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NEOTECTONIC STRUCTURE OF THE ARGOLIC GULF

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ABSTRACT

Seismic and bathymetric profiles within the Argolic Gulf permitted the study of its neotectonic structure. The morphological data were analysed in the form of a morphological mean slope map on which the morphological discontinuities and the planar surfaces were distinguished. The neotectonic structure of the gulf is mainly created by the following fault sets grouped:

(i) in two NW-SE zones of major border normal faults, separating the alpine basement from the sedimentary fill of the basin,

(ii) in several E-W transcurrent faults which create horizontally escaping neotectonic blocks and,

(iii) normal faults, some of which probably with oblique-slip motion, forming minor neotectonic blocks especially within the continental platform.

The overall geomorphological and neotectonic structure and other characteristics of the post-alpine sedimentation show an asymmetry with more intence phenomena along the western margin of the gulf. The continental platform is highly fractured and Holocene vertical block movements of the order of 20 - 30 m are detected.

1. INTRODUCTION

The material of this study has been obtained during 1987 and 1988 within the frame of a major research project on the tectonic stability of the Peloponnesian shelf.

The research was carried out with the O/V "AEGAEO" and a dense grid of seismic reflection lines was obtained. A Sparker system (model SIG) 2 - 9 KJOULES was used as seismic source and a single-channel reflection unit for recording.

Average velocities of 1750 M.S-1 for Holocene sediments and 2.000 M.S-1 for the other post-alpine formations were used in order to estimate the fault throw and reflector depths. In addition, a high resolution echo-sounder along the same profiles was used to enable the construction of a precise bathymetric map. Positioning was achieved by using radar fixes every 5 minutes with precision of ±50 m.

2. THE MORPHOLOGY OF THE GULF

2.1 Bathymetry

The bathymetry of the gulf is rather simple showing an elongate basin in the NNW-SSE direction (Fig. 1). The two margins of the basin are asymmetrical with

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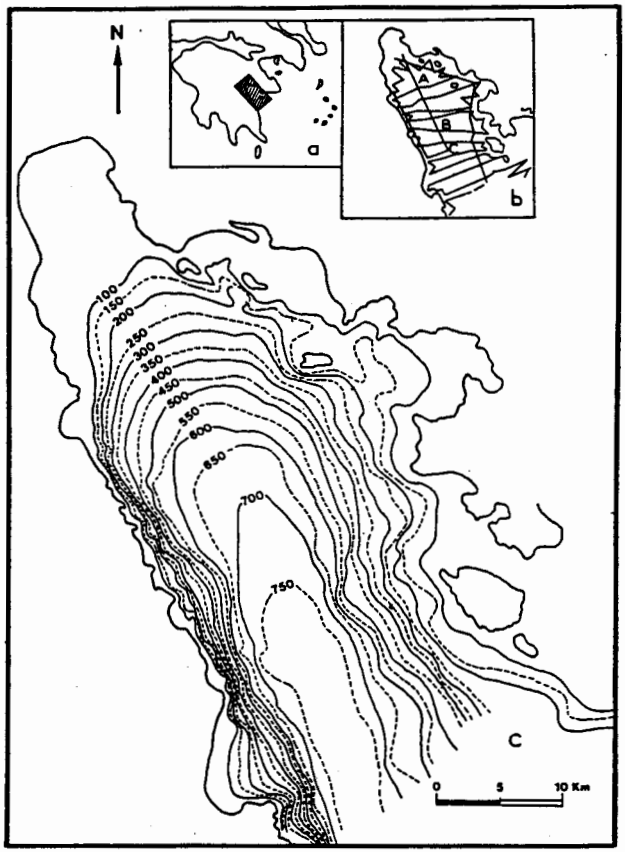


Fig. 1: Bathymetric map of the Argolic Gulf and sketch map showing the seismic profiles within the gulf (1b)

the axis of the basin running near the western coastline. The bottom of the gulf forms a sub-horizontal plane with a gradual depth increase to the SSE which ranges from depths between 600-750 m. The western margin is quite narrow, reaching the gulf bottom from the coastline at a distance of about 5 km, whereas the eastern margin is much larger reaching a width of about 10 km. The shallow depths over the shelf are extremely limited along the western coastline, the 100 m isobath occurring at only a few hundreds of meters from the cast. On the contrary the area of shallow depths at the eastern coastline is much wider with a distance of the 100 m isobath ranging between 2-3 km whereas at the NNW closure of the gulf the distance extends to 10-12 km.

2.2 Slope morphology

The elaboration of the available data permitted the construction of the morphological slope map of the Argolic Gulf (Fig. 2). This map includes two categories of morphological data:

(i) the slope distribution over areas characterized by some average values of slope and,

(ii) the morphological discontinuities with lines which locate a remarkable break in the morphological slope.

(i) The slope distribution areas can be divided in two different cases. The sub-horizontal planar surfaces with slope values between 0-5% and the inclined surfaces with slope values higher than 5%.

The sub-horizontal planar surfaces are further distinguished in two different forms.

The shallow surface which occurs at depths between 0-100m, reflecting the continental shelf, and the deep surface, which occurs at depths between 600-800 m, reflecting the gulf bottom. The continental platform of the shelf will be further analysed in the next chapter.

The gulf bottom is a planar surface with average slope values less than 1% with both boundaries running along a NNW-SSE direction. The width of this surface is about 5 km and its length is about 40 km.

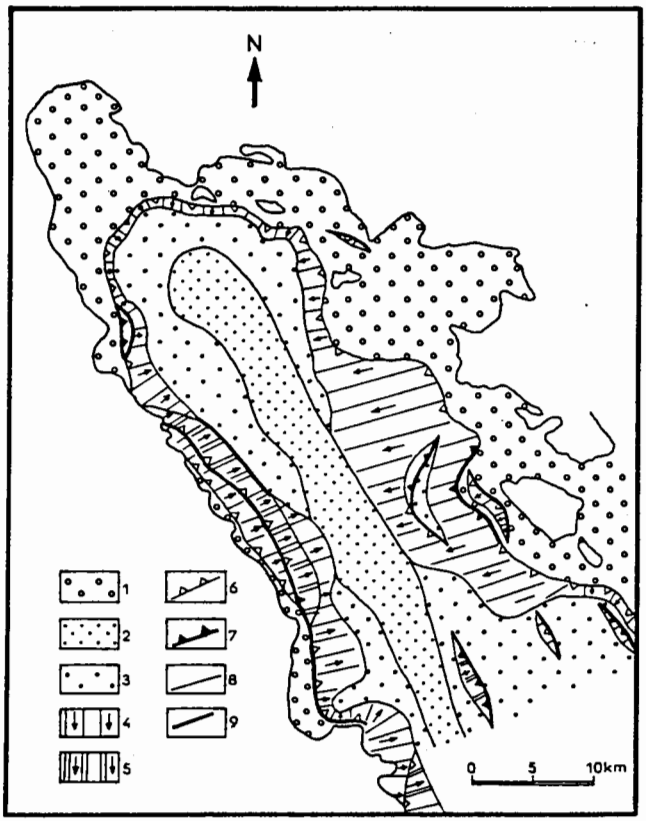


Fig. 2: Morphological slope map orf the Argolic Gulf. 1; very low slopes (less than 3%) on the continental platform, 2: very low slopes (less than 1%) on the basin's bottom, 3: low slopes, over 20%, 6: slope discontinuity, more than 5%, 7: slope discontinuity, more than 15%, 8: transition of slope and 9: slope discontinuity from steep to low slopes.

The inclined surfaces of the gulf are distinguished in three categories: those with low slope values between 1-5%, those with moderate slope values between 5-20% and those with high slope values depassing 20%.

The low slopes occur mainly around the planar gulf bottom with the exception of the area west of Spetses island where they are absent, because of the existence of slope discontinuities. The slopes are directed towards the morphological axis of the gulf with directions from ENE to WSW in the eastern margin and opposite, from WSW to ENE, in the western margin. The slope directions change only in the NNW closure of the gulf, where there is the form of a rather geometric amphitheater. The same pattern is followed also in the areas of the higher slopes. The moderate slopes occur extensively, usually between the edge of the continental platform and the low slopes. The steep slopes occur mainly along the western margin of the gulf, usually bounded by morphological discontinuities. The slope areas of the gulf form a slope zonation trending NNW-SSE with only local deviations towards the NE-SW or other directions.

(ii) The morphological discontinuities can be distinguished in two categories. The first category is the discontinuity which reflects the edge of the continental platform from the rest of the basin. This discontinuity is almost everywhere present. The second category consists of all the other discontinuities mainly occurring at deeper parts of the basin. These discontinuities are both "positive" and "negative", which means there are abrupt slope changes from low to high values but also abrupt slope changes from high to low values. The positive cases reflect those zones where the wall of the gulf's margin is found in immediate contact to the planar bottom of the basin.

Expect for the morphological discontinuities of the edge of the continental platform whose genesis is due to the complicate movements between Late

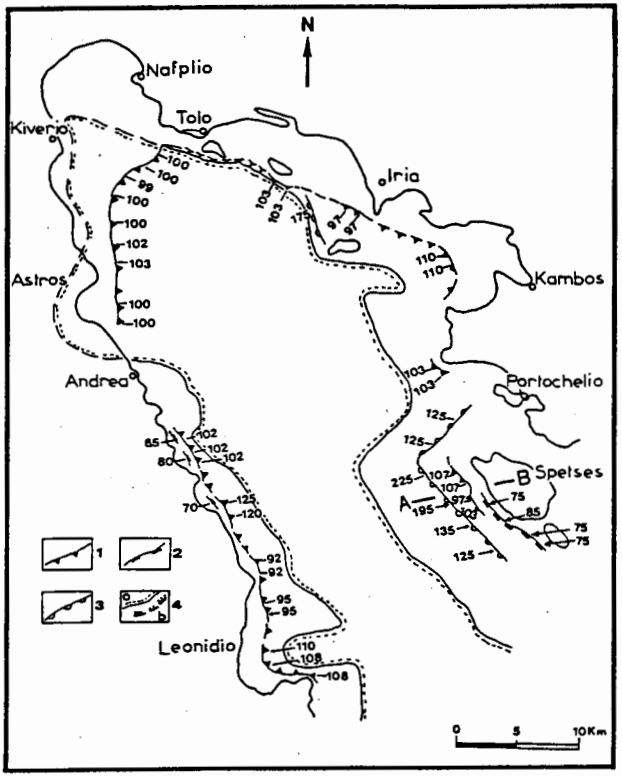
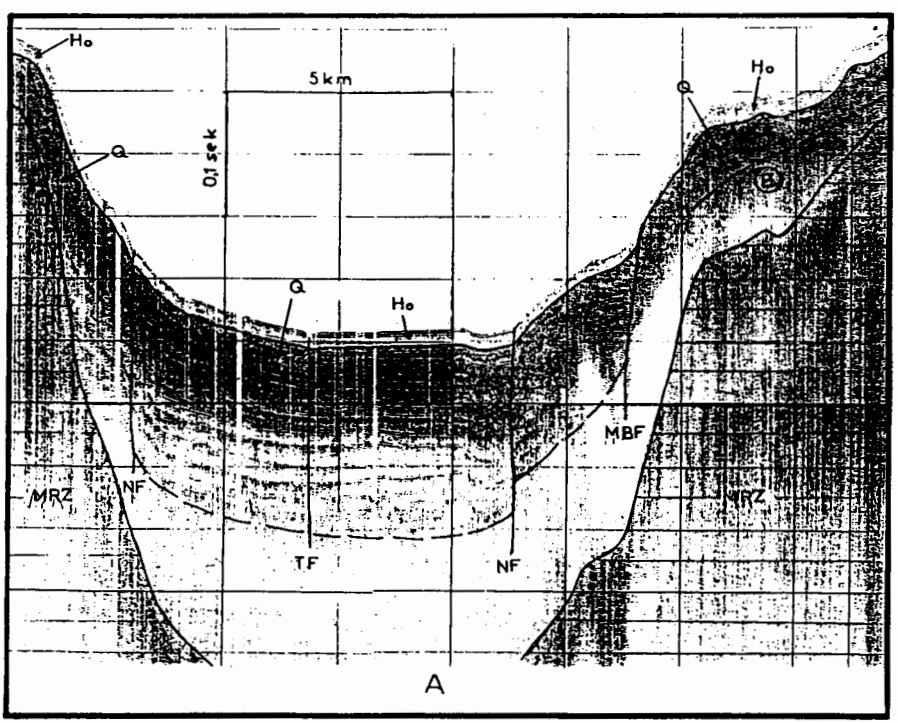


Fig. 3: Map of the continental platform of the Argolic Gulf with depth indications in meters.
1: edge of the continental platform, 2: edge of the sub-marine terraces over the continental platform, 3: edge of the older continental platform, 4: boundary of the alpine basement within the basin, certain (a) or probable (b).

Fig. 4a



Pleistocene and Holocene tectonics, the rest of the discontinuities are usually due to the existence of faults, which in the majority of cases are synsedimentary growth faults. The general direction of the morphological discontinuities is NNW-SSE.

2.3 The continental platform

The continental platform of the Argolic Gulf is only present in some segments of the gulf whereas elsewhere it is missing (Fig. 3). The absence of the edge of the continental platform is observed in the middle part of the gulf both at its western and at its eastern margin.

The depth of the edge of the continental platform ranges between 92 and 120 m. The change of depths is mainly observed as different neotectonic blocks which show vertical tectonic movements during Holocene. In some blocks the change of depth becomes gradual due to a tilting of the block. The general features and deformation of the platform in the Argolic Gulf resembles the case of Messiniakos Gulf (Papanikolaou et al. 1988, b, Pavlakis et al., 1989).

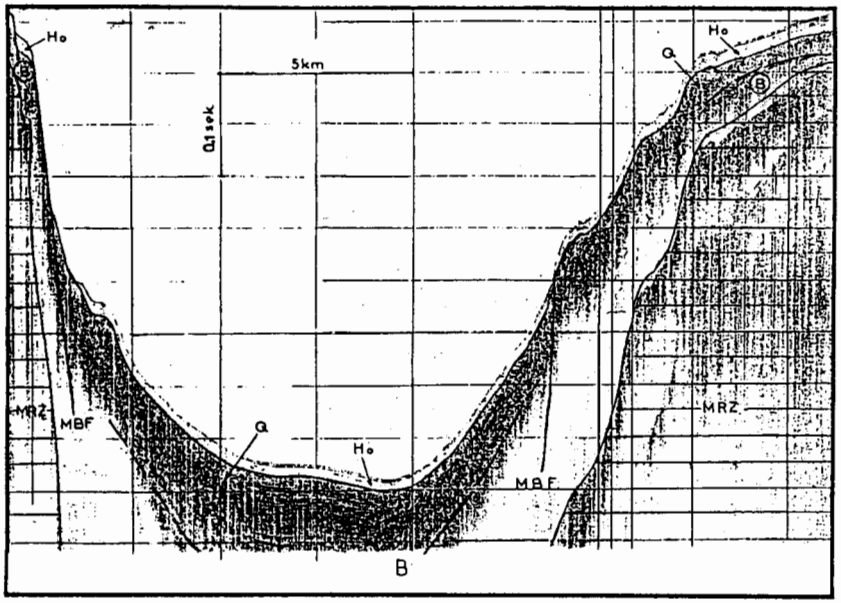
Besides the normal edge of the continental platform there are two more cases of additional platform edges. The first occurs at more shallow depths between 65-85 m, forming submarine terraces in various neotectonic blocks, similar to those observed in the northeastern part of Messiniakos gulf (Pavlakis et al., 1989, Papanikolaou et al. 1988, b) The second occurs at deeper between 125-225 m. It is mainly observed at the blocks west of Spetses island and there is a systematic subsidence of the platform to its NNW area where the maximum depth 225m was measured (Fig. 3). This deeper platform may be the result of older movements (Upper (?) Pleistocene) whereas the shallower terraces should be younger features related to the Holocene period. It is remarkable that the shallow terraces are observed at the southern part of the gulf both at its western and its eastern margin. The most important feature is the coexistence of all three edges of continental platforms at the composite neotectonic block of Spetses island, where along the E-W transect A-B one can observe the older edge of the platform at 195m depth, the normal edge of the platform at 97m depth and the upper edge at 75m depth.

The width of the continental platform is very narrow along the western coast emphasizing the asymmetry of the gulf to the west. However, the maximum width occurs to the north and northeast of the gulf where it reaches several km.

3. THE TECTONIC STRUCTURES

The tectonic structure of the gulf is the result of neotectonic movements which initiated the formation of the gulf a latemost Miocene-Early Pliocene times, whereas its main development took place within Pleistocene times. The neotectonic structure can be studied on the basis of fault kinematics but also of block kinematics. In the case of the fault analysis the main characteristic are the geometry and orientation of the faults, the fault throw and the relative motion of the adjacent tectonic blocks. These characteristics can be obtained from the seismic profiles on the basis of the local stratigraphy and the use of marker horizons (Fig. 4). In many cases the contact between the alpine basement and the Plio-Quaternary sediments is the best feature for estimating the minimum relative vertical motions.

In the case of the tectonic block analysis the main characteristics are



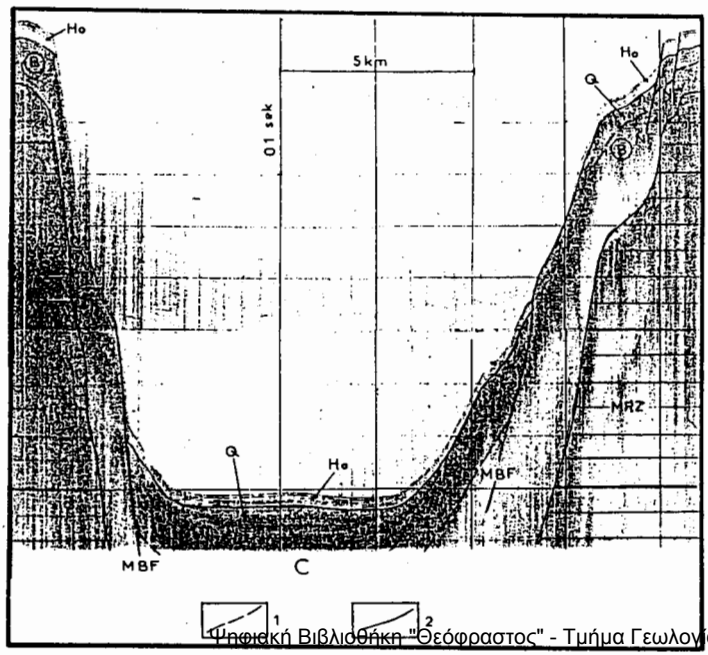


Fig. 4:

Seismic reflection lines showing seismostratigraphic and structural features of the Argolic Gulf. 1: Surfaces (marker horizons), 2: Faults. Seismostratigraphy : Ho - Holocene, Q - Quaternary, B - Alpine Basement.. Structural Features : MBF - Major Border Faults, NF - Normal Faults, TF - Transcurrent Faults. MRZ - Multiple Reflection Zone. Location on Fig. 1.b

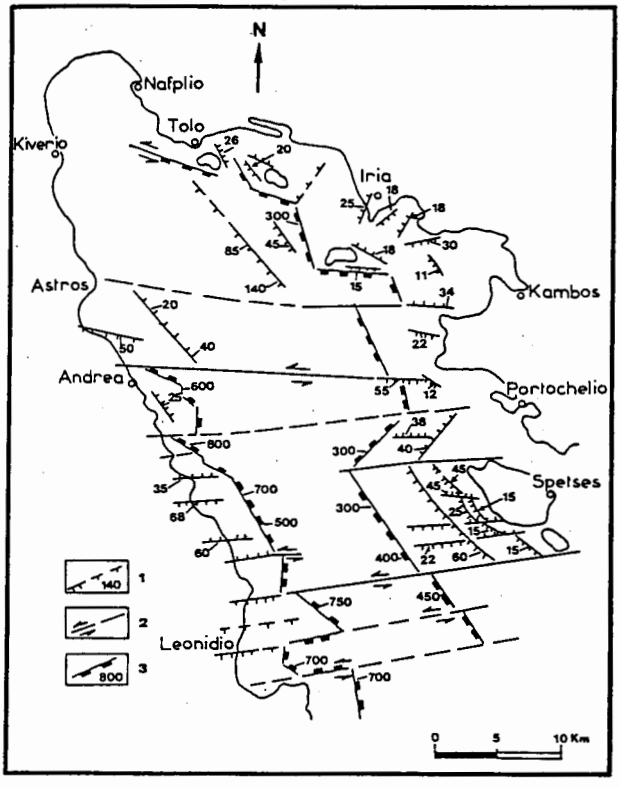


Fig. 5: Map of the faults of the Argolic Gulf.
1: fault and its probable prolongation with indication of its throw in m.'s, 2: transcurrent faults with indication of their strike - slip motion, 3: major border normal faults with indication of their throw in m.'s.

the geometry of the block, the vertical or rotational movement of the block and the relative motion in regards to the adjacent blocks. These characteristics can be estimated, besides the information obtained from the previously cited fault analysis, from the study of planar geometric features, such as the depth of the continental platform, which can give us the measure of the Holocen deformation.

3.1 The faults

The faults detected within the Argolic Gulf can be distinguished in (Fig. 5):

(i) the major border faults of the basin, which separate the continental prolongation of the alpine basement from the sedimentary fill of the basin,

(ii) the normal faults observed either over the alpine basement or over the Plio-Quaternary sedimentary sequence, and,

(iii) the transcurrent faults, which show a pronounced strike-slip component of movement and cut across the whole structure of the gulf. The main characteristic of these faults is the observed by the offset displacement they produce on the boundary zone of the alpine basement along the basin's margins.

(i) The major faults are observed along both margins of the basin (Fig. 5) with the exception of the area of Astros, where they penetrate into the continental area. In general terms, we can consider them as belonging to two sub-parallel fault zones trending NNW-SSE, each of them being composed of a succession of faults oriented at various directions forming a zigzag pattern as Papanikolaou et all. (1988, a) have noted. The basin seems to bordered to the north by an ESE-WNW border fault which however is belonging to the transcurrent faults.

The faults throw is considerable and can not be accurately estimated because the alpine basement disappears along the seismic profiles below the sediments at the deeper part of the basin. Nevertheless, the total throw is more than 700-800 m along the western margin and more than 300-400 m along the eastern margin showing the asymmetry of the overall structure.

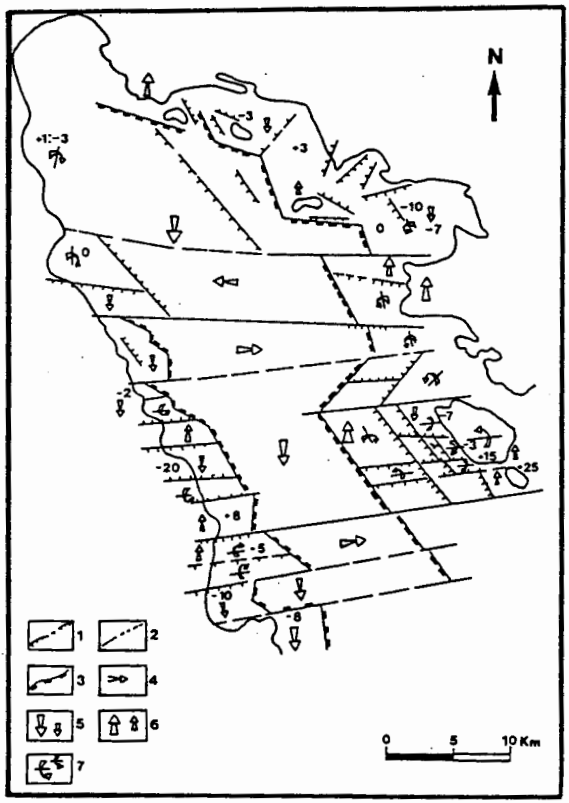


Fig. 6: Map showing the kinematics of the tectonic blocks of the Argolic Gulf.
1; faults, usually normal, oblique - slip, 2: transcurrent faults and their probable prolongation, 3: major border faults, 4: Horizontal escape of blocks, 5: subsidence motions of blocks, major and minor, 6: uplift motions of blocks, major and minor, 7: Block tilt, major and minor with indication of the sense of tilt.

(ii) The normal faults are mainly observed at the margins of the gulf, where the alpine basement is detected at shallow depths below a few decades (several meters) of sediments. Their vertical throw is moderate, not-depassing 70m (Fig. 5). Some of them may be oblique-slip normal faults, because they might have a horizontal component, which can not be determined, except for a few cases where they offset other features (faults, terraces, etc.). In fact, the majority of these oblique-slip normal faults are striking in the same direction approximately E-W, as the transcurrent faults. Their distinction is based on the fact that the normal possibly oblique-slip E-W faults are limited within certain neotectonic blocks in contrast to the transcurrent faults which cut through the composite blocks.

In the northern part of the gulf there are two sub-parallel NW-SE normal faults which create a graben structure (Fig. 4. A). It is interesting that their throw is increasing towards the SE (from 20 to 40 m and from 85 to 140m) and that, contrary to the overall asymmetry, the eastern normal fault shows more important displacement.

(iii) The transcurrent faults are all observed in an E-W direction and also show some vertical component. Their horizontal motion is indicated by the offset of the alpine basement and the edges of the continental platform. In all cases it is much higher than the vertical movements previously cited and occasionally reaches several km. Although both senses of horizontal motion are present, the prevailing motion is sinistral.

3.2 The tectonic block movements

The tectonic block movements can be distinguished in five cases:

(i) relative uplift,
(ii) relative subsidence,
(iii) tilt with simple rotation around horizontal axis,
(iv) rotation around more axes both horizontal and inclined and

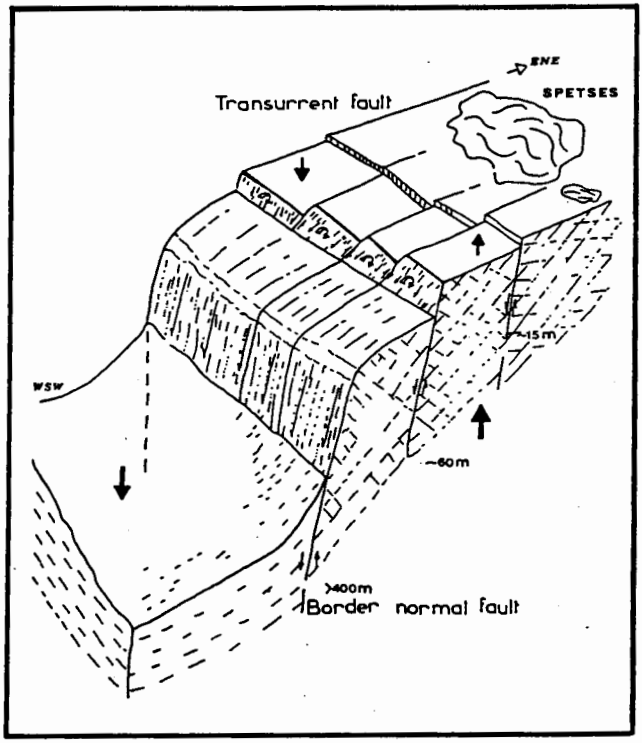


Fig. 7: Sketch of the submarine neotectonic structure of the area west of Spetses island, showing the relative block movements created by the fault activity.

(v) horizontal escape.

In several blocks, two or more of the above cases may co-exist. Thus, the vertical subsidence within the axis of the basin formed by the NNW-SSE border fault zones co-exists in some E-W blocks with the horizontal escape in the E-W direction effected by the E-W transcurrent fault (Fig. 6).

In the case of the Spetses block, there is a major vertical uplift, which is accompanied by a tilt around an almost horizontal E-W axis, which produces a relative subsidence of the northern part with respect to the southern part. This is beautifully shown by the differences at depth of all three edges of the continental platform (Figs 3, 5). Additionally, within the same Spetses block there are minor blocks, bordered by E-W normal, probably oblique-slip, faults, which are, each one, tilted along E-W axes with an opposite sense of rotation than that observed in the composite Spetses block, which displays relative subsidence to the south and uplift to the north (Figs 6, 7).

4. THE BASIN SEDIMENTATION

The sedimentation within the Argolic Gulf can be distinguished into two cases: The sediments deposited over the alpine basement on the continental platform, and the sediments deposited within the basin itself, inside the major synsedimentary border faults.

The sediments over the platform are very thin not depassing a few decades of meters. A difference is observed between the western margin, where only minor Holocene sediments occur, and the eastern margin, where some Pleistocene deposits are observed below the Holocene.

The sediments within the basin are several hundreds of meters thick with the maximum thickness of more than 400m occurring at the northern part of the basin (Fig. 8).

The thickness of the sediments as shown on fig. 8 follows the same NNW-SSE trend as all the other morphological and tectonic features of the gulf. However, the existence of thicker sediments towards the north of the basin instead of towards the south, where the open sea of Myrtoon occurs, is something not expected. This maximum sediment thickness occurs within a sub-basin formed by two major transcurrent E-W faults bordering the alpine basement mainly to the north (Nafplio and Tolo areas) and less to the South

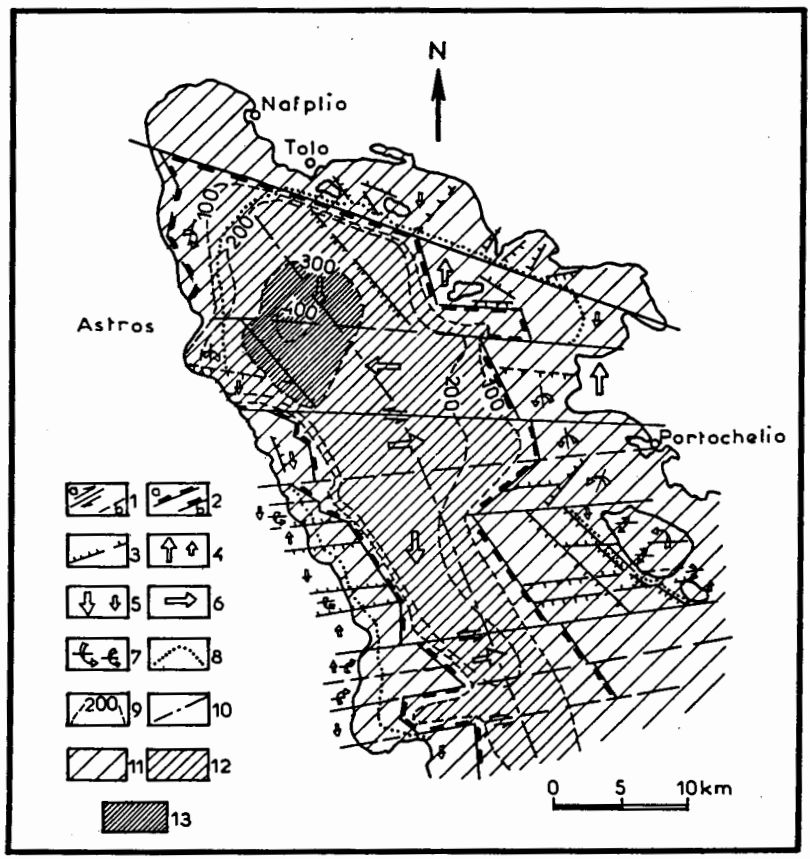


Fig. 8: Synthetic map of the Argolic gulf showing the sediment thickness in relation to the overall neotectonic structure.
1: transcurrent faults, certain (a) or probable (b), 2: major border faults, certain (a) or probable (b), 3: normal faults within the gulf, 4: uplifted block., 5: subsided block, 6: horizontal escape of blocks, 7: block tilt, 8: edge of the continental platform, 9: contours of sediment thickness in m, 10: morphological axis of the gulf, 11: sediment thickness less than 100m, 12: sediment thickness 100-300 m, 13: sediment thickness more than 300 m

(area south of Astros) (Fig. 8).

Besides this anomalous distribution of the sediments the other asymmetrical characteristics of the basin remain, with the maximum sediment thickness occurring close to the western border fault zone. Thus the axis of maximum sediment thickness does not coincide with the morpholo-gical axis of the basin but it runs parallel to it closer to the western margin.

5. CONCLUSIVE REMARKS

The previous analysis shows that the distribution of the morphological slopes and discontinuities, the overall neotectonic structure and also the characteristics of the post-alpine sedimentation are characterised by an

asymmetry of the gulf to the west, which controls the occurrence of the more intense geodynamic phenomena along the western margin.

The neotectonic structure of the Argolic Gulf is dominated by synsedimentary growth faults which affect its geomorphology and its sedimentary processes. The primary most important faults are those forming the two NNW-SSE major border normal fault zones, which separate the alpine basement from the axial zone of the sedimentary fill in the form of a NNW-SSE neotectonic graben. These border faults show a vertical displacement of several hundreds of meters, which if added to the present day topographic differences, indicate very important vertical neotectonic movements in the order of Km's.

The second important feature is the systematic existence of E-W transcurrent faults, which dissect the previous NNW-SSE structure of the tectonic graben, especially by considerable offset of the border faults separating the sedimentary basin of the gulf from its alpine continental margins.

These two fault systems are similar to the known model of longitudinal and transverse faults of Peloponnese (Mariolakos & Papanikolaou, 1982, 1987, Mariolakos et al. 1985).

The remaining minor faults create a mosaic of smaller neotectonic blocks with complicate kinematics, depending on which margin of the gulf they occur. In any case, the faulted blocks are mainly observed over the Peloponnesian shelf along both continental platforms, towards Arcadia to the west and towards Argolis to the east. On the contrary, only a few faults are observed within the Plio-Quaternary sediments of the basin.

Both fault sets NNW-SSE and ESE-WNW were active throughout the basin's neotectonic history, although the longitudinal NNW-SSE fault set seems to be older and responsible for the taphrogenesis of the Argolic Gulf.

The recent deformation within latemost Pleistocene and Holocene times is of the order of several decades of meters, whereas the neotectonic deformation is in the order of several meters, The general trends of deformation seems however to be similar for the recent period and the whole neotectonic period.

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