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GEOLOGICAL STRUCTURE OF INNER MESSINIAKOS GULF.

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ABSTRACT

Detailed geophysical survey carried out in the Inner Messiniakos Gulf resulted in the distinction of the tectonic structures and of the morphological features which influence the modern sedimentation. The consideration of all the new data permits the understanding of the active geodynamic processes at this basin located at 50-80 km from the Hellenic trench. Three major fault zones subdivide the inner gulf in five tectonic blocks each with its own differential motion. This is best illustrated by the disruption of the Holocene continental shelf. The deformation is limited in the northeastern part of the gulf which is rigorously uplifted by several hundreds of meters producing an unstable sea-bottom morphology.

In contrast, the western part is relatively non deformed with slight inclination of the basin and the strata to the East creating an assymetry of the gulf along the NW-SE direction. The whole movement in the gulf showes a considerable tilt towards the East-Northeast and some minor towards the south. This structure is maintained throughout the "neotectonic" period (Late Miocene - Present) in the gulf and is similar to that described on land at the sedimentary basins of Kalamata and Kyparissia.

ΣΥΝΟΨΗ

Λεπτομερής γεωφυσική διασκόπηση που έγινε στον Ανω Μεσσηνιακό Κόλπο επέτρεψε τον εντοπισμό των κύριων τεκτονικών δομών και των γεωμορφολογικών χαρακτήρων που αλληλοεπηρεαζόμενοι επιδρούν στην σύγχρονη ιζηματογένεση.

Το σύνολο των νέων στοιχείων επιτρέπει την κατανόηση των ενεργών γεωδυναμικών διαδικασιών στη λεκάνη αυτή που απέχει μόλις 50-80 Km από την Ελληνική τάφρο. Τρεις κύριες ρηξιγενείς ζώνες διαιρούν τον Ανω Μεσσηνιακό σε πέντε ρηξιτεμάχη, το καθένα από τα οποία έχει την δική του διαφορική κίνηση. Τούτο φαίνεται πολύ χαρακτηριστικά από τον κατακερματισμό της ολοκαινικής ηπειρωτικής τράπεζας. Η παραμόρφωση περιορίζεται στο βορειοανατολικό τμήμα του κόλπου το οποίο ανέρχεται σημαντικά κατά αρκετές εκατοντάδες μέτρων προκαλώντας αστάθεια στον υποθαλάσσιο πυθμένα. Αντίθετα, το δυτικό τμήμα είναι σχετικά απαραμόρφωτο με ελαφρά κλίση και της υποθαλάσσιας κλιτύος και των υποκείμενων στρωμάτων προς τα Ανατολικά προκαλώντας έτσι μια ασυμμετρία κατά τον άξονα ΒΔ-ΝΑ. Η όλη κινηματική του κόλπου δείχνει μία εξαιρετικά σημαντική στρέψη προς τα Ανατολικά-Βορειοανατολικά και μία μικρότερη προς Νότο. Η δομή αυτή υπάρχει και εξελίσσεται καθόλη τη "νεοτεκτονική" περίοδο (Ανω Μειόκαινο-Σήμερα) στον κόλπο και είναι αντίστοιχη της δομής των μεταλπικών λεκανών Καλαμάτας-Κυπαρισσίας στην ξηρά.

ΠΑΥΛΑΚΗ, Π., ΠΑΠΑΝΙΚΟΛΑΟΥ, Δ., ΧΡΟΝΗ, Γ., ΛΥΚΟΥΣΗ, Β. & ΑΝΑΓΝΩΣΤΟΥ, Χ. - Γεωλογική δομή του Ανω Μεσσηνιακού Κόλπου.

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1. INTRODUCTION

Immediately after the destructive earthquakes of Kalamata (September 1986) an oceanographic research was undertaken by the National Centre for Marine Research in collaboration with the University of Athens, financed by the Earthquake Planning and Protection Organization aiming to find out the active faults within the gulf and possibly also to detect submarine evidence for activation during the earthquakes. The research was carried out with the newly built O/V "Aegaio" mainly during October 1986. Additional shots have been operated during the summer period of 1987.

A dense grid of seismic reflection lines (Fig. 1a) especially in the area of the Inner Messiniakos Gulf permitted us to map various geological features and to compile a submarine neotectonic map of Inner Messiniakos Gulf (see also PAPANIKOLAOU et al, 1988). Air gun of 10 cubic inches as seismic source and a single channel reflection unit for recording were used. Precise positioning was achieved by using radar fixes every 5 minutes. In addition, high resolution echosounder was used to enable the construction of a precise bathymetric map.

2. THE MORPHOLOGY OF THE GULF

The data collected during our cruise, together with those previously existed, permitted us to compile a bathymetric map with 50 m contours interval (Fig. 1). The greatest depths, 900-1100 m, are observed close to the eastern coast and parallel to it and especially south of the Kitries peninsula.

The morphology of the gulf is rather simple comprising one assymetric basin with NNW-SSE direction. The lower parts of the basin delineate the main channel of the submarine valley system which divides the gulf in a broad rather homogeneous western part with standard gradients from a more complicated eastern part with varying gradients of slope-morphology. The distance of the main channel from the western coast ranges from 10-15 Km whereas from the eastern coast only 5-8 Km.

This assymetry is observed beyond the 100 m contour isobath which is close to the edge of the continental shelf in the area caused by the Holocene transgression.

A mean slope morphological map of the gulf was also obtained by analysing the morphological data (Fig. 2). The sea-bottom morphology was distinguished in three categories as far as the values of mean slope are concerned:

a) Flat areas where mean slope values are very low (less than 5%). These areas are of two types occuring at shallow and great depths respectively. a_1) The shallow area corresponds to the continental shelf and it is found at depths smaller than 110 m in average. It is the result of the Holocene transgression over the denudaded, during upper Pleistocene, coastal areas of the Messiniakos Gulf. Holocene practically horizontal strata occur all over this flat area. The width of this flat area differs around the coast of Messiniakos. In the west it is about 4-5 Km whereas in the east it is only 1.5-2 Km and especially along the coast of Kitries peninsula it is practically missing. Intermediate width is observed along the northern coast. a_2) The deep area with flat morphology is following the bottom of the Messiniakos basin on both sides of the main channel. It is observed from depths of about 300 m SSW of Kalamata port until depths higher than 1100 m at the exit of the channel towards the outer gulf. The width of this basinal flat area is growing southwards with about 3 Km in the North and more than 12 Km in the South. This deep flat area is characterized by the accumulation of alluvial subhorizontal sediments. b) Moderate slope areas where mean values range between 5-20%. They are found usually all around the gulf as an almost continuous zone forming an amphitheatre and bridging the previously described two flat areas a_1 and a_2. The boundary of this zone of moderate slope values with a_1 is abrupt forming a slope discon-

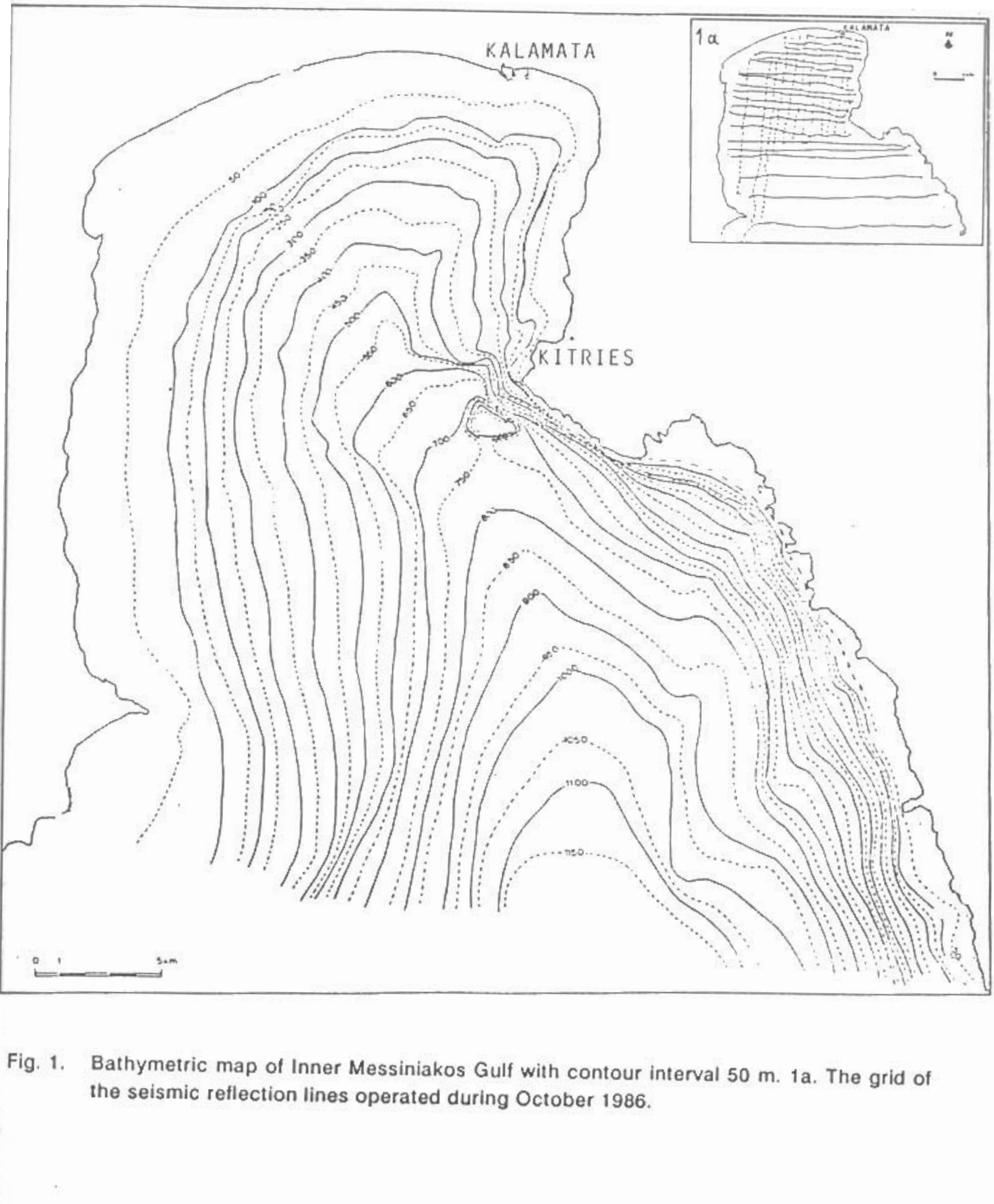


Fig. 1. Bathymetric map of Inner Messiniakos Gulf with contour interval 50 m. 1a. The grid of the seismic reflection lines operated during October 1986.

tinuity with local values of 15-60%. On the contrary the boundary with a_2 at depth is smooth and slope values gradually decrease from 10 to 5%.

c) Cliff areas where mean slope values range between 20-80% with locally much higher values. This high slope areas form a zone of NW-SE direction along the Kitries coastline. The result is a dramatic change of sea-bottom morphology from 100 m to 950 m within a distance of 1,5 Km. Another area where submarine cliffs are observed occurs at the exit of the gulf to the SE of Koroni. The direction of this zone is NNE-SSW and it comprises slope values of about 40%.

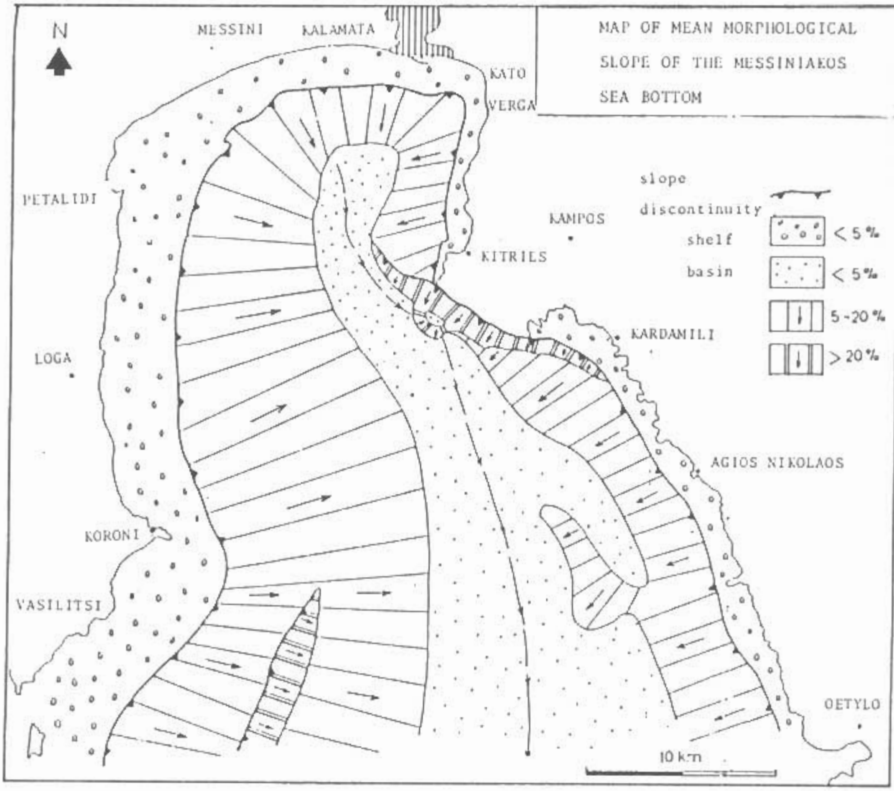
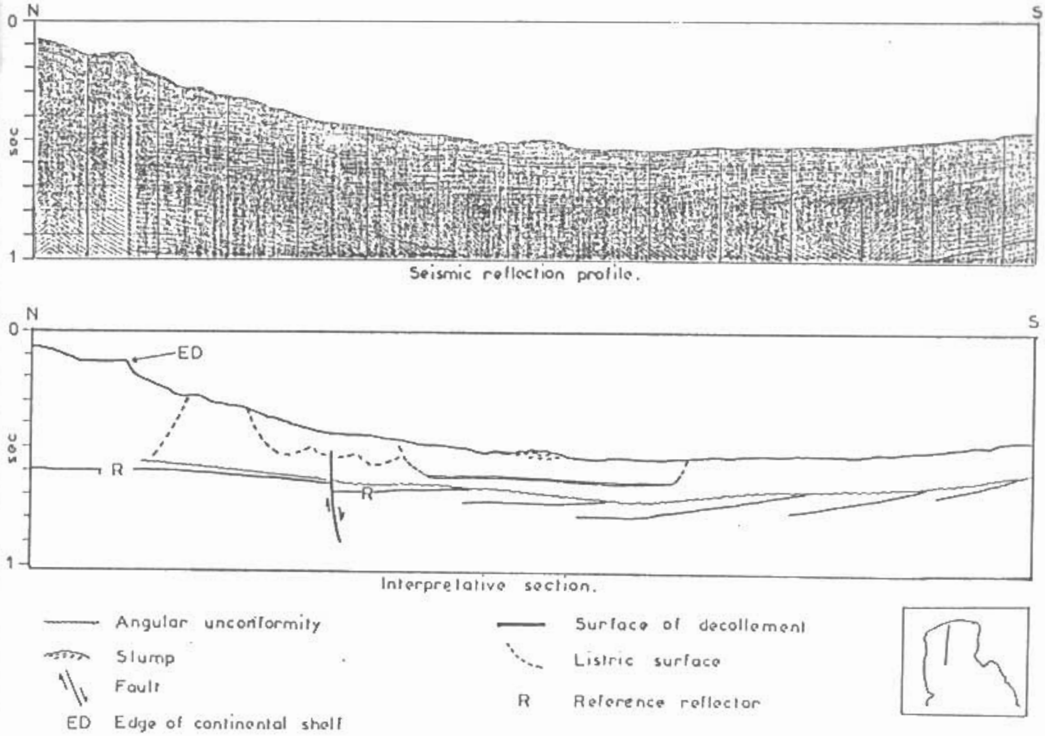


Fig. 2. Morphological mean slope map of the inner Messiniakos Gulf.

3. SEISMIC REFLEXION INTERPRETATION AND LOCATION OF FAULTS

The detailed survey allowed us to find out that the alpine basement has been subsided at great depths below sea bottom and has been covered by several hundred meters of post-alpine sediments. Although the seismic wave penetration reached 500 m and sometimes even more only in very limited areas the basement has been detected and especially at the area of Kitries peninsula. The non existence of the major unconformity between alpine basement and post-alpine sediments hardens the estimation of the faults' throw. However, from dynamic viewpoint it is extremely interesting to know that the basement occurs at -1500 m of elevation.

The sediments are probably unconsolidated, judging from their reflection character, and can be distinguished in two sequences separated by an angular unconformity (reflector R on Fig. 3). This reflector R occurs almost everywhere in the inner Messiniakos gulf usually at depths between 300-500 m and can thus be used as a reference level for the estimation of the displacements along the various fault zones. Tha main faults detected in the gulf are shown on Fig. 4 where the estimation of the throw in m is usually based on this reflector R.



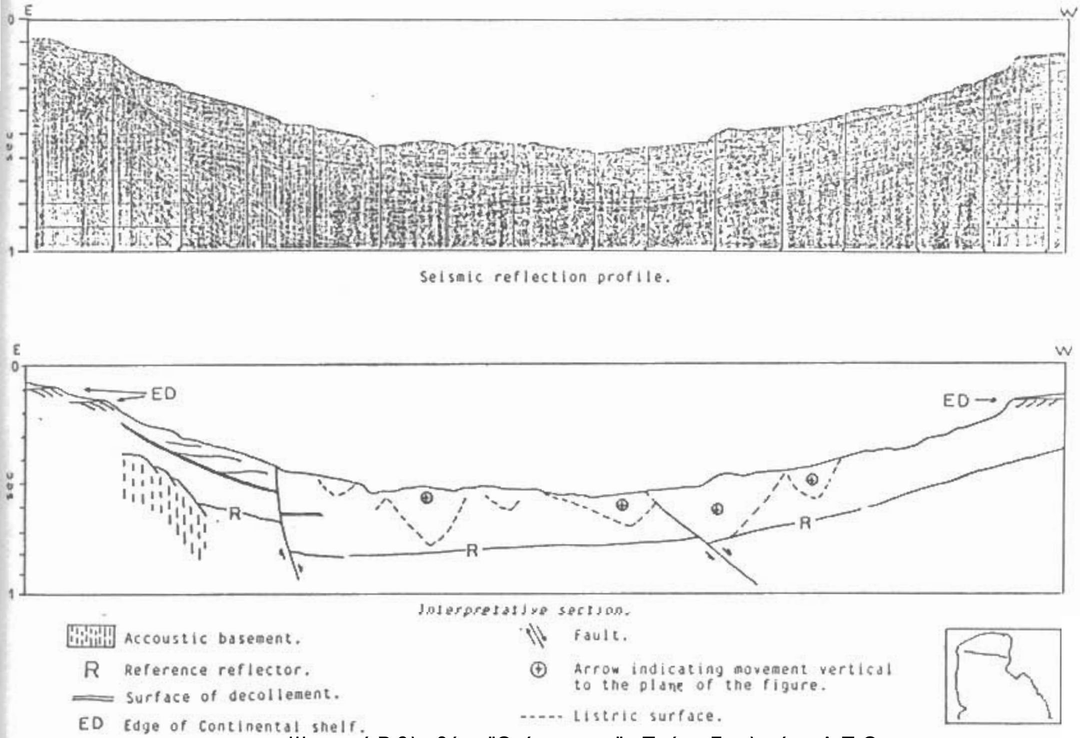


Fig. 3. Representative E-W profile of inner Messiniakos Gulf.

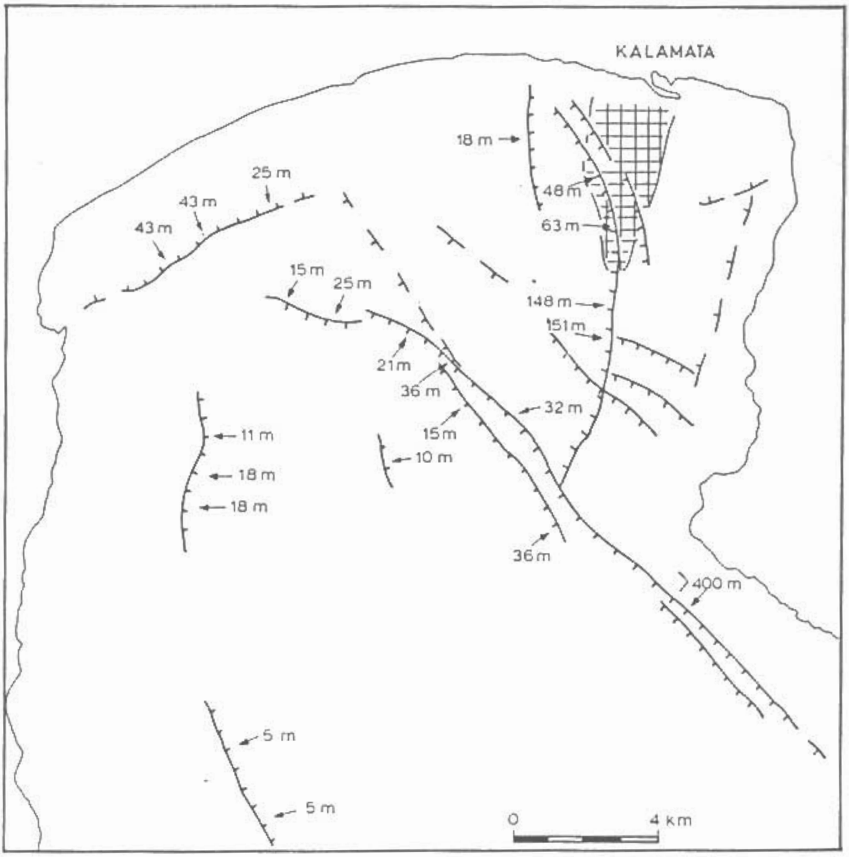


Fig. 4. The detected faults within the Inner Messiniakos Gulf.
- fault and its probable prolongation with barb on the subsided block.
15 - locality where the fault throw has been calculated in m.
- zone of recent surface rupture probably due to the earthquake of September 1986.

The detected faults are considered as normal faults with indication of the relative vertical motion. However, it should be kept in mind that the possibly existing horizontal component of the slip can not be determined. Thus, some of the faults may in fact be oblique-slip or even strike-slip faults. All the faults shown on the map have cut the post-alpine, plioquaternary in age, sedimentary sequence and most of them definitely cut also the Holocene sediments reaching up to the sea bottom. Thus, these faults can be considered as active or probably active faults! The distrimination of their importance is based on their length (1 to more than 40 Km) as well as on their throw. Since these faults are synsedimentary structures they are in fact growth faults and their throw is increasing downwards.

*The greatest fault is oriented in the NW-SE direction striking parallel to the coastline of Ki*tries peninsula. It has produced a relative subsidence of the SWrn block of more than 400 m. This movement is responsible for the abrupt submarine cliff topography previously described and also for the non-existence of the shallow flat area a_1 representing the continental shelf.

Two more fault zones are important in the gulf; one striking N-S observed immediately south of Kalamata with more than 12 Km length and another striking ENE-WSW observed at the NWrn part of the gulf with more than 7 Km length.

The N-S fault zone at the NErn part of the gulf is running parallel to the eastern coastline and is characterized by an increase of the throw from 48 m in the North to 151 m in the south. The same increase of throw towards the SE is observed also along the main fault of NW-SE direction which towards its northwestern prolongation has throw values of only a few decades of meters. A representative seismic profile of NW-SE direction cutting across both major fault zones of NE Messiniakos gulf is given in Fig. 5.

It is noteworthy that at the shallow area south of Kalamata a peculiar microfracture zone was observed. on the sea bottom by the precise recording of the echosounder (Fig. 6). This sea bottom fracture zone coincides with the northern edge of the N-S fault zone previously described and has to be correlated with the seismic activity of September 1986. This interpretation is supported by the fact that the recording was taken only a few weeks after the earthquakes in October 1986 and that these fractures can not be attributed to slump movements because they occur on the continental shelf. Finally, it is interesting that the fault plane solution of the September 1986 Kalamata earthquake showed a NNW-SSE fault direction (DELIBASIS et al, 1987) which is compatible with our observations.

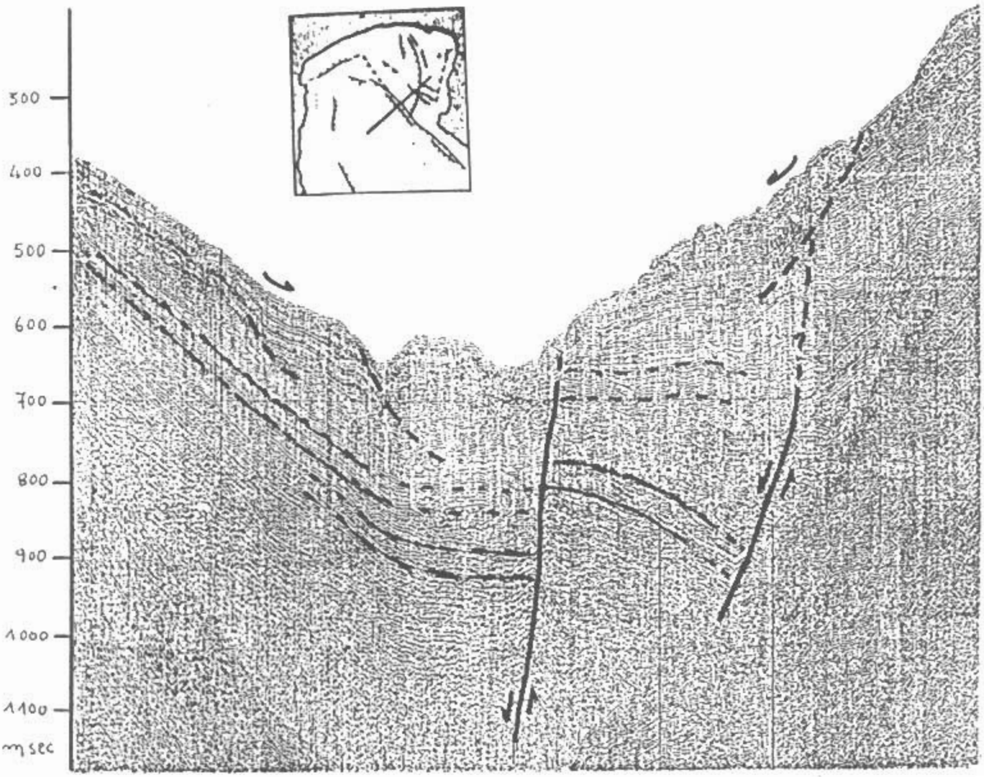


Fig. 5. Seismic profile across the two major fault zones NW-SE and N-S taken during July 1987.

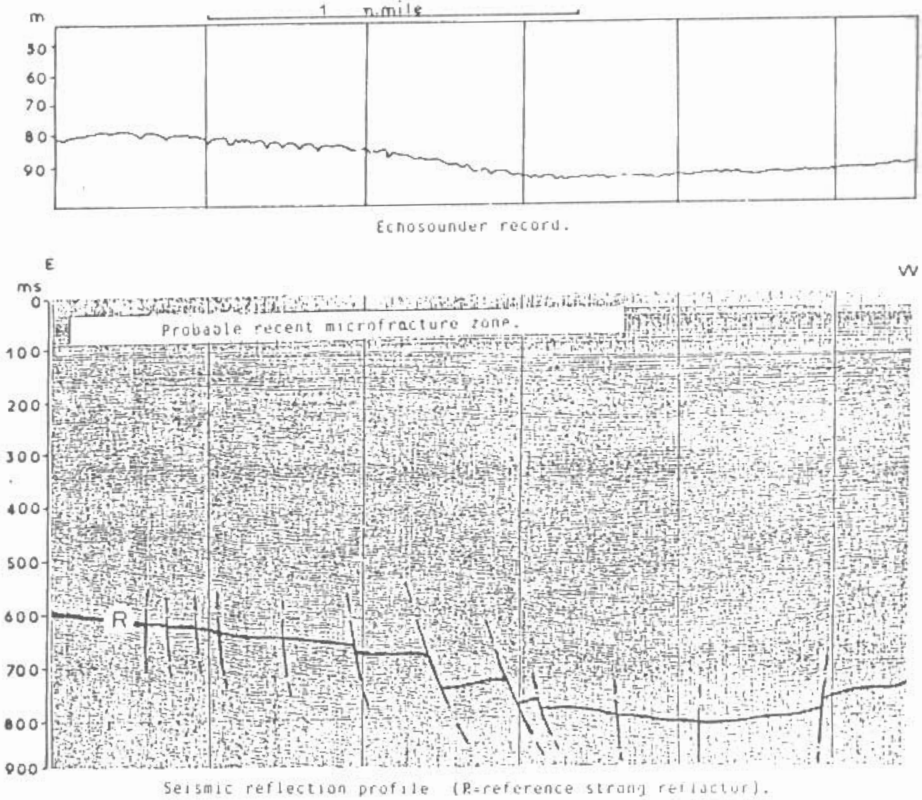


Fig. 6. The echosounder record and the seismic profile immediately south of the harbour of Kalamata showing the recent fracture zone on the sea-bottom corresponding to the N-S faults at depth.

4. THE DEFORMATION OF THE CONTINENTAL SHELF

The quantitative estimate of deformation as well as the discrimination of the major active faults is highly facilitated when a reference level of known age is used.

In the Inner Messiniakos gulf we choose as such reference level the edge of the continental shelf. This line represents the edge of the nearly horizontal surface of the Holocene transgression over the pre-holocene paleocoast. The Holocene transgression, is generally accepted, to have occured in the Mediterranean about 14000 years ago. This was due to the last glacier melting, resulting to a rise of the sea level approximately 100 m from the level of the last glacier period. Therefore, without the influence of anyother cause (primary e.g. tectonism or secondary e.g. slumping) the present-day level of this horizon has to be at a constant depth. This depth in the Mediterranean Sea is usually about 110-120 m.

A detailed investigation of the depth of this edge established the results shown in figure 7. On this map it is shown that the continental shelf has been disrupted into at least 5 blocks. Each of them is characterized by different depth of the edge. All over the western coast of the gulf, from southeast of Koroni until northeast of Petalidi, the edge lies at a constant depth of 107 m. This area has been taken as the reference tectonic block 1. The edge at the next area northwards is

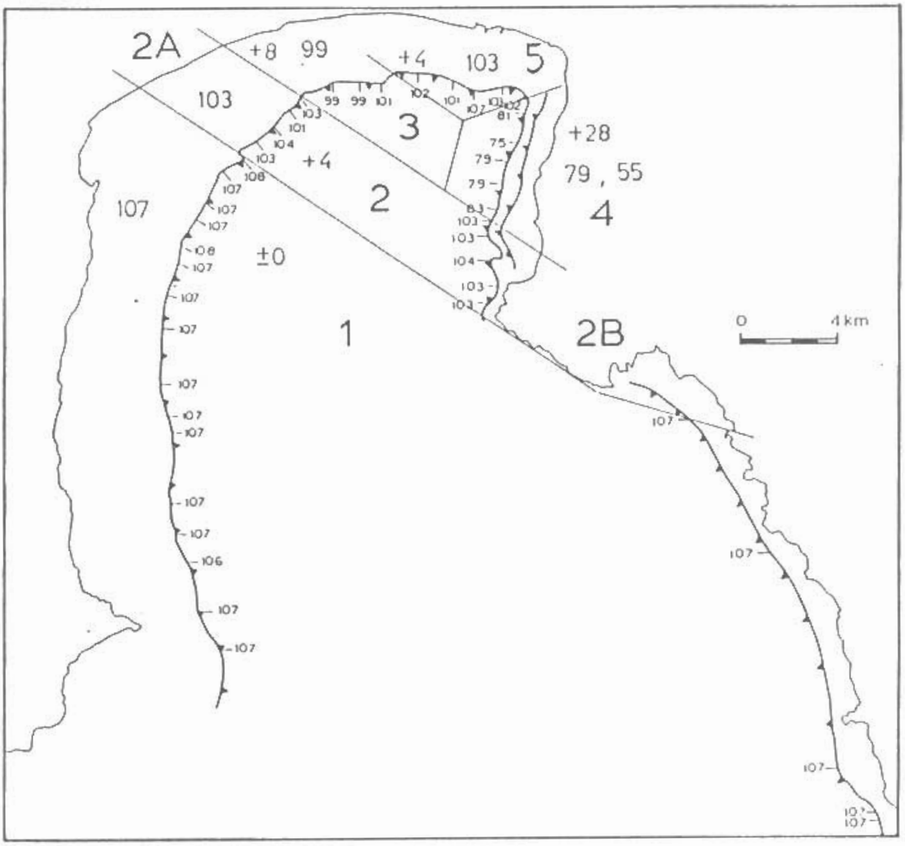


Fig. 7. The measured points of the depth of the continental shelf arount the Inner Messiniakos Gulf and the resulting blocks with differential vertical motion during Holocene.

characterized by 103 m depth just as its opposite coast at the northwestern edge of Kitries peninsula. This area represents the tectonic block 2 which has been elevated 4 m relatively to block 1.

The next area at the northern central park of the gulf represents the tectonic block 3. In this block the edge of the continental shelf lies at a depth of approximately 99m. It implies that it has been elevated 8m in relation to block 1. Further to the east a kind of double submarine terrace appears on the continental shelf. In this case there are two edges. The first one lies at 79m depth, while the second one at 55m. This area represents the tectonic block 4, which has been strongly elevated comparatively to all the rest blocks. If the recent location of the edge of the continental shelf, in this block, is due to pure tectonic movements then this block has been elevated 28m relatively to block 1. Finally the area of the northeastern corner of the gulf around the coast of Kalamata is assigned to the tectonic block 5. Here the edge of the shelf is approximately 103 m deep. This sujests that this block has been subsided in relation to its neighbouring blocks 3 and 4 but it is located at the same depth with the block 2 and elevated with regard to the datum block 1 by 4 m.

The above discrimination of 5 tectonic blocks delineates 4 main fault zones. Each of them seems to have caused vertical motions of several meters with the exception of the tectonic block 4 which shows greater movements, of the order of 28 m.

Regardless the imprecise magnitude of elevation of the tectonic block 4, resulting from the existence of two submarine terraces representing the edge of the continental shelf which are probably separated by an active fault, the result that the northeastern part of the gulf is uplifted relatively to the southwestern part, by 4 to 20m, within the last 14000 years is significant. The maximum of this motion is located at the area of Almiro SSE of Kalamata and it implies an average displacement of the order of 3 to 15 cm per century.

5. STABILITY OF THE SURFACE SEDIMENTS

As we mentioned before, the gulf is suffering from gravity transportation of sediment and slumping movements. The transported mass of sediments appears on the seismic profiles as an area of chaotic reflections. An attempt to map the surfaces of these movements, showed that their stereographic shape ressembles to spoon like surfaces, probably corresponding to listric surfaces. The greatest of these surfaces could even be characterized as listric faults, but their effect appears to be very limited at depth reaching some distinctive decollement horizons (Figs. 3,5).

The main listric surfaces as well as the major axes of the submarine valley system are shown in Fig. 8. Here we have to mention that the valley system observed at great depths in the gulf is not due to submarine errosion but to fronts of slumping masses. The most of the boundaries of slumping areas coinside or approach to such submarine valley axes.

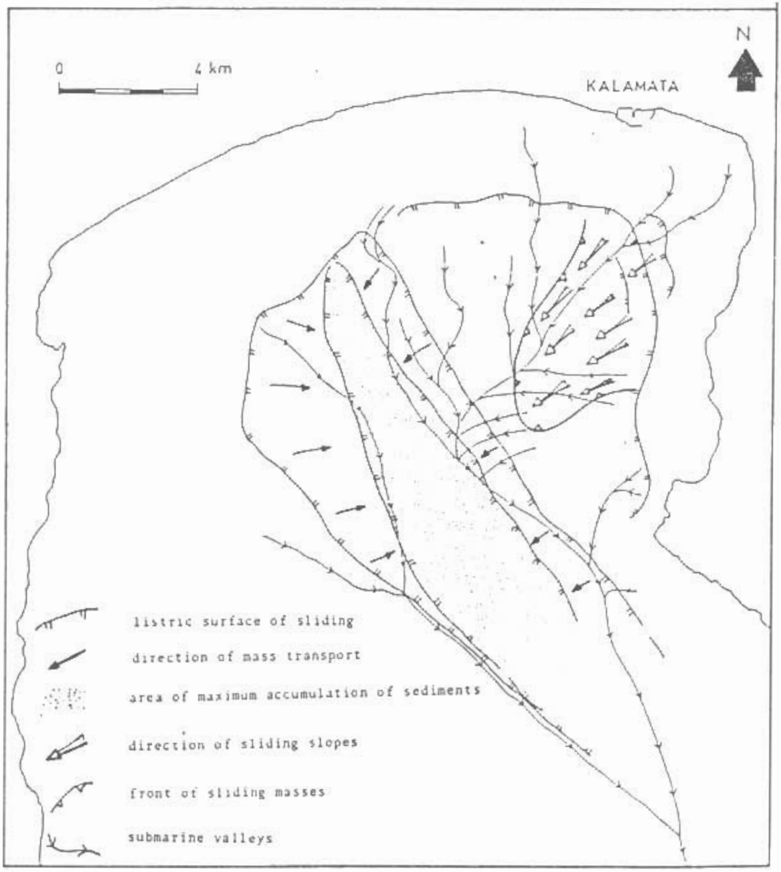


Fig. 8. The submarine valley system and the unstable areas within the Inner Messiniakos Gulf.

The most unstable area as far as the bottom surface sediment is concerned, is located at the northeastern corner of the gulf. Here, a wide tongue-like mass of unconsolidated material is affected by southwestward sliding. On the other hand the greatest concentration of chaotic reflections is located along an elongate basin in the central parts of the gulf, oriented NW-SE. The eastern boundaries of this unstable area are in contact with the major NW-SE fault zone of the region. The greatest depression as well as the greatest sediment accumulation within the gulf seem to happen along the axis of this basin. On the contrary the shallow valley system observed on the continental shelf, particularly at the eastern side of the gulf, (from Kitries until the coast of Verga) is probably the continuation of the ravines observed on land (Xerilas, Kako Lagadi, Mili, Agios Nikitas, etc.). This implies that they were created earlier on land before the Holocene transgression.

6. NEOTECTONIC STRUCTURE OF INNER MESSINIAKOS GULF

The neotectonic structure of the gulf can be illustrated by the projection of all the seismic profiles of the same direction N-S in Fig. 9 and E-W in Fig. 10. These two synthetic profiles can be interpreted as panoramatic projections seen from south and can give a general image of the neotectonic structure because their direction is oblique to the main NW-SE, neotectonic direction of the gulf.

The synthetic profile in the E-W direction (Fig. 9) shows the holocene transgression on both sides of the gulf but mainly in the west and below it a rather assymetric structure with a thick sedimentary sequence of plio-quaternary age dipping with 10-20_o to the East until an oblique running major fault which borders the uplifted alpine basement to the East.

The synthetic profile in the N-S direction (Fig. 10) shows the distinction of an upper shallow basin-graben representing the NE part of the gulf from the main deep basin to the South. The submarine barrier of the NE basin is a tectonic horst created by the uplifted alpine basement which is in fact the submarine continuation of the Kitries peninsula structure. It is characteristic that this NE part is highly disrupted with faults every 300-500 m. At this synthetic profile the Holocene transgression is observed only to the North.

The overall neotectonic structure of the gulf is schematically given in Fig. 11 in the form of a stereo-diagram including most of the submarine features such as faults, sediments, alpine basements, slumps, edge of continental shelf. The general geodynamic process in the gulf is the separation of two major blocks. The western block is relatively non deformed by faults but is subjected to a considerable tilt along a NW-SE axis with rotation towards the ENE. This process is maintained throughout the Plio-Quaternary and produced accumulation of sediments in the centre of the gulf and small unconformities in the western coastal area. The Eastern block comprises in fact more blocks with major characteristic the overall uplift, which is maximum in the eastern part. In this area there is a pronounced unstability with a lot of secondary mass movements towards the west.

Besides the above main rotation there is a smaller similar movement caused by the ENE-WSW striking fault in the NW of the gulf with rotation towards the south. Unfortunately, this fault was not detected in many profiles because it is limited in shallow depths.

The above described submarine neotectonic structure of Messiniakos gulf is similar to that described on land for the basins of Kalamata and Kyparissia by MARIOLAKOS & PAPANIKOLAOU (1982). The same rotations with complex neotectonic block tilting has been produced by the activation of NW-SE faults in Kalamata and Ano Messinia and E-W faults in Kyparissia.

It should be noted that the submarine N-S fault zone south of Kalamata is in fact in the prolongation of the major N-S fault on land separating the basin of Kalamata from the alpine outcrops to the East (Fig. 12).

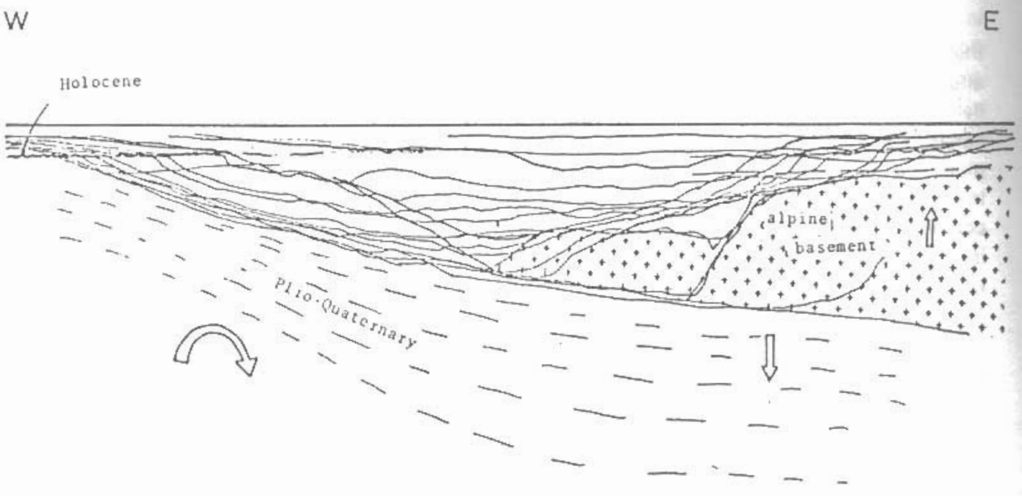


Fig. 9. Panoramatic projection of E-W profiles seen from South. The Holocene uncorfomity and the Eastward tilt of the Pleioquaternary sediments are evident as well as the abrupt uplift of the alpine basement towards the NE.

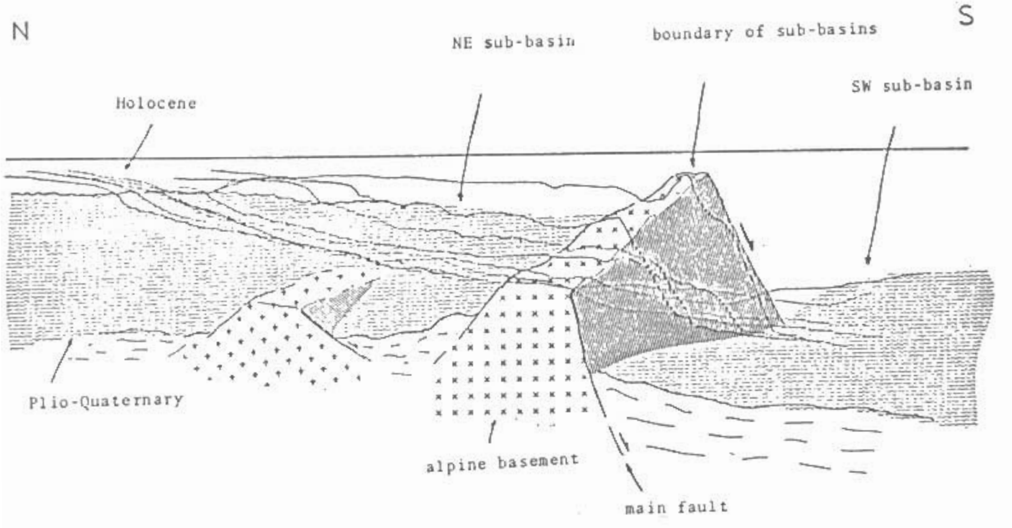


Fig. 10. Panoramatic projection of N-S profiles seen from West. The distinction of the upper shallow sub-basin in the NW from the major deep sub-basin in the SE can be easily made by the tectonic horst of the uplifted alpine basement.

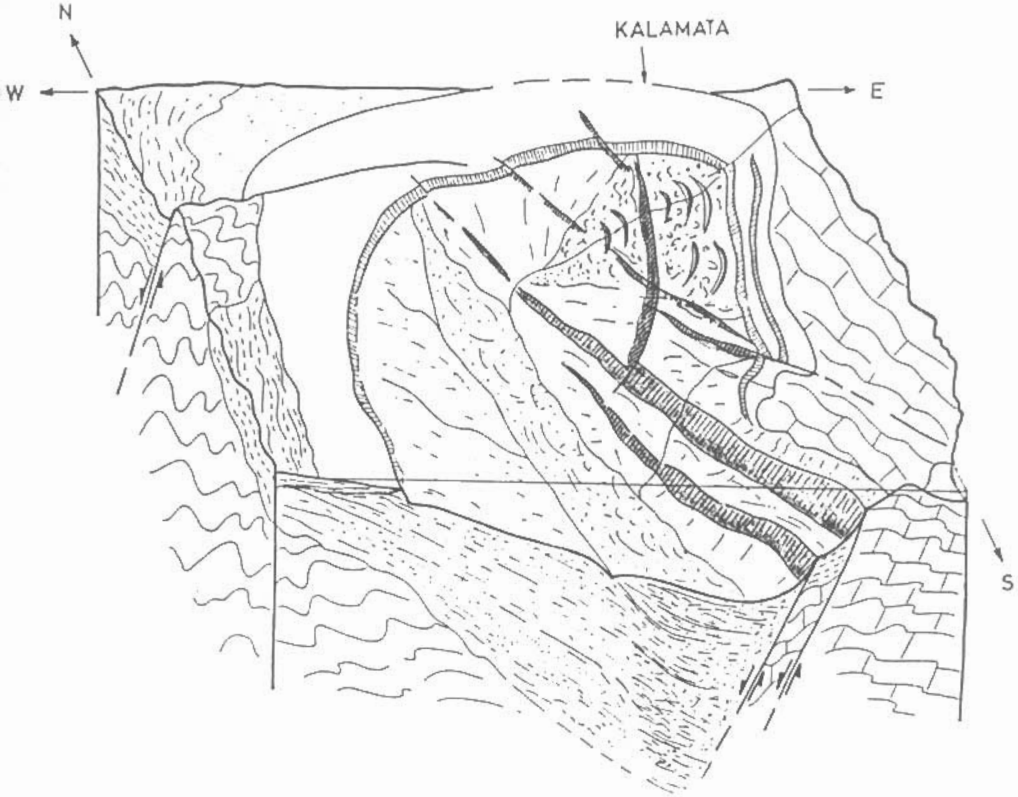


Fig. 11. Stereographic block-diagram showing the neotectonic structure of the Inner Messiniakos Gulf and the major geodynamic processes.

The position of Messiniakos gulf at a distance of only 50-80 Km from the Hellenic trench (Fig. 12) permits to correlate from geodynamic view point the considerable tilt of Kilometric order along the NW-SE axis with rotation to the ENE with the overriding process of the Hellenic margin of the European plate onto the subducting lithosphere of the East Mediterranean basin. Thus, the westward movement and uplift of the front of the Hellenic arc is compatible with a similar movement of eastward tilt immediately behind it.

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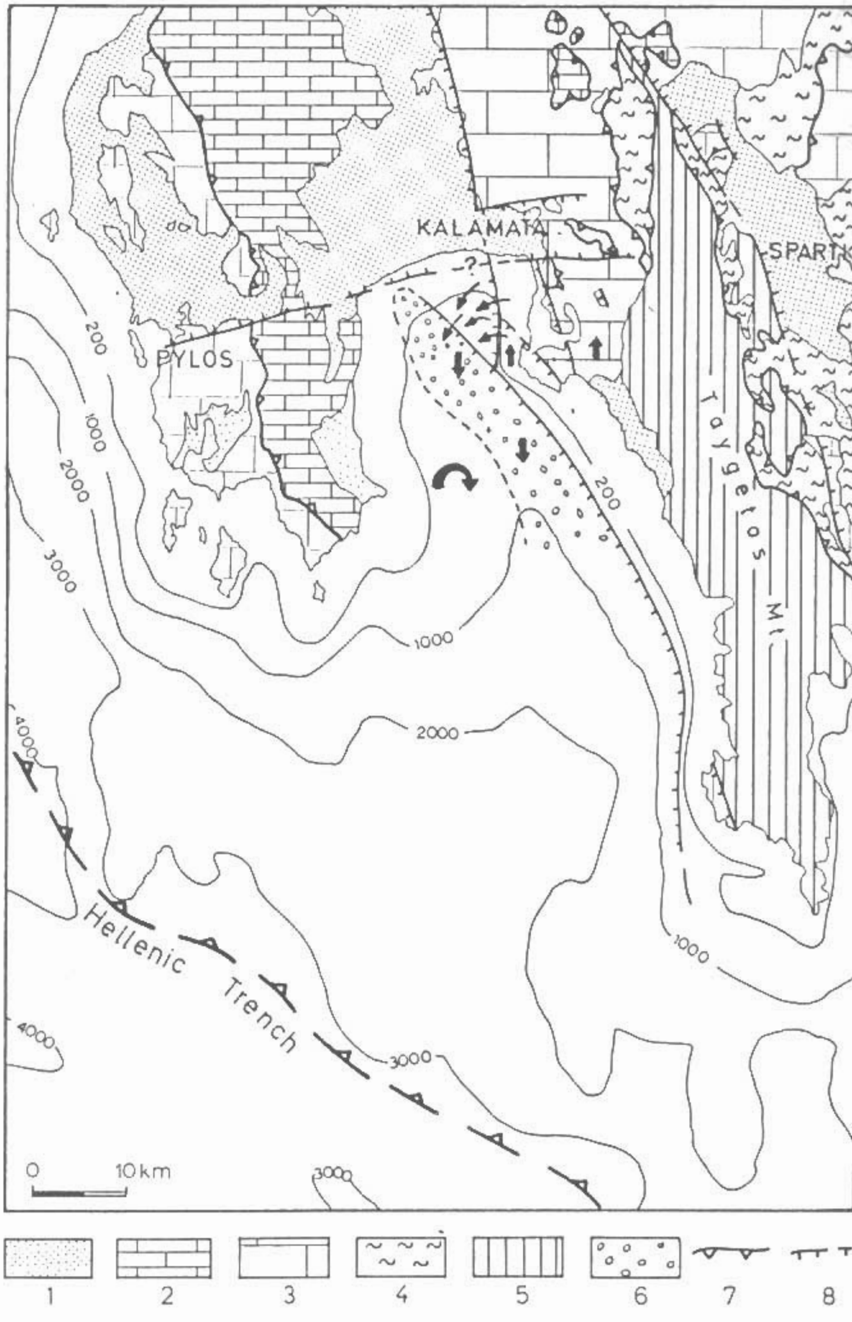

Fig. 12. Schematic geological map of the area around Messiniakos Gulf showing the relation of its neotectonic structure to the regional structure. 1: Plioquaternary, 2: Pindos nappe, 3: Tripolis nappe, 4: Arna nappe, 5: Mani autochthon, 6: maximum sediment accumulation, 7: overthrust, 8: normal fault.

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