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NEOTECTONIC MACROFOLDS AT THE FILIATRA AREA (SOUTHEWESTERN PELOPONNESUS, GREECE)

by

I. MARIOLAKOS and I. FOUNTOULIS

Abstract

In order to understand the type of the deformation of the western Messinia area, the drainage network, the planation surfaces that are present on the Lower Pleistocene marine deposits, the fault zones and the faults were studied. In addition, the structural contour map of the contact between the Lower Pleistocene marine deposits and the flysch of Gavrovo - Pylos geotectonic unit was constructed. Taking into account the results of the above mentioned analysis, we believe that the deformation of the area is not of the brittle type, but of the brittle - ductile, resulted of a rotational couple stress-field.

INTRODUCTION

Western Messinia (Filiatra area), located at the SW part of Peloponnesus, is one of the most tectonically active areas of the Hellenic Arc. This is due to the fact that it is near to the Hellenic Trench (approx. 60 km), which is considered as the collision boundary between the African and Eurasian plates (Fig. 1). Therefore, it is one of the most suitable areas to study the neotectonic deformation at the eastern Mediterranean region.

From neotectonic point of view, Western Messinia could be considered as a part of the Hellenic Island Arc, although at the present time this area is a part of the mainland (Peloponnesus peninsula). Lykodimon Mt., for example, was a real island from Early Pliocene up to the end of Early Pleistocene, whereas Kyparissia Mts were a small peninsula connected to the mainland the Messinian paleo-gulf through a narrow and low strip of land (the Kopanaki - Meligalas paleo-isthmus, Fig. 5) which was similar to the present day Isthmus of Korinthos connecting Peloponnesus to the mainland of Greece.

From the kinematic and dynamic point of view, the neotectonic and consequently the morphotectonic evolution of Messinia area is considered to be among the most complex ones of the Hellenic Arc.

The study area is located between the small town of Kyparissia to the north and the town of Pylos to the south. whereas to the east is bounded by the Kyparissia Mts (Fig. 5).

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This neotectonic study is based not only on fault analysis but on the analysis of the geomorphology and paleogeography of the area as well. More specifically the morphotectonic study was based on the analysis of:

a) the drainage network

b) the geographical distribution of the planation surfaces that are present on the alpine and post-alpine (mainly Early Pleistocene) deposits.

Furthermore, a structural contour map of the contact between the Lower Pleistocene marine deposits and the flysch of the Gavrovo - Pylos geotectonic unit (Late Eocene - Early Miocene) was constructed.

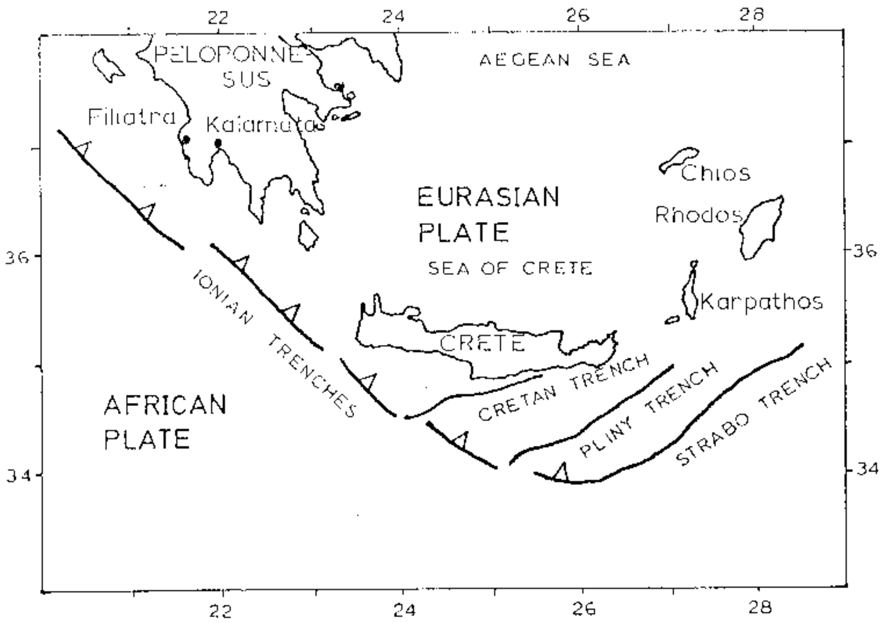

Fig. 1. Location map.

GEOLOGY

Alpine Units

At the western Peloponnesus three alpine geotectonic Units occur (from lower to upper, Fig. 2).

i) The Ionian unit, consisting mainly of thinbedded limestones and flysch.

ii) The Gavrovo-Pylos unit, consisting of neritic carbonates (limestones and dolomites) and flysch.

iii) The Pindos unit, consisting of pelagic limestones, radiolarites (mainly Jurassic), the so called "first flysch" (alternation of pelites, sandstones, turbiditic calcarenites or polymictic arenites and thinbedded limestones), pelagic limestones and flysch (Danium - Eocene). The whole unit is intensively folded.

From tectonical point of view, the above mentioned three geotectonic units build a succesion of three nappes, overthrusted one upon the other, whereas the Ionian unit is considered as the relatively autohthonous one; so Gavrovo-Pylos unit overthrusts Ionian unit and Pindos unit onverthrusts Gavrovo-Pylos unit.

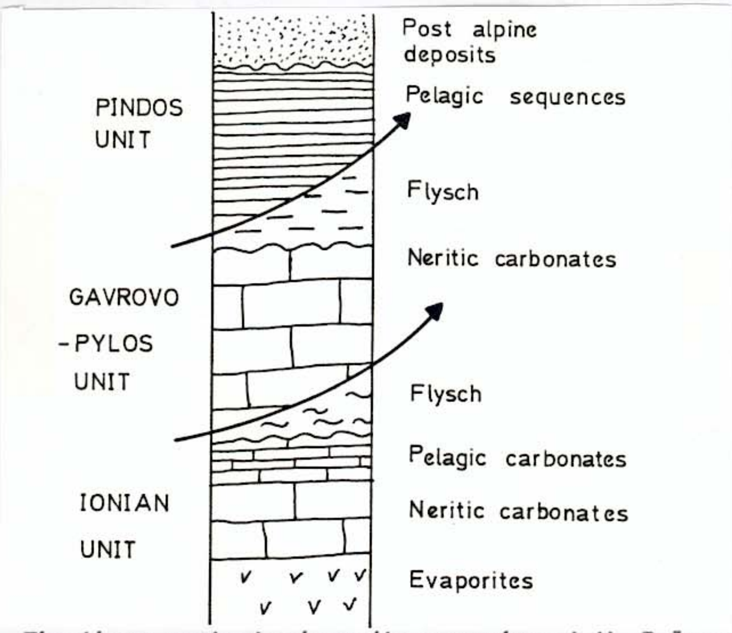

Fig. 2. The three geotectonic units occuring at W. Peloponnesus.

At the study area only flysch and Eocene carbonates of Gavrovo-Pylos unit occur (Fig. 3).

i) <u>Flysch (Late Eocene - Early (most) Miocene)</u>
The flysch consists of silty blue marls, pelites and small intercalations of sandstones. It occurs mainly at the northern part of the study area, as well as at the valleys of the central and southern sub-areas (Fig. 3 geological map). The beds generally dip towards east. At the northern sub-area the beds dip to the northeast, whereas at the southern sub-area they dip to the southeast.

ii) <u>Carbonates (Eocene)</u>
The carbonates (dolomites - limestones) are massive or thickbedded, neritic white to gray and belong to the Gavrovo - Pylos unit. These carbonates (dolomites - limestones) are intensively karstified. In some cases the karstification coincides with neotectonic faults (younger phase), whereas in other cases the karstification is created on the paleo-planation surfaces, which have been covered by Lower Pleistocene marine deposits.

Post - alpine Deposits

i) Older post - alpine formation (Conglomerates of Messinia)

The older post-alpine formation occur mainly at the north-western slopes of the Kyparissia Mts (Fig.3). They consist of highly compacted polymictic conglomerates, marls and pelites. The age of these sequences is not well known but most likely is Late Miocene. The pebbles are well rounded, come mainly from the limestones and the radiolarites of the Pindos unit and are cemented with sandstone. The beds dip towards east. The visible thickness of the formation is about 700 m.

In our opinion, the Conglomerates of Messinia, which are considered to belong to the Gavrovo - Pylos flysch (PERRIER, 1980), belong to the post alpine deposits and most likely represent a molassic formation (KISKYRAS, 1964).

ii) Lower Pleistocene marine deposits

The shallow marine deposits overlie unconformably the flysch, the Eocene carbonates and the Conglomerates of Messinia (Fig. 3). These deposits consist of calcitic sandstones, marly sandstones, marls, as well as thinbedded intercalations of sandy conglomerates. The upper parts of the sequence consist mainly of calcitic sandstones.

The thickness of the lower pleistocene marine deposits varies from place to place. According to drilling data (K. KANTAS and A. TINIAKOS, 1985), the thickness is more than 100 m.

The age of the deposits is of Early Pleistocene (presence of *Hyalinea balthica* and *Globorotalia truncatulinoides*, MARCOPOULOU - DIACANTONI et al., 1990).

iii) Pleistocene continental deposits

The Pleistocene contintental deposits consist mainly of red-colored polymictic but always siliceous clastic sediments, i.e. sand and pebbles coming exclusively from the radiolarites of the Pindos unit. They overlie unconformably the older formations and they are deposited on a well-shaped paleorelief, which in some places is totally different from the recent one.

iv) Holocene

These are unconsolidated or partly consolidated mainly coarse material deposited as scree, talus, river deposits, alluvial fans etc.

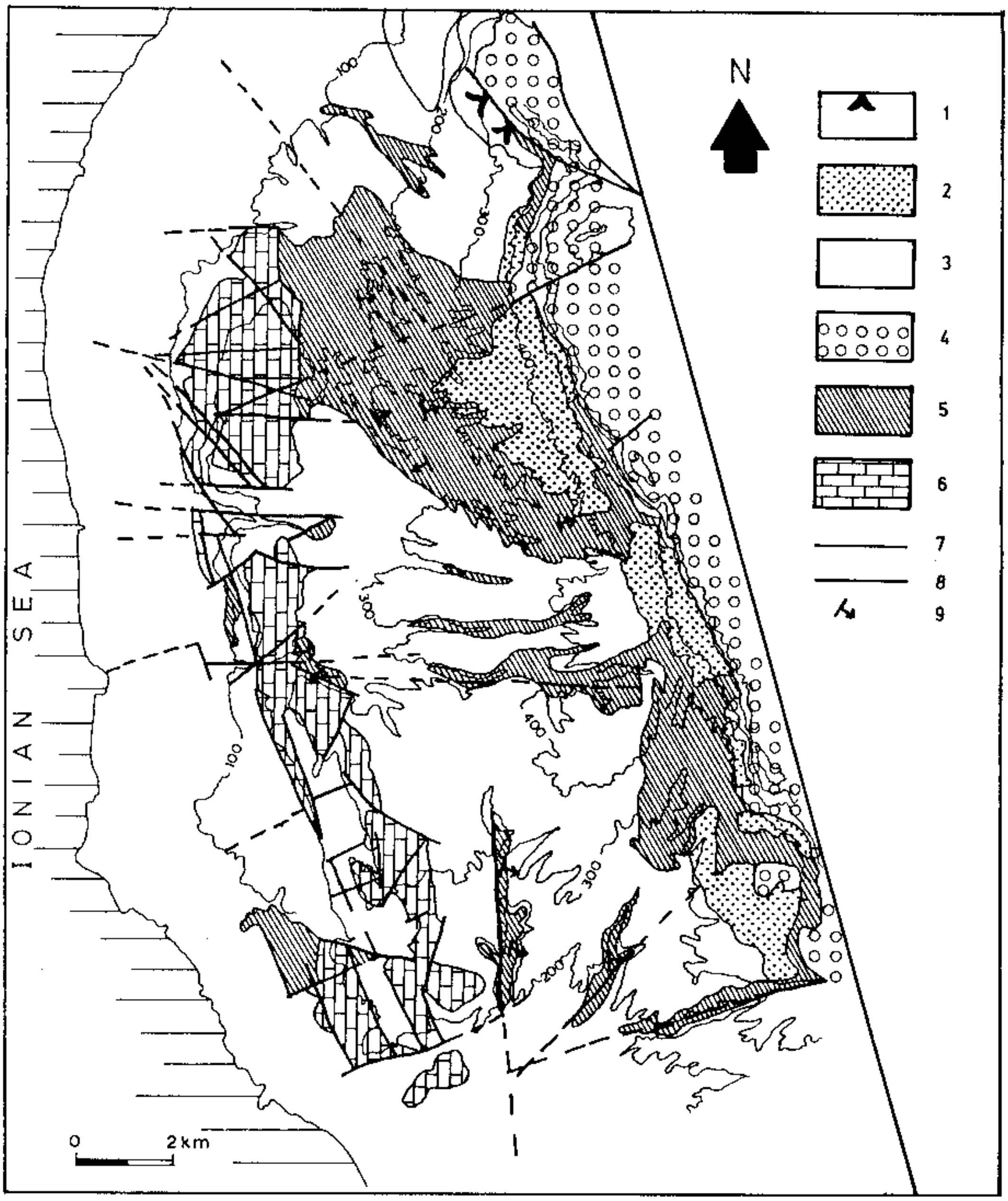

Fig. 3. Geological map of Filiatra area based on the geological map of IGME, FILIATRA Sheet, scale 1/50.000 with structural and stratigraphic revisions and additions. 1: Talus, 2: Pleistocene continental deposits 3: Lower pleistocene marine deposits, 4: Conglomerates of Messinia, 5: Flysch, 6: Carbonates, 7: Geological boundary, 8: Fault, 9: Strike and dip of strata.

GEOMORPHOLOGY

Generalities

The study area, is of smooth relief and extends at altitudes up to 450m, but mainly between 100m and 450m. It can be distinguished in three (3) sub-areas taking into account:

i) the direction of the main tributaries of the drainage network and

ii) the spatial distribution and the dip of the planation surfaces, that have been created on the Lower Pleistocene marine deposits.

These three basic sub-areas are the Northern, the Central and the Southern one.

Northern sub-area

The Northern sub-area extends between the villages Christiani - Plati - Chalazoni - Spilia at a mean altitude of 200m (Fig. 4).

The torrents crossing this sub-area are directed from SE to NW and have eroded the Lower Pleistocene marine deposits, so that a great part of the Gavrovo - Pylos unit flysch peleorelief has been revealed.

The most characteristic torrent draining this sub-area is Filiatrino **Rema** (Fig. 4). The upper part of Filiatrino Rema crosses the Conglomerates of Messinia and firstly is directed from NE to SW, then it changes direction to SE, always crossing the Conglomerates of Messinia. Somewhere between Christiani and Mouzaki villages, the torrent changes its direction abruptly to the west, crossing the flysch. From this point on and for a long distance, Filiatrino Rema flows parallel to the upper part of the Evagelistria Rema torrent, which belongs to the central sub-area. Filiatrino Rema torrent changes its direction towards NW, western of M. Lakka and finally drives out to the Ionian sea getting around the Eocene carbonate mass (Fig. 4).

Obviously the observed inversion of the flow direction from SW to NW is mainly due to tectonic activity, which took place after the deposition of the Lower Pleistocene marine deposits.

The planation surfaces in this sub-area can be divided in two groups, that is the group of the altitude 0-200m occuring near Chalazoni - Spilia villages and the one of 200-400m occuring near the Plati and Christiani villages. Both groups of the planation surfaces have been created on the lower pleistocene marine deposits. Consequently their evolution began by the end of Early Pleistocene, when the area became gradually land. Both groups of the planation surfaces dip towards NW.

The above mentioned indicate that the flow direction of the torrents coincides with the dip direction of the planation surfaces.

Central sub-area

The Central sub-area extends between the villages Mouzaki - Pyrgos - Floka - Gargaliani - Valta and has a mean altitude more than 350m (Fig. 4).

The northern watershed between the Northern and Central sub-areas trends E-W, whereas the southern watershed coincides with the theoritical line passing through Pyrgos and Floka villages with the small town of Gargaliani.

Two main torrents crossing this sub-area are the **Evagelistria Rema** and **Lagouvardos Rema**, which are directed from E to W and they flow almost parallel to each other. The lower order tributaries are directed from SE to NW.

The planation surfaces on the Lower Pleistocene marine deposits are dipping to the west at the eastern part. whereas near the Eocene neritic limestones at the western part of the Central sub-area are almost horizontal.

The above mentioned indicate that the direction of the torrents is in good accordance with the dip direction of the planation surfaces.

Southern sub-area

The Southern sub-area extends between the villages Gargaliani and Koryfasi.

The main characteristic of this sub-area is that it is crossed by dip valleys, while the whole study area displays a smooth relief.

The main torrents crossing this sub-area are: **Arapi Poros, Alafinorema, Kambirova** and **Nassorema**, which create the corresponding valleys. All these torrents are directed from NE to SW.

The steep slopes of these valleys can be attributed to: (i) the relatively low porosity of the geological formations - as the bedrock is flysch (clay, silts, marls), (ii) the relatively small distance between the watershed and the sea-level and (iii) the relatively high uplift rates of the area. The mean uplift rate has been estimated to be 0.62mm/y since the end of Early Pleistocene (MARCOPOULOU - DIACANTONI et al., 1990).

It is remarkable that the torrents flow parallel to the neotectonic faults, which are very characteristic in this sub-area.

South of Pyrgos and Chora villages, the planation surfaces created on the Lower Pleistocene marine deposits dip towards SW.

Even in this sub-area, the coincidence of the torrents direction with the dip direction of the planation surfaces is obvious.

Linear erosion

Concerning the linear erosion, it should be mentioned that the torrents which cross the three sub-areas can be distinguished in three parts, except Filiatrino Rema at the Northern sub-area and Kambirova Rema at the southern one. The valleys of these two torrents, that start their flow from the conglomerates of Messinia, could be distinguished into four (4) parts. All other torrents start their flow from the lower slopes of Kyparissia Mts and they exclusively flow in the area that was covered by the Lower Pleistocene marine deposits.

In other words, the first part, which is the lower flow of all torrents, is developed at an altitude of 0-100m. At this part no remarkable linear erosion is observed.

In the second part, which is the area with a mean altitude of 200m, in which the torrents cross the Prof. Ilias - Gargaliani tectonic horst consisting of neritic limestones, a strong linear erosion that can be related with neotectonic fault zones is observed. This particular horst should have been covered by the Lower Pleistocene marine deposits. In other words. the horst has functioned as a dam during the last evolutionary stage of the relief, because it is difficult limestones to be eroded compared with this of the other clastic formations (flysch, marls etc).

The third part extends between the Prof. Ilias - Gargaliani horst and the western slopes of Kyparissia Mts and more specifically the western slopes of Aegaleon Mt.

In this part the linear erosion is very weak.

Springs

At the eastern margins of the Pyrgos - Christiani morphotectonic depression, some characteristic springs are present. They flow out near the contact between the Conglomerates of Messinia and the flysch of Gavrovo - Pylos unit. These springs occur (i) very close to Plati village, (ii) at Kefalovriso - Christiani, (iii) at Mati Moutzouri - Mouzaki (iv) at Kefalovriso Choras, whereas they are located at altitudes 310m, 420m, 500m and 340m correspondingly (Fig. 4).

For these springs KANTAS and TINIAKOS (1988, p.73) indicate that: " from the groundwater sub-basin of Mati Moutzouri-Mouzaki spring, the water flow follows two main directions almost opposite that is:

a) towards Kefalovriso Christiani and Plati springs (NW direction) and

b) towards the Kefalovriso Choras spring (SW direction)".

This is the reason that in the first case the hydraulic gradien is directed from SE to NW, while in the second case from NE to SW.

In our opinion, this is an indication that the location of the springs, as well as the hydraulic gradient of the ground water table, are not random but it is due to the neotectonic deformation that has created a very big anticlinal structure with an axis passing through the Mati Moutzouri Mouzaki spring which is located at the highest altitude (500 m).

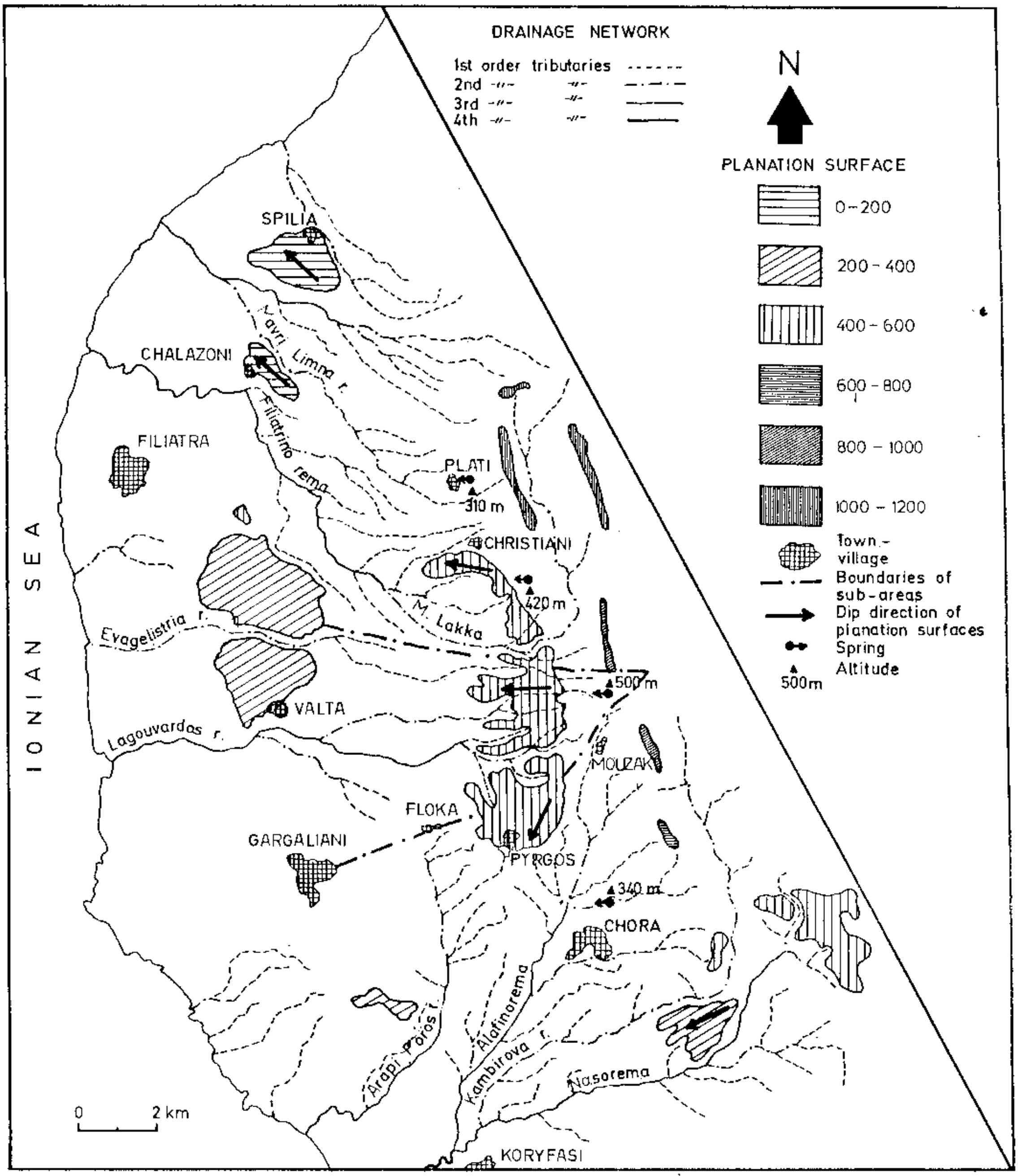

Fig. 4. Map of planation surfaces and drainage network.

TECTONICS - NEOTECTONICS

Generalities

The deformation is distinguished in two main periods, the alpine and the post-alpine or neotectonic one.

We are not directly interested in the alpine deformation, but in the deformation of the already existing alpine tectonic structures during the neotectonic period. For this reason we infer to the alpine tectonic structures in some cases only.

The neotectonic structure of SW Peloponnesus is charasterized by the presence of large grabens and horsts bounded by wide fault zones. Such big megastructures from East to West are: (Fig. 5).

i) The **Taygetos Mt megahorst** to the east. striking N-S.

ii) The **Kalamata-Kyparissia megagraben**, striking in its southern part N-S, whereas further to the North (approx. 30 km) the trend changes to E-W.

iii) The **Kyparissia Mts** and **Lykodymon Mt.**, morphotectonic structures which represent a very complex morphotectonic structure striking NNW-SSE. This megastructure compared to the eastern Kalamata-Kyparissia megagraben is a horst. whereas compared to the western occuring Gargaliani - Filiatra megahorst, is a graben, although from topographical point of view lies about 900m higher than the highest point of the Gargaliani - Filiatra megahorst.

iv) The **Gargaliani - Filiatra megahorst** which occurs along the western coast of Messinia.

At the margins or inside these 1st order neotectonic megastructures, a great number of smaller order (2nd. 3rd. ...) neotectonic macrostructures with a totally different paleogeographic evolution occur. These 2nd or 3rd order structures trend either parallel or roughly perpendicular to the 1st order neotectonic megastructures.

The neotectonic structures are bounded more or less by fault zones with the following characteristics (MARIOLAKOS et al.. 1987a,b).

i) The faults do not have constant strike along their whole length.

ii) The faults are not continuous but they are interrupted by other faults which, although they belong to the same fault zone, they strike differently. In other words, these are conjugate faults as they have been created during the same deformation period (phase) by the action of the same stress field.

iii) The faults have an en-enchelon arrangement.

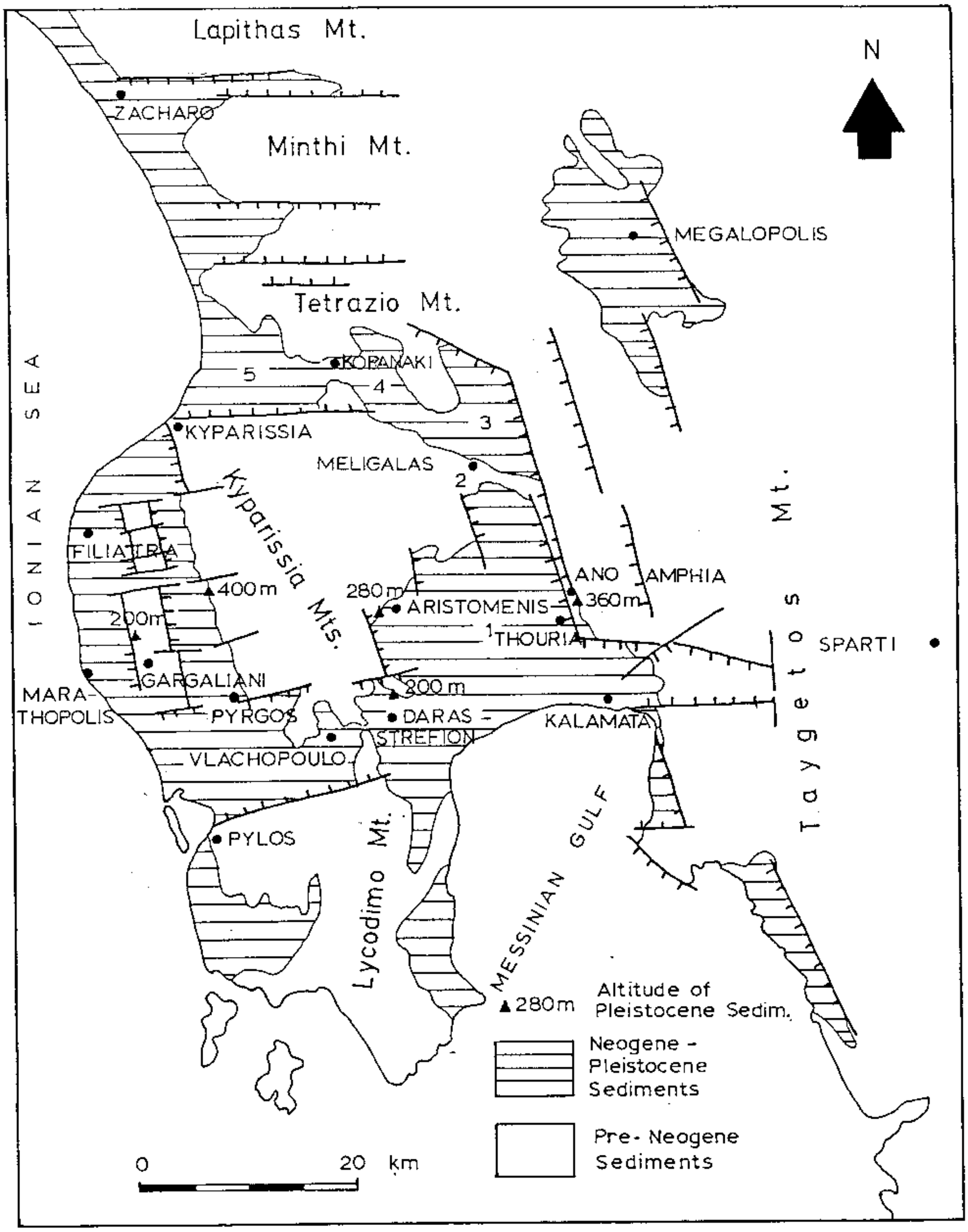

Fig. 5. 1st order neotectonic macrostructures.

iv) A lot of slickenside generations of different plunge occur on some fault surfaces. They usually show oblique slip but, dip slip and even strike slip are almost everywhere present.

These are the reasons that the neotectonic grabens or horsts do not trend towards a constant direction. The geometry of the neotectonic mega-structures, combined with other observations (MARIOLAKOS,1986, MARIOLAKOS et al., 1987a,b, 1989), result to a different interpetation from kinematic and consequently from dynamic point of view of the deformation, from one somebody should have accepted, if the study had been restricted only to the tectonic analysis of the faults, which are apparently normal.

The en-echelon arragement of the marginal faults, as well as the slickensides on fault surfaces, indicate that they are not dip slip but oblique slip normal faults. Hence, from dynamic point of view, the deformation is not due to a tensional. but to a rotational couple stress field and, consequently, the rotational phenomena are present in all scales, as it has been proved by the detail geological, morphological and neotectonic study of the adjacent areas (MARIOLAKOS 1986, MARIOLAKOS et al., 1989).

The study area belongs to the 1st order Gargaliani - Filiatra megahorst (Fig. 5, 6, 7a).

The smaller order neotectonic macrostructures which are developed inside the Gargaliani - Filiatra megahorst are the: **Marathopolis - Agia Kyriaki graben** and the **Gargaliani - Prof. Ilias horst**. Eastern of Gargaliani - Prof. Ilias horst the **Pyrgos - Christiani morphotectonic depression** is located. This is the main study area (Fig. 6, 7b). We prefer to use the term "morphotectonic depression" because fault zones of NNW-SSW direction are observed only at the western margin of the unit. whereas at its eastern side no fault has been observed.

Fault zones - Faults

The fault zone, eastern of Filiatra, represents the western margin of the Gargaliani - Prof. Ilias horst. It strikes NNW-SSE and it consists of many faults in an en-echelon arragement.

The bigger escarpment on the morphology of the area is due to the reactivation of this fault zone. Many fault surfaces are covered by successive generations of tectonic breccia and scree. which are indicative of the repeated.

Fault surfaces are not observed in the post-alpine deposits. However, in some places besides the escarpments, it is possible, to observe locally zones of very loose material or intesively brecciated rockmass.

The eastern margin of Gargaliani - Prof. Ilias horst is not as impressive as the western one, but even this coincides with a fault zone, which has the same charasteristics with the western one.

Besides the big NNW-SSE striking marginal fault zones of the Gargaliani - Prof.Ilias horst, there are also some faults transversal to them, with general strike E-W. These transversal

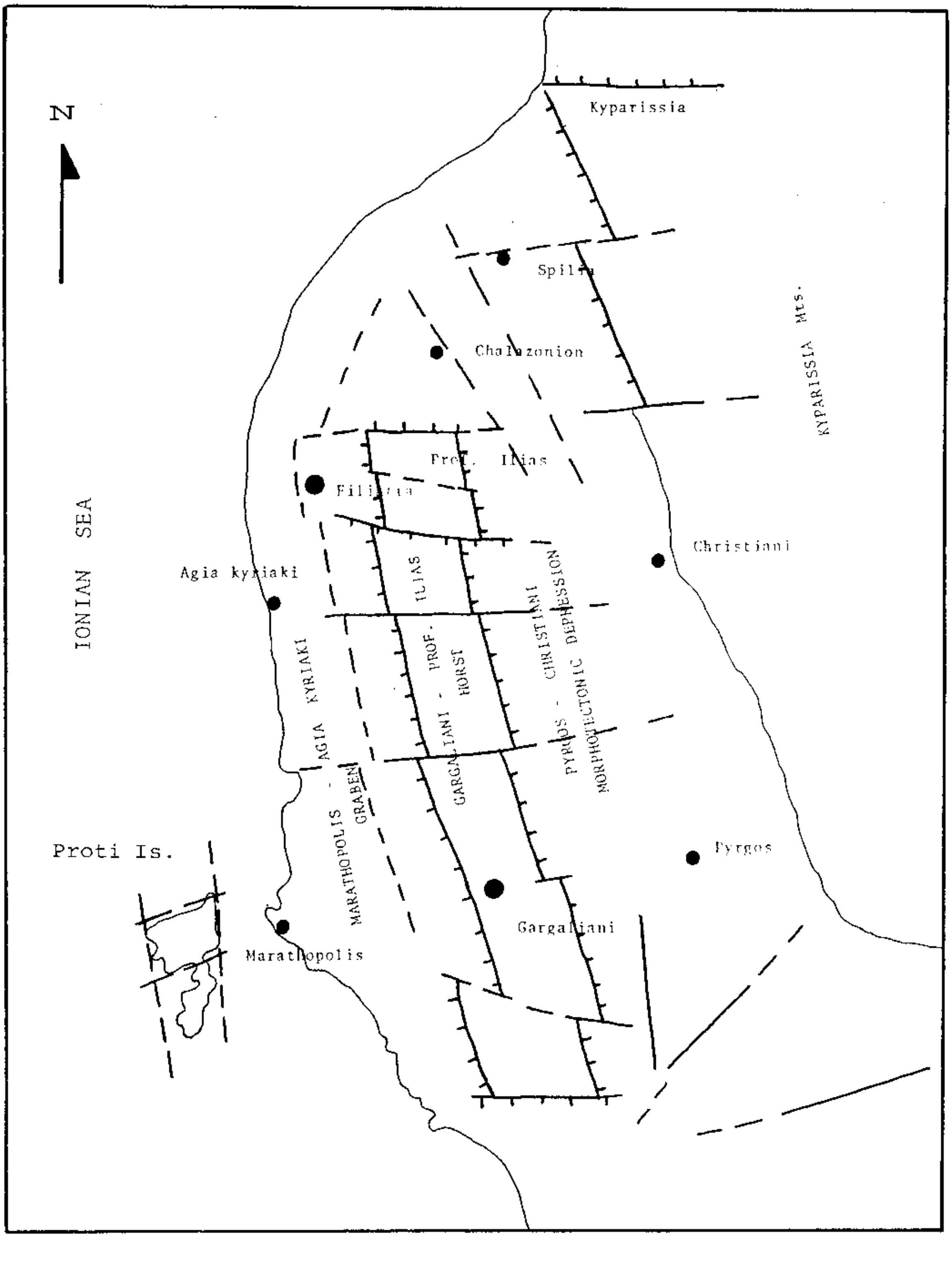

Fig. 6. Neotectonic macrostructures of 2nd order.

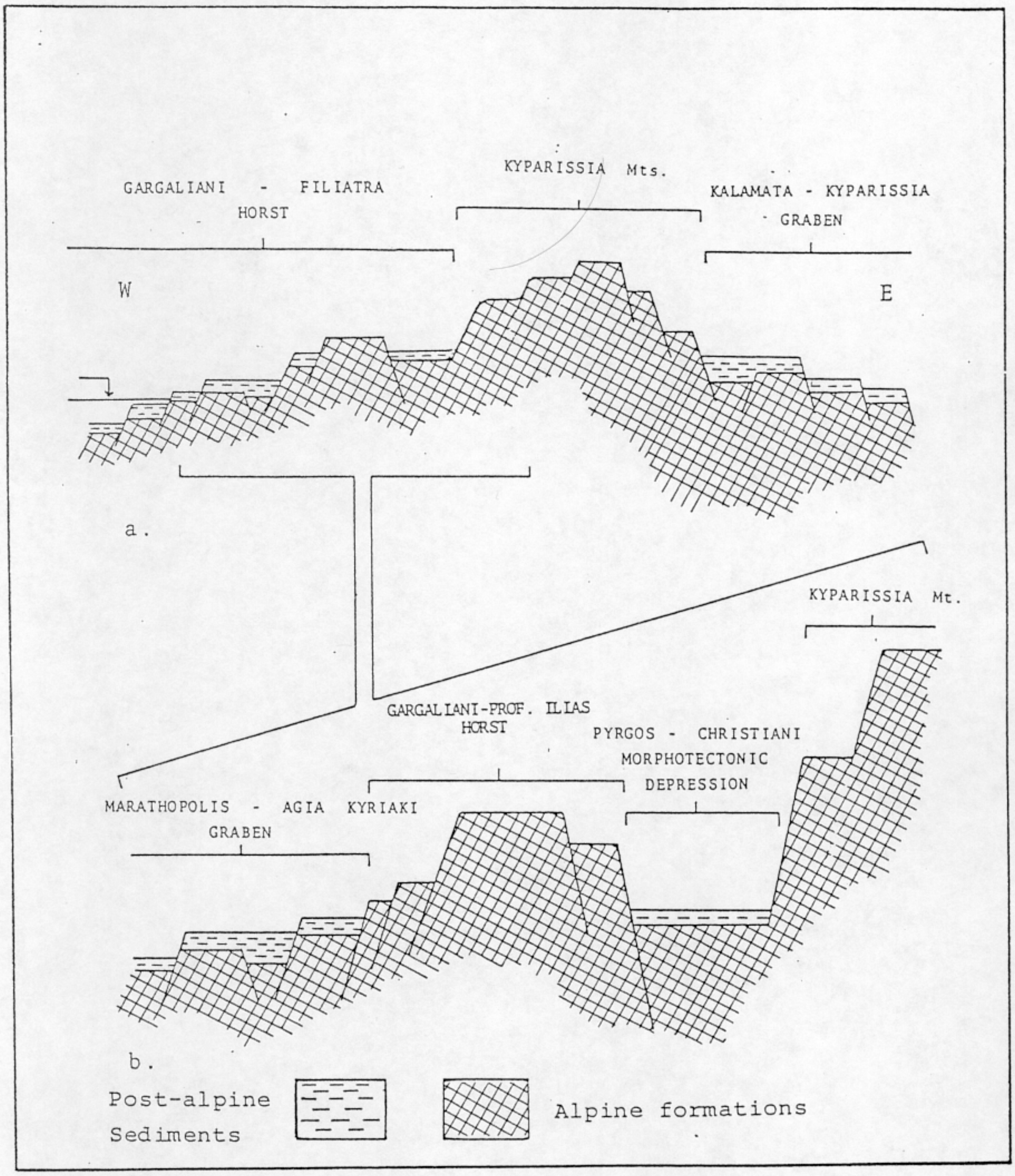

Fig. 7. Shematic cross sections.
a. 1st order neotectonic macrostructures.
b. 2nd order neotectonic macrostructures.

fault zones cross the Marathopolis - Agia Kyriaki graben the Gargaliani - Prof.Ilias horst and the Pyrgos - Christiani morphotectonic depression.

These fault zones are characterized by relatively pronounced escarpments, which are observed at both the post-alpine and the alpine formations. Very often, along these fault zones, many tectonic breccia or very loose rockmass and rarely fault surfaces are observed. Fault surfaces are observed mainly on the carbonate rocks.

Another characteristic of the E-W trending fault zones is that all these cut and displace the big NNW-SSE striking fault zones (Fig. 6). In the southern sub-area as well as in the area of the conglomerates of Messinia these are faults trending NE-SW and ENE-WSW. Slickensides observed on these fault surfaces indicate that the faults are of oblique-slip normal or oblique slip reverse (Fig. 8).

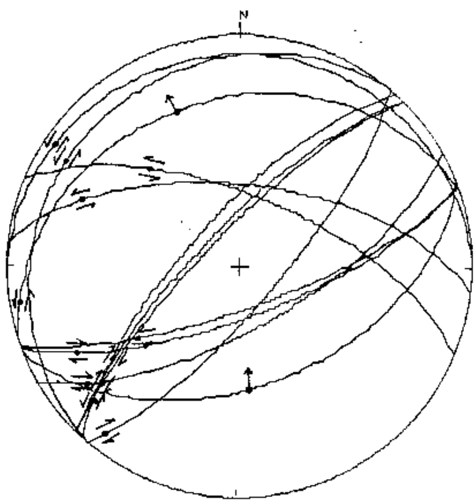

Fig. 8. Schmidt-net projection of the faults, Aegaleon Mt. area.

Structural contour map

For a more detailed study, from kinematic and consequently from dynamic point of view the Gargaliani - Filiatra megahorst since the end of Early Pleistocene, the structural contour map of the contact between the Lower Pleistocene marine deposits and the flysch of Gavrovo-Pylos unit was constructed (Fig. 9).

The study of this contour map reveals the following:

i) The area including the highest points (400 m) of the contact between the Lower Pleistocene marine deposits and the flysch is located at the eastern margin of the horst and is extended into the three sub-areas.

ii) At the northern sub-area, the lower points are in the western part and at the altitude of about 100.

iii) At the central sub-area the lower points are at the western part at 240m altitude, while at the southern sub-area, the lower points are at the southwestern part and at an altitude of 80m

In other words the dip direction, as well as the degree of dipping, differs from one sub-area to another. Namely in Northern sub-area the contact surface is dipping towards NW, in the Central sub-area towards W and in the Southern sub-area towards SW. The degree of dipping in the Central sub-area is lower than in the two others.

The geometrical shape of the unconformity surface looks like an elongated sphaerical part which tectonically represents an anticlinal structure with an axis trending approximately ENE-WSW, which coincides partly with the northern watershed of the central sub-area.

It is remarkable that the general shape of the contours of the structural contour map is similar to the shape of the present shorelines (Fig. 9).

DISCUSSION - CONCLUSIONS

In order to interprete the deformation type of the study area during the last 0.8 to 1.0 My, that is the end of the deposition of the Lower Pleistocene marine deposits, we took into account the following:

i) the radial pattern of the drainage network

ii) the distribution and the dip direction of the planation surfaces that have been created on the lower pleistocene marine deposits.

iii) the shape of the contours of the structural contour map.

iv) the topographic position of the springs and the hydraulic gradient of the ground water table.

v) the shape of the shorelines.

vi) the faults.

All these indicate that the study area has been deformed to a fold with a great curvature radius. The axis of this fold is more or less parallel to the theoretical line passing through the Valta village to the west and somewhere between Christiani and Mouzaki villages to the east.

Furthermore, we believe that it is not a casual coincidence that the eastern prolongation of the axis of this anticlinal structure coincides with: (a) higher occurence points of the Conglomerates of Messinia, and (b) the highest altitudes of the Kyparissia Mts to which the southern part of the watershed of Sella (or Arkadikos) River corresponds.

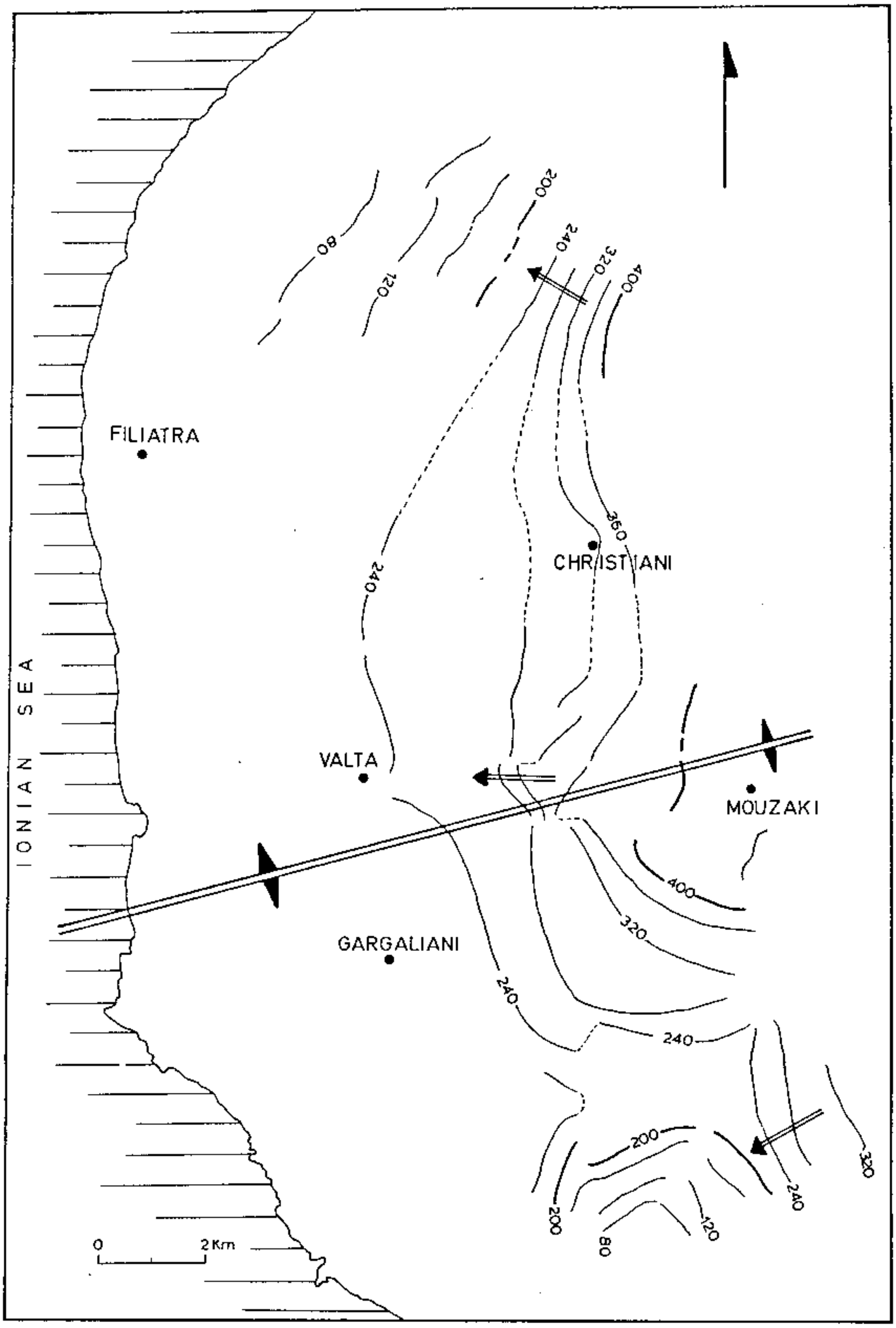

Fig. 9. Structural contour map of the contact between the Lower Pleistocene marine deposits and the Flysch of Gavrovo-Pylos Unit.

Therefore, we have to accept that the neotectonic deformation is not of pure brittle type but that of **brittle-ductile** type.

Consequently, the normal faults, that correspond to an extensional brittle type of deformation,represent the local stress field and not the regional one, which is expressed in the study area by the anticlinal structure and which is the result of a compressional stress field. On the other hand, the plastic deformation is due to creep phenomena.

More especially we believe that the deformation is the result of transpressional phenomena which are connected with a stress field of rotational couple type, as it has been described from many other places (S.SPENCER 1969, p.126).

In this special case, the axis of the maximum compression σ_1 should trend NNW-SSE, whereas a horizontal component of the movement is always present. This is the reason that almost everywhere the fold axis of the alpine cycle have been dragged in the vicinity with big faults as, for example, near the marginal fault zones of the neotectonic megastructures, as it happens at the northern marginal fault zone of the Kyparissia Mts, which is the Kyparissia-Aetos fault zone, which is of normal type.

If this interpretation is correct, the E-W trending normal faults of the study area should be the result of **compression** and **not of extension.**

In this point it should be mentioned that the observed folding could be connected to diapiric phenomena of the permotriassic evaporites of the Ionian Unit occuring elsewhere (e.g. Kyllini area, about 100 km NNW of the study area, KOWALCZYK & WINTER 1979, UNDERHILL 1985, 1989).

Nevertheless, the deep borehole at Filiatra area, down to a depth of 3.750m has not encounter any diapir except some thin intercalations of anhydrite included in Jurassic formations (KABBERIS, 1987).

Consequently, there is no evidence of diapiric phenomena at least down to this depth, but nobody can exclude the possibility that such a diapiric dome in deeper levels might exist. Unfortunately we have no geophysical information from this area.

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