The study area locating close to the Hellenic Arc system at the central-western part of Peloponnese and constitutes the eastern margin of the Pyrgos-Olympia basin and from the neotectonic point of view is one of the less studied areas. More specifically, is located at the transitional zone between the horst of Gortynia Mt. (Arcadia) and the Pyrgos-Olympia basin (Fig. 1). The broader western Peloponnese is dominated by extensional tectonics as expressed by the E-W oriented normal faults on the northern and southern part (Mariolakos and Papanikolaou 1987).

In order to understand the neotectonic deformation in this area, the geomorphological and morphotectonic features as well as the deformation of the alpine structural features during the neotectonic period were studied. More specifically, our study was based on: (i) mapping of the tectonic structures and especially the active ones and recording of kinematic indicators, (ii) the study of the drainage network as well as the incision it presents, (iii) the spatial distribution of the planation surfaces, (iv) the construction of the structural contour map of the contact between the Pindos geotectonic unit and the Tripolis geotectonic unit iu the wider area and (v) the correlation of the seismicity with the faults.

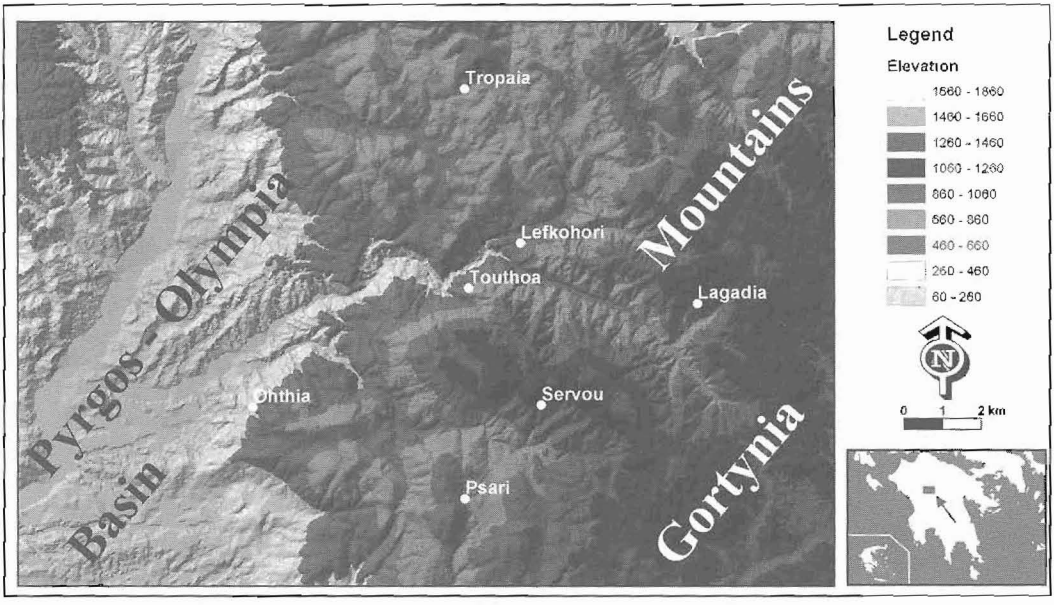


Figure 1 - Gortynia Mts and Pyrgos-Olympia basin as well as the relief of the study area are shown

2. Geological Setting

In the broader area two main alpine units (Pindos and Tripolis) and post-alpine deposits occur (Lalechos 1974, Jacobshagen *et al.* 1978, Katsiavrias 1991, Lekkas *et al.* 1992, Fountoulis 1994).

Pindos uuit constitutes a nappe that overthrusts the Tripolis unit. The formations of Pindos nappe can be distinguished into three groups that are clastic sediments of Upper Triassic, Lower Cretaceous and Tertiary age, limestones with pelagic facies of Upper Triassic - Upper Cretaceous age and radiolarites s.l. mainly of Jurassic age. The whole unit is intensively folded and faulted, forming successive thrusts with movement direction from east to west.

Tripolis unit crops out in the form of tectonic windows below the nappe of Pindos unit at the mountains of Gortynia reaching altitudes of 1300 m. The stratigraphic column can be distinguished into two groups; the neritic carbonate sequence from Triassic to Eocene and the flysch at the top mainly of Oligocene age (Papanikolaou 1986).

The post-alpine sediments occur in the broader western part of the study area. They can be distinguished into marine, lacustrine, lagoonal and terrestrial formations lying unconformably on the alpine basement. The present geographic distribution and the relations between these sediments are determined mainly by the ongoing active tectonics. The post-alpine sediments in the broader area are of Quaternary age (Hagemann 1977, Lekkas *et al.* 1992, Lekkas *et al.* 2000):

- Holocene age formations include recent fluvial deposits, talus, scree and terra rossa with pebbles coming mainly from Pindos unit and
- The Erymanthos formation is of Pleistocene age and consists mainly of continental polymictic conglomerates, in a loose fine-grained matrix.

3. Morphotectonics

This neotectonic study is based not only on fault analysis, but also on the analysis of some geomorphic features of the area. More specifically the morphotectonic study was based on the study of: (a) the drainage network and (b) the spatial distribution of the planation surfaces.

Drainage network

Lagadiano River developed in the study area (Fig. 2) consists a part of the of Ladou River drainage network. The Lagadiano River is a 5^{th} order drainage network whose 5^{th} order tributary presents a NW-SE direction and is created by the confluence of three 4^{th} order tributaries, which are Liaporrema, Touthoa and Goura from north to south respectively. In most sites these tributaries are perpendicular to the main faults whereas in few other sites are parallel to the faults. For example, Liaporrema River initially has a NW-SE direction almost perpendicular to Lefkohori fault zone (LFZ) (Fig. 2). Thereinafter, it change abruptly direction to NE-SW and is parallel to Lefkohori fault zone (LFZ).

The incision zones are directly and dynamically related to the tectonic regime of the area and developed mainly perpendicular to fault zones (Fig. 2). An incision zone is located in the area between Lefkohori and Touthoa and especially in the NW-SE trending Touthoa River. This zone is perpendicular to NE-SW striking Lefkohori fault zone (LFZ) forming an impressive canyon. Another interesting incision zone is observed to the south-southeast of Aetorrahi in Goura River. The river and the zone initially have an E-W direction progressively changing to NW-SE direction parallel to Kokkinorrahi – Arapides fault zone (K-AFZ).

These abrupt changes of the stream directions and its relation with the fault zones suggest that the neotectonic deformation affect directly the configuration of the drainage network. These geomorphological structures are the result of intense uplift movements of segments bounded and controlled by the fault zones of the area.

Planation Surfaces

The spatial distribution, the shape and the elevation are elements of the planation surfaces, which are affected by the tectonic movements of a region. The methodology applied for the study of planation surfaces includes the following stages:

(i) Editing of topographic elements (contour lines) from the topographic map sheets TROPAEA and DHIMITSANA (Hellenic Army Geographical Survey) in 1:50.000 scale.

(ii) Construction of Digital Elevation Model (DEM) with 20m-elevation range.

(iii) Construction of planation surfaces map, distinction into destructive and constructive planation surfaces and separation into elevation groups of >0-200 m, 200-400 m, 400-600 m, 600-800 m, 800-1000 m, 1000-1200 m and 1200-1400 m. Surfaces with slope from 0^{o} to 5^{o} considered as destructive planation surfaces.

(iv) Study of air photos in 1:50.000 scale.

(v) Fieldwork and confirmation of the results of the stages above.

Planation surfaces in elevations of >0-200 m, 200-400 m and 400-600 m cover larger areas than the planation surfaces in elevations of 600-800 m, 800-1000 m, 1000-1200 m and 1200-1400 m. This is due to the fact that the planation surfaces in higher altitudes are older structures that have undergone erosion processes for a longer period of time than the planation surfaces in lower altitudes.

The planation surfaces created on Pindos nappe present an arrangement with N-S trending parallel zones and their altitude ranges from 200 to 1000m from southwest to northeast (Fig. 2). This arrangement occurs west of Ohthia, Aetorrahi, Touthoa and Lefkohori fault zones bnt the altitude range from 400 to 1000m and from northwest to southeast.

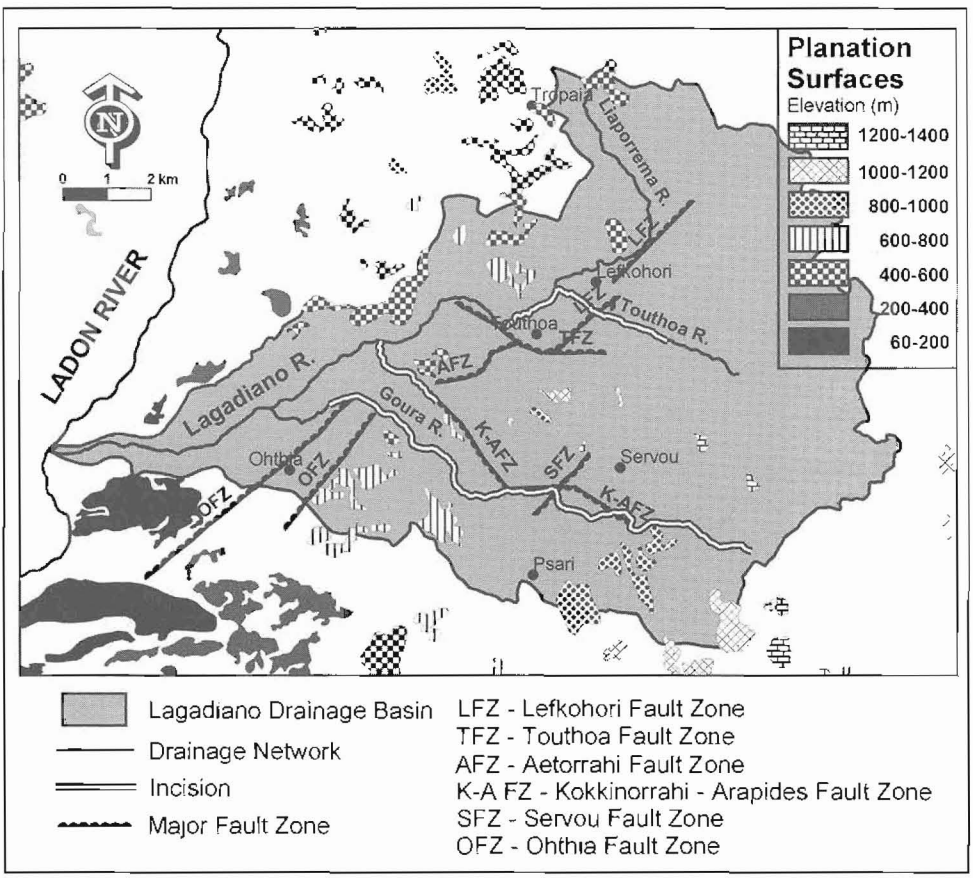


Figure 2 - Map showing the main geomorphic features (planation surfaces, incision zones, and the main tributaries of the drainage network) as well as the major fault zones of the study area

The successive formation of these geomorphological structures is disordered in the west of Ohthia fault zone region. There is an absence of planation surfaces in elevations from 200 to 600 m and an abrupt transition from the group of 60-200 m to the group of 600-800 m.

4. Neotectonics

The tectonic deformation of the area can be distinguished into two main different deformation phases: the alpine and the neotectonic phase. The alpine deformation is characterized by the creation of overthrusts, thrusts and folds and it took place from the Upper Eocene to the Early Miocene. Vertical movements characterize the neotectonic phase. It is the period during which the formation of neotectonic macrostructures (neotectonic grabens and neotectonic horsts bounded by fault zones) takes place. New faults rupture post-alpine and alpine formations or old faults formed during the alpine phase are reactivated. This is the most usual condition and thus traces of reactivations can be observed on the fault surfaces. These are tectonic breccias with different lithologies, different striations sets, tectonic gashes and other types of kinematic indicators with different kinematic character.

The neotectonic structure of W. Peloponnese is characterized by the presence of large neotectonic blocks that correspond either to grabens or horsts (Mariolakos and Papanikolaou 1981, 1987, Lekkas *et al.* 2000). These blocks are bounded by fault zones (Mariolakos *et al.* 1985) striking E-W and NNW-SSE and creating a complex mosaic, with particular neotectonic structural and evolution characteristics in every single part of the area.

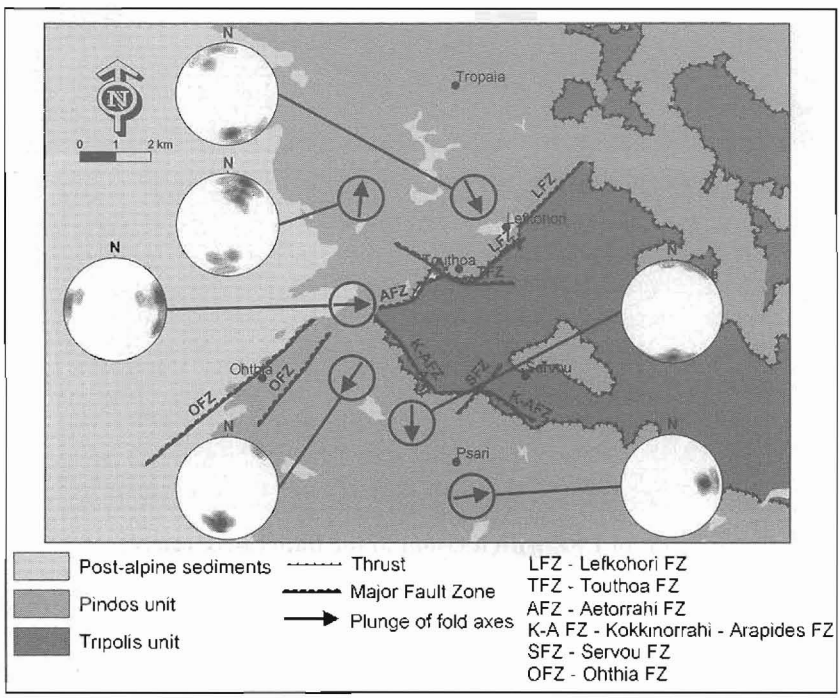


Figure 3 - Structnral map showing the tectonic window of Tripolis unit and the main fault zones of the study area as well as the statistical analysis of the fold axes (lower hemisphere, equal area projeetion) occurring in the Pindos uuit formations (see text)

The main neotectonic structures in the study area are the Olympia basin and the Gortynia Mt. horst bounded by major fault zones, which are: Lefkohori fault zone (LFZ), Touthoa fault zone (TFZ), Aetorrahi fault zone (AFZ), Kokkinorrahi-Arapides fault zone (K-AFZ), Servou fault zone (SFZ) and Ohthia fault zone (OFZ) (Fig. 3).

Lefkohori FZ (LFZ) is a NE-SW directed fault zone and constitutes the tectonic boundary between the formations of Tripolis unit and the pelagic carbonates of Pindos unit (Fig. 4A). It forms a large escarpment in the morphology (Fig. 4B) and intense incision transversal to its strike (Fig. 4C). It consists of NW-SE and NE-SW striking faults characterized by a dip-slip kinematics.

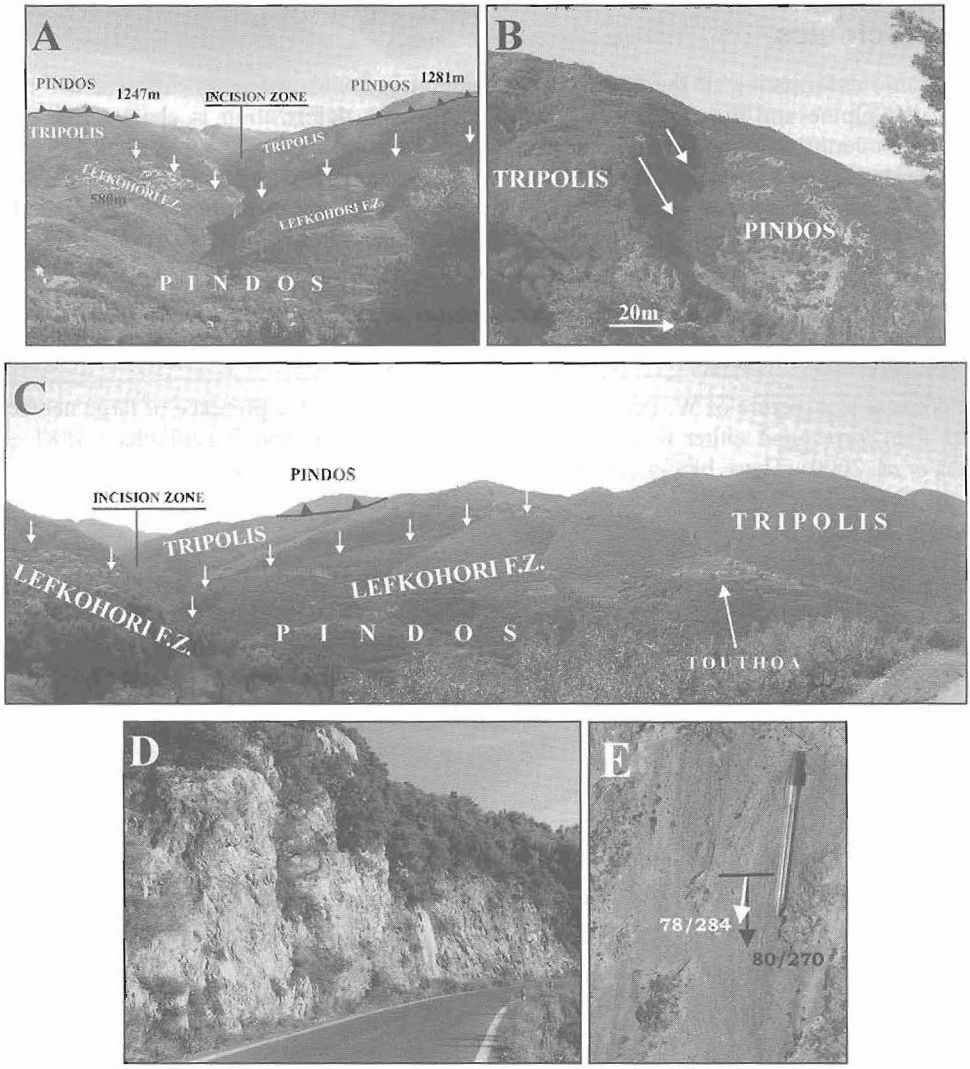


Figure 4 - (A) Partial view of LFZ with incision in the impressive canyon of Touthoa River. The remains of Pindos nappe in Lagadia (left) and Servou (right) indicate a vertical displacement at least 700m for LFZ. (B) LFZ forms a large escarpment in the morphology. (C) Panoramic view of LFZ from northwest. (D) A NW-SE striking fault that cut carbonates of the Tripolis unit and (E) fault surface with dip slip striations

Large remains of Pindos nappe are located in the east and south of Lefkohori FZ in Lagadia and Servou areas respectively. These remains of Pindos unit occur at an altitude of 1241m and they overthrust Tripolis flysch (Fig. 4A). Taking into consideration the occurrence of Pindos formations in the areas of Lefkohori, Lagadia and Servou, the vertical throw of Lefkohori FZ is estimated to be more than 700m.

Touthoa FZ (TFZ) does not present a certain direction (Fig. 5A). In the south and east of Touthoa this fault zone initially has an E-W direction progressively changing to NW-SE in the west of Touthoa. It constitutes the contact between the carbonates and the flysch of Tripolis unit with pelagic limestones and clastic sediments of Pindos unit. It is an E-W striking fault (Fig. 5B) with different striation sets (Fig. 5D).

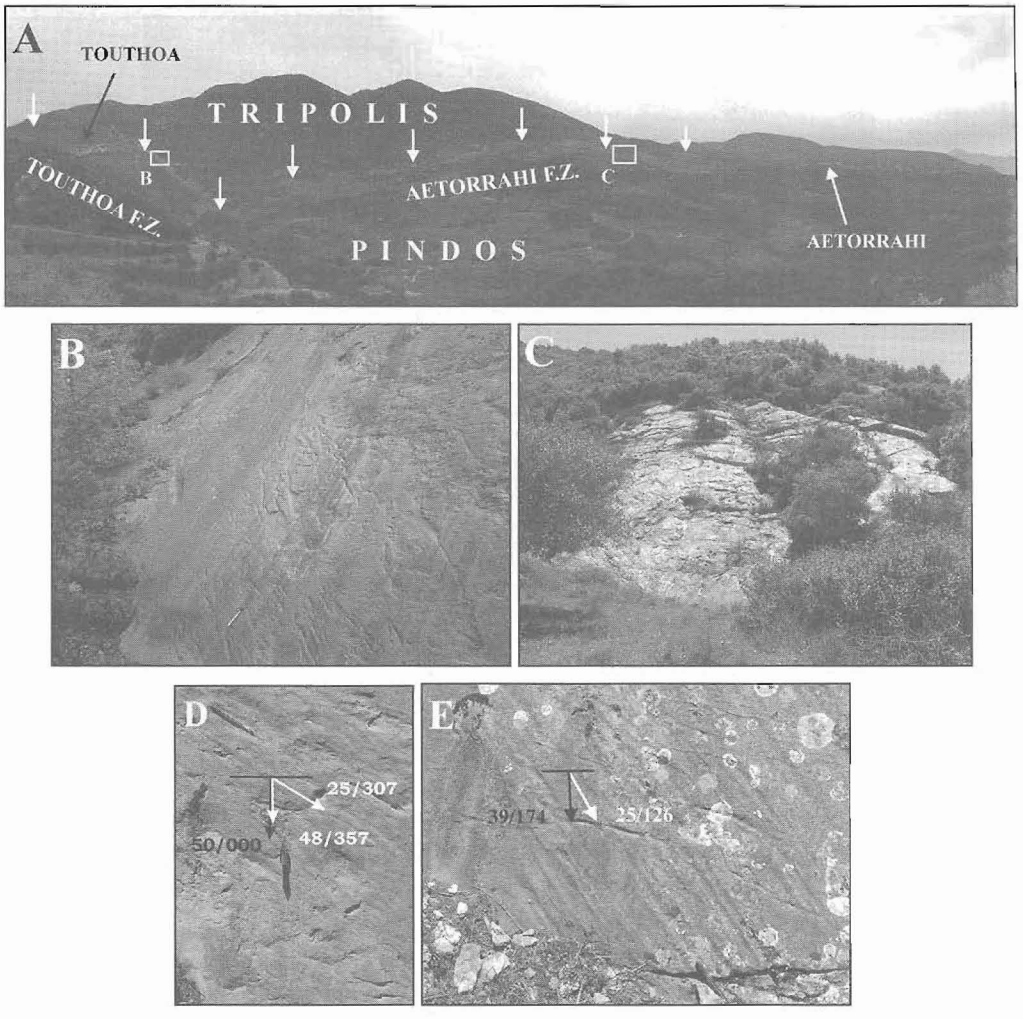
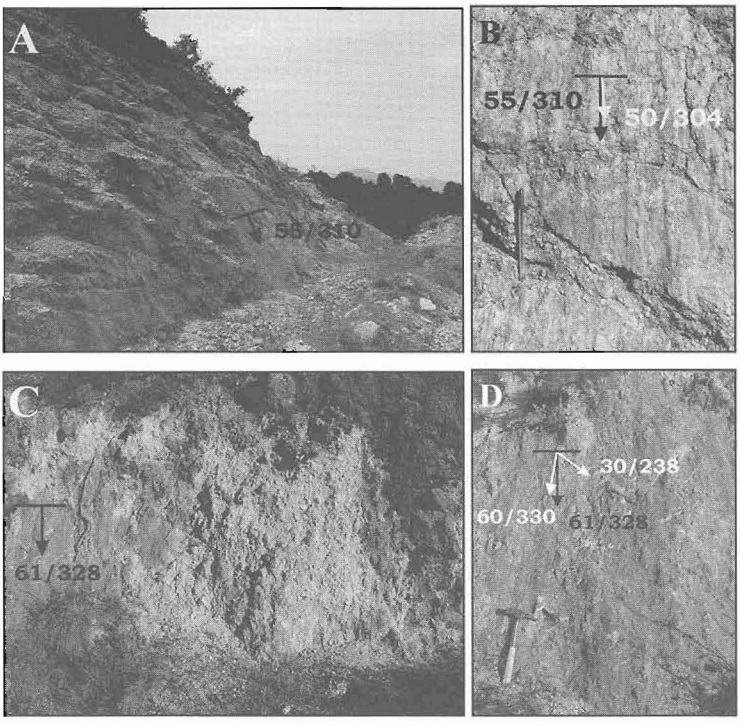


Figure 5 - (A) Panoramic view of Toythoa (TFZ) and Aetorrahi (AFZ) fault zones from uorthwest. (B) Fault surface of TFZ trending E-W with (D) two sets set of striations. (C) Curved low angle fault surface of AFZ with (E) a set of striations

A large remain of Pindos nappe is located northeast of Touthoa in the region of Servou. The occurrence of Pindos unit that overthrusts Tripolis unit flysch is located at an altitude of 1281 m. Taking into consideration the altitudes that Pindos unit occur in the area of Touthoa (500 m) and Servou (1280 m), the vertical displacement of Touthoa FZ is estimated to be more than 700 m.

Aetorrahi (AFZ) is located in the east-northeast of Aetorrahi village and presents a NE-SW direction (Fig. 5A). It brings to contact the carbonates of Tripolis unit with clastic sediments of Pindos unit. To the east of Aetorrahi a low angle E-W striking fault presents a curved surface dipping 39°/174° (Fig. 5C) and a set of striations plunging 25°/306° (Fig. 5E). The vertical displacement of AFZ is estimated to be at least 650m taking into account the occurrence of Pindos formations in the altitudes of 630 and 1281 m in the Aetorrahi (hangingwall) and Servou (footwall) areas respectively.

Ohthia FZ (OFZ) is NE-SW directed fault zone and consists of two segments in en echelon arrangement. The eastern segment cuts carbonate rocks of Pindos unit (Fig. 6A). On a fault surface of it tectonic breccia and a set of striations is observed (Figs 6A, 6B). The breccia is compact and oligomictic and consists of fragments coming from the Pindos limestones.



Fignre 6 - (A) A NE-SW fault surface of the Ohthia (OFZ) fault zone cutting the limestones of Pindos unit. (B) Tectonic breccia and dip slip striations on it observed on the previous fault surface. (C) A NE-SW fault surface of the same fault zone beiug the contact between the Pindos limestones and the pleistocene age Erymauthos formation. This surface belongs to the western segment of the OFZ and has (D) two sets of striations

The western segment brings to contact carbonate rocks of Pindos with Erymanthos formation of Pleistocene age (Hagemann 1977, Lekkas *et al.* 1992, Lekkas *et al.* 2000) (Fig. 6C). This segment consists mainly of NE-SW striking faults with two sets of striations and three different types of tectonic breccia taking into account the lithology of the fragments they consist and their relative age (Fig. 6C). The older tectonic breccia consists mainly of fragments coming from Pindos unit and is compact and oligomictic. The intermediate tectonic breccia consists of fragments of Pindos limestones and of Erymanthos formation, as well as from the older breccia and is polymictic and not so compact. The younger tectonic breccia consists of fragments from Erymanthos formation and other breccia and is polymictic and not cohesive. On the fault snrface occurring on the younger breccia two sets of striations were observed (Fig. 6D).

Frantzeta Mt. is located west of Servou at an altitude 1240m. Fault zones reactivations cause the uplift of the mountain relatively to the neighboring areas (Fig. 7A). Servou FZ (SFZ) is a NE-SW directed low angle fault zone (Fig. 7B) with surfaces on which three sets of striations as well as iron oxides occur and constitutes the boundary between the neritic limestones and the flysch of Tripolis unit. It. Two of the striation sets show significant horizontal component in the movement as well as dip slip one (Fig. 7C).

Kokkinorrahi - Arapides FZ (K-A FZ) is traced at the northeast of Kokkinorrahi and at the south of Arapides (Fig. 7A). It constitutes the contact between the carbonates and the flysch of Tripolis unit or between the carbonates of Tripolis unit and the clastic sequence of Pindos unit. Eastern of Kokkinorrahi this fault zone initially has an NW-SE direction progressively changing to E-W and again to NW-SE to the south and southeast of Arapides respectively.

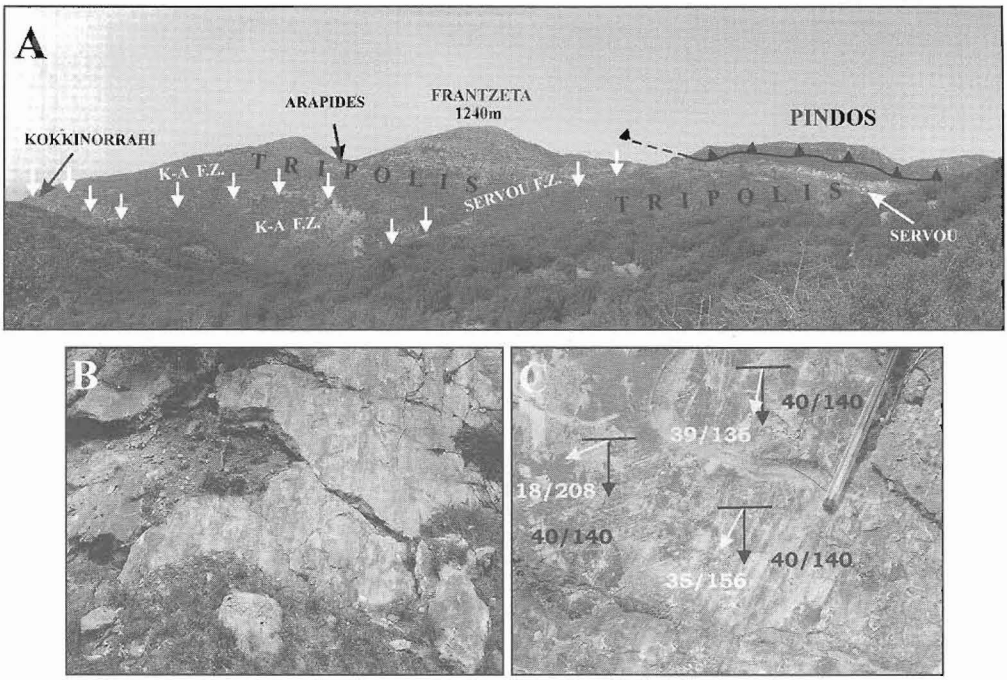


Figure 7 - (A) Panoramic view of Servou (SFZ) and Kokkinorrahi-Arapides (K-AFZ) fault zones with the remains of Pindos nappe in Servou wider area (view from the south). (B) Fault surface of SFZ presenting three sets of striations plunging 35°/156°, 39°/136° and 18°/208° from the older to the younger respectively (C)

In order to understand the kinematics of the area we also studied the deformation of alpine tectonic structure during the neotectonic period. According to the aforementioned, the alpine tectonic structure includes folds and thrusts. Normally, fold axes and thrusts strike N 10-30° W, which is the normal strike of the fold axes and thrusts in the external Hellenides (Mariolakos *et al.* 1985, Mariolakos and Papanikolaou 1987). The strike of the fold axes in the area west of Lefkohori FZ is NNW-SSE and change to E-W in the area west of Aetorrahi area and to N-S in the area northwest of Psari. These changes of the fold axes strike in area close to the fault zones imply that there is an important horizontal component in the Lefkohori, Aetorrahi and Kokkinorrahi - Arapides fault zones (Fig. 3). The effect of the uplift movement of Gortynia Mt. on the alpine tectonic structure of the study area becomes more obvious because of rotations and direction changes of alpine structural elements. The alpine tectonic structure is being deformed during the neotectonic period.

The following comments can be done concerning the construction of the structural contour map of the contact between formations of Pindos geotectonic unit and formations of Tripolis geotectonic unit in the wider area: (i) the general dip direction of the Pindos nappe is towards the west, (ii) the tectonic contact between Pindos unit and Tripolis unit reaches its higher altitudes at the areas of Servou (1100-1200 m) and Lagadia (1200-1300 m), (iii) there are many anticlinal and synclinal structures in the Pindos formations, (iv) the dip direction of the Pindos nappe at the area south-east of Tropaia is towards the west-southwest whereas the dip direction of the Pindos nappe at Touthoa area is towards the northwest, (v) the dip direction of the Pindos nappe at Psari area is towards the south-southwest and (vi) the existence of the faults zones becomes clear near the contact because of the form of the contour lines of structural map (Fig. 8).

The whole structure at the western part present a macro curvature structure of very open anticlinal type with an E-W striking axis in Frantzeta Mt. It has to be noticed that neotectonic macrofolds formed in the post-alpine sediments in different scales have been studied by Mariolakos and Fountoulis (1991) and Fountoulis (1994).

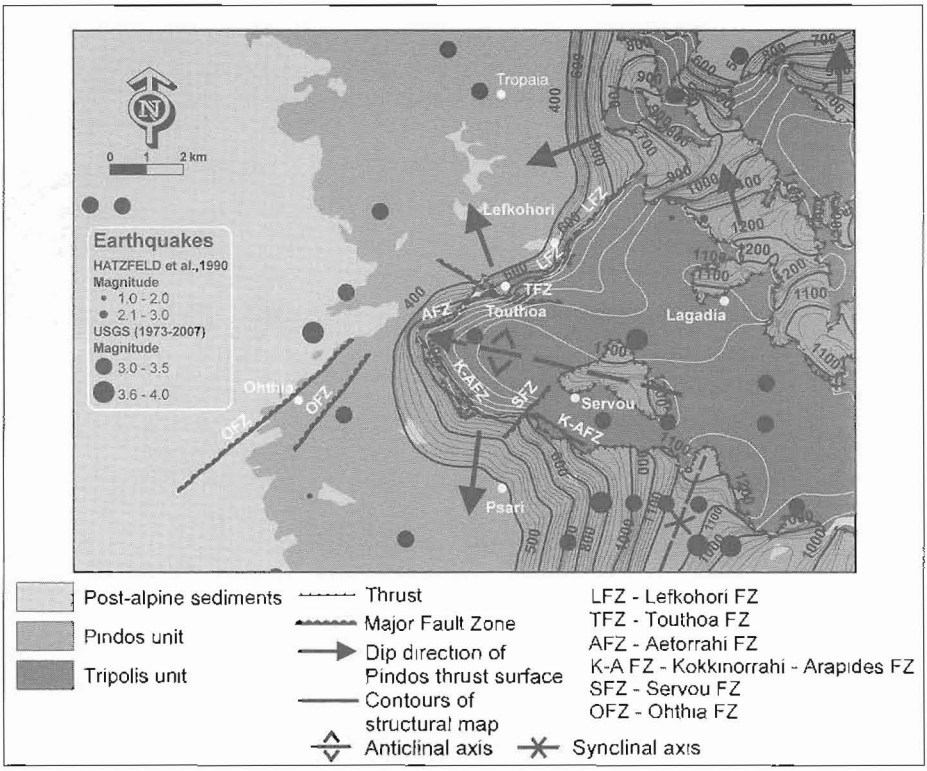


Figure 8 - Structnral contour map of the contact between the formations of Pindos and Tripolis geotectonic units and the plot of earthquake epicenters (USGS) in the study area

The earthquake activity in the study area is not so intensive as in the western part of Pyrgos – Olympia basin, but there are several earthquake epicenters. Some of these epicenters could be correlated with the Ohthia fault zone, but it true that there is no seismic evidence that can be correlated with the reactivation of a fault zone.

5. Conclusions -Discussion

Taking into account all tbe above mentioned we come to the following conclusions:

The endogenic (tectonic) processes control tbe spatial distribution, the size, the shape, and the elevation of the planation surfaces created on tbe alpine basement. Furthermore, morphogenetic processes that configure the incision and the geometry of the drainage network are mainly controlled by the neotectonic deformation.

Concerning the activity of all the described neotectonic fault zones, two of them (Ohthia and Lefkohori) are the younger and could be characterized as active due to: (i) the escarpment they present, (ii) the spatial distribution of the planation surfaces created on their footwall and hangingwall blocks, (iii) the incision developed on the footwall transversal to them, and (iv) the reactivation of the faults during the neotectonic period as it is certified by the presence of successive tectonic breccia oligomictic and especially polymictic containing fragments coming from the alpine formations as well as from the Pleistocene age Erymanthos formation. Moreover, the vertical displacement especially of the active fault zones is more than 700 m.

The alpine tectonic structure is intensively deformed during the neotectonic period. This is established by the change of the strike and plunge of the fold axes, especially in the areas close to the studied fault zones.

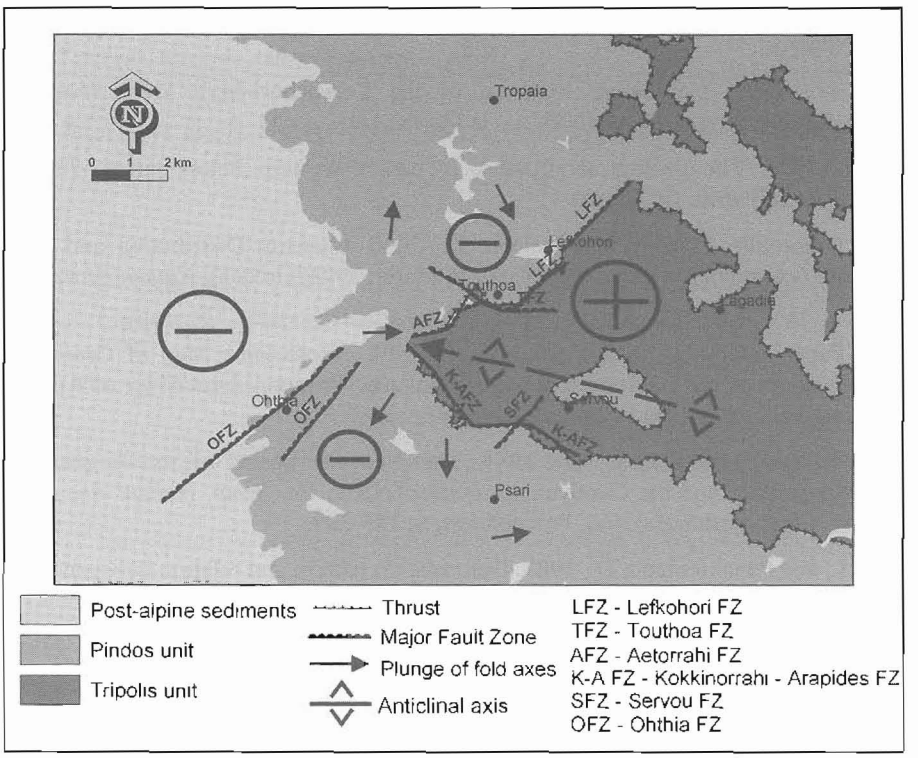


Figure 9 - Map depicting the main neotectonic fault zoues of the study area. The symbol (-) corresponds to subsidence and the symbol (+) corresponds to inteuse uplift

More specifically, it is evident that the geometry of the thrust surface of Pindos tectonic unit has changed considerably, dipping towards NW in the area between Lefkohori - Touthoa and towards SW in the area south of Servou village (Fig. 8) and the fold axes of Pindos unit present a pluuge towards south to southwest and in some cases they change plunge towards east (Fig. 8). This change in geometry of the Pindos unit fold axes can be explained taking in to account that the marginal fault zones occurring in the study area and bordering the tectonic horst, present a sinistral strike slip component in the movement causing the dextral rotation of the fold axes especially in the areas close to these fault zones. It has to be mentioned that the observed oblique striations disclose a significant vertical component in the movement.

6. References

Fountoulis, I., 1994. Neotectonic evolution of Central - West Peloponnese, *Thesis*, Sector of Dynamic, Tectonic and Applied Geology, Faculty of Geology, University of Athens, GAIA, 7, 386pp. (in Greek with abridged English version)

Hagemann, J., 1977. Stratigraphy and sedimentary history of the Upper Cenozoic of the Pyrgos area (W. Peloponnesus, Greece), *Ann. Géol. Pays Hellén.*, 30/2, 441-454. XXVIII, 299-333.

Hatzfeld, D., Pedotti, G., Hatzidimitriou, P., and Makropoulos, K., 1990.The strain pattern in the western Hellenic arc deduced from a microearthquake survey, *Gophys. J. Int.*, 101, 181-202.

Jacobshagen, V., Dürr, S., Kockel, F., Kopp, K.O., Kowalczyk, G., Berckhemer, H., and Büttner, D., 1978. Structure and geodynamic evolution of the Aegean region. In H. Closs, D. Roeder

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THE MORPHONEOTECTONIC STRUCTURE OF THE TRANSITIONAL ZONE BETWEEN THE GORTYNIA MT. HORST AND THE PYRGOS-OLYMPIA BASIN (CENTRAL - WESTERN PELOPONNESE, GREECE)

Fountoulis I.[1], Mavroulis S.[1], and Theocharis D.[1]

[1] *National and Kapodistrian University of Athens, Faculty of Geology and Geoenvironment, Department of Dynamic Tectonic Applied Geology, fountoulis@geol.uoa.gr, smavroulis@yahoo.gr, dtheocharis@geol.uoa.gr*

Abstract

The present paper aims to the understanding of the neotectonic deformation in areas where no post-alpine sediment occurs. The study area is located at the transitional zone between the horst of Gortynia Mt. (Arcadia) and the Pyrgos-Olympia basin in the central-western Peloponnese and is tectonically and seismically active. The studied neotectonic faults can be distinguished in low to mid angle faults and high angle faults. The majority of them present striation sets with significant horizontal component that causes the change in the direction and plunge of the fold axes of Pindos unit. The younger and with more active characteristics fault zones are the Lefkohori and Ohthia ones.
Key words: *neotectonic, low angle fault, active fault, structural contour map.*

Περίληψη

Στην παρούσα εργασία στόχος είναι η κατανόηση της νεοτεκτονικής παραμόρφωσης σε περιοχές όπου δεν απαντούν μεταλπικές αποθέσεις. Η περιοχή μελέτης ευρισκόμενη στην ΚΔ Πελοπόννησο, στη μεταβατική ζώνη μεταξύ του βυθίσματος Πύργου-Ολυμπίας και των ορέων της Γορτυνίας που είναι μία από τις γνωστές τεκτονικά και σεισμικά ενεργές περιοχές. Τα νεοτεκτονικά ρήγματα που μελετήθηκαν διακρίθηκαν σε μικρής-μέσης κλίσης και μεγάλης κλίσης, στην πλειονότητα των οποίων παρατηρήθηκαν ομάδες γραμμών προστριβής με σημαντική οριζόντια συνιστώσα η οποία έχει ως αποτέλεσμα την αλλαγή στη διεύθυνση και τη βύθιση των αξόνων των πτυχών της Πίνδου. Οι νεότερες με χαρακτηριστικά ενεργών ρηξιγενών ζωνών είναι αυτές του Λευκοχωρίου και της Όχθιας.
Λέξεις κλειδιά: *νεοτεκτονική, ρήγμα μικρής κλίσης, ενεργό ρήγμα, υπεδαφικός τεκτονικός χάρτης.*

1. Introduction

The study of the neotectonic deformation is usually focused in neotectonic grabens that have been filled in with sediments and less in the tectonic horsts.

and K. Schmidt (eds), *Alps, Apennines, Hellenides*, Inter. Union Comm, Geodynamics Sci. Rep. Stuttgart. vol. 38 (1978), 537–564pp.

Katsiavrias, N., 1991. Geological structure of the Lefkochori-Myli area, West - Central Peloponnesus, *Thesis*, 172pp, NTUA. (in Greek)

Lalechos, N., 1974. The geological structure of central-western Peloponnisos, *Thesis*, 94pp., University of Patras. (in Greek)

Lekkas, E., Fountoulis, I., and Papanikolaou, D., 2000. Intensity Distribution and Neotectonic Macrostructure Pyrgos earthquake data (26 March 1993, Greece), *Natural Hazards*, 21, 19-33.

Lekkas, E., Papanikolaou, D., and Fountoulis, I., 1992. Neotectonic Map of Greece, Pyrgos - Tropaia sheet (scale 1:100.000). Applied Scientific Program, University of Athens, Sector of Dynamic, Tectonic and Applied Geology.

Mariolakos, I., and Papanikolaou, D., 1981. The Neogene basins of the Aegean Arc from Paleogeographic and the Geodynamic point of view, Int. *Symp. Hellen. Arc and Trench, Athens, 1981*, Abstracts 65-66, Proceedings, S, 383-399.

Mariolakos, I., and Papanikolaou, D., 1987. Deformation pattern and relation between deformation and seismicity in the Hellenic arc, *Bull. Geol. Soc. Greece*, XIX, 59-76. (in Greek)

Mariolakos, I., and Fountoulis, I., 1991. Neotectonic macrofolds in the area of Filiatra (SW Peloponnese, Greece), *Proceedings 5th Geol. Congress of the Geol. Soc. Greece, May 1990, Thessaloniki, Bull. Geol. Soc. Greece*, XXV/3, 19 – 38. (in Greek)

Mariolakos, I., Papanikolaou, D., and Lagios, E., 1985. A Neotectonic Geodynamic Model of Peloponnesus Based on Morphotectonics, Repeated Gravity Measurements and Seismicity, *Geol. Jb.*, B 50, 3-17.

Papanikolaou, D., 1986. Geology of Greece. 240pp. Athens. (in Greek)

USGS National Earthquake Information Center – NEIC: http://earthquake.usgs.gov/regional/neic