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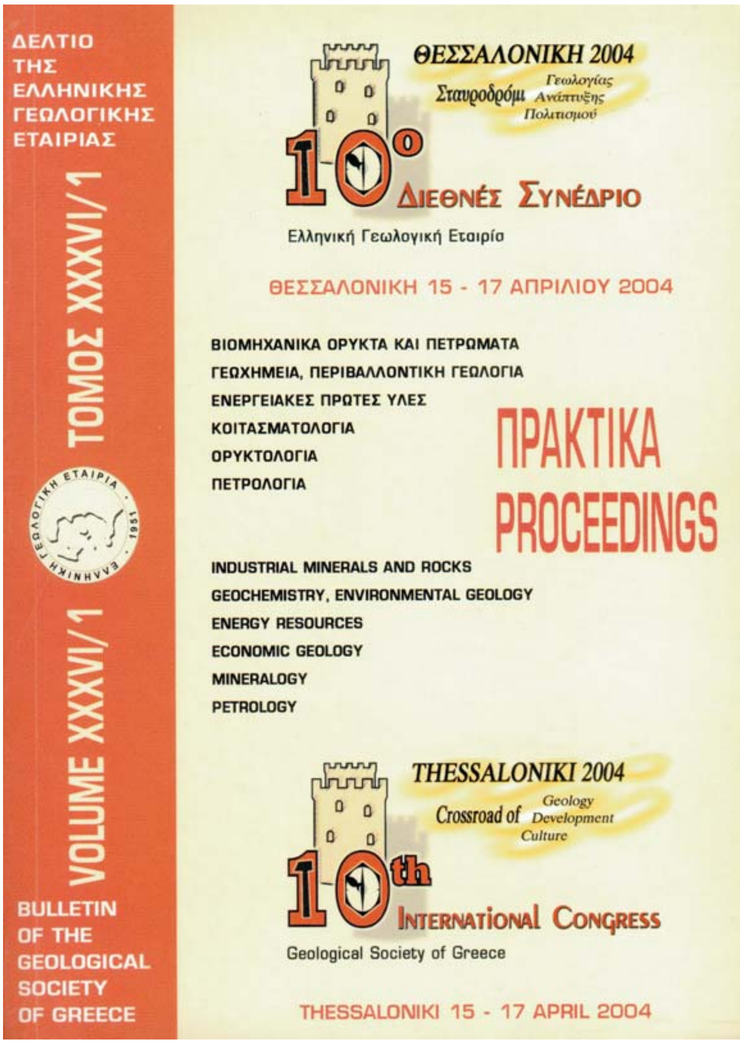

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NEOTECTONIC DEFORMATION OF EASTERN PYLIA (SW PELOPONNESE, GREECE)

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ABSTRACT

The present paper aims to the understanding of the effect of the morphotectonic factors on the formation of the morphoneotectonic macrostructures that comprise the eastern part of Pylia Peninsula (SW Peloponnese).

As the broader area of Pylia is one of the tectonically and seismically most active areas of the Hellenic arc, due to the fact that it is very near to the Hellenic trench (approximatly 50Km), the peninsula of Pylia is strongly considered to be a suitable area to study the neotectonic deformation at the Eastern Mediterranean region.

1 INTRODUCTION

The peninsula of Pylia consists the south-westernmost part of Peloponnesus. It exhibits a composite morphotectonic structure due to the occurrence of many small morphological units of various directions (Fig. 1). The dominant mountainous masses is Lykodimo (960m) at the north-eastern section, which exhibits a characteristic conical shape and Mavrovouni (518m) at the south-eastern part of the peninsula, which exhibits an elogated shape of NW-SE direction.

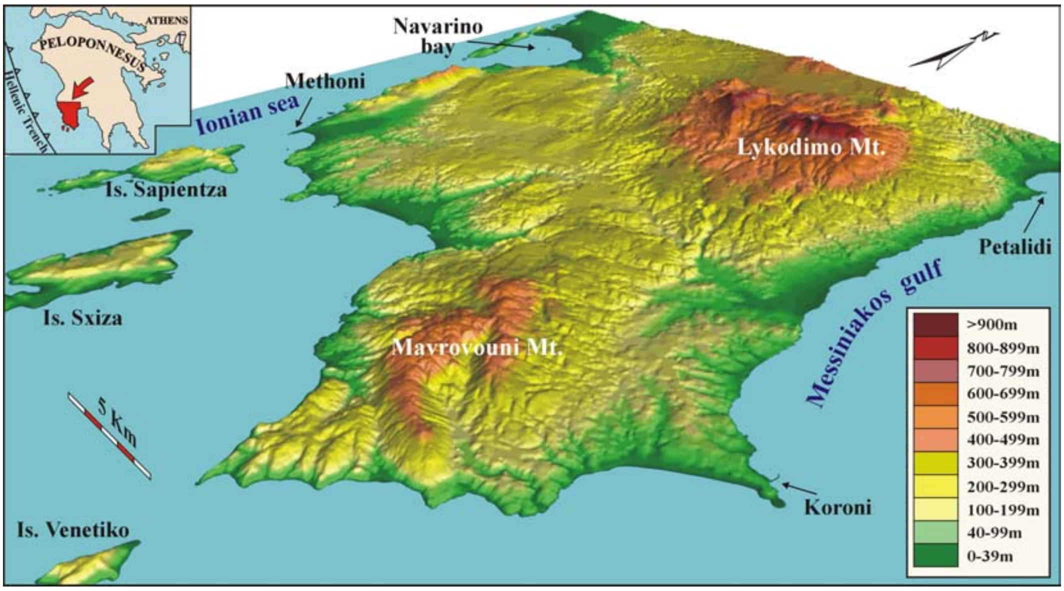


Figure 1. Perspective view of the digital elevation model of Pylia peninsula. The view of observation is towards NW (azimuth of observation N130^o) with 45^o inclination angle from the horizon. Illumination is from the east.

2 GEOLOGY

The alpine nappe sequence of Pylia peninsula is comprised of a relatively autochthonous unit, the Gavrovo-Pylos unit, and an allochthonous one, the Pindos unit. The Gavrovo–Pylos unit which consists of neritic carbonates and flysch, outcrops at the western part of the peninsula. On the other hand the Pindos unit occupies the eastern part of the peninsula forming a classic nappe, which has overthrusted Gavrovo – Pylos unit (Fig, 2). Pindos unit is represented with all its wellknown characteristic formations from the Triassic clastic formation at the bottom of its column up to the Eocene flysch at the top. The whole unit is intensively folded and faulted, forming succesive thrusts with movement direction from east to west.

The post alpine deposits can be distinguished into (i) marine, (ii) terrestrial and (iii) lacustrine formations.

The marine deposits consist of marls, sandstones and conglomerates. They occur in all basins of Pylia peninsula. Their total thickness differs from place to place. In the Falanthi basin the thickness of these sediments has been estimated, based on drilling data, to be 200m at a location near the city of Koroni. At this basin the upper sequences of the marine deposits are of Early Pleistocene age or younger (Mariolakos et al. 2001). At the other basins of Pylia peninsula (Pylos, Pygassos and Achladochori basins) according to previous studies marine sedimentation took place during Late Pliocene (Koutsouveli 1987, Kontopoulos 1984). In our opinion, it also continued during the Early Pleistocene as indicated at the adjacent areas of Triffilia and Lower Messinia basin by palaeontological studies (Marcopoulou-Diacantoni et al. 1989, 1991).

The overlying continental deposits consist mainly of red-coloured siliceous sands and sandstones and of polymictic conglomerates which should be of Middle and Late Pleistocene age. It is important to mention that these conglomerates consist of pebbles originated not only from the alpine formations outcroping at Pylia peninsula but also from the metamorphic rocks of Taygetos Mt. (that is from schists, quarzites and marbles). The Holocene is represented by alluvial deposits and talus scree.

Lacustrine deposits outcrop only at the western margin of Falanthi basin consisting of marls with xylite bed intercalations. They are considered to be of Early Pliocene age (Koutsouveli 1987).

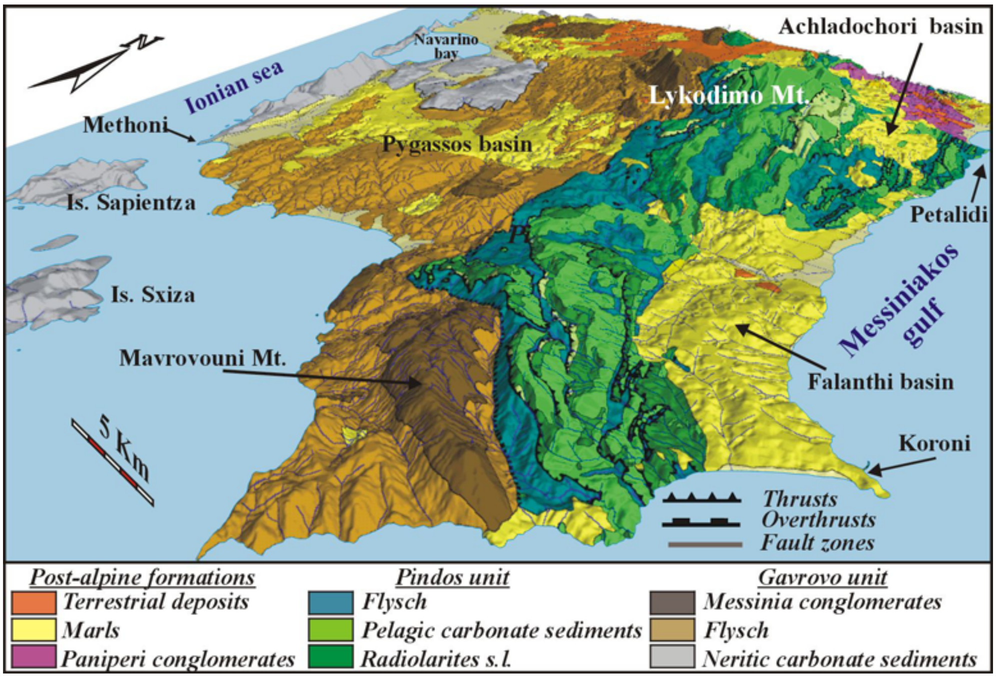


Figure 2. Perspective view of a simplified 3D geological map of Pylia peninsula. The view of observation is towards NW (azimuth of observation N140^o) with 35^o inclination angle. Illumination is from the east.

3 GEOMORPHOLOGY

3.1 Drainage network

The main watershed in the study area has a general NNW-SSE direction and is developed at the central part of the peninsula, parallel to the nappe front of Pindos Unit. This watershed divides the drainage network of Pylia in two sections, (i) the eastern section where the final branches discharge in Messiniakos Gulf, (ii) the western section where the final branches discharge in the Ionian Sea and the Sea of Oinousses.

The larger rivers that are located at the eastern section are Kalorrema (5th order) and Epis (6th order), (Fig. 3). Within this section two cores presenting radial distribution of the drainage network are observed, one in the area of Lykodimo Mt., and the other at Mavrovouni Mt., (Fig. 3). At the northern slopes of Lykodimo Mt., the branches of Kalorrema River have an initial N-S direction which progressively changes to NE-SW, to E-W and finally to NW-SE where the main 5th order branch discharges in the Messinian Gulf.

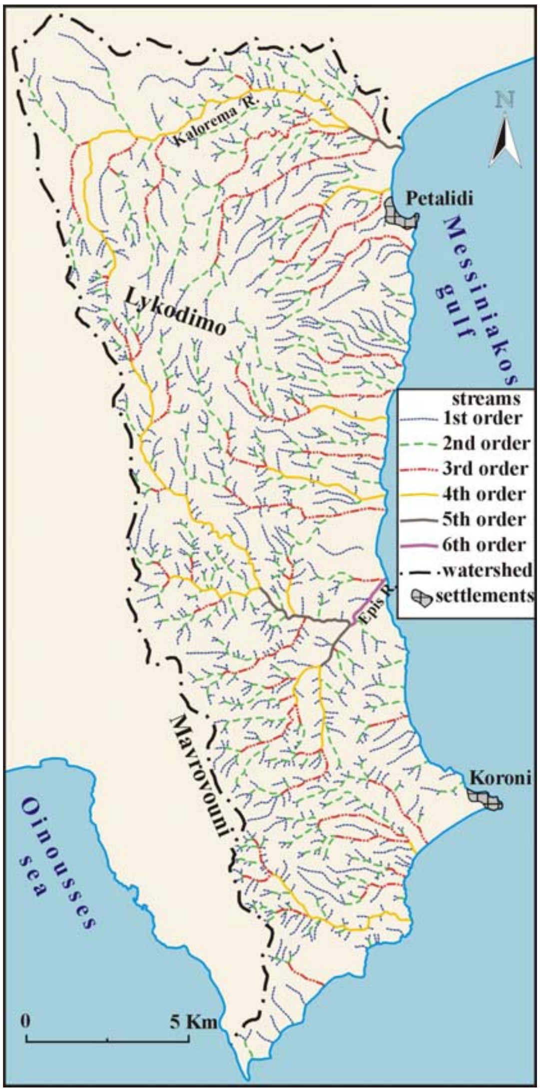


Figure 3. Map depicting the drainage network of eastern Pylia.

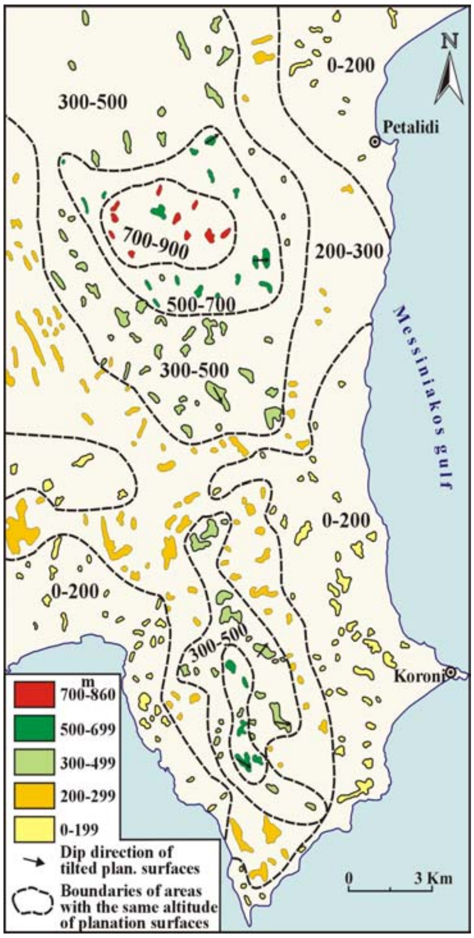


Figure 4. Map depicting the erosional planation surfaces of eastern Pylia.

On the other hand, at the southern slopes of Lykodimo Mt., the local branches initially have a N-S direction progressively changing to NW-SE and finally to E-W, discharging in Messiniakos Gulf. In between, at the eastern slopes of the mountain, the branches have initial WSW-ENE and WNW-ESE directions that progressively are changing to E-W direction.

The curved shape of the branches in the Lykodimo Mt. area is also expressed by the elongation of the respective basins which present increased elongation coefficient S.

A similar distribution is observed southwards at the NE slopes of Mavrovouni Mt., where the branches of Epis River network have a NE-SW direction (perpendicular to the alpine tectonic trends). When the branches enter the Falanthi basin are diverted towards the North, parallel to the basin margin and finally are diverted again following a NE-SW direction. At the SE slopes of Mavrovouni the branches are following an initial NW-SE direction and progressively are diverted and discharge in Messiniakos Gulf at an E-W direction.

3.2 Planation surfaces

The planation surfaces have been distinguished into (i) erosional and (ii) depositional. The depositional planation surfaces occur at the coastal areas while the erosional ones are observed both on the alpine basement and on the Plio-Pleistocene marine deposits. The present distribution of the planation surfaces within the study area is determined mainly by the undergoing active tectonics that are impressed on the landscape since the Upper Miocene. Important elements for the study of planation surfaces are their geographical distribution and their dipping direction in case of tilted surfaces.

In figure 4 some groups of planation surfaces based on their altitudes have been distinguished.. We can identify two areas where uniform and symmetrical distribution of planation surfaces occur around a central area. This geographical zonation in the Mavrovouni area presents an elongation in a N-S direction while in Lykodimo area it is presented in the form of approximately co-central circles. The higher in altitude surfaces at Mavrovouni are located at 500-520m and at Lykodimo at 800-900m. The decrease in altitude exposure for both mountains is gradual without steep intervals to lower altitudes that could suggest fault zone action.

At these mountainous areas the erosional planation surfaces generally follow the average dip of the relief surface. Therefore, their dip direction exhibits radial distribution around these morphological units.

4 TECTONICS - NEOTECTONICS

The neotectonic macrostructure of SW Peloponnesus is characterized by the presence of large grabens and horsts bounded by wide fault zones, striking N-S and E-W. As shown in figure 5 the main 1st order macrostructures at the broader area are (a) the Taygetos horst, (b) the Kalamata-Kyparissia megagraben, (c) the Kyparrisia Mts. morphotectonic unit, (d) the Vlahopoulo graben and (e) the Pylia Mts horst. The kinematic evolution of these neotectonic units is complicated since block rotation differentiates the uplift and subsidence rates thoughout the margins of the neotectonic blocks (Mariolakos et al. 1994b).

At the margins or within the 1st order neotectonic macrostructures of SW Peloponnesus a great number of smaller structures is present. This neotectonic structures of minor order strike either subparallel or perpendicular to the trends of the 1st order ones. They are dynamically related, as they have resulted from the same stress field but they have a different kinematic evolution. This diffferentation has appeard either from the first stages of their creation, or later, during their evolution (Mariolakos et al. 1995).

The study area belongs to the 1st order complex neotectonic horst of Pylia Mts which strikes N-S and is bounded to the north by an E-W striking fault zone (South Vlachopoulo fault zone, SVFZ). This marginal fault zone divides the uplifted area of Pylia to the south from the Vlahopoulo graben to the north, which represents an area that was submerged below the sea levell during Early Pleistocene, forming an E-W trending sea channel, whereas at the same time the greater part of Pylia megahorst continued to be above the sea level forming a separate island (or islands ?), (Mariolakos et al. 1994a). The reactivations of this fault zone have formed large escarpments on the morphology of the area west of Pylos town where many fault surfaces on the carbonate rocks of Gavrovo unit are covered by successive generations of tectonic breccia and scree. It traverses the whole peninsula consisting of many faults in an en-echelon arrangement. Slikensides observed on these fault surfaces indicate that they have an oblique-slip (sinistral) normal character.

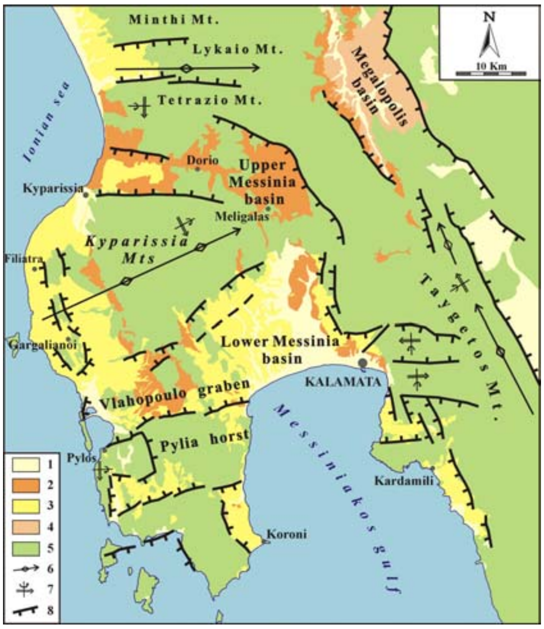


Figure 5. The Neotectonic macrostructure of SW Peloponnesus. 1:Holocene deposits, 2:Post-alpine continental deposits, 3:Post-alpine marine deposits, 4:Lacustine deposits, 5:Pre-neogene basement (Alpine units & Messinia conglomerates), 6:Macrofold axis, 7:Rotational axis, 8:Fault zones.

Figure 6. The 2nd order neotectonic macrostructures of Pylia horst. 1:Agios Nikolaos horst, 2:Pylos-Methoni graben, 3:Kynigos horst, 4:Lykodimo morphotectonic structure, 5:Pygassos basin, 6:Mavrovouni horst, 7:Falanthi graben, 8:Achladochori basin.

Within the Pylia Mts. horst the following main 2nd order neotectonic structures can be distinguished, (Fig. 6): (i) Agios Nikolaos horst, (ii) Pylos-Methoni graben, (iii) Kynigos horst, (iv) Lykodimo morphotectonic structure, (v) Pygassos basin, (vi) Mavrovouni horst, (vii) Falanthi basin, (viii) Achladochori basin.

At the eastern part of Pylia the morphotectonic structure of Lykodimo Mt. is bounded to the south by an E-W striking fault zone (Logga – Evaggelismou fault zone, LEFZ). This fault zone which also presents a horizontal left lateral component of movement, seperates Lykodimo mountainous area to the north from Falanthi basin and Mavrovouni horst to the south. It does not form large escarpments on the morphology, due to the variety of the geological basement, but traverses the whole peninsula consisting of many faults in an en-echelon arrangement.

Falanthi basin presents a characteristic elongated rectangular parallelogram shape at NNW-SSE direction. It is bounded at the west from Mavrovouni horst by an NW-SE strking marginal fault zone (Falanthi fault zone, FFZ) which stops when it cross-sects the LEFZ.

Only few fault surfaces can be observed in the post-alpine deposits of eastern Pylia, however except of normal faults we have also observed reverse ones.

At the study area the distribution of the boundary of the marine Plio-Pleistocene deposits at unequal altitudes makes more complicated the three-dimensional kinematic evolution of each separate neotectonic structure. The uplifted regime that was established after Middle Pleistocene has resulted in the occurrence of the marine deposits at the present day altitude of 360m at the eastern slopes of Lykodimo Mt., whereas at the western margin of Falanthi basin the marine deposits have been uplifted up to an altitude of 180m.

5 STRUCTURAL CONTOUR MAPS

It is well-known that the overthrusting of Pindos unit was completed in Early Miocene. Consequently, it is expected that the nappe surface of Pindos unit have been affected by the deformation that took place during the neotectonic period. Therefore the actual morphology of this structural surface is an important indicator concerning the kinematic and consequently the dynamic evolution of the study area. In our case, in order to study the morphology of Pindos nappe surface we constructed the structural contour map between Pindos unit and Gavrovo unit for the whole area of Eastern Pylia.

Additionally, we also constructed the structural contour maps of the contacts (unconformities) between the marine deposits and the formations of Pindos unit at Falanthi and Achladochori basins. Finally, we combined these structural maps with the Pindos nappe structural map as it is shown in figure 7 and figure 8. The following comments can be done concerning the structural contour maps:

NE area:

As shown in figure 7 at this part of the peninsula the tectonic contact between the Pindos unit and the flysch of Gavrovo unit reaches its higher altitudes at the western part of Pindos nappe outcrop and dips to the east until it gets partially buried under the post alpine secuences of Achladochori basin. This tectonic contact reaches its maximum altitude of 540m at the front of Pindos nappe somewhere between Kokkino and Miliotakion villages, whereas it decreases towards the north and south across the nappe front reaching an altitude of 360 and 240m respectively.

From the shape of the contours of the structural map we could distinguish two distinct structures:

(i) At Lykodimo Mt., the overthrusted surface presents an anticlinal type curvature with an axis trending at an E-W direction and plunging towards the east. The plunge of the tectonic surface at the central part of this area is towards the east while it changes towards the NE at the northern part and towards the SE at the southern part. It is important to mention that the western prolongation of this axis coincides with the highest altitude of the outcrops of the Messinia conglomerates formation.

(ii) At the area east of Kato Ampelokipi village the overthrust surface forms a syncline warping with an axis also trending at an E-W direction and plunging towards the east.

At Achladochori basin the contact between the marine deposits and the alpine basement reaches its higher altitudes of 320 to 380m at the western margin of the basin and dips towards the east, (Fig. 7). The geometrical shape of the unconformity surface at this area seems like a wide spheroid which tectonically represents an anticlinal structure with an axis trendind E-W and plunging towards the east at the western prolongation of the axis observed on Pindos overthrust surface.

SE area:

As shown in figure 8, at this part of the peninsula the tectonic contact between the Pindos unit and the flysch of Gavrovo unit reaches its higher altitudes at the western part of Pindos nappe outcrop and dips to the east until it gets buried under the post alpine secuences of Falanthi basin. The maximum altitude of this tectonic contact is odserved at Mavrovouni Mt. (SW of Chrisokellaria village) where it reaches 420m whereas it dicreases towards the north and south across the front of the nappe reaching 160 and 80m respectively.

At Mavrovouni mountainous area the overthrust surface of Pindos unit is more deformed and displays an anticlinal warping with an NE plunging axis trending at an NE-SW direction. At this area, we don't have any indications to support the above structure with fault tectonics. At Falanthi basin the contact between the post-alpine Plio-Pleistocene deposits and the formations of Pindos unit reaches its higher altitudes of 200 to 240m at the northern margin of the basin while at the western margin of the basin the unconformity surface reaches its highest altitudes at 180m and dips towards the east, (Fig. 8). From the shape of the contours of the structural map we could distinguish at the southern part of this basin an anticlinal curving structure which gives to the unconformity surface the geometrical shape of a wide sphere. The axis of this structure is trending at an NE-SW direction and plunging towards the NE. It follows an imaginable line passing near Charokopio village almost at the western prolongation of the axis observed on Pindos overthrust surface. It has to be mentioned that the dip of the marine deposits generally follows the dip of this anticlinal structure.

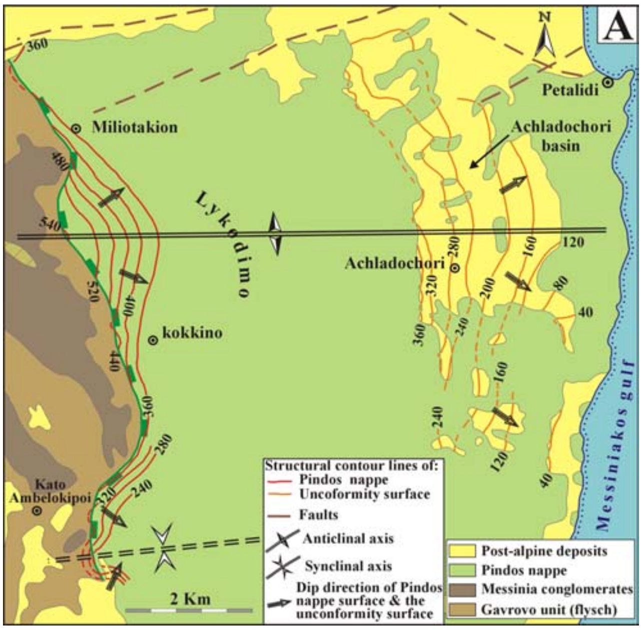
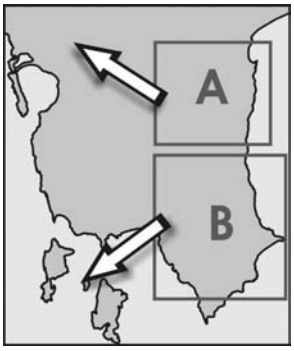


Figure 7. Structural contour maps of: (i) Pindos nappe thrust surface at NE Pylia and (ii) the contact between the post-alpine deposits and Pindos unit at Achladochori basin.



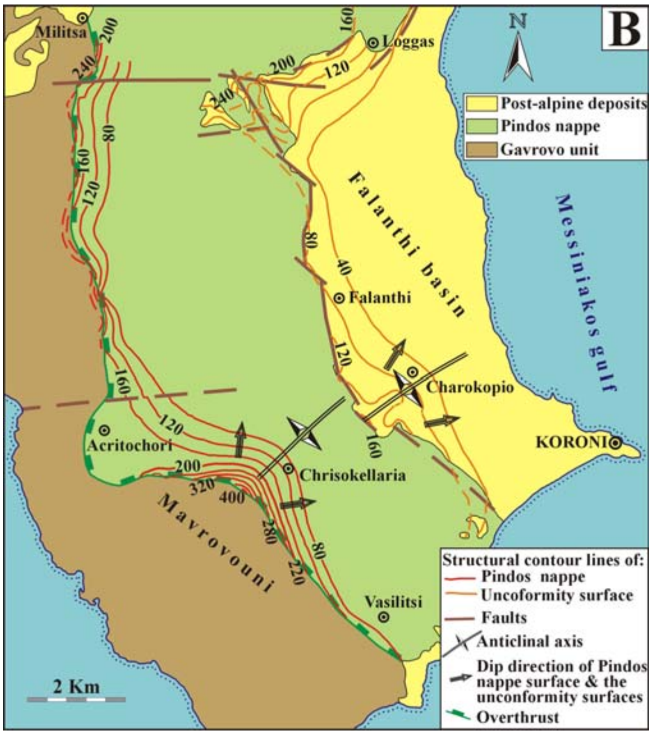


Figure 8. Structural contour maps of: (i) the Pindos nappe thrust surface at SE Pylia and (ii) the contact between the post-alpine deposits and the Pindos unit at Falanthi basin.

At the northern part of Falanthi basin the general shape of the contours of the structural map is deformed due to the action of Logga-Evaggelismou fault zone and the structural contours degree of dipping is greater.

6 DEFORMATION OF THE ALPINE STRUCTURES (PINDOS FOLD AXES) DURING THE NEOTECTONIC PERIOD

In order to understand the deformation of the alpine structural elements during neotectonic period we carried out a detailed micro-tectonic analysis concerning the orientation and the plunge direction of the fold axes of Pindos unit formations for the whole area of Eastern Pylia. The projections of all measured fold axes are shown in figure 9.

From the micro-tectonic analysis of the fold axes, a general N-S direction is suggested. However, the plunge direction varies from one location to another. At the northern flanks of Lykodimo Mt., the plunge direction is towards the north while at its southern part the plunge direction is towards the South. Moreover within Mavrovouni tectonic horst, the plunge direction of the axes in the area between Chrisokellaria and Yamia settlements is towards the NNW, while further to the South at the area between Chrisokellaria and Vasilitsi settlements the fold axes trend towards the NW-SE and plunge towards the SSE-SE.

These data are in accordance with the subsurface maps for the Pindos nappe as the plunge direction changes on both sides of the imaginary lines of the anticlinal axes mentioned on chapter 5.

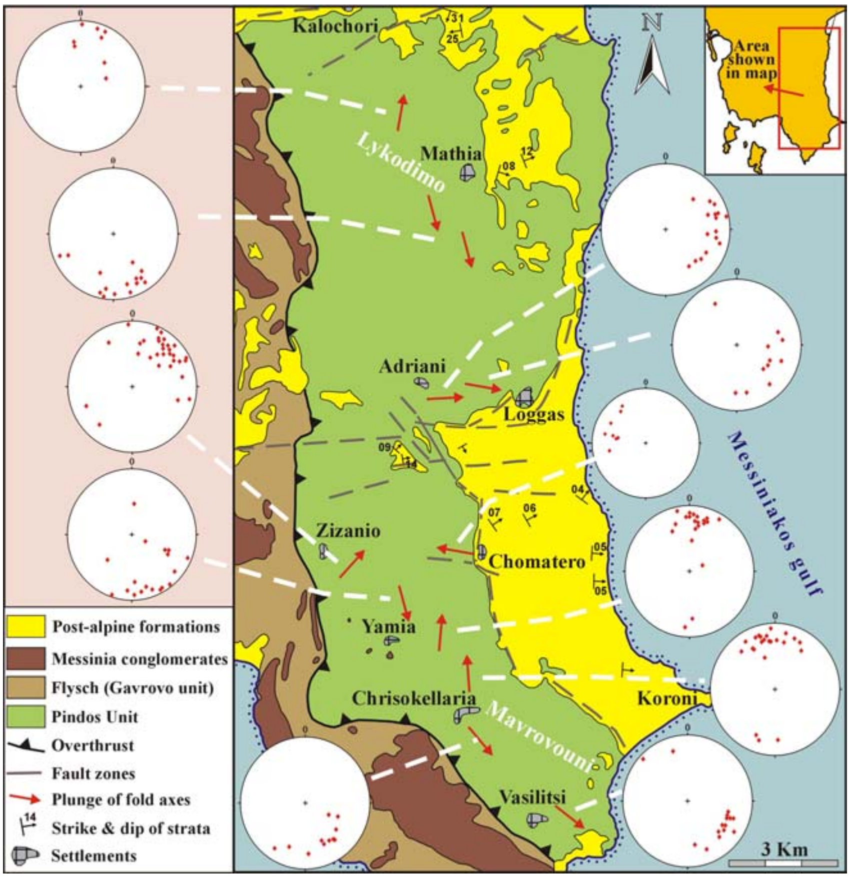


Figure 9. Equal area, lower hemisphere projections of the fold axes of the Pindos formations from several locations in eastern Pylia. Note the plunge variation of the axes from north to south at Lykodimo Mt and from NNW to SE at Mavrovouni Mt.

Near Adriani and Loggas settlements, significant horizontal displacement of the fold axes is observed, forming dragged folds, since their trending changes from N-S to E-W. These dragged folds are dipping towards the E. This displacement suggests that the Logga-Evagelismou fault zone (LEFZ) which separates the Falanthi basin from the Lykodimo Mt., has a significant left lateral character.

7 CONCLUSIONS

From all the aforementioned, the most interesting conclusions for the kinematic and dynamic analysis of the neotectonic deformation of the stydy area can be drawn by the following:

- The spatial distribution and the dip direction of the planation surfaces that have been developed both over the alpine basement and over the marine Plio-Pleistocene deposits.
- The shape and characteristics of the drainage network.
- The spatial distribution of the marine post-alpine deposits and their present day highest altitude occurances.
- The neotectonic macrostructure of Pylia.
- The presence of normal marginal faults striking N-S and oblique normal ones that strike E-W.
- The presence of both normal and reverse faults inside the neotectonic grabens.
- The synclinal and anticlinal structures of the Pindos nappe overthrust surface.
- The anticlinal structure of the unconformity between the marine Plio-Pleistocene deposits and Pindos unit at the basins of eastern Pylia.
- The deformation of the alpine structural elements during neotectonic period as suggested by the detailed micro-tectonic analysis regarding:
  a. the trend and the opposite plunge direction of Pindos fold axes
  b. the drag displacement of Pindos fold axes near fault zones that present strike slip movement.

All these observations which are characteristic of the neotectonic deformation of the study area suggest the existence of two anticlinal mega-structures at the region of eastern Pylia peninsula described as follows (Fig. 10):

- one at the NE part of the peninsula, trending E-W and
- one at the SE part of the peninsula trending ENE-WSW.

These structures deform both alpine formations and marine Pleistocene deposits. It is therefore concluded that the Quaternary morphogenetic processes have been determined by the regional complicated tectonic deformation which is not of pure brittle but of brittle-ductile type.

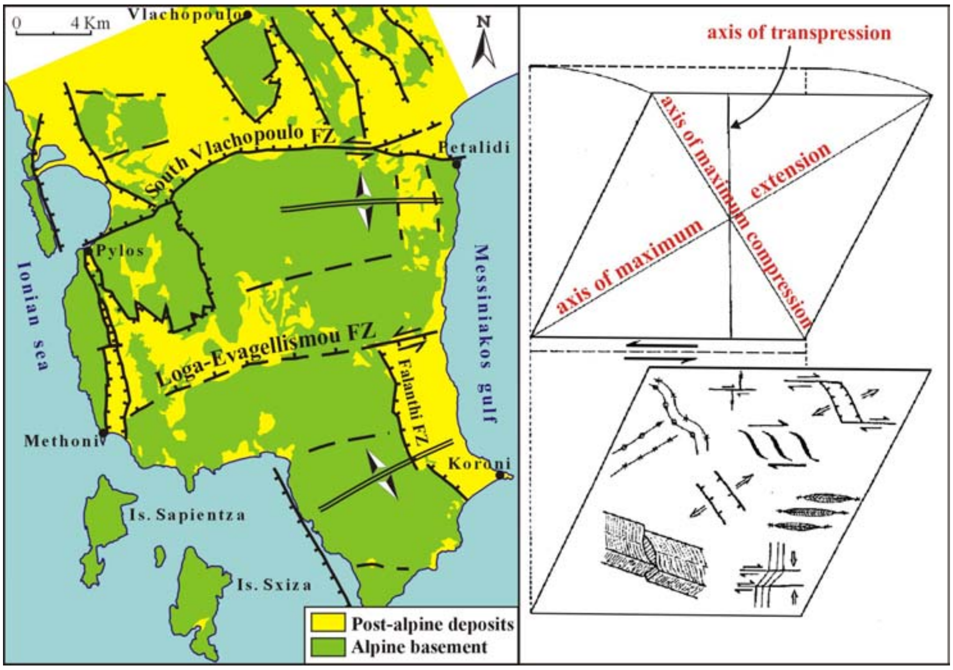


Figure 10. The macrostructures of the Pylia Peninsula and schematic representation of the rotational deformation patterns after Mariolakos *et al*., 1991b.

Therefore, the deformation that has affected the study area can not be attributed to the action of a simple compressional or extensional stress field but to a more complex one that can produce simultaneously structures of brittle and ductile deformation that coexist in the study area.

In our opinion, the deformation model that can be suggested for the observed tectonic structures of the Pylia Penisnula is that of torsional deformation, due to the existence of large strike-slip E-W striking fault zones. These zones are bounding regions inside of which local stress fields of different types can exist. Therefore, under the influence of such stress field all the aforementioned neotectonic structures can be interpreted.

- The large anticlinal structures are formed parallel-subparallel to the axis of maximum extension as the result of a local compressional or transpresional stress field and,
- The large marginal faults of normal character striking NNW-SSE are formed parallel-subparallel to the axis of maximum compression as a result of a local extensional stress field.

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