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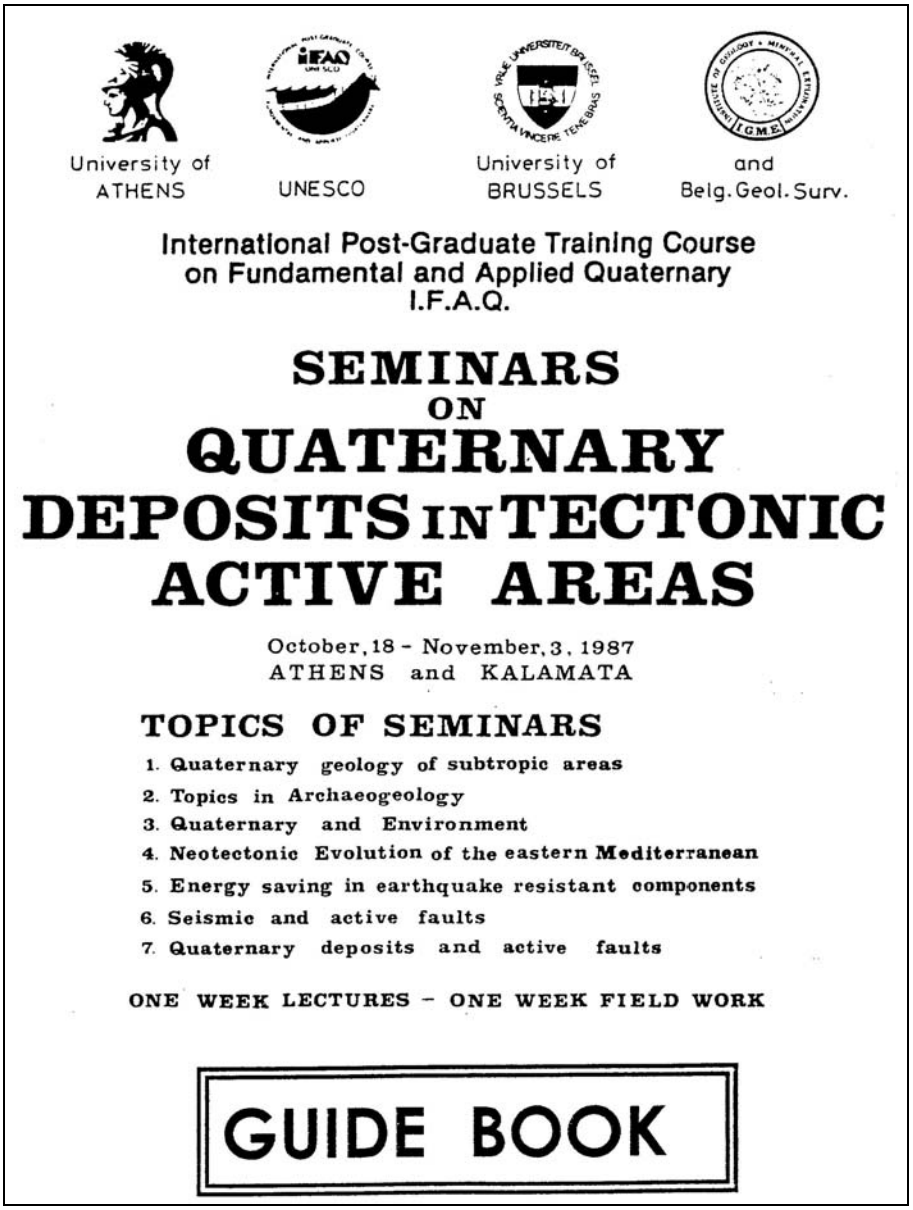

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ON THE GEOMORPHOLOGY - GEOLOGY- NEOTECTONICS AND SEISMOTECTONICS OF KALAMATA AREA

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INTRODUCTION

The area of Messinia is one of the most seismically active areas of Greece (fig.1). Its behavior is due to te fact that it is near by the Hellenic trench that represents the Subduction of the African plate under the European one.
Consequently, a large number of active neotectonic fault zones (seismically active), cross the Messinian gulf, as well as its geological prolongation on land, that is the graben of Kalamata-Kyparissia and the surrounding mountainous region.

A lot of destructive earthquakes have taken place in the area, since 550 BC. (Fig 2).
The characteristics of the seismicity of Kalamata are:
i) All major earthquakes are at a small depth (H 10 Km)
ii) The large macroseismic intensity
At September 13, 1986 the Kalamata earthquake occured.
Its magnitude was M= 6.2R and caused tremendous damages.
At September, 15 a strong aftershock took place (M=5.6R) (Fig3)

Concerning the geographical distribution of the destructions, as well as those caused by previous earthquakes, a lot of observations can be done.

(i) The destructions were limited within a narrow zone (width 5-7 Km) in the NE-SW direction.

(ii) Destructions or major damages have not been observed neither to the east of the major fault zone of Verga.

(iii) The caused damages are not depended only on the age, type, height.....etc of buildings.

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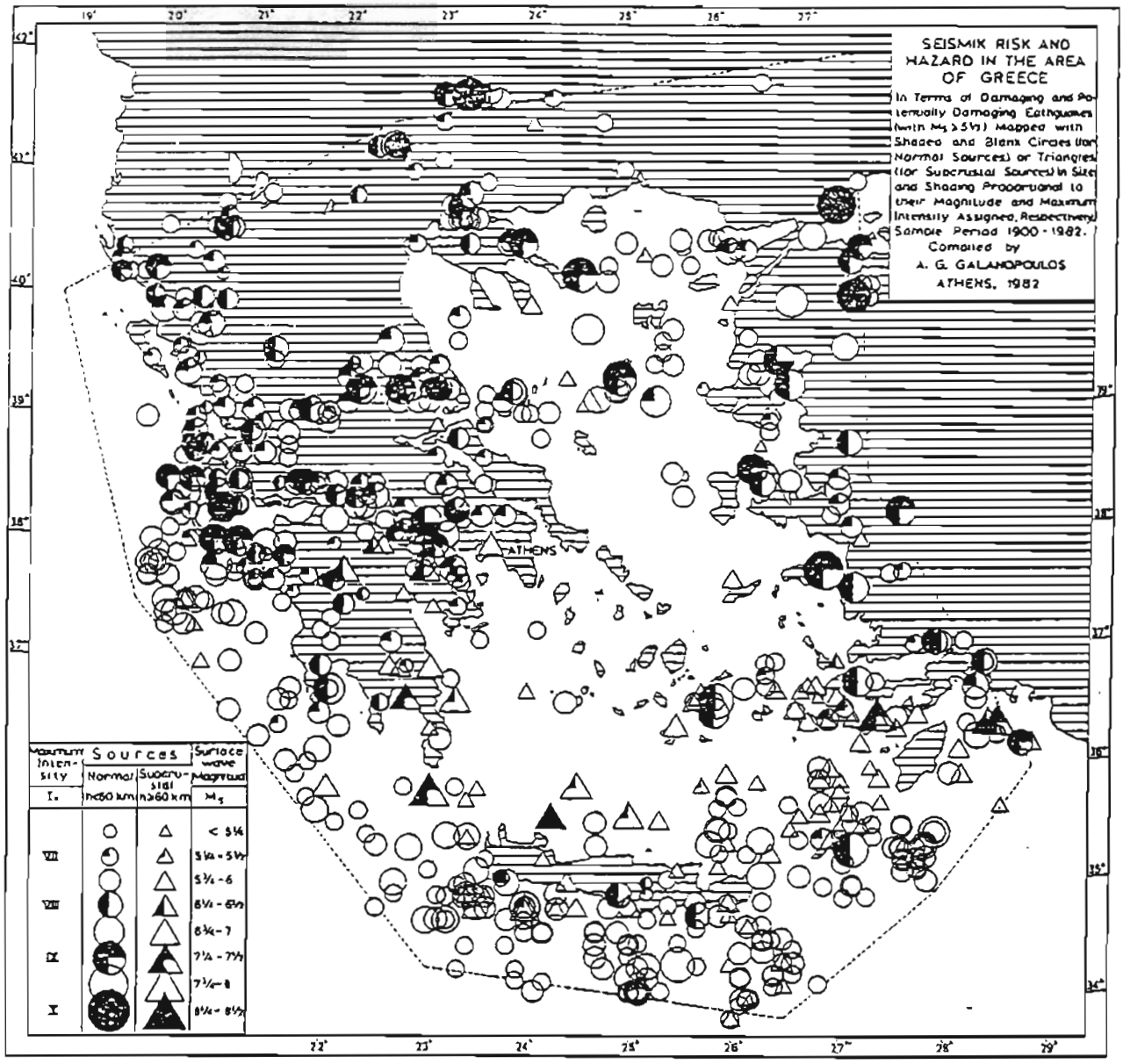

Fig.1 Seismic Risk and Hazard showing up in the distribution pattern of damaging and potantially damaging shocks, respectively.Heavy dashed line denotes the approximate limit of potentially damaging shocks of Greece.

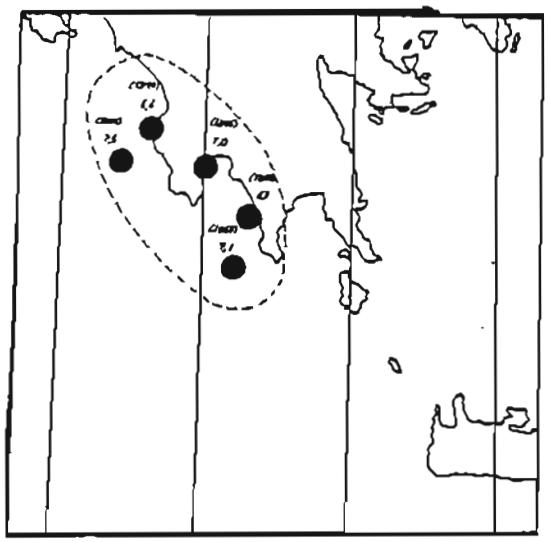

Fig.2 The historical earthquakes in the Messinian area.

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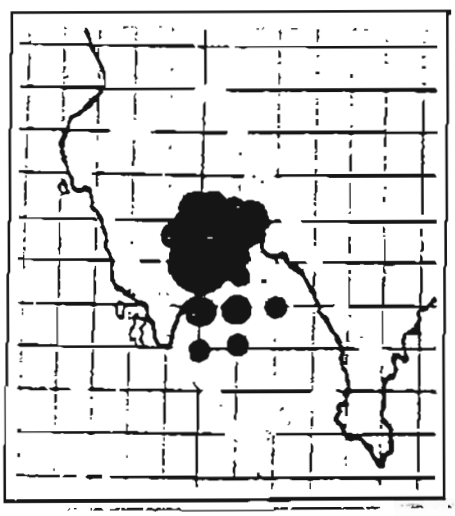

Fig.3 Post seismic action and the epicenters of September earthquakes.

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(iv) Very old constructions (monasteries .....etc) have been destroyed almost totally. This fact was not noticed on previous earthquakes.

(v) In many cases, the building destructions are connected directly to seismic fractures.

(vi) The rockfalls show a straight genetic relationship to the reactivation of some certain fault zones, whereas the dip of the slopes and the discontinuities surfaces had only a helpful role. So we talk about seismic rockfalls, seismic talus, and seismic erosion

G E O M O R P H O L O G Y

From a geomorphological point of View, the basin of Lower Messinia is distinguished into the three following regions.

(i) The Plane region: It takes up the central part of the graben and it's characterized by small slopes. The study of the airphotos doesn't show some certain tectonic lines. Howerer, the study of the topographical maps, (scale 1:5.000) reveals a systematical arrangment and bending of the curves and minor currents. This leads to the Conclusion that there is a systematical NW-SE direction, wich is one of the dominant tectonic directions of the area.

(ii) The hilly region: It is characterized by a "finger-shaped" prolonged structure system, beginning from the calcareous front and dereloped in the Neogene formations at a NE-SW direction. Each one of these structures represents a series of small hills in a " step by step" arrangement, coincide with the main tectonic lines.

(iii) The mountainous region: It is developed exclusively on alpine formations and its geomorphological features (Such as the formation of intense ravines, the large slopes ..... etc) are under neotectonic control.

As far as it concerns the relief of the Messinia gulf, it is remarkable that two of the dominant tectonic directions of the area, (NW-SE and NE-SW), appear in the morphological map of the Messinian gulf's bottom.

The study of the drainage network gives a systematical sudden bending of the currents to certain directions, whitch coincide with the major tectonic lines of the area.

The formation of intense ravines is quite obrious within the whole area. This fact is an evidence of the action of uplifting. At the cases of the rivers Nedon, Tziroreema, and Xerilas we can distinguish, through the morphology of the river bands, at least three weathering phases (uplifting also)
The arrangement of the mean slope contouring : coincide with the major tectonic lines.

G E O L O G Y

ALPINE FORMATIONS

At the surrounding area of Kalamata the following tectonic Units appear: (See fig.9 and the geological map of Kalamata)

(i) M a n i U n i t: It's slightly metamorphosed and Consists of marbles (Up. Senonian - Up. Eocene) and the transition to flysh beds (Up. Eocene- Oligocene).

(ii) T r i p o l i s U n i t: It Consists of the Tiros beds, the cretaceous and Eocene neritic limestones and the flysh formations.

(iii) P i n d o s U n i t: Consists of thin layered- multi folded limestones (Up. Cretaceous) and the first flysh formation (Up . Jurasic - L. Cretaceous)

From the geotectonic point of View the Pindos Unit overthrusts Tripoli Unit, wich in it turn overthrust the Mani Unit (fig. 4)

POST ALPINE FORMATIONS

Pleiocene and Lower Pleistocene?

Consists of marls, sandstones and conglomerates . The total thickness of the formation is different from sub- basin to sub- basin and from place to place (Fig. 4, 5)

Pleistocene

Consists mainly of red- coloured siliceous clastic sediments (sands and conglomerates exclusively from metamorphic rocks, radiolarites etc)

Holocene:

Allavial deposits, Uncosolidated material, river deposits and fluvial terraces, talus cones.....etc. (Fig. 6, 7).

TECTONIC

THE GRABEN OF KALAMATA - KYPARISSIA

The neotectonic basins of Upper and Lower Messinia the neotectonic basin of Dorion and the one of Kyparissia- Kalo Nero, form a zone of land of low altitude wich connects the Messinian gulf with the Kyparissia bay. They are parts of a larger graben that is limited by fault zones. This is the graben of Kalamata- Kyparissia

The detailed geological and tectonic studies, the drillings and the geoelectric survey performed at the grabens of Messinia and Kyparissia showed that the morphotectonic evolution of the previous grabens, is complex, both from the Kinematic and geodynamic point of view.

The Kalamata graben, is limited between two major fault zones. The First one defines the eastern and northern border of the graden and the second the western and southern one. The characteristics of the first fault zone are:

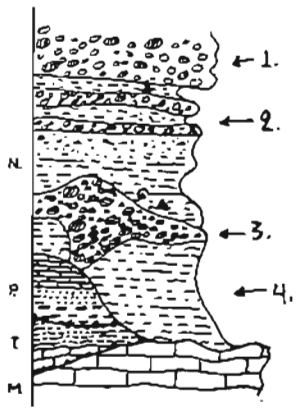

Fig. 4. Schematic stratigrafic column of Kalamata Basin

N = Neogen, P = Pindos Unit, T = Tripolis Unit, M = Mani Unit.
1 = Ag. Ioannis Formation, 2 = Velanidia Formation, 3 = Skopeftirion Formation, 4 = Asprohoma Formation.

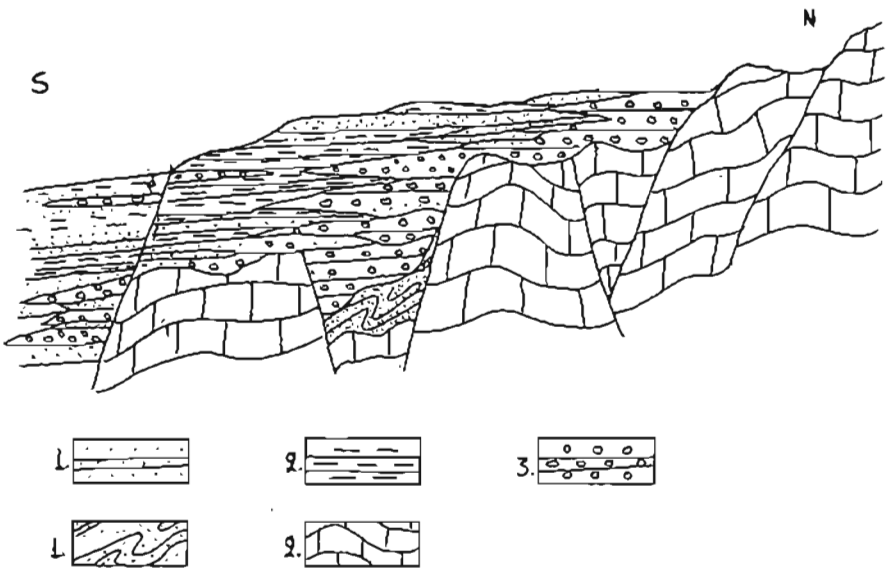

Fig. 5. Schematic cross section of the post-alpine basins of Messinia area.

Neogene: 1 = Sandstones, 2 = Marles, 3 = Conglomerates
Alpine basement: 1= Flysch, 2 = Limestones

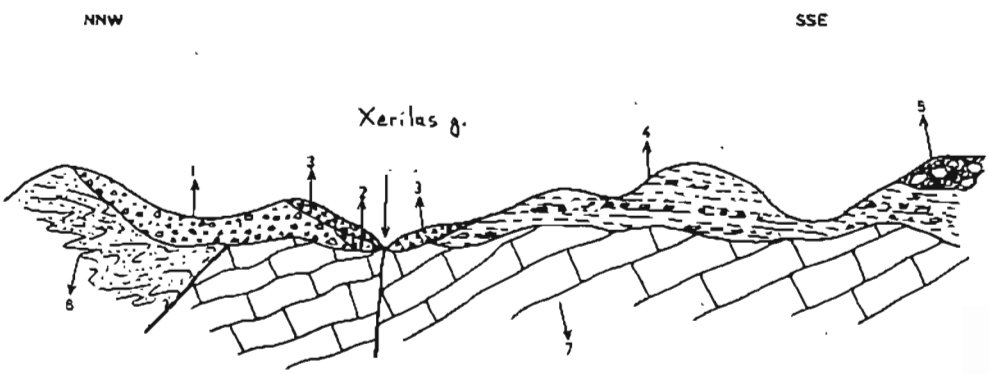

Fig. 6. Schematic cross section at Xerilas gorge.

1, 2, 3 = Pleistocene, 4, 5 = Neogene, 6 = Flysch & 7 = Limestones of Tripolis Unit

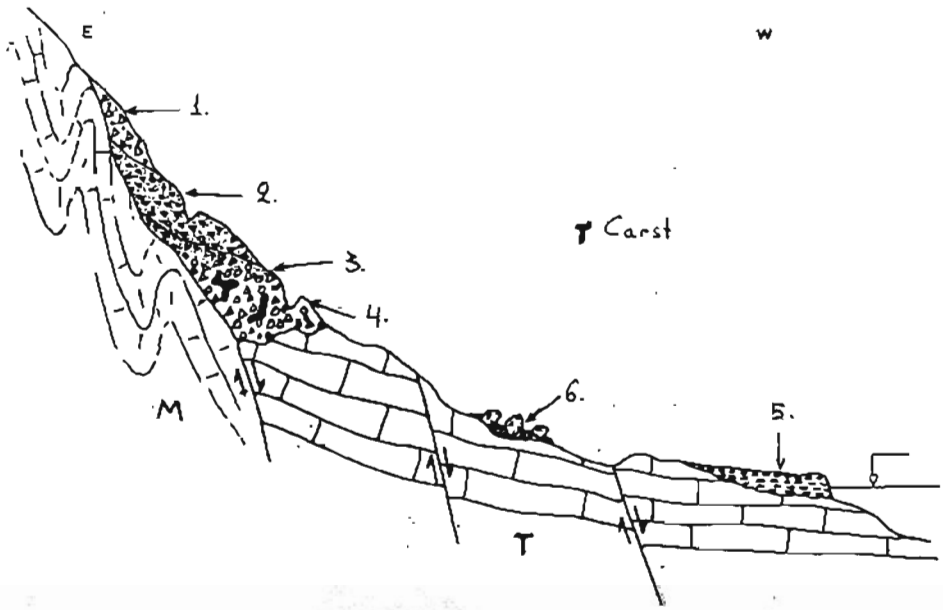

Fig. 7. Schematic cross section showing the generations of scree at Kato Verga area.

M = Mani Unit, T = Tripolis limestones.
1 = Holocene (3.900 BP), 2 = Holocene (8.000 BP), 3 = Up. Pleistocene ?, 4 = Med. - Up Pleistocene, 5 = Red ciliceous clastic formation, 6 = rockfalls.

(i) The strike of the partial faults are not stable along the border

(ii) The faults are not Continuous but interrupted by some other ones, wich allthough they belong to the same fault zone, their strike is different. As a matter of fact, they build conjugate systems wich have been created during the same deformation phase and they are the result of the same stress field.

In the described marginal fault zone of the graben of Kalamata-Kyparissia, the faults strike are NNW- SSW and ENE-WSW,but the dominant direction is the first or the second depending on the area.

Another characteristic of this marginal fault zone is the "en echelon" arrangment of fault s . Therefor, from the dynamic point of view the deformation is not connected with an axial extensive stress field, but with coupling.

Another fact is the existance of lower order neotectonic macrostractures at the eastern margin of Kalamata-Kyparissia graben
Some of them are parallel to the higher order macrostructure whereas others are perpenticular to it.

So, east of kalamata there exist a number of macrostructures as the graben of Kampos which strikes N-S, (parallel to the higher order macrostructure) and the graben of Dimiova- Perivolakia , which strikes E-W.

Some other important second order neotectonic macrostructures at the southeastern margin of Kalamata-Kyparissia graben, are the inpressive horst of Kalathion mountain and the smaller horst of Asprohoma- Koutalas, west- northwest to the city of Kalamata.

Lower order neotectonic macrostructures are also created within the Kalamata-Kyparissia big graben, like the grabens of Ano and Kato Messinia and the graben of Kyparissia-Kalo Nero. Although from the dynamic point of view, all these neotectonic macrostructures of lower order are exactly the same, as they are the result of the same stress field, from the kinematic point of view are diferent.

This diferentiation begins at the first stage of their creation as well as during their development.

THE GRABEN OF DIMIOVA-PERIVOLAKIA AREA

The graben of the Dimiova-Perivolakia area, is the most important second order neotectonic macrostructure at the eastern margin of Kalamata-Kyparissia graben, and strikes E-W.

The area of this graben, the most seismic fractures and reactivated faults and the most damages and destructions, have been observed. The margins of the Dimiova- Perivolakia graben are the fault zone of Kato Karveli- Venitsa at the North which strikes E-W, the fault zone of Arahova at the East which strikes N-S and the fault zone of Xerilas (at the south which strikes E-W). The western margin coincides with the Nedon- fault zone.

The study of the tectonic and the geomorphological elements of this garben, shows that the endogenetic processes-responsible for its creation- are complexe, both from the Kinematic and the dynamic point of view and they are expresed on the relief through concrete landforms. The study of the marginal faults, the structural map of the Pindos nappe the formation of intense ravines and the planation surfaces prove that the graben is the result of rotational movements, with one N-S principal rotation axis and another secondary in the E-W direction, so that the western and more especially the southwestern part of the graben is the most subsiding area

F A U L T S - F A U L T Z O N E S

The September 13 earthquakes at Kalamata, accompanied by surfacial fractures, small scale reactivations, and rockfalls were quite revealing for understrunding the deformation during the neotectonic period and its erolution up to present time.
The general conclusions are the following

(i) density of the active, the possibly active and generally the neotectonic faults, seems to be irregular in the major area.

(ii) Consequently, in the quaternary deposits the faults and the fault zones are rare. Real active faults, have been observed

but not within narrow kalamata area.

(iii) A large number of seismic microfaults as well as seismic fractures, have been observed in the Neogene formations but not so many as in the quaternary deposits.

(iv) Many faults have been observed in the limestones of Pindos Unit. In this Unit has been created the greatest seismic fault, caused by the Kalamata earthquake (Diaselo area, north of Kalamata)

There are a lot of faults in the flysh of Tripolis Unit. Some faults have been observed from airphotos. The flysh limestones contact is primarly tectonosedimentary as it usually happens in a large number of sites at central Peloponnesus. At the area of Messinia some of these faults seem to have been reactivated, during the Neotectonic period.

A typical case of such a fault is that observed on the road from Eleochorion to Dimiova monastery. The following habe been observed on this fault surface.

(i) a tectonic breccia including small calcareous peaces wich comes to contact with the limestone

(ii) a caleite crust wich covers the previous one

(iii) Polymictic tectonic breccia wich covers both previous It contains fragments from limestones and flysh and from the calcite crust.

On the fault surface there have been observed defferent striatious. These are :

S	L
60/326	40/266 & 02/234
44/315	68/232 & 33/273
53/322	25/242

Three generations of joints are also observed in an " en echelon" arrangement, wich cut all the tectonic rocks .

So, the system 1 is cut by the system 2 and both of them are cut by the system 3 which has cut the fault plane, creating a "en echelon" arrangement.
The dynamic analysis shows a compression in NE-SW direction and a extension in NW-SE (Fig. 8).

During the recent earthquakes, a lot of seismic fractures that have been observed, especially at Perivolakia area, have disturbed the layers of the flysh.

(vi) On the calcareous formation, the systematic study of the reactivated faults, combined with the rock falls, the photo-interpretation, the morphology and the microfractures gave- perhaps for the first time- the chance of soalving many problems concerning neotectonic faults.

(a) In the major area occupied by limestones it is possible to distinguish areas that are intensively fractured, from others where faults are relatively rare.

(b) A great number of faults is observed in the internsively fractured zones. The number is so great that in certain places the dominat geological features are the fracture surfaces. They can be separated into two big categories. These are:
the curved surfaces and the plane ones
In the first category, surfaces can be Convexed or Concave when they are small, and they are wavy when big; They strike in two main directions:N 60°E and N 30°E. The axes of these wavy S- Surfaces plunge usually to SW.
At some cases a lot of striations have been observed.
The dynamic analysis by the E.M. ANDERSON method is given in diagram (Fig. 9)
The active fracture surfaces of Tziroreema area, are almost plane and cross the non- active ones.
Their direction is NW-SE and they form an "Y" type consugate system. No striations have been observed because the fault surfaces

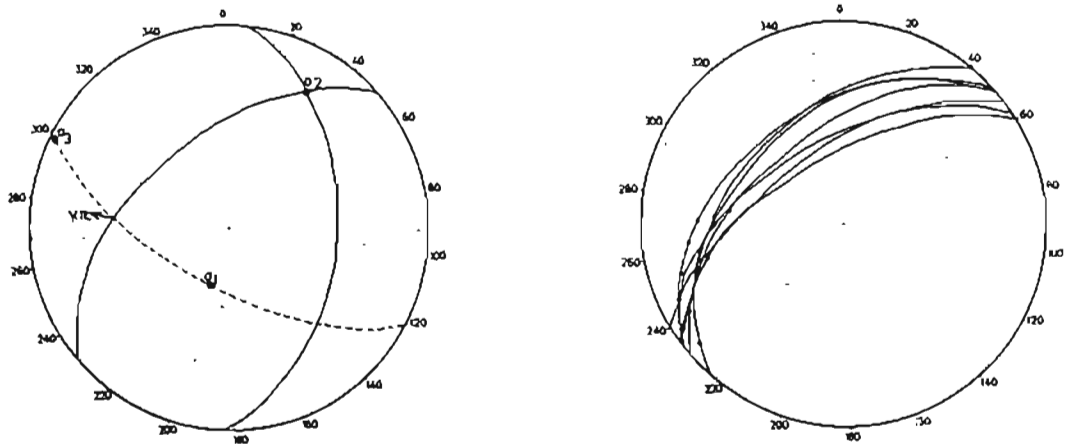

Fig. 8. Dynamic analysis of a typical fault near Eleochori Village, which separates the flysch and the limestones of Tripolis Unit.

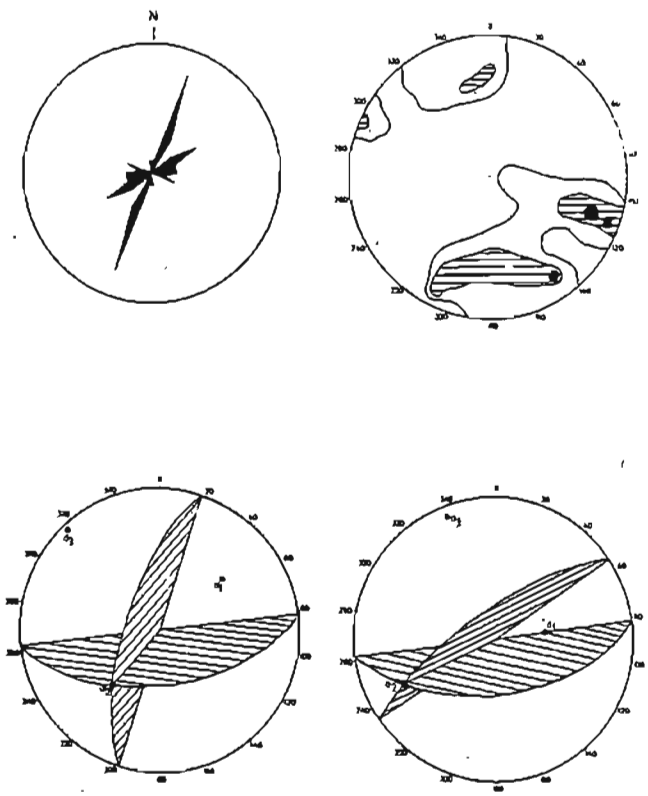

Fig. 9. Rose and Poles diagrams and Dynamic analysis of the non active faults of the area.

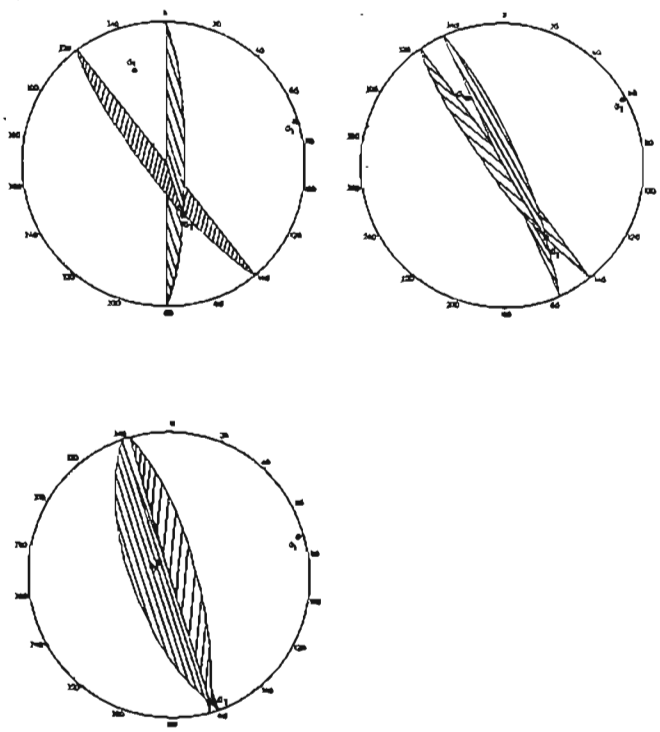

Fig. 10. Dynamic analysis of some active faults of the area.

are few and not polished. They are usually acompanied by a tectonic breccia zone. Intense carstification is observed parallel to the active fracture surfaces. Some of these have been reactivated during the second earthquake of 15/9/86.

On the ground surface these fracture surfaces form a small anomaly on the relief. These are features that allow their recognition from airphotos too. These surfaces and consequently these faults are active, while the curved ones (and Consequently the faults) are alpine structures and non- active.

The density of the neotectonic faults is so great that at some areas the whole mountain is fractured in small pieces giving to the limestone the image of a gigantic mass, more or less " loose". These faults are crossed and break the whole area to big rhomboeder shaped blocks. All these areas represent an enormous dimension tectonic macrobreccia or a macromylonited zone.
Within this, due to neotectonic faulting, multi fractured zone, some less faulted areas have been isolated, which give the impression of "compact mountanous mass".

THE NEOTECTONIC FAULTS

As neotectonic faults are characterized all those that have been created after the accomplishment of the alpine tectonism. The neotectonic faults are distinguished in active and non active.

THE NON ACTIVE NEOTECTONIC FAULTS

A number of the faults which cross the area can be considered as non active, allthough the possibility of their reactivation in the future, can not be excluded.

THE ACTIVE FAULTS

As active faults are considered these that have reactivated or created from Up. Pleistocene up to present. It is a problem, the identification of these faults especially in some nulti faulted areas that during Pleistocene were under. In the case of Messinia area it has become possible to approach the problem, based on the detailed study of the features of the faults reactivated with the September earth-

quakes.

THE SEISMIC FAULTS

As seismic faults are characterized the seismic fractures which present an obvious slip.Seismic faults, actually are reactivated parts of an older fault.
In many cases however, there is no close relation of those fractures to the already existing faults.
Hence, sometimes, as for example in the area on the way to Eleochorion, a reactivation of the fracture surfaces has taken place in both, the first and the second earthquake.
On the contrary in other areas, as in Tzirorema, a reactivation-and Consequently seismic fractures - has taken place only during the second earthquake.
The general characteristics of the seismic faults are the following

(i) Old faults of various derectious have been reactivated
(ii) The throw of these seismic faults is small in contrast with the seismic faults from other earthquakes with a big one (e.g. seismic faults caused by Alkyonides earthquakes 1981)

(iii) Reactivations has been observed
in the calcareons rocks of Tripolis Unit
in the formations of Pindos Zone
in the neogene formations

(iv) No reactivations has been observed in the other formations.
(v) All reactivations were accompanied by rockfalls in the cases that the relief was intense.

THE SEISMIC FRACTURES

General observations:

(i) Seismic fractures have been observed in almost every formation (apline and post alpine)
(ii) Their size is relatively small (4-5m)

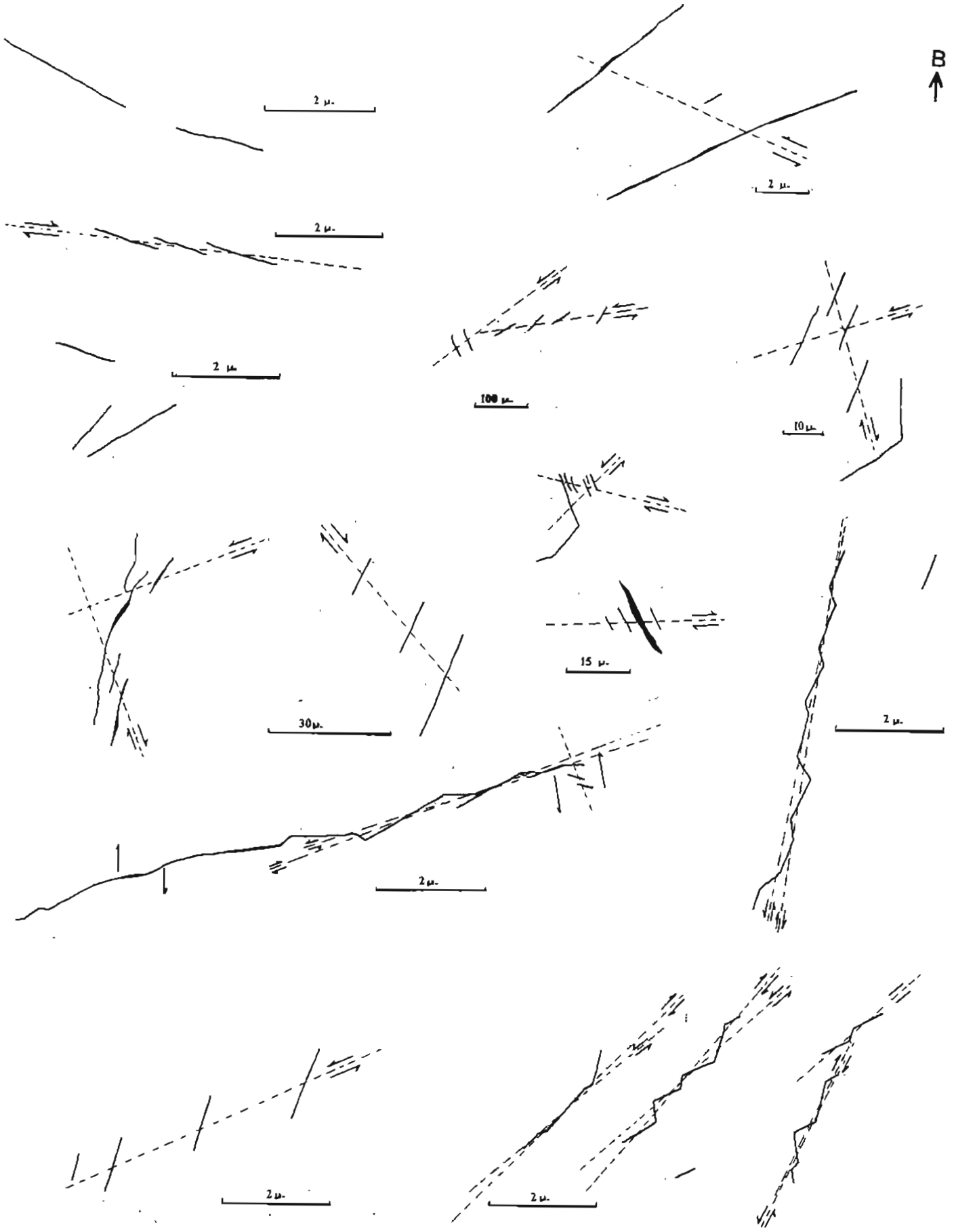

Fig. 11. Kinematic analysis of some reactivated faults and seismic fractures during the Kalamata earthquakes.

(iii) The seismic fractures form a Zone or Zones of some smaller ones (3-5 m long). They show a typical "en echelon" arrangement. The width of these zones is usually about 2-5m and they were observeded in many places

(iv) Seismic fractures as well as minor seismic faults were created both during the earthquake of 13.9.86 (M=6,2R) and during the one of the following day. In such a case, two succesive fractures of the first earthquake, were joined by another, created by the earthquake of the next day.

(v) The density of the surfacial fractures Varies from place to place. In one case the density was 10 fractures/100m.

(vi) A number of fractures became wider or longen during the second earthquake.

(vii) The seismic fractures are not plane surfaces so they are not presented as straight lines on land surface. In some places the principal system becomes secondary and vice-Uersa.

In the following figures the arrangement of some seismic fractures created by the recent earthquakes, are presented.