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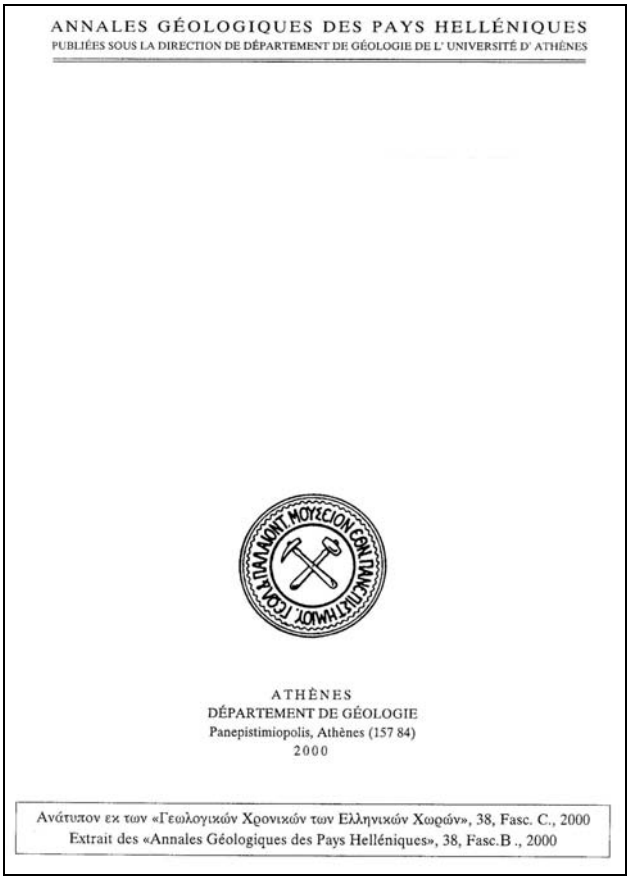

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THE ATHENS EARTHQUAKE SEPTEMBER 7, 1999: THE NEOTECTONIC REGIME OF THE AFFECTED AREA

by

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INTRODUCTION

At September 7th 1999, an earthquake with a magnitude of M_w=5.9 struck mainly the western suburbs of Athens. According to the data collected by the National Observatory of Athens and other research institutes, the earthquake was the result of a seismogenic fault, of WNW-ESE direction and a dip of 40° towards SW. The focal depth has been initially estimated to be 8-20 km, but no surface occurrence of the seismogenic fault was observed. The damages in the broader area affected by the earthquake were extensive, and generally not expected, because the Athens basin was generally considered as:

i) An area of non-existent earthquake foci.
ii) A very sound founding basement
iii) An area not crossed by active faults.

The above-mentioned don't seem to be completely correct for the following reasons:

- It is a fact that the larger part of the Athens basin hosts no earthquake foci, but between Parnis and Pendeli Mt. and the S. Evoikos Gulf, there are some foci.

- It is a fact that the founding basement is sound for the largest part of the basin, but it does not remain the same throughout Athens. It is also known that some founding basements (marls, conglomerates, sands, red soils) could be characterised as soft, with a different mechanical behaviour.

- Seismic faults are not mentioned in the wider area of Athens basin, but the morphotectonic characteristics and other geological criteria of the area surrounding Parnis Mt. and the Aegaleo Mt., leave no doubt that there are, in fact, active faults.

In this paper, an attempt for the description of the morphotectonic evolution of the area affected by the earthquake will be made. This attempt is based on observations concerning the general morphotectonic structure of Attica and on data concerning the geological –alpine and post-alpine- formations and structure.

GEOLOGICAL-TECTONIC CHARACTERISTICS OF THE BROADER STUDY AREA

Alpine tectonic structure

The earthquake affected area presents a complex alpine structure comprising mainly by two basic rock types. The Mesozoic metamorphics of Attica geotectonic unit, occurring mainly at Pendeli, and Ymittos mountains and the wider eastern Attica area, and the Mesozoic non-metamorphics of Eastern Greece unit, occurring mainly at Parnis and Aegaleo mountains (**Fig.1**). It is important that the affected area is located at the boundaries of the above-mentioned units and towards Parnis Mt., but their tectonic relation is yet to be determined in this area, since a thorough and detailed geological mapping has not been hitherto carried out. Furthermore, this old tectonic contact is covered by an allochtonous system, called *"Athens schists",* as well as Neogene and quaternary deposits. All that is certain is that the allochtonous system is tectonically overlaid on the two previously mentioned units (KOBER, 1929, PETRASCHECK & MARINOS, 1953, KATSIKATSOS, 1977). There is some evidence at certain sites though, that the metamorphic unit is overlying the non-metamorphic one (boreholes in Kalamos NE Attica, DOUNAS et al., 1980). Both the metamorphic and the non-metamorphic units are characterised by a complex tectonic structure characterised by two systems of folds, with axes trending NE-SW and E-W. The latter is the younger one. Folds, ranging from closed to isoclinal ones, with axes trending E-W, are also found at the limestone of Tourkovounia hills, belonging in *"Athens schist"* unit of Athens basin, which tectonically overlay both the non-metamorphic unit at Aegaleo Mt. and the metamorphic unit at Ymittos Mt. The tectonic contact between the metamorphic and non-metamorphic units must have a direction of NE-SW and its location must coincide with the riverbed of Kifissos R.

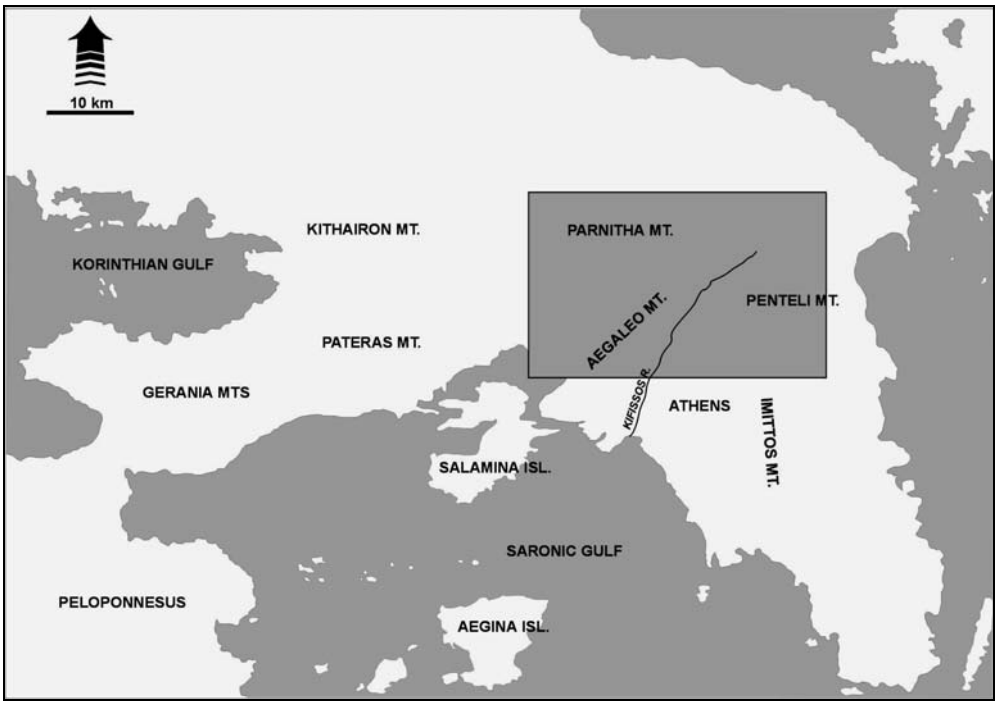

Fig.1: *The study area*

Post-alpine tectonic structure

A part of the Athens Basin constitutes a complex neotectonic graben trending NE-SW, that has been formed between Parnis and Aegaleo Mt. to the west, and Pendeli and Ymittos Mt. to the east, filled with lacustrine and fluvial deposits, since Late Miocene. The oldest post-alpine deposits are lacustrine marls and clays with lignite occurrences of Late Miocene age. The lignite deposits were under exploitation at Peristeri and Neo Irakleio areas. The marls have a considerable thickness that, according to B. v. FREYBERG (1951), exceeds 300 m. (**Fig. 2,3**). That is an indication of an average deposition rate of 0.06 mm/year. The deposition of fine material during Late Miocene indicates a low energy of relief, which means that the marginal faults of the basin of the era must have been inactive.

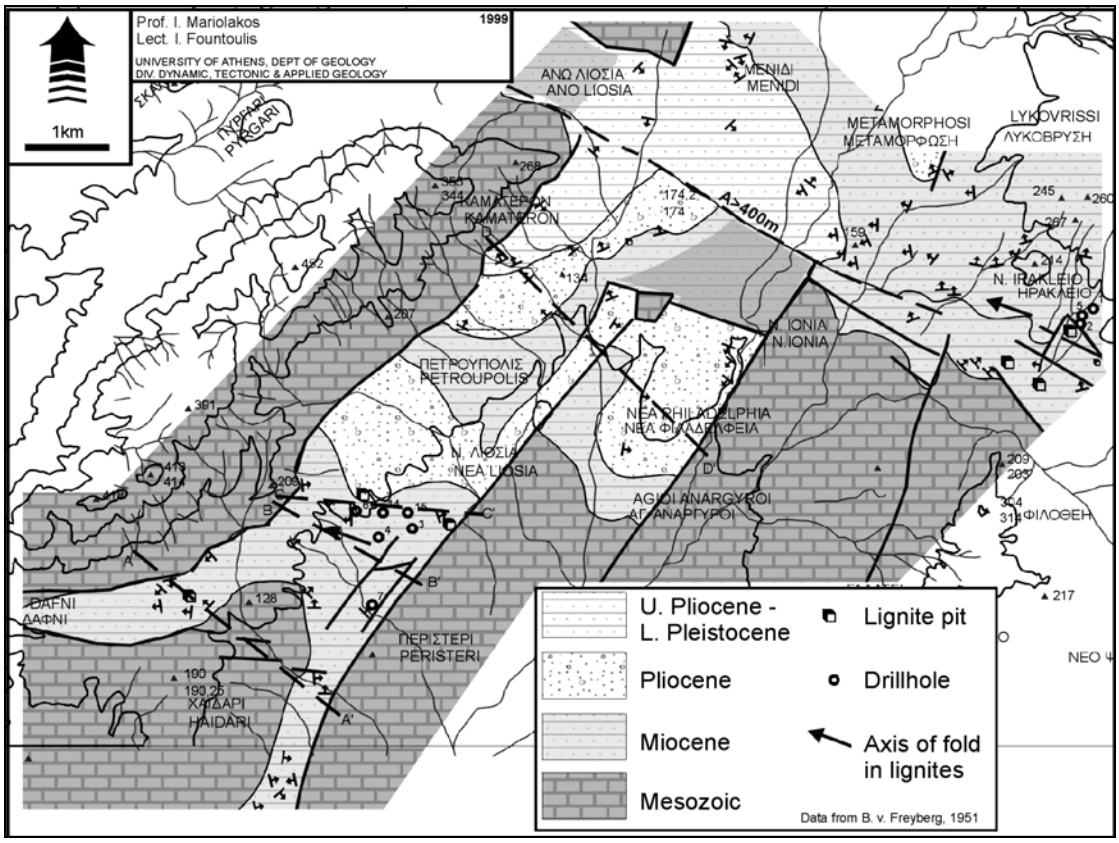

Fig.2: *Geological map of the post-alpine basins in the earthquake affected areas (from B.v. Freyberg, 1951, modified).*

During Pliocene, the deposited material is coarser compared with that of Late Miocene. At the base there are sands and sandstones, developing to conglomerates, while the sedimentary cycle closes once more with the deposition of fine-grained material, i.e. white limestones and clays, which very likely pass over to Pleistocene (B.v. FREYBERG, 1951). It is notable that the origin of the pebbles forming the conglomerates is exclusively from metamorphic rocks. The conglomerates are not found at the SW part of the basin, i.e. in Dafni and Peristeri areas, while to the NE the thickness of the conglomerates, and the Pleistocene deposits in general, is increasing. For example, the thickness of the Pleistocene deposits at Menidi area is over 400 m. (**Fig. 2, 3**). Quaternary, terrestrial deposits overlay the Neogene sediments, mainly

coarse grained, formed by fluvial deposits and debris cones. The origin of the clastic material is exclusively of non-metamorphic rocks from Parnis Mt. and forms a very characteristic alluvial fan at Thrakomakedones area.

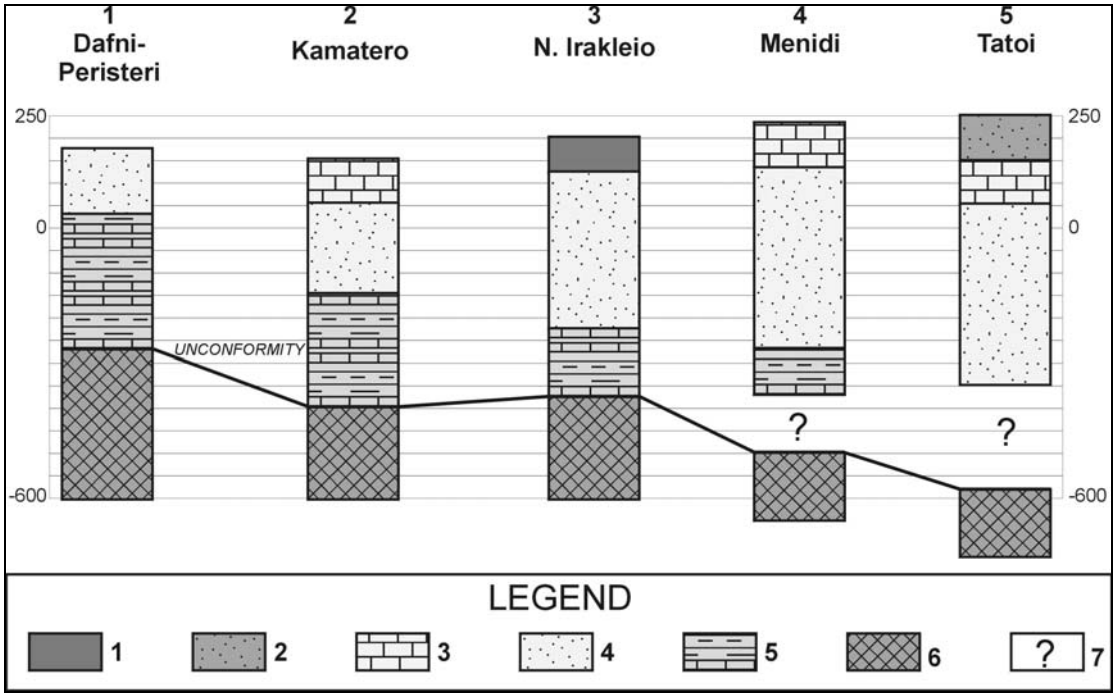

Fig. 3: *Stratigraphic columns of the post-alpine sediments of the basin in the earthquake affected area (Data from B.v. Freyberg, 1951, updated and modified): 1. red clay, 2.breccia, 3. marly limestone, 4. sandstone and conglomerate, 5. marl, marly limestone with lignite intecalations, 6. alpine basement, 7. unknown.*

Summarising the above mentioned for the post-alpine sediments of the western part of Athens basin, the following comments can be made, concerning their deposition period:

- Today, one can observe the remains of the deposits of a great lake during Late Miocene times, since lacustrine deposits of a similar age are found north of Parnis Mt. (Malakasa and Avlona areas etc.) as well as to the south (Megara basin). So, it is very likely that below the quaternary deposits of the Thriassio plain, there are lacustrine deposits of the same age. This indicates that the wider area of Parnis was surrounded by one(?) great lake or lakes, and it must have been far from the sea, since no trace of sea influence is observed, while there are some evidence indicating that the lake water level of that age did not present significant elevation difference from the sea level of that time.

- The low tectonic activity of the Late Miocene followed a phase of intense tectonic activity of the Pliocene, which seems to affect only the eastern part of the basin since the pebbles exclusively originate from rocks of the metamorphic units. So, during Pliocene, Parnis Mt. must have had the lowest relief energy compared to Pendeli and Ymittos Mts, and it did not supply the basin with erosional material, since no pebbles of the formations of Parnis have been found in the Pliocene conglomerates.

NEOTECTONIC STUCTURE AND DEFORMATION

The broader Attica area represents a complex post-alpine morphotectonic stucture, formed by the following great fault-blocks of 1st order: the tectonic horsts of Parntitha, Aegaleo, Ymittos and Pendeli mountains and the tectonic grabens of Thriassion plain and that of the W.Athens basin (**Fig.4**). Within these major structures of 1st order smalller horsts and grabens are distinguished (2nd, 3rd order etc.). The geometry of these structures is very complex. Their main directions are E-W and NE-SW.

The major fault zones of the misoseismal area are the following (**Fig. 4**).

i) Kifissos fault zone
ii) W. Aegaleo – Parnis fault zone
iii) Thriassion – Kamatero fault zone

The two first fault zones strike NE-SW and the third strikes WNW-ESE (**Fig. 4**). The two last fault zones are typical scisor fault zones. More specifically, the Thriassion – Kamatero fault zone consists of two segments named Thriassion and Kamatero. In the Thriassion segment, the footwall is the northern block and the hangingwall is the the southern block, whereas in the Kamatero segment the footwall is the southern block and the hangingwall is the northern one. The same happens in the W. Aegaleo – Parnis fault zone, which also consists of two segments the W. Aegaleo and the Parnis segment. In the W. Aegaleo segment the footwall is the eastern block and the hangingwall is the the western one, whereas in the Parnis segment the western block coresponds to the footwall and the eastern block coresponds to the hangingwall.

Taking into account (i) all the above elements, (ii) the detailed geological mapping of the Neogene formations carried out by B. v. FREYBERG (1951) and (iii) the morphotectonic study, the following conclusions can be drawn, regarding the movements of the different fault-blocks, as well as their internal deformation.

- The earthquake affected area constitutes a “block mosaic” defined mainly by faults of NE-SW and WSW-ENE directions.

- Striations on fault surfaces have been observed in several cases, both on the marginal faults of Athens basin and on Neogene formations, showing an important horizontal component.

- The lignitic horisons found whithin the Late Miocene deposits are folded, both at the eastern margin-N. Irakleio area- (B. v. FREYBERG, 1951), and the western margin -Peristeri area- (O. De PIAN, 1950) with axes trending again WNW-ESE. Folds are also found in the Neogene deposits with a low angle axial plane with a NE dip, that indicates a local compressional stress field with σ_1 directed from NE to SW.

- Most of the blocks are rotated around axes trending E-W, while Parnis Mt., with its blocks, rotates around a NE-SW axis to the west. Using morphotectonic evidence, Parnis Mt. appears to dip at its NW extremities relative to its SE part, where it appears to have the maximum uplift. That is the reason that Parnis Mt.

presents the highest altitudes in this area, with the consequence of high erosion, high relief energy and slope gradient.

- The throws of the faults defining the margins of the fault-blocks, are different, e.g. between the blocks of Petroupoli and Menidi the throw since Pliocene is greater than 400 m., while the throw between Menidi and Fyli blocks is greater than 600 m., since Pliocene. (**Fig. 4**).

- The Ano Liosia-Menidi area belongs in a graben that, as a whole, presents greater subsidence the last 5 m.a., within an area that rotates around an horizontal axis, trending NE-SW and dipping to NE, gradually decreasing the surface of the lake to the NW, remains of which exist even today, since, periodically, a small lake forms in the same area (see area which is known today as "Limni" –lake- at Ano Liosia).

- The actual alpine basement of many blocks (neotectonic horsts and grabens) is below the present sea level, which indicates a continous subsidence, in spite the fact that the whole area is uplifting.

- The highest altidute of the lacustrine occurences (500 m. aprox.) is located at Thrakomakedones area, i.e. at the margins of Parnis Mt., where the highest mountain altidutes occur (more than 1100m.). In this area the dip of the lacustrine beds is 35^{o} to the NE. This means that the uplift of Parnis must have occurred after the deposition of the Pliocene lacustrine sediments,during Pleistocene times. The result of this movement is the formation of a large talus, with material supplied exclusivelly from Parnis Mt.. Within the Fyli basin the same lacustrine deposits have uplifted up to an altitude of 350m.

- The area of the 1st order tectonic graben, apart from the rotation of each block, shows an overall continuous rotation throughout the whole period between Pleistocene-today (?).

- Parnis Mt. is uplifting, forming one of the active margins of the great Parnis-Kithaironas complex morphotectonic multi-block, and specifically its southeasten extremity. The north-western margin, located close to Korinthian Gulf, is uplifting in the same way, forming the Kitheron Mt.horst.

- The above analysed complex kinematic evolution is the result of complex dynamics and therefore, a more complex stress field, difficult to interpret by the existence of a simple tensional regime, which is unable to explain the continual uplift of Parnis Mountain.

CONCLUSIONS

After the recent earthquake events, it has been generally realized that the wider Attica area is not only a tectonically active area, but it is also seismically active. This fact is also evident when the stratigraphic and morphotectonic features of the area are being examined, as shown above. Although the area had not been historically recorded as seismically active, all the collected data prove high rates of vertical movements since the Pliocene.

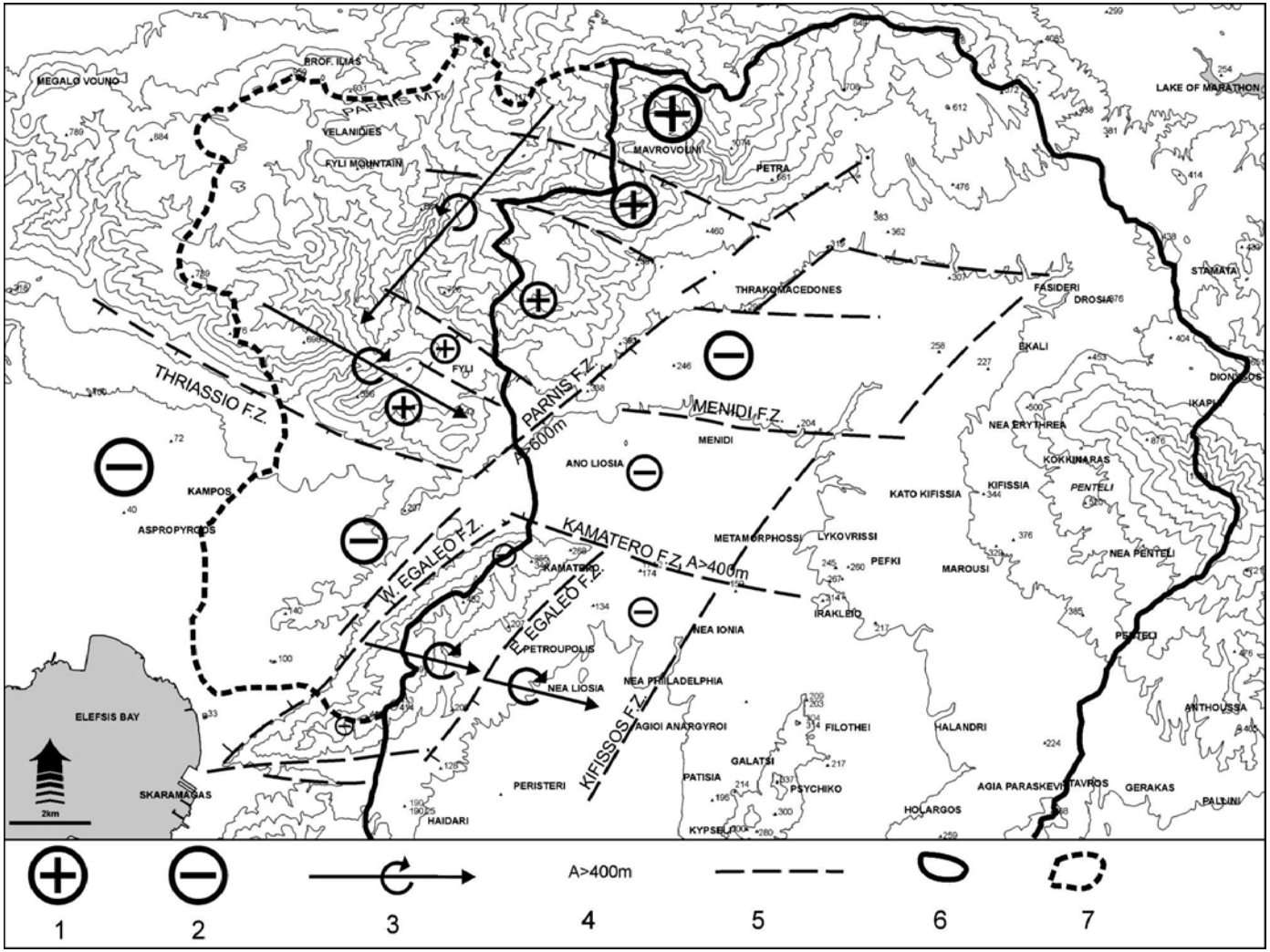

Fig.4: *Sketch map depicting the major fault zones of the earthquake affected area: 1: uplift, 2. subsidence, 3. rotational axis, 4. estimated vertical throw, 5. fault zone, 6. watershed of Kifissos R. basin, 7. watershed of Giannoulas R. basin. The relative size of the markers for uplift or subsidense indicates respective rate.*

The distinguished tectonic blocks of all orders are characterized by differential rotational movements. Thus, the marginal faults that bound the tectonic blocks present varying throws along their length, and in some cases scisor-type faults are well evident.

It is thus concluded that Parnis Mt., during the present period, is uplifting, forming an active margin of the great Parnis-Kithaironas morphotectonic multi-block, characterised by a complex kinematic and dynamic evolution, which is impossible to interpret within a pure extentional regime. Consequently, the regional stress field has to be more complicated so that the geometry and kinematics of the area, as described above, are interpreted sufficiently. The further thorough examination of all geological, tectonic, morphotectonic and seismotectonic data in combination with geodetic and remote sensing derived data, will give a picture of the present regional stress field.

REFERENCES

DOUNAS, A., KALLERGIS, G., MORFIS, A., PAGOUNIS M. (1980): Hydrogeological study of the semi-salt karstic springs of Agioi Apostoloi (Kalamos). *IGME Publ.* No **35**, 55 p.

FREYBERG, B. V. (1951): Das Neogen-Gebiet nordwestlich Athen. *Ann. Geol. Pays Hellen***. III**, 65-86, Athens.

FREYBERG, B. V. (1973): *Geologie des Isthmus von Korinth*. Erlanger Geol. Abh., **95**, 183 s., Erlangen.

KATSIKATSOS, G. (1977): La structure tectonique d' Attique et l' ile d' Eubee. *Proc. Vth Coll. On the Aegean Region,* Athens, (IGME Publ.), v. **1**, 211-228.

KATSIKATSOS, G., METTOS, A., VIDAKIS, M. & DOUNAS, A. (1986): Geological Map of Greece in scale 1:50.000, "Athina-Elefsis" sheet, *I.G.M.E. Publ., Athens.*

KOBER, L. (1929): Beitrage zur Geologie von Attika. *Sitzungsb. Akad. Wiss. Mat-Nat. Kl.,* **138**, 299-327, Wien.

KOBER, L. (1929): Neue geologische Forschungen in Attika. *Forsch. U. Fortschr.,* **5**, 271-272.

LEPSIUS, R. (1893): Geologie von Attica. *Zeitschr. F. prakt. Geol.,* **4**, 196 S., Karte 1/25.000, Berlin.

MARINOS, G., KATSIKATSOS, G., GEORGIADOU-DIKAIOULIA, E., MIRKOU, M.R. (1971): The system of Athinian schists: Stratigraphy and tectonics. *Ann. Geol. Pays Hellen***. XXIII**, 183-216, Athens

MARIOLAKOS, I. (1971): Tectonic analysis of the joints occurring at N. Hymettos Mt. *Ann. Geol. Pays Hell.,* **23**, pp. 323-379, Athens.

MARIOLAKOS, I. (1972): Observations on the folds of the metamorphic system of Pendelikon and Hymmetos (Attica), *Ann. Geol. d. Pays Hell.,* **24**, 276-302, Athens.

MARIOLAKOS, I. & STIROS, S. (1986): Surface faulting and the present-day tectonic evolution of the Korinthos Isthmus. *IGME, Geol. & Geoph. S., tom. out of ser*., 243-248, Athens.

MARIOLAKOS, I. & STIROS, S. (1987): Quaternary deformation of the Isthmus and gulf of Corinthos (Greece*), Geology*, **15**, 225-228.

MARIOLAKOS, I., LOGOS, E., LOZIOS, S. & FOUNTOULIS, J. (1989): Neotectonic deformation of the Zimbeli fault surface (east of Kalamata, south Peloponnisos), *Bull. Geol. Soc. Greece,* **XXIII/3**, 241-258, Athens.

O. DE PIAN (1950): Peristeri, *IGME Unpublished Report, 12 p., Athens*

PAPANIKOLAOU, D., MARIOLAKOS, I., LEKKAS, E. & LOZIOS, S. (1988): Morphotectonic observations of the Asopos basin and the coastal zone of Oropos. Contribution to the neotectonics of Northern Attica. *Bull. Geol. Soc. Greece,* **XX/1**, 251-267, Athens (in greek).

PETRASCHECK, W.E. & MARINOS, G., (1953): Zur Geologie von Attika. *Kober Festschr.,* 52-59, Wien.