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Chen Qingxuan (Editor)
Institute of Geomechanics, CAGS, Beijing

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Methods to Study the Torsional Neotectonic Deformation: the Case of Kalamata Area (SW Peloponnesus, Greece)

I. Mariolakos, I. Fountoulis, E. Logos, S. Lozios
Univ. of Athens, Greece

Introduction

Southwestern Peloponnesus (Greece) and especially the province of Messinia, from neotectonic point of view represents, for several reasons, one of the most interesting and typical areas in Greece. Some of these reasons are the following:

- It is one of the most seismically active areas of Greece.
- It extends not far away from the Hellenic Trench.
- The western part of Messinia and mainly the Kyparissia Mts, although land today from geotectonical point of view belongs to the Island Arc of the Hellenic Arc.
- Messinia is the area where the two main trends of the neotectonic structures of Peloponnesus are encountered in relative short distance. The mega-structure of Kalamata-Kyparissia Graben, for example, with a length of about 60 Km, has a trend of N-S at the area north of Kalamata whereas about 30 Km farther to the north changes its trend to E-W (fig. 1).

Because of these reasons Messinia is one of the most suitable area for studying the kinematic and the dynamic of the neotectonic deformation. In addition the reactivation of neotectonic structures by present day earthquakes provide the possibility for correlation of recent kinematic and dynamic with those of older deformation phases.

The methods that have been applied in the kinematic and the dynamic analysis on a part of Messinia as well as the interpretation and the followed results are given in this paper.

The interpretation is based on the analysis of the following geological and morphological data mainly in meso- and macroscopic scale.

- the structural contour maps of the overthrust surface of several alpine units
- the faults and fault zones
- the intensity of linear erosion e.. the geometry of ravins
- the facies and the thickness of the marine post-alpine sequences as well as their present day highest occurance
- the results of the repeated levelling survey
- the spatial distribution of planation surfaces.

The analysis that has been done so far has proved that the kinematic and consequently the dynamic of the

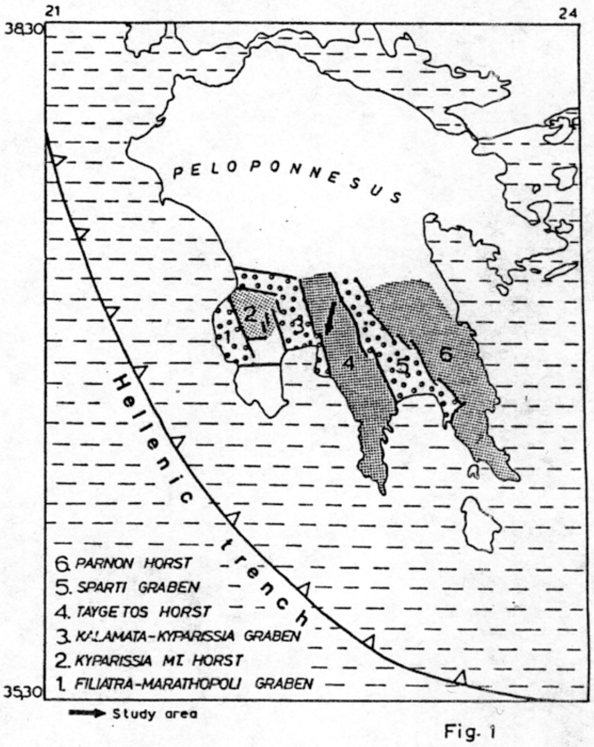

Fig. 1

area, during the neotectonic period is not so simple as it is believed.

In our opinion, the neotectonic deformation isn't connected with an extensional stress field of regional scale, but it is more complicated, namely it is mainly the result of a regional coupling, whereas compression, torsion and extension are of local scale.

In addition to that, the deformation is not of pure brittle type but of "brittle-ductile" type; this "plastic" deformation is the result of creep due to the long time that this stress field has acted on the area. The latter has been totally ignored up to now.

Alpine nappes

As it is shown in fig. 2, the following (from lower to upper) four alpine geotectonic units occur in the study area: (i) the Mani unit, (ii) the Arna unit, (iii) the Tripolis unit, and (iv) the Pindos unit. The Mani unit is considered as autochthonous(?) whereas the next three as nappes (allochthonous). It is accepted that the overthrust movements (mainly the overthrust of Pindos unit) have finished until Early Miocene.

Consequently, it is expected, that the alpine structural elements (fold axis, overthrust (nappe) surfaces, etc) have been affected by the deformation that took place during the neotectonic period. Therefore, their recent situation, mainly at areas where post alpine sediments are not existed, is an important indicator concerning the kinematic, and in many cases helps to estimate the throws of the marginal fault zones to which the neo-tectonic macrostructures are bounded, etc.

For example in the Dimiova-Perivolakia Graben, the southern fault zone which separates the Mani (lower) unit of the Kalathion Horst from the Pindos unit (the upper one) of the Dimiova- Perivolakia Graben, the total throw should be very big, compared to the nothern fault zone that separates the limestones from the flysch of the Tripolis Unit. A decrease of the throw from W to E has also been observed. Consequently it can be concluded that the SW part of the graben is the most subsided area (MARIOLAKOS et al., 1987).

Neotectonic structure of SW Peloponnesus

The neotectonic structure of southwestern Peloponnesus is characterized by the existence of big grabens and horsts bounded by fault zones. The partial faults inside the fault zones strike mainly NNW-SSE and WNW-ESE. Such big structures are the Taygetos Mt. Mega- Horst, the Sparti Mega-Graben, the Kalamata-Kyparissia Mega-Graben, the Kyparissia Mt. Mega-Graben, the Filiatra- Marathopolis Mega-Horst... etc. (fig.1).

Another main feature of the neotectonic structures in this area is the existence of 2nd order neotectonic macrostructures, in other words smaller horsts and grabens, which are developed not only at the margins but also inside the mega structures, which trend either parallel or perpendicular to them. All these neotectonic macrostructures from dynamic point of view are connected each other as they are located between two 1st order neotectonic mega-structures, one positive (horst) and one negative (graben) which are the result of the same stress field. On the contrary, from kinematic point of view, they differ and this differentiation is appeared either very early, that is from the very first stages of their creation, or later during their evolution (MARIOLAKOS et al., 1989).

The observations in this study are mainly refered to the 2nd order neotectonic macrostructures, which are developed at the western margin of Taygetos Mt. Horst and at the eastern margin of Kalamata - Kyparissia Graben. In other words these 2nd order macrostructures are located at the transition zone between two 1st order megastructures. Four of these 2nd order macro- structures from N to S are the following (fig. 2, 3):

- the Akovos-Kamara Graben striking in NNW-SSE
- the Dimiova-Perivolakia Graben in E-W direction,
- the Kalathion Mt. Horst which strikes E-W and
- the Altomira Graben in NW-SE direction.

Structural contour maps

The morphology of alpine overthrust surfaces, which is the result of the alpine and postalpine tectonism provides some very interesting information, concerning the kinematic and dynamic of the macrostructures. The morphology of the overthrust surfaces can be studied by constructing the structural contour maps. In the case of southwerstern Peloponnesus, we choose the overthrust surface of the upper tectonic unit (Pindos nappe). Remnants of Pindos unit outcrop at many places in the area. From the countor maps (fig. 3, 4) the following can be observed:(i) At the Akovos-Kamara Graben, this surface dips to NNE and presents a curving of synclinal type with a curving axis dipping towards NE. (ii) At the Dimiova-Perivola

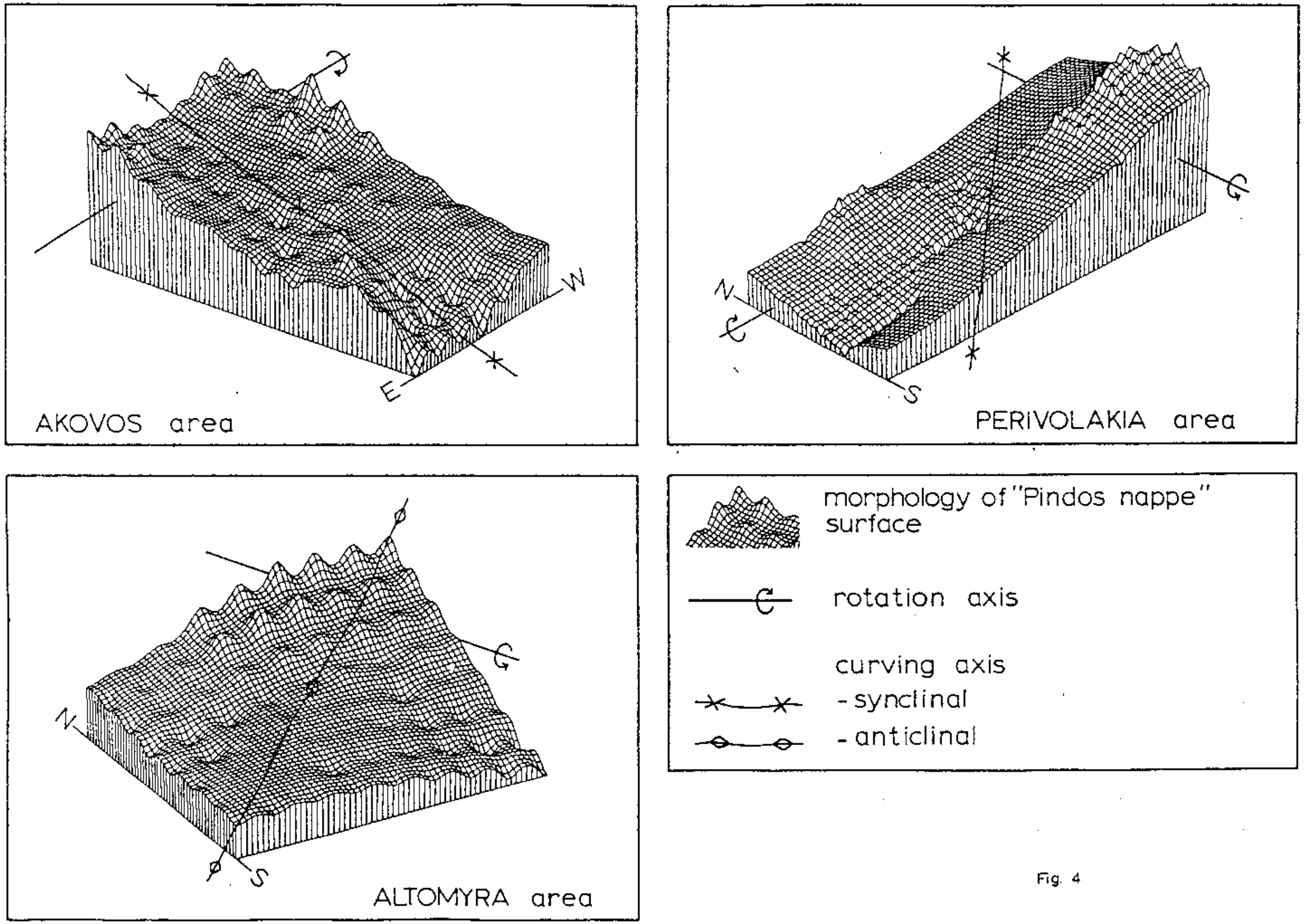
E
W
AKOVOS area
N
S
PERIVOLAKIA area
N
S
ALTOMYRA area
morphology of "Pindos nappe" surface
rotation axis
curving axis
- synclinal
- anticlinal

Fig. 4

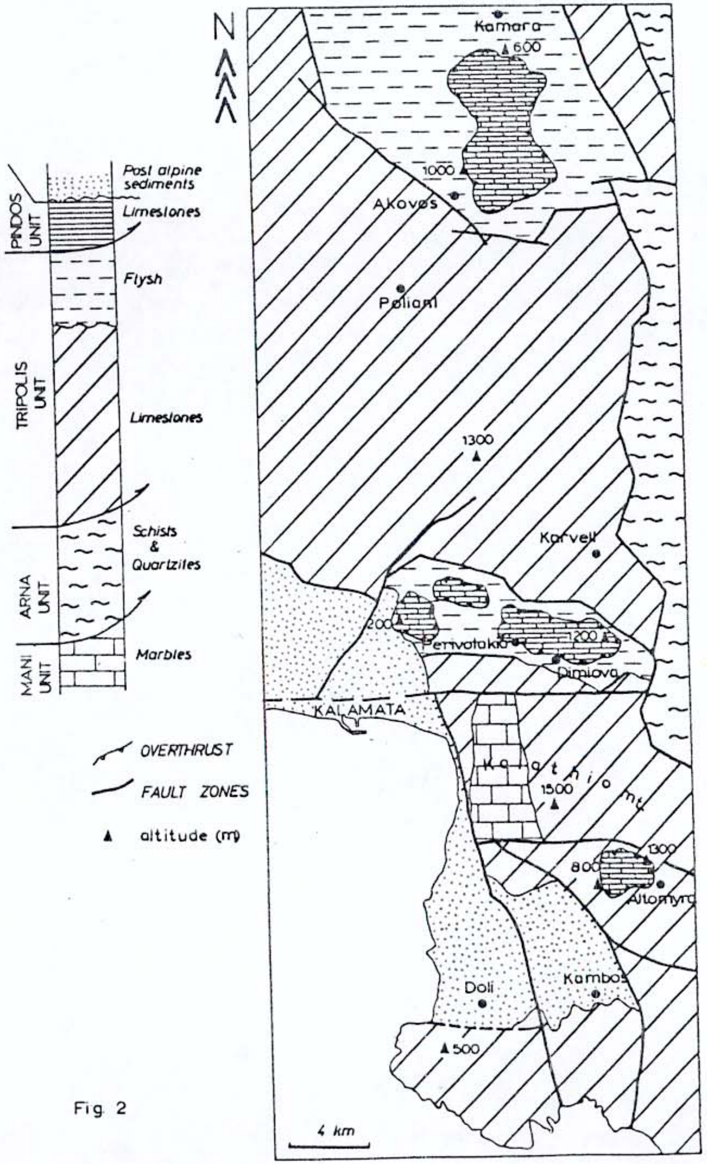
N
Post alpine sediments
Limestones
Flysh
Limestones
Schists & Quartzites
Marbles
PINDOS UNIT
TRIPOLIS UNIT
ARNA UNIT
MANI UNIT
OVERTHRUST
FAULT ZONES
altitude (m)
Kamara
600
1000
Akovos
Poliani
1300
Karveli
200
Perivolakia
200
Dimiova
KALAMATA
Kalathio mt
1500
800
1300
Altomyra
Doli
Kambos
500
4 km

Fig. 2

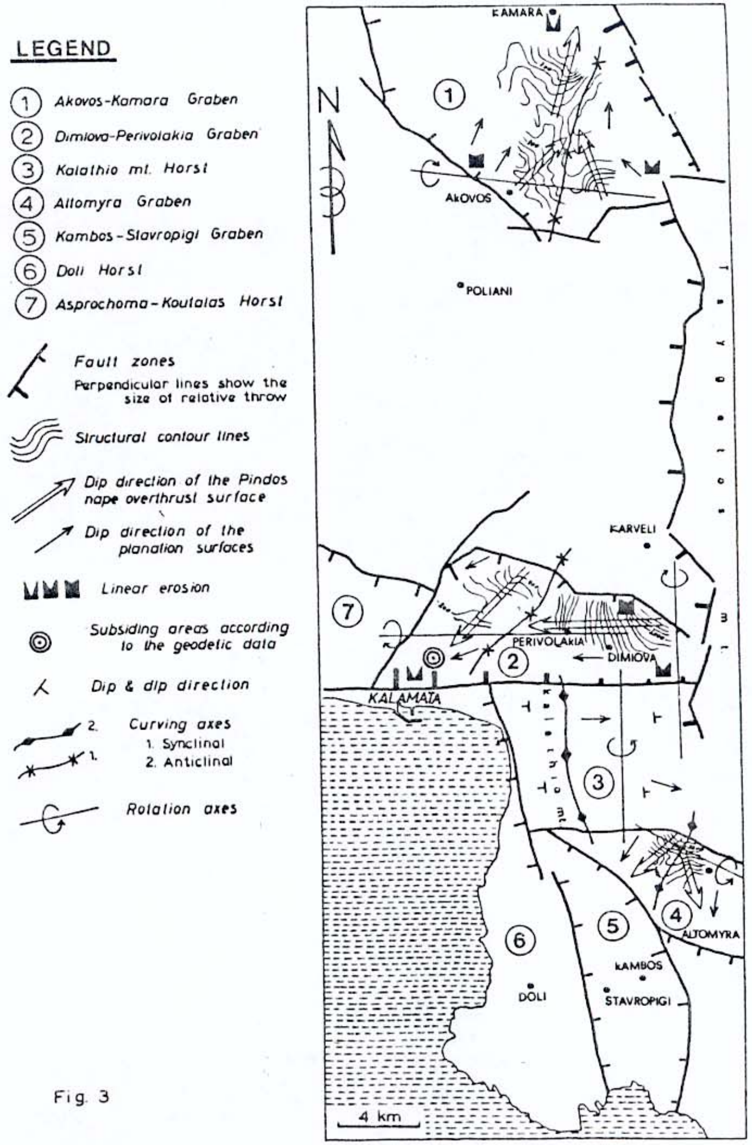
LEGEND
1 Akovos-Kamara Graben
2 Dimiova-Perivolakia Graben
3 Kalathio mt. Horst
4 Altomyra Graben
5 Kambos-Stavropigi Graben
6 Doli Horst
7 Asprochoma-Koutalas Horst
Fault zones
Perpendicular lines show the size of relative throw
Structural contour lines
Dip direction of the Pindos nape overthrust surface
Dip direction of the planation surfaces
Linear erosion
Subsiding areas according to the geodetic data
Dip & dip direction
Curving axes
1. Synclinal
2. Anticlinal
Rotation axes
N
KAMARA
AKOVOS
POLIANI
KARVELI
PERIVOLAKIA
DIMIOVA
KALAMATA
Kalathio mt
ALTOMYRA
KAMBOS
STAVROPIGI
DOLI
Taygetos mt.
4 km

Fig. 3

kia Graben the overthrusting surface shows a curving of synclinal type whose axis is striking in a NNE-SSW direction. In this case the eastern part of the surface dips towards W whereas the western part towards SW. (iii) At the Altomira Graben the overthrust surface presents an anticlinal curving, so that the nothern part dips towards SW whereas the southern part towards SSE.

Geomorphology

The spatial distribution of the planation surfaces as well as the intensity of the linear erosion are good indicators for the kinematic interpretation (MARIOLAKOS et al., 1987). At the study area, the planation surfaces follow the average dip of the overthrust surface of Pindos nappe, dipping more or less towards the same direction. So, the planation surfaces, in Akovos-Kamara Graben dip towards NNE, those of Dimiova - Perivolakia Graben dip towards WSW, whereas at Kalathio Mt. Horst dip towards E and at Altomira Graben dip towards SW.

The linear erosion is intensive mainly near the fault zones with high rate of vertical displacement, especially at those parts of the area in which the maximum rate of uplifting occur. This is more evident especially in ravins trending normal to the fault zones. In the map of fig. 3 it is indicatevely given the intensity of linear erosion, which is stronger near the areas with the highest uplifting movement.

Geodetic data

During the study of the contemporary tectonic characteristics of a region, the use of geodetic data gives valueable information for the present kinematic regime. For the study area such data exist only for the area of the Dimiova-Perivolakia Graben in which a repeated leveling survey began just after the earthquakes of September 1986.

The result of repeated leveling confirmed that the WSW part of the graben is subsided with higher rate. The same has been confirmed by the results of the previous methods (STIROS & MARIOLAKOS, 1989).

Post-alpine sediments

The distribution of post-alpine marine sediments in neotectonic macrostructures of a region, proves the diachronic evolution of these structures, e.g. the relative movement of the blocks on both sides of fault zones. A typical example of this, is the Dimiova-Perivolakia Graben and the adjacent Asprochoma-Koutala Horst. On both neotectonic structures the remnants of the plio-pleistocene marine deposits reach about the same altituted that is around 460 m. (KOWALCZYK & WINTER 1979, MARCOPOULOU-DIAKANTONI et al., 1988). This is an evidence that these structures were already completed before the deposition of the plio-pleistocene marine deposits. Consequently these two neotectonic structures during their last stage of evolution, that is during the uplifting they behaved as a single block, whereas during the earlier evolution stages, that is during the stages of their subisdence the kinematic of these two structures was totally different (MARIOLAKOS et al., 1987).

Faults - Fault zones

The faults of the marginal fault zones, as well as the faults occured inside the macrostructures itself have the following characteristics, both in meso-and macroscale.

i) The fault strike is not constant along the margins.

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. These are considered as conjugate faults, as they have been created during the same deformation phase by the action of the same stress field.

iii) The faults show an en echelon arrangement.

iv) The throw is not the same along a fault, but it changes from a minimum to a maximum rate. In some big marginal fault zones the throw is up to 2000 m.

v) A lot of slickensides of different direction occur on some fault surfaces. They usually show oblique slip but dip slip and even strike slip are almost everywhere present.

vi) The presence of successive tectonic breccias on the fault surfaces is a common phaenomenon which indicates the reactivation of these faults.

vii) The older fault surfaces are usually intersected by younger fractures. In the case of the small Zimbeli fault, around 5 Km east of Kalamata towards the Dimiova Monastery, the length of the fractures amounts up to 6 m but usually is smaller. These fractures can be grouped in different sets of different age and different geometry. Reactivation phenomena are common. The fractures of the youngest set are greater whereas they show a small displacement (throw). Characteristics of these fracture sets are, the en echelon arrangement, the gradual increase of the displacement and the openning normal to the walls of the fractures, so that the displacement (throw) is 0 at the extremities of the fractures and maximum (4-5 cm) in the middle of the fracture length. These fractures are actually microfaults of normal character (MARIOLAKOS et al., 1988).

viii) Very often the older fault surfaces are curved with a wave lentgth of some meters. In some cases this curving is evidently connected with the fracturing, and the described displacement.

Discussion - Conclusions

From all those mentioned before we believe that the most interesting points for the kinematic and dynamic analysis of the neotectonic deformation are the following:

i. The presence of marginal fault zones with large discrepancies in the amount of the total displacement in connection to the en echelon arrangement of the faults inside the fault zone as well as inside the macro- structures.

ii. The dipping of the overthrust surface of the Pindos nappe as well as the planation surfaces in opposite direction on adjacent neotectonic macrostructures, e.g. the case of Dimiova-Perivolakia Graben and Kalathion Mt. Horst (fig. 3, 5).

iii. The synclinal and anticlinal form of the overthrust surface of Pindos nappe (fig. 4).

iv. The differences in the intensity of linear erosion (fig. 3).

v. The spatial distribution of the postalpine deposits.

vi. The results of the repeated levelling survey.

vii. The curvature of some fault surfaces.

viii. The presence of oblique and even horizontal slicknesides on the older fault surfaces.

ix. The shape and the spatial arrangement of the younger fractures and small faults that intersect the older fault surfaces

All these observations which are characteristic for the neotectonic deformation indicate that: (I) the regional stress field is that of rotational couple type and (II) the deformation is not of pure brittle but that of brittle-ductile type.

Inside this regional stress field of rotational couple type local stress fields of different type can

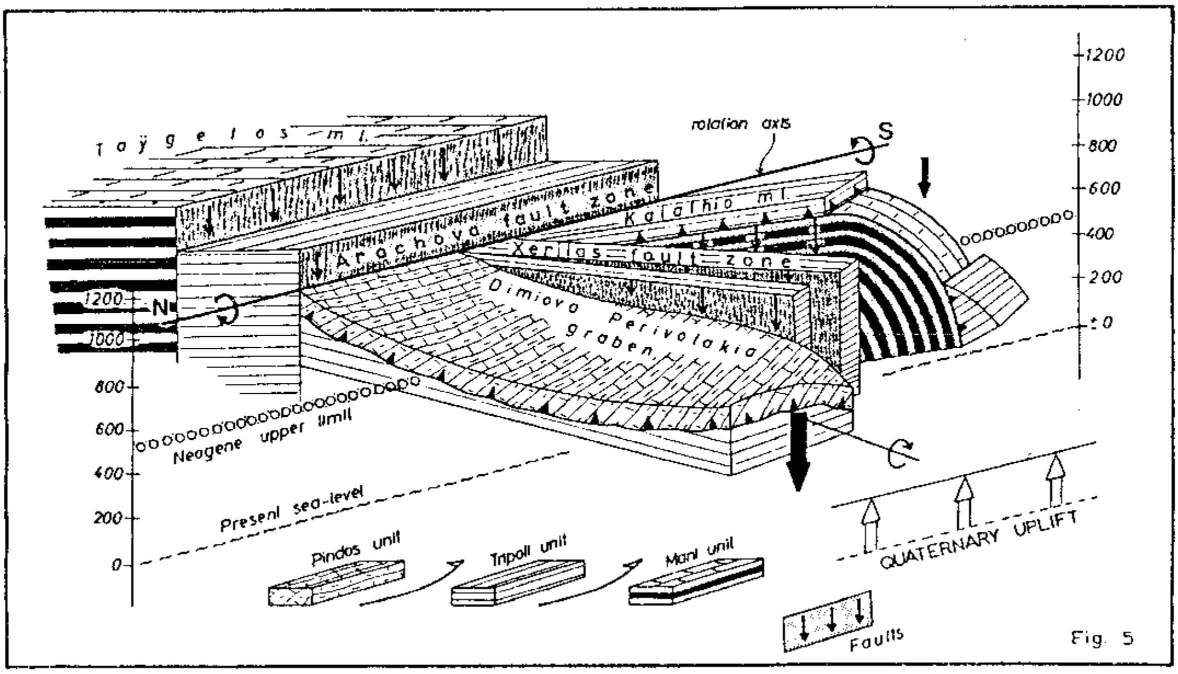

Fig. 5

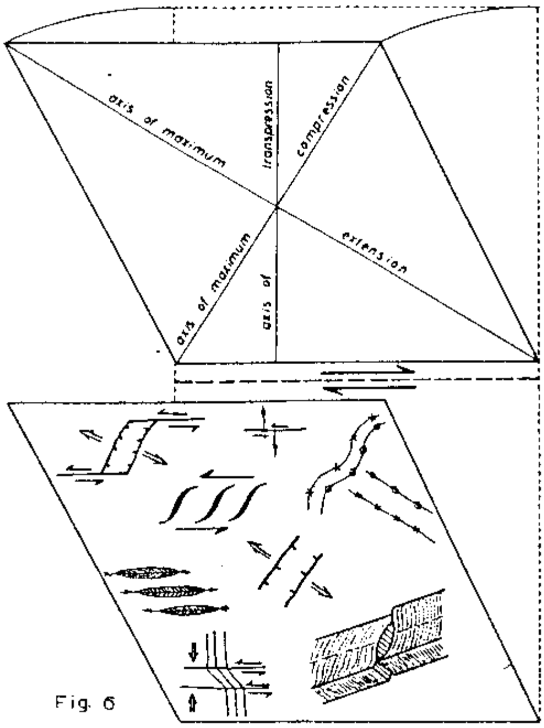

Fig. 6

exist e.g. extensional, compressional and even transpressional and transtensional.

Under the influence of such a stress field, all mentioned neotectonic structures can be interpreted. The torsional deformation existing between the Dimiova - Perivolakia Graben and the Kalathion Mt Horst for example could be interpreted as result of a local transpressional stress field (fig. 5).

The normal faults on the other hand can be created either normal to the axis of extension or parallel to the compressional axis. In our view a great number of neotectonic normal faults are connected with local compressional stress-field and especially in connection with deformation of ductile-brittle type (MARIOLAKOS et al., 1988), (fig. 6).

With these deformation mechanisms, could be interpreted the fact that in many cases at the transition zones from neotectonic Horst- to Graben-megastructures, the beds dip towards grabens. The latter case is observed at the western steep slope of the Kalathion-Horst, creating by this way a huge anticlinal horst, in other words a folding which has been develop to a horst when the rock body could not follow further the plastic deformation.

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