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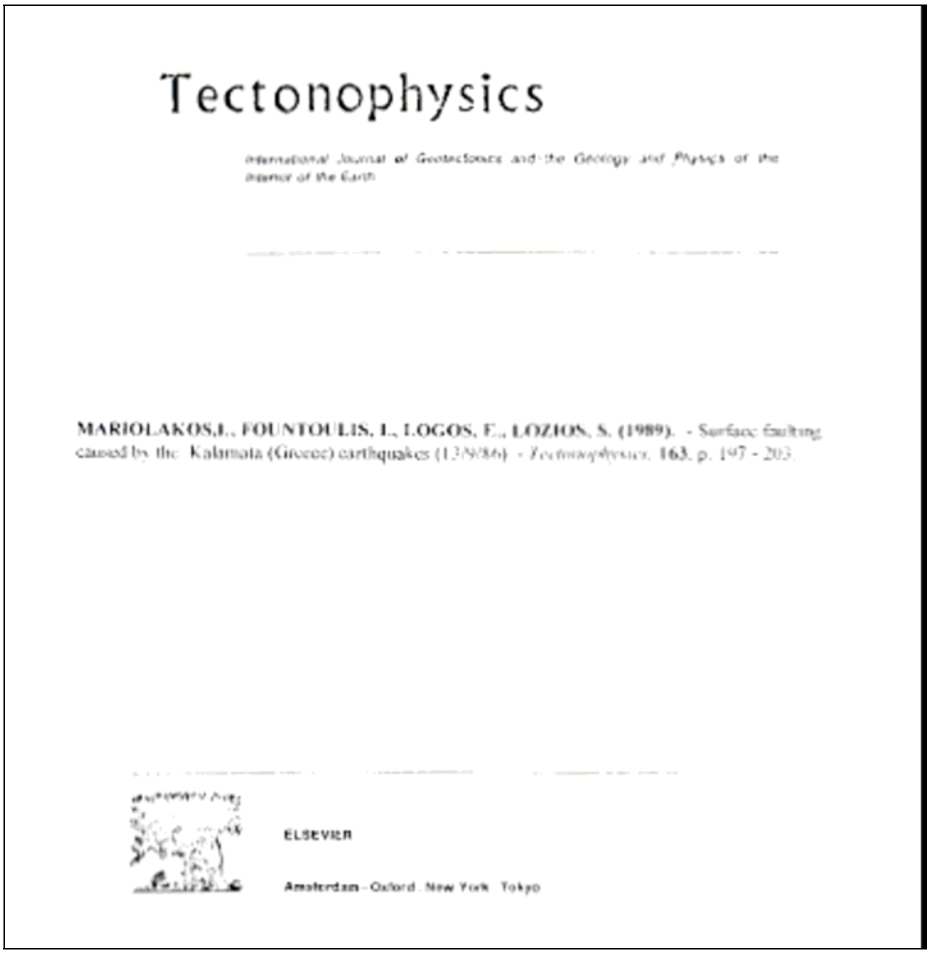
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Surface faulting caused by the Kalamata (Greece) earthquakes (13.9.86)

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Abstract

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A great number of neotectonic faults traverse the Messinian gulf and its geological prolongation on the continent towards the north, which forms the Kalamata–Kyparissia tectonic graben.

On the 13th September 1986, the whole Messinia area was shaken by an earthquake ($M = 6.2$); it caused much damage, mainly in the city of Kalamata. Catastrophes were limited to a relatively small area, in the form of a triangle.

The striken area is a second-order tectonic graben (called the Dimiova–Perivolakia graben) which is developed on the eastern margin of the greater Kalamata–Kyparissia tectonic graben. Alpine and post-Alpine (Neogene and Quaternary) formations outcrop in the graben.

The recent earthquakes caused small fractures (4–5 m long) and small-scale reactivation of neotectonic faults. Both have been observed in almost all formations.

The seismic fractures form a zone or zones. They consist of small parallel fractures arranged en échelon, which allows us to conclude that in some places the fracture zones are of right-lateral and in others of left-lateral character. This, in fact, coincides with the kinematics of the main neotectonic fault-zones of the graben.

This, in conjunction with other morphotectonic observations, suggests that the deformation of the area is connected with coupling or even torsion phenomena.

Introduction

The province of Messinia (southwestern Peloponnesus) is one of the most tectonically active areas in Greece. This is due to the fact that it is near the Hellenic Trench. Destructive earthquakes from a large area (Sparti) are known since 550 B.C.

On September 13, 1986, an earthquake of Richter magnitude 6.2 occurred, followed by a strong aftershock ($M = 5.6$) on the 15th. The earthquakes (mainly the first one) caused much damage in the city of Kalamata and in some villages to the east and northeast. The damage has been limited to a relatively small graben area in the form of a triangle, which extends between the following fault zones (f.z): the Xerilas river f.z in the south, the Nedon river f.z in the west and the Arachova–Nedhousa (north of Karveli) f.z in the east (Figs. 1 and 2).

A large number of active faults cross the eastern margin of the Messinian Gulf as well as its geological prolongation on land, forming the Kalamata–Kyparissia graben.

The recent earthquakes have also caused small-scale reactivation of neotectonic faults and a great number of small fractures. In this paper we discuss the kinematics and dynamics of this frac-

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turing based on the neotectonic evolution of the area.

Geology

Alpine formations

In the area surrounding Kalamata the following Alpine geotectonic units occur (Fig. 1). (1) The Mani unit, which consists mainly of marbles (Upper Senonian–Upper Eocene), (2) the Tripolis unit, which consists of neritic limestones–dolomites and the flysh formation (Upper Eocene–Lower Miocene (?)), and (3) the Pindos unit, consisting of the "first flysch" formation and thin-layered, multifolded limestones (Upper Cretaceous).

From the geotectonic point of view the Pindos unit overthrusts the Tripolis unit, which in its turn overthrusts the Mani unit.

Post-Alpine formations

The Pliocene and Lower Pleistocene (?) consist of marls, sandstones and conglomerates. The total thickness of the formation differs from sub-basin to sub-basin and from place to place. In the central part of the sub-basin, where Kalamata is situated, it is over 1200 m thick.

The Pleistocene consists mainly of red-coloured siliceous sands-sandstones and conglomerates. The Holocene is represented by alluvial deposits, unconsolidated or consolidated clastic material and talus cones.

Tectonics

The Kalamata–Kyparissia graben

Four neotectonic basins, Kato (Lower) Messinia (south) and Ano (Upper) Messinia (north), the smaller basin of Dorion and the basin of Kyparissia–Kalo Nero (west), form a land strip of low elevation ($h = 120$ m.), which connects the Messinian Gulf with the Kyparissia Bay (Ionian Sea). They are considered as separate morphotectonic units and parts of the larger Kalamata–Kyparissia graben.

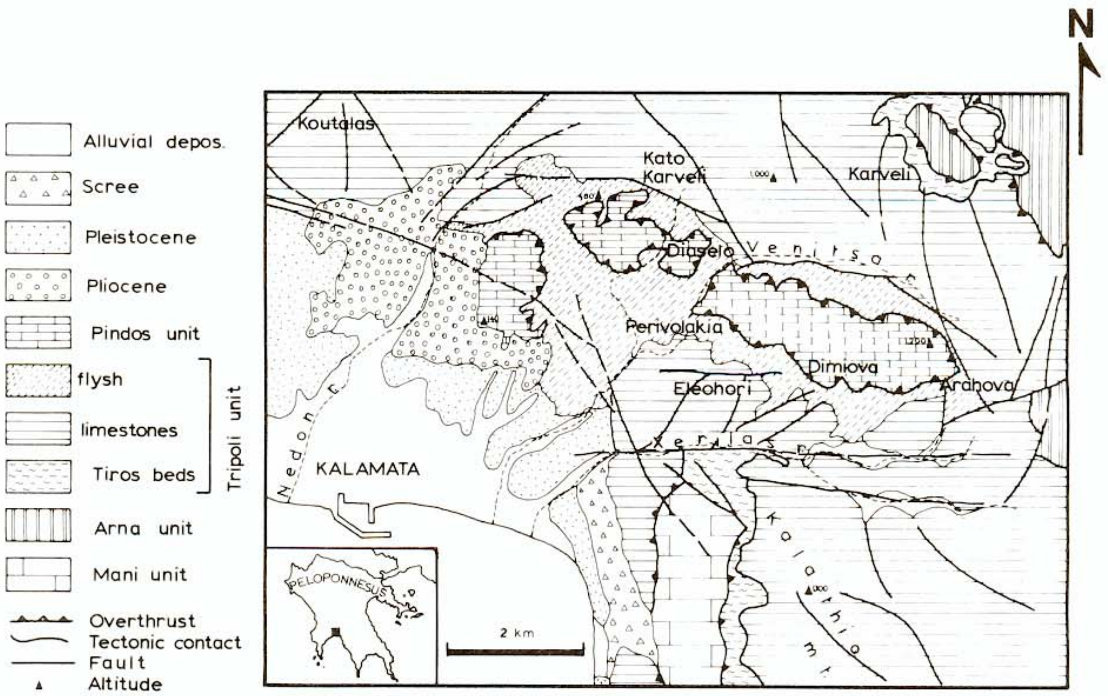

Fig. 1. Simplified geological map of the Kalamata area (from the geological map of Greece, sheet Kalamata).

The Kalamata–Kyparissia graben is bounded by two major fault zones. The first defines the eastern and northern borders of the graben, whereas the second forms the western and the southern borders. The faults are not continuous, but are interrupted and intersected by others, which although they belong to the same fault zone, have different strikes. As a matter of fact they form conjugate sets of faults.

In the eastern marginal fault zone of the Kalamata–Kyparissia graben, the faults strike mainly NNW–SSE and ENE–WSW. A characteristic of the eastern marginal fault zone is the en échelon arrangement of the faults. Therefore, we believe that the deformation, from the dynamic point of view, is not connected with an axial extensional stress field, but with coupling.

At the eastern margin of the southern part of the Kalamata–Kyparissia graben a smaller scale of neotectonic macrostructures exists. Some are parallel to the Kalamata–Kyparissia graben (the first-order macrostructure), whereas others are perpendicular to it. These second-order neotectonic macrostructures east of Kalamata include the following (Fig. 2): (a) the N-S striking Kampos graben; (b) the E-W striking Dimiova–Perivolakia graben; (c) the impressive Kalathion mountain horst; and (d) the Asprohoma–Koutalas horst.

Neotectonic macrostructures of second order have been developed also inside the Kalamata–Kyparissia graben, such as the graben basins of Lower and Upper Messinia and others. The differentiation of second order grabens inside and at the margins of the Kalamata–Kyparissia graben should have begun in the early stages of the neotectonic period, but their later evolution has differed in its details, as shown by facies, sediment thickness and kinematic behaviour.

The Dimiova–Perivolakia graben

The Dimiova–Perivolakia graben has a general E–W strike (Fig. 2) and lies at the eastern margin of the Kalamata–Kyparissia graben, east of Kalamata city. It is the most important structural unit relative to the earthquakes of September 1986, as most of the seismic fractures and reactivated faults and much of the damage and destruction occurred therein.

The graben in bounded by the E–W striking fault zone of Kato Karveli–Venitsa to the north, by the N–S striking fault zone of Arachova to the

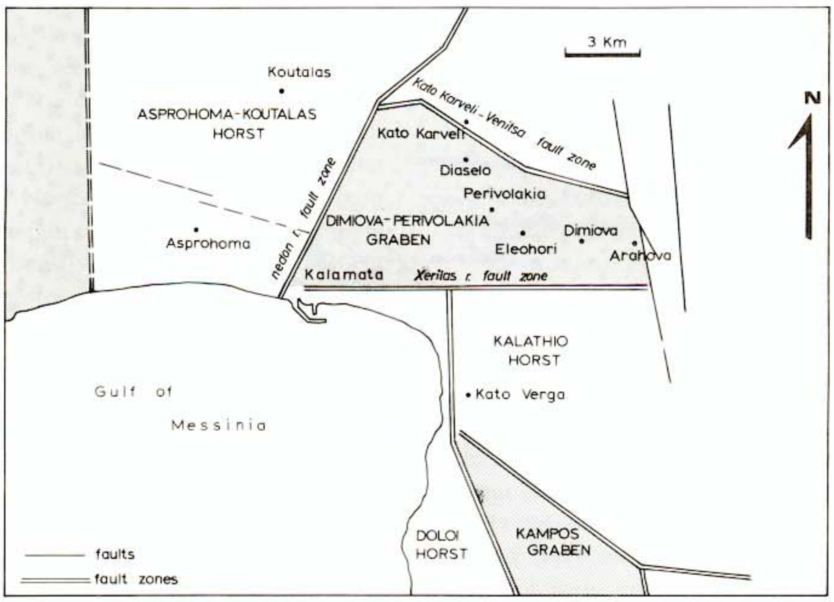

Fig. 2. Sketch of the second order neotectonic macrostructures at the eastern margin of Kalamata–Kyparissia graben.

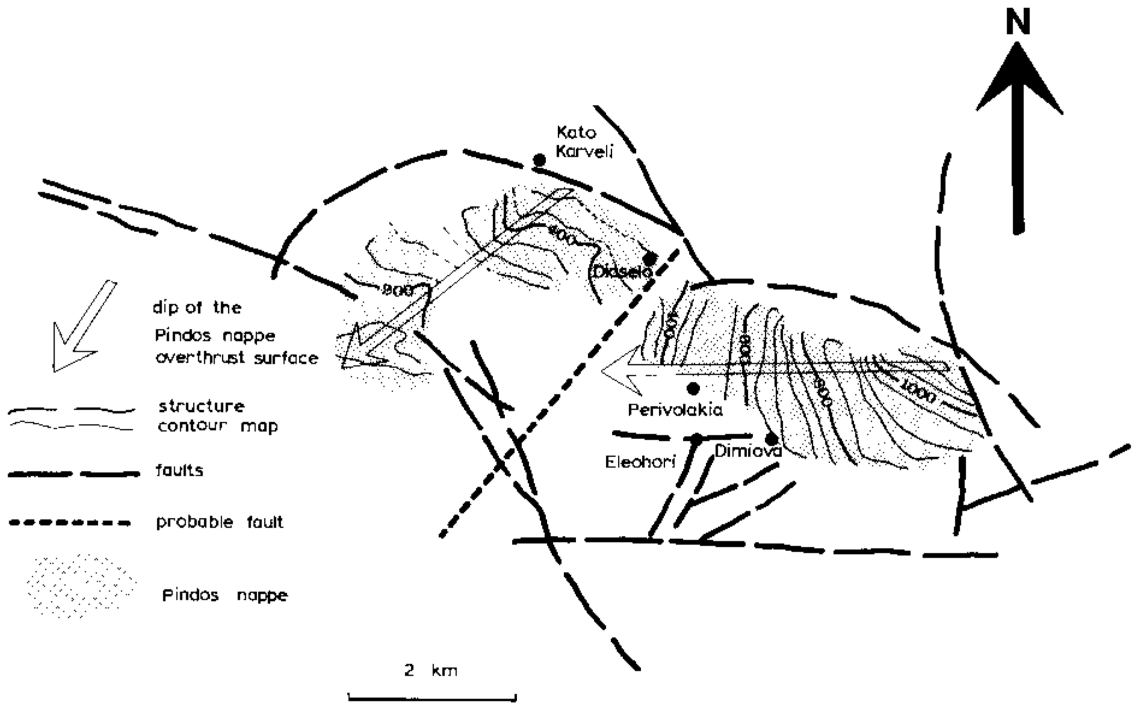

Fig. 3. Structure contour map of the basement of the Pindos nappe (in metres above sea level).

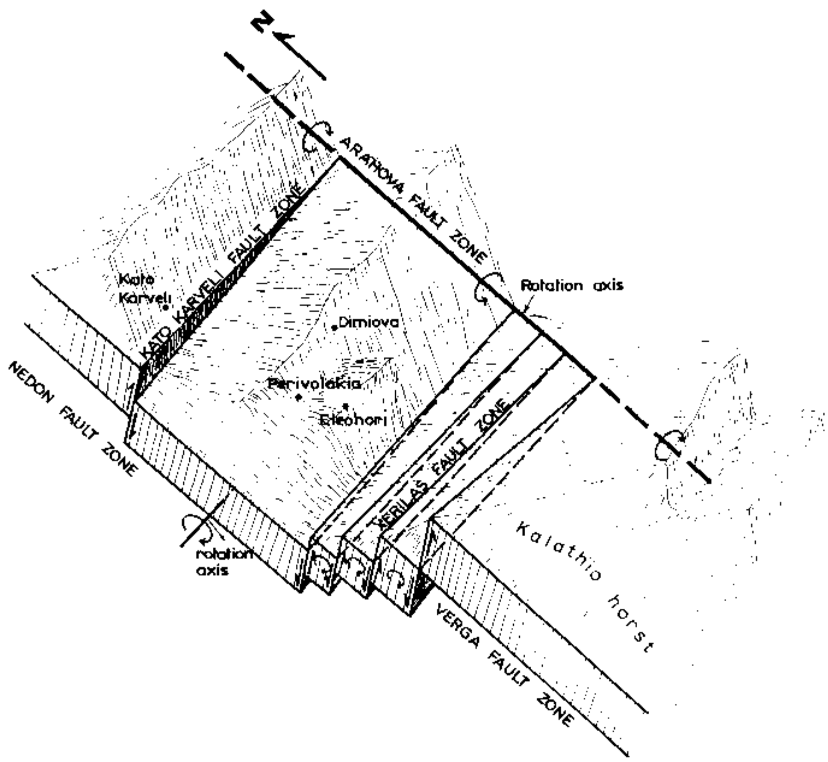

Fig. 4. Schematic block diagram showing the rotational movement of the Dimiova–Perivolakia graben.

east, by the E–W striking fault zone of Xerilas to the south, and by the Nedon fault zone to the west.

The study of the structural and geomorphological elements of this graben, has proved that the endogenetic processes connected with its creation and its evolution until the present, are complex, from both the kinematic and dynamic points of view.

A structural contour map of the basement of the Pindos unit nappe (Fig. 3) proves that the graben is the result of rotational movements which took place around a N–S striking principal axis and secondarily around an axis of E–W direction, so that the western and more especially the southwestern parts of the graben are relatively the most subsiding area, as is depicted in Fig. 4. These rotations have influenced the relief, the morphology and mainly the distribution and the dip of the planation surfaces, which dip towards the west.

Faults and fault zones

The Kalamata earthquake (13.9.86) which caused surficial fractures, small-scale reactivation and rockfalls, was quite revealing for understanding the deformation during the neotectonic period and its evolution up to the present.

The main characteristics of the neotectonic faulting are the following: (1) The density of the neotectonic faults seems to be irregular in the major area. (2) The density of the faults in the Quaternary deposits around the city of Messini (west of Kalamata) is relatively higher than that observed in the Neogene deposits which outcrop at the eastern margin of the Kalamata–Kyparissia graben. (3) The density of the neotectonic faults in the Tripolis limestones is much higher than that observed in the Cretaceous limestones of the overthrusted Pindos unit.

The boundaries between the limestones and the flysh of the Tripolis unit are, in many cases, primarily tectono-sedimentary. In the Messinia area, some of these faults have been reactivated many times during the neotectonic period. A typical example is the small Zimbeli Fault, which crosses the road from the village Elaeochori to Dimiova Monastery.

On this slightly curved fault surface (dip/dip direction: 45/315) the following has been observed: (1) three successive tectonic breccias of different age; (2) six different slickenside generations with the following plunges 34 /266, 42 /333, 36 /000, 45 /317, 25 /015, 5 /247; (3) at least three joint sets, of different age and one set of small faults showing an en échelon arrangement.

The seismic faults

The general observations on the fault ruptures (seismic fractures with apparent slip) caused by the earthquakes at Kalamata are the following:

(1) The observed ruptures are mainly the result of the reactivation of older neotectonic faults. However, in one case, such as in the area of the small village of Diasello, a totally new fault was created on the uppermost tectonic unit (Pindos unit).

(2) Faults occurred mainly during the first earthquake ($M = 6.2$) and only one (west of Elaeochori) during the second one.

(3) The reactivated faults strike in different directions.

(4) The throw of the seismic faults is generally small (max = 20 cm) and of normal character. It is very interesting that the maximum throw has been observed at the seismic fault caused by the second and smaller earthquake ($M = 5.6$).

(5) Seismic faults have been observed in the calcareous rocks of the Tripolis unit, in the formations of the Pindos unit, and in the Neogene formations (marls, sandstones, conglomerates).

(6) No faulting has been observed in the other formations (flysch, Quaternary deposits).

(7) In many places of high relief, the faulting was accompanied by rockfalls.

The seismic fractures

The general observations of the seismic fractures (ruptures without apparent throw) caused by recent earthquakes, are the following:

(1) Seismic fractures have been observed in almost every formation (Alpine and post-Alpine). Most of them are relatively small (4–5 m long), whereas some of them are very large.

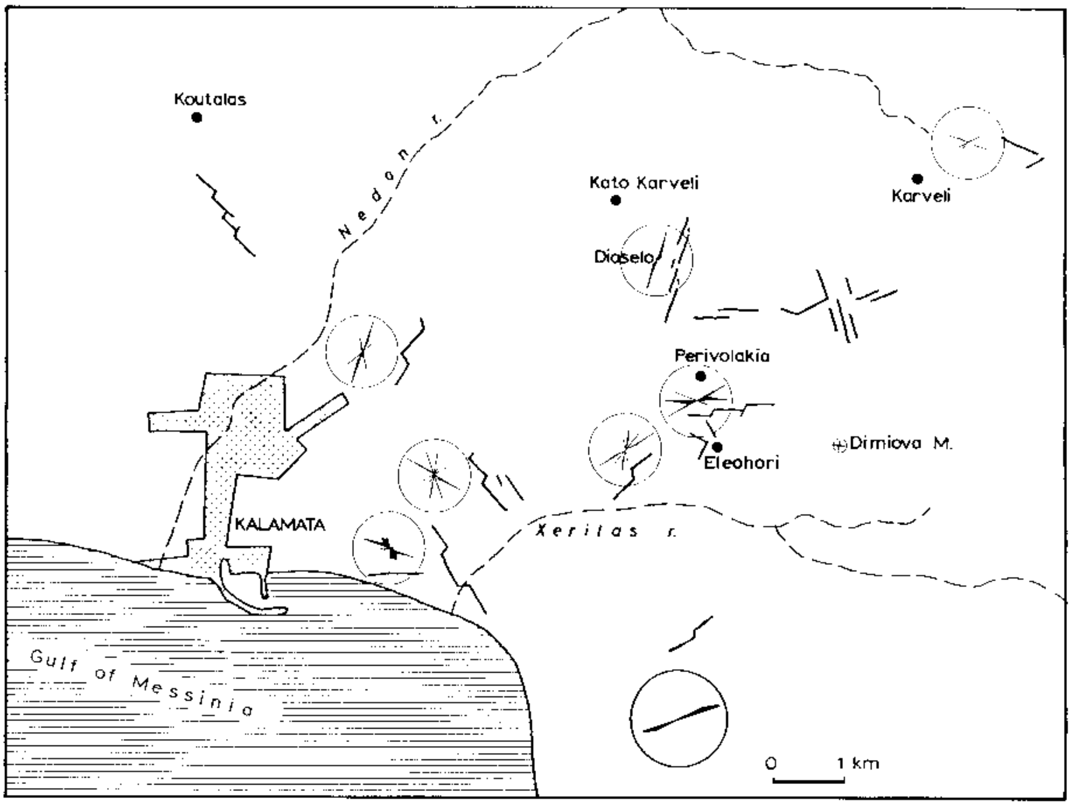

Fig. 5. Sketch-map of seismic fractures with the fracture roses.

(2) The seismic fractures form a zone or zones. The arrangement of the seismic fractures inside the zones is typical en échelon. These fracture zones are in some places of right-lateral and in others of left-lateral character (Fig. 5).

(3) Seismic fractures were created during both the first and the second earthquakes. In some cases, two fractures created by the first earthquake were joined by another one, created during the second. A number of fractures increased in width and length by the second earthquake.

(4) The seismic fractures are not plane surfaces, so they are not represented as straight lines on the land surface, but as angular ones, which consist of two sets of straight lines of different strike. The set consisting of the greater fractures is of first order, whereas the set which consists of the smaller fractures is of second order. In some places, the first-order set becomes secondary and vice-versa.

(5) The density of the fracture zones of large fracture varies from place to place. In one case the density was ten fracture zones / 100 m.

Discussion and conclusions

From the data referred to above we take into consideration the following main observations:

(1) The en échelon arrangement of the older neotectonic faults of the eastern margins of the southern part of Kalamata–Kyparissia graben.

(2) The en échelon arrangement of the seismic fractures created during the recent earthquakes.

(3) The six different generations of slickenside on the Zimbeli fault surface and the fact that almost all of them are the result of an oblique slip or even strike-slip movement.

(4) The fact that the 2nd order Dimiova–Perivolakia graben has been rotated down towards WSW around a N–S striking axis.

(5) The fact that the Kalathion Mt. horst has been rotated towards the east around the N–S striking axis.

These facts suggest that during the whole neotectonic period up to the recent earthquake, the deformation of the Dimiova–Perivolakia graben was due to a stress field of a coupling or torsional character. Therefore, the neotectonic normal faults (active or non-active) that occur everywhere in the area are (1) normal faults with oblique slip and not with dip slip and (2) these normal faults are not the result of a large - scale extensional stress field, but of a local one. Similar conditions of neotectonic deformation are described by other authors from some other areas of Greece, such as for example, from the Isthmus of Corinth (Von Freyberg 1973; Mariolakos et al., 1981; Mariolakos and Stiros, 1987) the Gulf of Corinth (Mariolakos, 1975) and from the area of Kyparissia (southwest Peloponnesus) (Mariolakos, 1986).

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