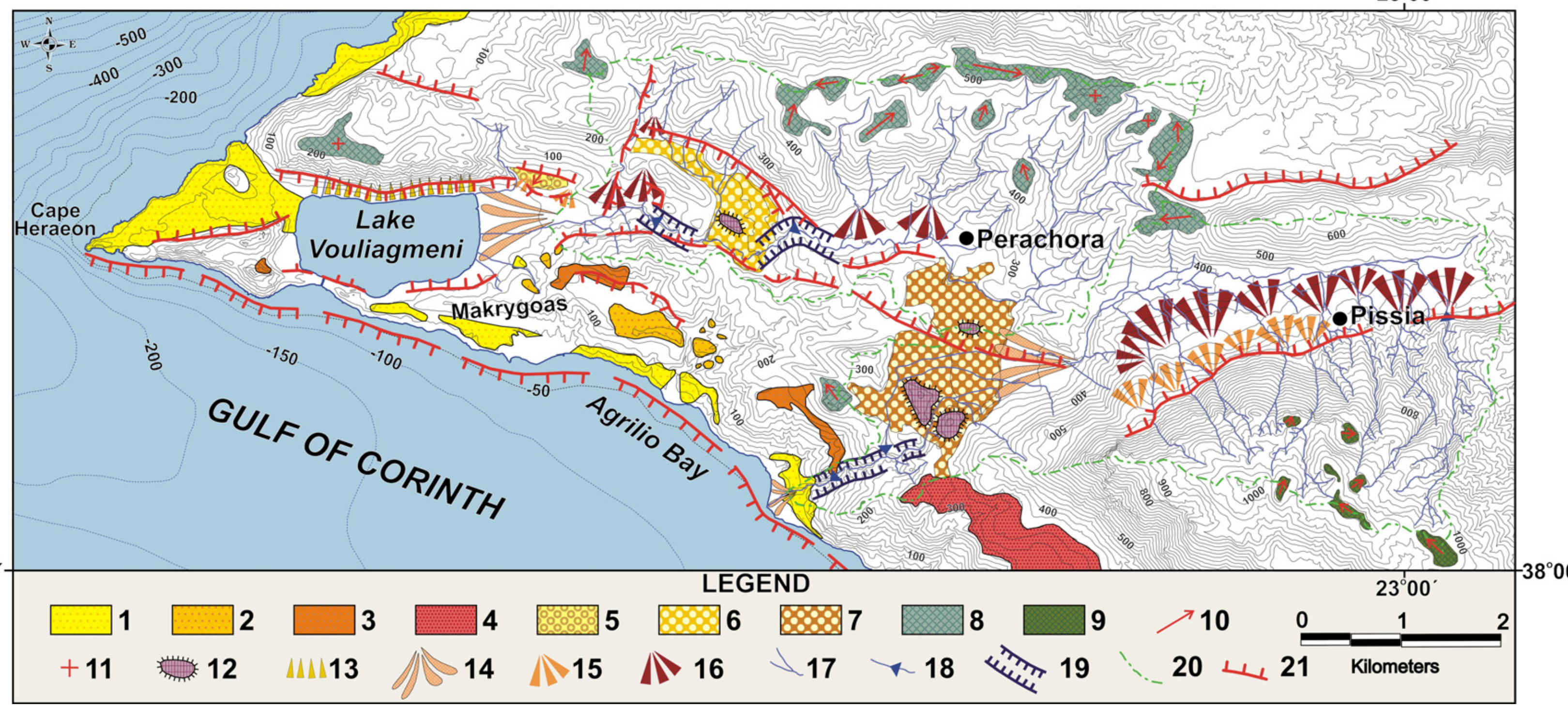

Fig. 5. Geomorphological map of the Perachora and Pissia drainage networks. Legend: 1: marine terrace 1 (35–80 m), OIS:5e, 2: marine terrace 2 (80–120 m), OIS: 7e, 3: marine terrace 3 (120–245 m), OIS: 9c, 4: marine terrace 4 (280–360 m) OIS: 11c, 5: depositional surface (40–50 m), 6: depositional surface (120–160 m), 7: Perachora depositional surface (280–360 m), 8: planation surfaces (200–520 m), 9: planation surfaces (860–1050 m), 10: planation surface dip, 11: horizontal surface, 12: hum, 13: Holocene scree slopes, 14: Late Pleistocene–Holocene alluvial fan, 15: Holocene talus cone, 16: Pleistocene talus cone, 17: drainage network, 18: knickpoint, 19: gorge, 20: watershed, 21:normal fault.

tectonism of the area. Based on the existing earthquake catalogues and relevant work, these catastrophic events occurred in the 20th, 8th, 6th centuries BC, 420, 227 BC, 77 AD, 2nd century AD, 524, 543, 580, 1858, 1887, 1928 and 1981 AD, (Galanopoulos, 1961; Jackson et al., 1982; Vita-Finzi and King, 1985; Makropoulos et al., 1989; Ambraseys and Jackson, 1990, 1997; Guidoboni, 1994; Ambraseys and White, 1997; Maroukian et al., 1997; Papazachos and Papazachou, 1997, Gaki-Papanastassiou et al., 2005).

The correlation of these events with the rupture of particular faults is not possible even for the recent earthquakes. Research associated the earthquakes of 227 BC, the 6th AD century and 1928 with the reactivation of the big offshore fault, located NW of the Perachora Peninsula (Jackson et al., 1982; Ambraseys and Jackson, 1990; Hubert et al., 1996). Evidence also exists that this fault must have been reactivated after the 9th AD century (Gaki-Papanastassiou et al., 1996; Maroukian et al., 1997).

The most recent earthquakes that provided important information about the tectonic movements at Perachora Peninsula are those of 1981, which helped better understand the tectonic regime of the area. These shocks comprised a sequence of quakes and caused heavy damage in the areas of eastern Corinth Gulf. The first two occurred during the night of 4 February at 20:53 GMT and 25 February at 02:35 GMT and the third, 7 days later, on 4 March at 21:58 GMT. As a result of the first two events, surface breaks on the normal faults of Pissia and Alepochori were observed, along the northern coast of the Perachora Peninsula. They extended for about 15 km dipping north, with throws of about 60–70 cm on the average (Jackson et al., 1982; King et al., 1985). Small scale ruptures were also observed at the faults around the study area. The third event, ruptured the south dipping Kaparelli fault at the eastern end of the gulf. Jackson et al. (1982) implied that the Perachora Peninsula had risen as a result of the motion on the submarine fault extending offshore along the NW shores of the peninsula, that was thought to have moved in the first event. Vita-Finzi and King (1985) reported that the peninsula sank as this fault did not move. Along the southern coast of the peninsula the subsidence was of the order of 0.2 to 0.3 m. Almost 10 years later, Pirazzoli et al. (1994) maintained that the coastal zone showed no evidence of significant perturbation. Hubert et al. (1996) indicated that the subsidence in the region was probably much less than the changes reported, and by modelling the vertical motions associated with the first two events showed that they were produced by rupture of the two on-land faults, Pissia and Alepochori faults, located north of Mount Gerania and not with the activation of the submarine fault extending offshore Perachora. More precisely, they concluded that the first shock was considered to have moved the southern fault and the second event the northern one (Fig. 2).

Collier et al. (1998) performed palaeoseismological trenching at the western end of Alepochori fault and deduced average recurrence intervals of strong earthquakes every 330 years for the last 2000 years, accompanied with vertical displacements of 0.7–2.5 m. The same rates for strong earthquakes in this area were also suggested by Vita-Finzi and King (1985), while Pirazzoli et al. (1994) proposed that uplift movements have occurred in increments of 0.8±0.3 m with return periods of the order of 1600 years, during the Holocene.

4. Geomorphological analysis

The major drainage networks which drain the southwestern part of the Perachora Peninsula are two: the Perachora drainage network located in the central part of the peninsula flowing west and the Pissia fluvial system draining to the southwest (Fig. 4).

Geomorphological mapping was undertaken at a scale of 1:5000 in the two drainage basins (Fig. 5). This work included the determination of features such as gorges, knickpoints, alluvial fans, talus cones, hums (residual limestone hills), depositional surfaces and planation surfaces. Additionally, longitudinal profiles of the main stream channels were drawn and the rivers were divided into sections according to the slope of each channel. Furthermore, hypsometric curves of the two drainage basins were also constructed.

4.1. Perachora drainage network

The Perachora drainage basin has an area of 12.36 km^2, is elongated with an east–west orientation reaching an elevation of 558 m at its eastern end (Fig. 6). The shape of the basin is influenced by the fault pattern of the broader area. The main characteristic of this drainage network is the strong asymmetry. At the northern part of the basin it comprises many rejuvenated streams which join the main channel at almost right angles. In contrast, there are only a few, short, low order streams south of the main stream channel. The main channel has a total length of 9.44 km. Initially it flows in a NNE–SSW direction for 2.86 km and then it abruptly turns to the west and empties into the Lake Vouliagmeni forming at the river mouth a relatively extensive alluvial fan (Fig. 5).

A set of planation surfaces have developed at higher elevations ranging from 200 to 520 m in the northern half of the basin. An

Fig. 6. Panoramic view of the drainage basin of Perachora, showing the depositional surface in the left center and Lake Vouliagmeni in the background.

Fig. 7. Knickpoint K1, with a drop of about 30 m looking downstream.

alluvial depositional surface is located around the village of Perachora at elevations of 280–360 m.

Two knickpoints, the first one (K1) ranging between 80 and 110 m (Fig. 7) and the second one (K2) ranging between 140 and 160 m (Fig. 8), are located 1.93 and 3.76 km upstream from the mouth.

Downcutting is especially intense at parts of the main channel forming up to twenty-meter deep gorges. The longitudinal main channel profile can be divided into six main sections (Fig. 9): The first one near the river mouth has a 3.9% mean slope. The second section has a 24.2% slope which corresponds to the first knickpoint (K1). The third has a 4.4% mean slope and corresponds to the part of the stream between the two knickpoints. In this section the river crosses an alluvial depositional surface between 120 and 160 m. In the fourth section, the mean channel slope increases to 17.4% for a distance of about 230 m. Here the river crosses a fault scarp forming the second knickpoint (K2) and a gorge. The fifth section has a mean slope of 3.6% and flows over a second alluvial depositional surface, that of Perachora village, at 280–360 m. The last mountainous section comprises a mean slope of 11.5%.

4.2. Pissia drainage network

The Pissia drainage network drains an area of 13.93 km^2. Its drainage basin is elongated with an E–W orientation and reaches the elevation of 1057 m at its southeastern end. The basin is controlled by E–W trending faults.

The total length of the main stream channel is about 11.03 km. It maintains a N flow-direction for about 3.0 km and then follows an E–W direction for 3.24 km. Its flow changes to NE–SW 7.69 km before reaching the river mouth. It empties into the Gulf of Corinth where a small alluvial cone has developed.

Planation surfaces are located at 280 m and higher elevations ranging from 460 to 1050 m.

The most characteristic morphological feature of the basin is the asymmetric development of the drainage network. The southern part consists of almost parallel, much younger than the Perachora network, elongated streams of high gradient with a N flow direction. They have developed on the newly formed slopes of the hanging wall by the reactivation of the Pissia fault. It is noteworthy that there is almost no stream north of the main channel.

The longitudinal main channel profile may be divided into six morphological sections (Fig. 9): The first one near the river mouth, through the alluvial cone, has a 4.1% slope. The second section has a mean slope of up to 22.4% affected by the reactivation of the Loutraki fault. This part is characterized by deep incision. The third one has a 10% mean main channel slope. The fourth is the longest one and comprises a slope of 4.9%. At the lower part of this section the river crosses an alluvial depositional surface, that of Perachora village, which is developed at an elevation of 280–360 m. This depositional surface is also observed along the Perachora longitudinal main channel profile. Therefore, the four upper sections of Pissia drainage system, could have very well been a part of Perachora drainage network. The fifth (41%) corresponds to a knickpoint (K) which is the result of the Pissia fault. Finally, the sixth mountainous section has a slope of 18.1%.

The hypsometric analysis of the two drainage basins (Perachora and Pissia) shows an anomalous evolution. Instead of exhibiting a normal concave shape, they present a convex discontinuous form

Fig. 8. Knickpoint K2, with a drop of about 20 m looking upstream located at the crossing of a fault scarp.

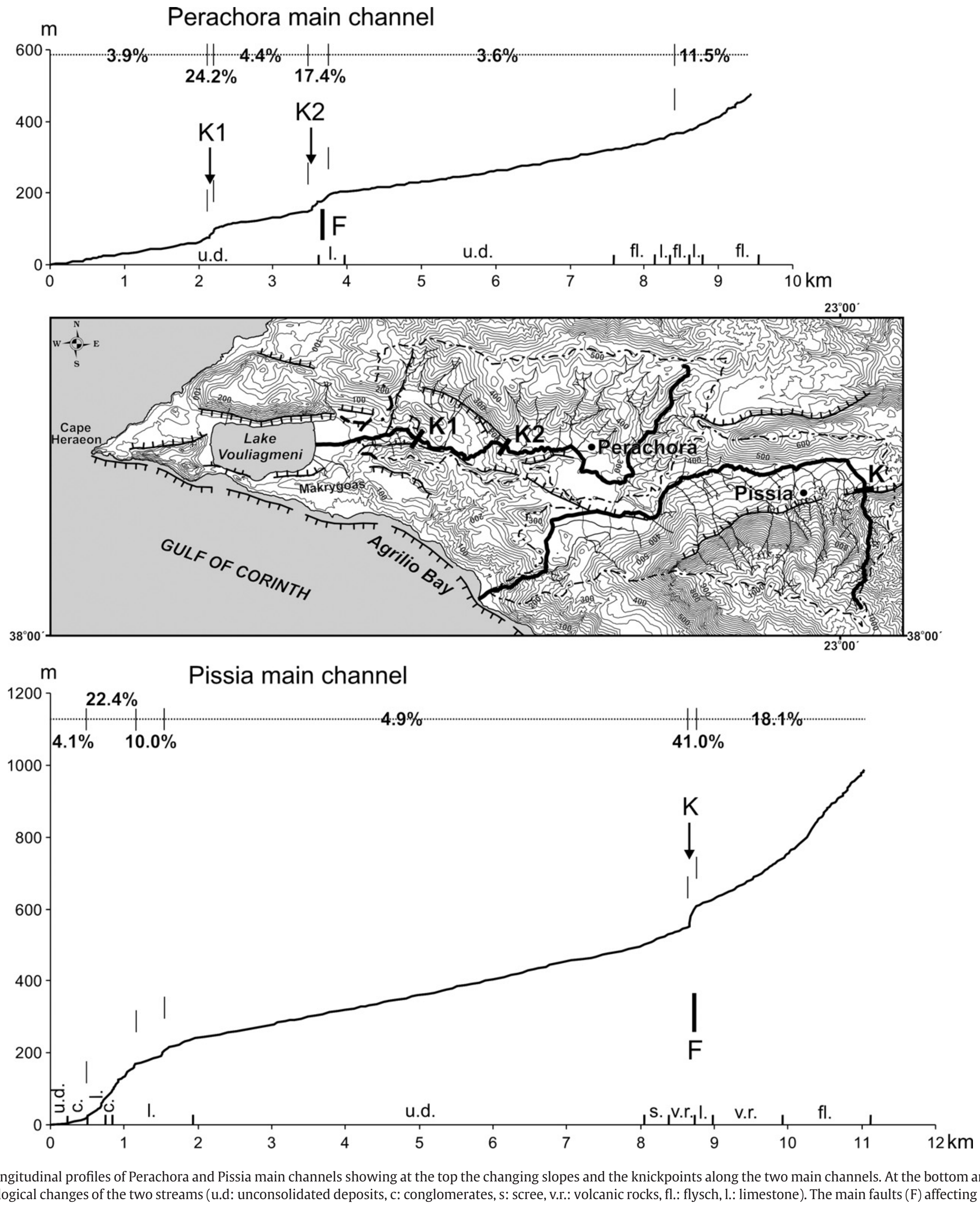

Fig. 9. Longitudinal profiles of Perachora and Pissia main channels showing at the top the changing slopes and the knickpoints along the two main channels. At the bottom are shown the lithological changes of the two streams (u.d: unconsolidated deposits, c: conglomerates, s: scree, v.r.: volcanic rocks, fl.: flysch, l.: limestone). The main faults (F) affecting them are also depicted. K1 and K2 stand for the two important knickpoints of the Perachora main channel and K for the Pissia channel.

(Fig. 10). The curve of the Perachora drainage basin is affected by the presence of two depositional surfaces in the lower half at elevations of 260 and 125 m, the prominent knickpoint at 80 m and the area between the two depositional surfaces in which the higher knickpoint (190–210 m) is located.

Concerning the hypsometric curve of the Pissia basin it also presents a convex form, affected by the occurrence of one depositional surface, a knickpoint at an elevation of 330 m and the area just below the major Pissia fault (460 m).

The hypsometric curve analysis reflects the discontinuous evolution of the topography, especially for the Perachora basin, illustrating the influence of the surrounding main faults.

4.3. Marine terraces

Pleistocene marine terraces have been identified on Perachora Peninsula as well as at other locations in the southern part of the Gulf of Corinth (Vita-Finzi and King, 1985; Keraudren and Sorel, 1987;

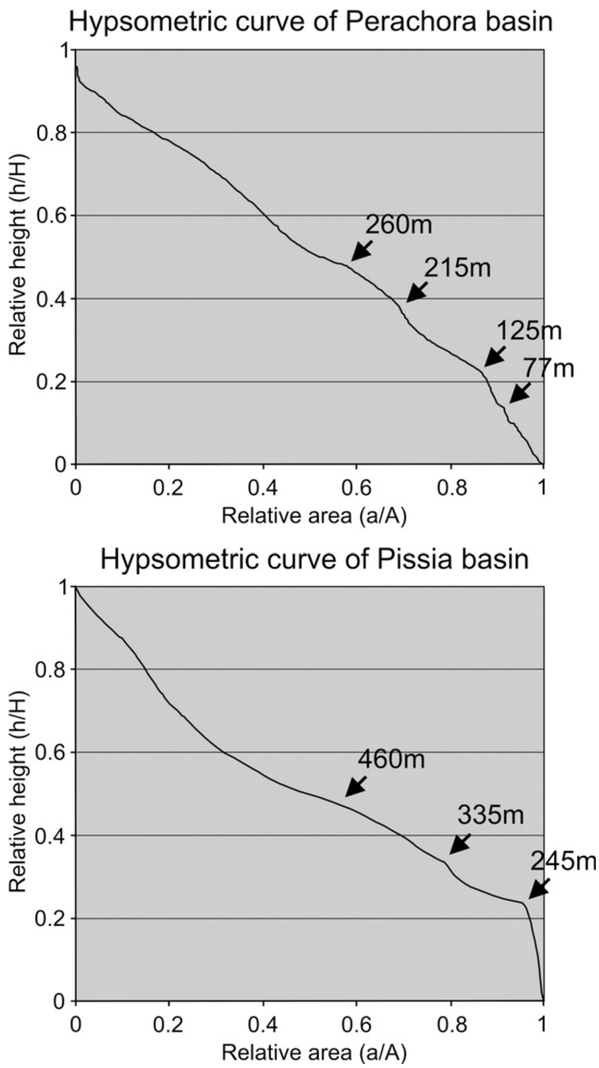

Fig. 10. Hyspometric curves of the Perachora and Pissia drainage basins.

Collier, 1990; Doutsos and Piper, 1990; Collier et al., 1992; Armijo et al., 1996). In the southeastern Gulf of Corinth, Armijo et al. (1996) mapped up to eleven marine terraces and correlated them with Late Pleistocene oxygen-isotope stages of sea-level highstands.

In the Perachora Peninsula, four (4) marine terraces can be distinguished (Fig. 5). The lowest one, Terrace 1, is the most continuous and well preserved. The inner edge is found at elevations ranging from 35 m to 80 m, having an OIS age of 5e (125 kyr) (Morewood and Roberts, 1999). The second (Terrace 2) and the third (Terrace 3) are located at elevations between 80–120 m and 120–245 m and correspond to the OIS 7e (240 kyr) and 9c (330 kyr) respectively (Morewood and Roberts, 1999). In this study, a fourth, higher and older terrace, has been recognized around the area of Perachora village at elevations 280–360 m to which the OIS stage 11c is assigned (400 kyr). In the drainage basin of Perachora, marine terrace 1 (OIS 5e) and 2 (OIS 7e) correspond to the first knickpoint (K1) while the second (K2) can be related to terrace 3 (OIS 9c).

All the terraces are tilted towards the west. The oldest one, occupying higher elevations, could be attributed to the cumulative uplift action of the Pissia and Loutraki faults. More specifically, in the area east of Lake Vouliagmeni, the inner edge of Terrace 1 shows a difference of 45 m in elevation (80–35 m), for Terrace 2 the elevations of the inner edge vary between 120 m and 80 m showing a difference of 40 m, while Terrace 3 occurs between 245 m and 120 m (125 m difference in elevation). In the case of terrace 4 the difference is 80 m (280–360 m). In the area of cape Heraeon, the younger terrace reaches higher elevations in comparison to the same terrace east of Lake Vouliagmeni. This could be explained by the combined action of the offshore Xylokastro and Loutraki faults. The older terraces are more tilted due to cumulative deformation.

5. Discussion

Based on all the previously presented observations, it becomes evident that the two drainage networks have been affected not only by local but also by regional tectonics. The Pissia fault has played an important role in the evolution of the networks studied. The two main offshore faults of Xylokastro and Loutraki have affected the coastal and fluvial environments in the form of marine terraces and palaeosurfaces with knickpoints. The presence of two important knickpoints at 80 m and 180 m and two gorges in the lower parts of Perachora drainage network is the end product of previous coastlines corresponding to Oxygen Isotope Stages 5e, 7e and 9c (125, 240 and 330 kyr respectively). The analysis of the hypsometric curve verifies two depositional surfaces, one at Perachora village (280–360 m) and a second one between the two knickpoints at 120 and 160 m. The Perachora one should be related to the sea level highstand of OIS 11c, 400 kyrs old and the second depositional surface to the 7e highstand, 240 kyr old. The most recent Tyrrhenian sea-level 5e stage corresponds to the apex of the lowest alluvial cone just before reaching Lake Vouliagmeni. Headward erosion has formed the prominent lower knickpoint at 80 m when it reached the hard to erode limestones during the last glacial period and the Holocene.

The two longitudinal profiles of the main channels of Perachora and Pissia streams exhibit different evolutionary trends. We could assign the term “transverse” drainage for Pissia stream as in its lower reaches it has to overcome the uplift of the Loutraki fault, thus acquiring a very convex profile. On the other hand, in the case of Perachora main channel we have a case of “parallel” evolution as the Loutraki fault has the same orientation of Perachora stream to the south. In this case, the changing sea levels in Late Pleistocene and Holocene times have played a significant role in the evolution of Perachora drainage basin.

The two drainage systems exhibit opposing networks. The Pissia network is well developed south of the main channel in the area of the footwall of the Pissia fault, as well as in a part of the hanging wall on which alluvial cones have formed, shifting the main channel to the north. In the case of the Perachora drainage system, things are more complicated as the basin is located in an area where the presence of the two main faults of Xylokastro and Loutraki affect the evolution of the network. The Xylakastro fault is more active (Armijo et al., 1996) uplifting the northern part of the basin where the drainage network has developed, shifting the channel to the south.

Although the Pissia network is not well developed due to the continuous activation of the Pissia fault in recent times, it should be older than the Perachora, because parts of the latter were underwater when sea level reached high elevations during interglacial period 11c (Fig. 11). This is the fourth sea-level highstand which formed the highest marine terrace located around today's village of Perachora. The geomorphological map depicts this terrace as depositional because it is covered by fluvial-torrential deposits. However, this marine terrace extends to the SE towards Loutraki, where it is well defined due to the absence of fluvial action.

Evidently, the Perachora Peninsula has a complex morphological evolution owing to the presence of two main offshore fault systems (Xylokastro and Loutraki) which formed the marine terraces and planation surfaces but also to the secondary inland faults (Pissia and Alepochori) which locally affect various landforms such as depositional surfaces and knickpoints.

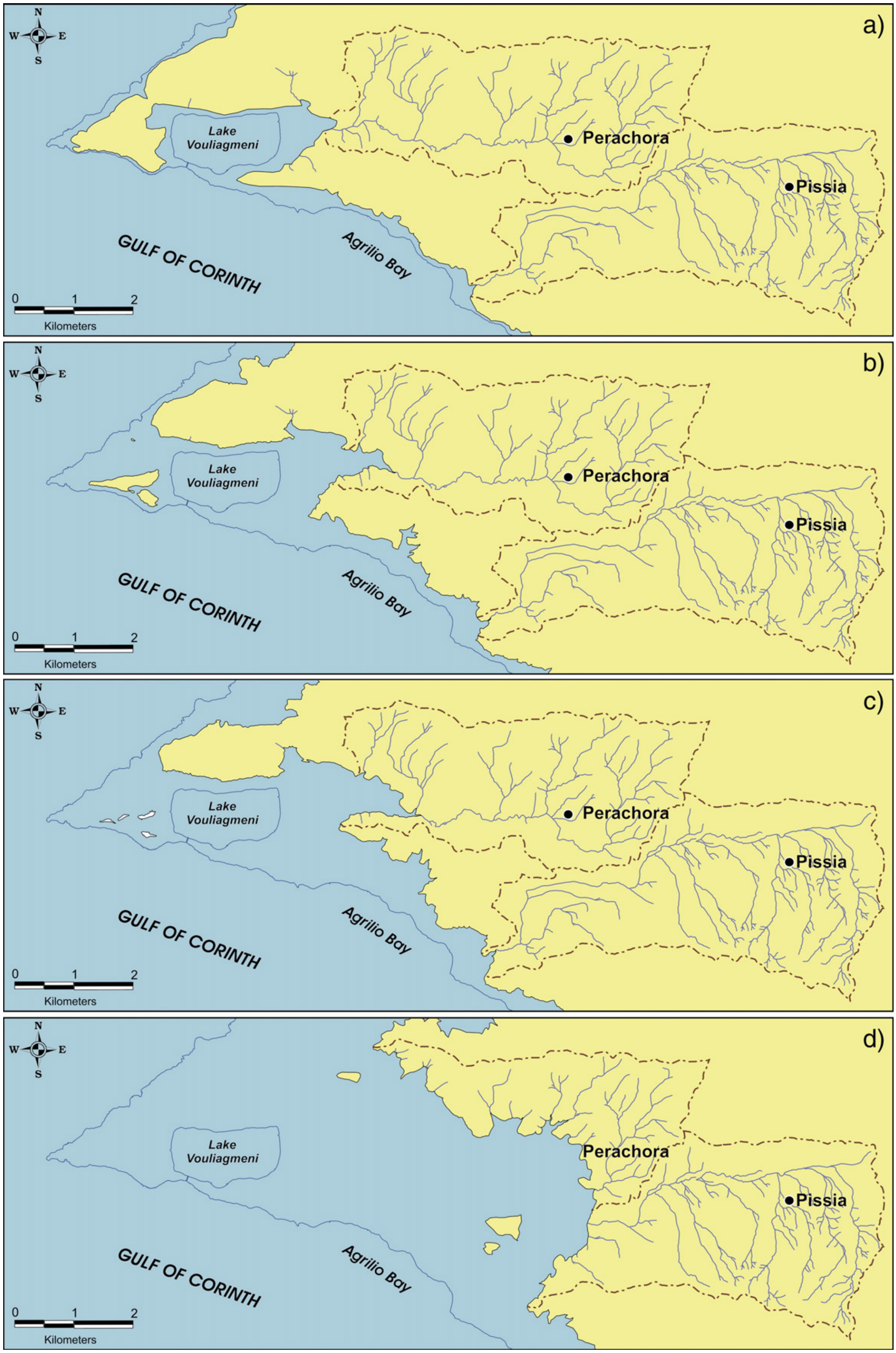

Fig. 11. Palaeogeographic evolution of the study area during the Late Quaternary high sea level stands OIS 5e (a), 7e (b), 9c (c) and 11c (d). Figures a, b and c are based on Morewood and Roberts (1999), while d is derived from the present work showing the coastline 400 kyr ago (OIS 11c). In all figures, today's shoreline is depicted with a solid line.

6. Conclusions

Summarizing the results of this study, the following conclusions are obtained:

- The two major drainage systems were primarily affected by regional and local tectonism and secondarily by eustatism.
- Besides the previously recognized three marine terraces, in this study a fourth higher and older one, at elevations of 280–360 m having an age of 400 kyrs (OIS 11c) was identified.
- The two drainage networks display different evolutionary development. The Perachora system has a “parallel” evolution along the Loutraki fault, while the Pissia has a “transverse” trend. The upper part of the Pissia network could have been part of the Perachora drainage basin in the recent geologic past.
- The lower parts of both drainage systems are much younger than their upper mountainous parts.
- The severance of Perachora drainage network from the sea occurred during the last glacial period.

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