Δελτίο της Ελληνικής Γεωλογικής Εταιρίας, 2010
Πρακτικά 12ου Διεθνούς Συνεδρίου
Πάτρα, Μάιος 2010

Bulletin of the Geological Society of Greece, 2010
Proceedings of the 12th International Congress
Patras, May, 2010

ENGINEERING GEOLOGICAL MAPPING IN THE URBAN AND SUBURBAN REGION OF NAFPLION CITY (ARGOLIS, GREECE)

Em. Apostolidis and An. Koutsouveli

Institute of Geology & Mineral Exploration, Department of Engineering Geology, Olympic Village, Entrance C, 136 77 Acharnae, Greece, emmapost@ath.forthnet.gr

Abstract

In our days the strategy of an integrated planning approach in dealing with urban development matters, is a reality and engineering geology plays a primary role. In the present study an approach of the engineering geological conditions of Nafplion city and the wider area are given.

In the region of interest, four (4) sampling boreholes were drilled by IGME, up to the depth of 40m. During the boring procedure in situ SPT and permeability tests were carried out, as well as the lithology of obtained material has been described. Samples, undisturbed and disturbed, have also collected for further laboratory tests. After the completion of each borehole, piezometric tubes were installed, for the monitoring of the underground water table. Laboratory tests for the determination of physical and mechanical characteristics of all drilled formations were executed.

The geotechnical distinction and unification of the geological formations was made on a 1:5,000 topographical map, in accordance with the up to date international practice. The engineering geological map in the urban and suburban region of Nafplion city is presented and the geotechnical characteristics of the formations structuring the area are evaluated. The combination of the results of the drilling programme as well as on the engineering geological approach and the geological structure of the studied area, resulted the compilation of the engineering geological map (scale 1:5,000) of Nafplion city wide area, where 18 engineering geological types are distinguished. The boreholes data of other public bodies have been also taken into account for this compilation. As the task of this project was the contribution to the urban development of Nafplion city, this engineering geological map will be a useful tool for engineers, planners, civil authorities, etc.

Key words: *engineering geological mapping, urban development, Nafplion, Argolis, Greece.*

1. Introduction

The region of study is extended north the city of Nafplion up to Tiryntha, southern up to the Stefaniotiko hill and eastern up to Exoni region. The morphology of studied area is characterized by the mountainous landscape that prevails in southern and the soft flat landscape that dominates to the north, with the exception of certain small hills. The drainage pattern in the mountainous part has a short length, as well as in the flat part small streams and torrents are seasonal developed. In the coastal region, according bibliographic references, the aquifer is found about the sea level, while in the plain is found in depth 1-4 meters. This happens because of the in-

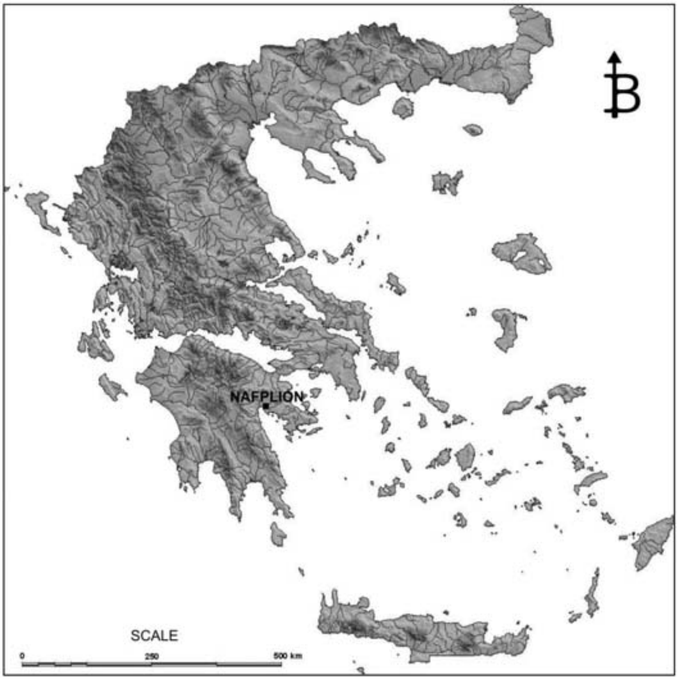

Fig. 1: Location of the wider Nafplion area, Argolis, Greece.

tensive exploitation of the wells and boreholes of the area, resulting to the subsidence of the aquifer and the salinity of waters.

2. Seismicity and seismic hazard

The wider area of Nafplion is characterized by low seismic hazard, as far as it has not been affected by very big earthquakes, but is influenced by neighbouring centres of seismic activity. Relating to the seismic action planning, according to the last modification of Greek Antiseismic Regulation (EPPO, 2001), the wider area is classified in the category I of seismic hazard, with seismic acceleration of territory A=a.g, where a=0,16 and g the acceleration of gravity (=981 cm/sec^2).

3. Geological structure

According to the IGME Geological map of Greece in scale 1:50.000 (sheet NAFPLION, by Tataris et al.) the dominated geological formations in the wide studied area from the older to younger are:

- Limestones of Middle Triassic age: They occur southern of Palamidi and eastern of Nafplion city. It concerns a carbonate rock group in which the lower members consist usually of reddish, hard limestones with cherts and thin intercalations of marls, they are followed by white-yellow slabby limestones with thin intercalations and cherts and thick-bedded ones with coarse clastic material.
- Limestones of Lower Cretaceous age: They are well bedded to massive, usually gray, and

in places with intercalations of marls. They occur at Palamidi, Akronafplia, Exostis and Profitis Elias regions.

- Limestones of Upper Cretaceous age: They occur in small outcrops at Akronafplia region and consist of thin bedded to thin slabbed limestones of white-pink colour, in places with intercalations and nodules of cherts.
- Idivided flysch of Maestrichtian age: It dominates in eastern and southeastern of Nafplion city and consists of calcite shales, sandy marls, sandstones and conglomerates with intercalations of clastic limestones. In the lower layers and towards the transition sediments to the underlying limestones serpentines are presents.
- Quaternary deposits: They occur mainly in the plain area, which is extended north of Nafplion city. They consist of thin-grains to gross-grains loose materials of coastal and terrestrial origin. On the mountainsides and hillsides of the area, old and recent screes and talus cones are developped

The tectonic activity in the studied area is quite complicated with faults, folds and upthrusts jn large scale.The folds and the large scale upthrusts appear to the preneogene formations, while the faults usually normals are responsible for the morphology of the recent landscape and the creation of seashores, such as the trench of Argive plain. The main faulting directions are E-W, NW-SE, and NE-SW.

4. Engineering geological mapping and structure of the wider Nafplion area

Engineering geology developed in response to the increasing demands of various technical works, which required a better understanding of the interaction between the ground, foundations and constructions, in order to build more economically and on a safer base.

In the Hellenic territory, engineering geological maps have been progressively developed and as far as practical have incorporated information from various technical works. Even a few years ago, there was lack of regional maps giving basic engineering geological information, such as for planning land use and technical works, the selection of the most appropriate types and methods of construction and the better protection of the environment. To this end, the engineering geological map of Greece, at a scale of 1:500,000 (IGME, 1993), constituted one of the first important efforts. In addition, the 1:10,000 engineering geological map of the wider Thessaloniki area is considered to be a basic infrastructure tool for more detailed investigations, as well as a useful aid for responsible civil authorities and technical personnel, during the preliminary stage of various technical works (Hadzinakos et. al, 1990; Rozos et. al, 1990; Rozos et. al, 2004).

The engineering geological distinction and unification of the geological formations was made on a 1:5,000 topographical map, in accordance with the up to date international practice. Necessary adjustments for the peculiarities of the Greek territory (Koukis, 1980; Koukis, 1988) and especially of the area under study were also taken into account. According to the international views and recommendations (Anon, 1972; Anon, 1979; Anon, 1981; Bell, 1981; Carter, 1983; Dearman and Matoula, 1976; Matoula et. al, 1986; UNESCO/IAEG, 1976), the above map is characterised as a multi purpose, synoptic and large scale engineering geological map, and is shown with a simplified legend in Figure 3. In the above map (Figure 2) the surface development of all lithological types is given, while their geotechnical description is presented below.

The data used in the description of the lithological types were obtained from many boreholes executed by a number of investigators from both the public and private sectors. Also, in the region of interest, four (4) sampling boreholes were drilled by IGME, up to the depth of 40m. During the boring procedure in situ SPT and permeability tests were carried out, as well as the lithology of obtained material has been described. Samples, undisturbed and disturbed, have also collected for further laboratory tests. After the completion of each borehole, piezometric tubes were installed, for the monitoring of the underground water table. Laboratory tests for the determination of physical and mechanical characteristics of all drilled formations were executed (Apostolidis and Koutsouveli, 2007).

The engineering geological map of the wider Nafplion area, at a scale of 1:5,000, contributes significantly to the optimization of land use and better planning of technical works. However, such maps cannot be considered a substitute for in situ geotechnical investigations at the microscale for every individual construction. This map distinguishes eighteen (18) engineering geological types, ET (Figures 2 and 3). Many geotechnical boreholes as well as in situ observations and sampling were used in the preparation of this map. Special emphasis was given to those units, which are present in inhabited/industrial areas. The brief descriptions of the engineering rocks and soils follow those prepared for Engineering Geological Mapping. The engineering geological type (ET) has the highest degree of physical homogenerty. It should be uniform in lithological character and physical state. These units can be characterized by statistically determined values derived from individual determinations of physical and mechanical properties and are generally shown only on large-scale maps (UNESCO/IAEG, 1976).

A little lower are given in details the descriptions of eighteen (18) engineering geological types (ET) that were divided in the region of interest, from the younger to the older one (Apostolidis and Koutsouveli, 2008):

- Type Ia: Loose materials of embankments of historical and younger age, small thickness (less than 1 m). These materials consist of structural stones, tiles, coats and other constructive materials mixed with soil deposits, which mainly have a silty-sandy composition, with some grits and gravels.

- Type Ib: Loose materials of embankments and recent deposits of sandy clays, sands and gravels in places. The thickness of this formation usually varies between 1- 4 m.

The formations of type Ia and Ib appear in a great section to the down town of Nafplion. Their geomechanical behaviour is unsatisfactory imposing the improvement of the soil to the safety of the various constructions.

- Type IIa and IIb: Deposits in river-beds. They are incohesive materials of small thickness, from cobbles of various size and origin, sands and locally silty-clays. They have divided in two types, type IIa (mainly coarse-grained materials) and type IIb (mainly fine-grained materials and sand). In general, their geomechanical behaviour is controlled by the characteristics and percentage of the fine material.

- Type III: Clays, silts and locally sandy-silts, soft, mainly grey or grizzled colour. At places, it contains organics, shells and plant remains. They are characterized, usually, by high plasticity, while locally, under certain conditions, are expected phenomena of subsidences and liquefactions.

Physical and mechanical properties (usual range of values):

$w_L = 22.0 - 67.0\ \%$ $\qquad c = 6 - 122$ KPa

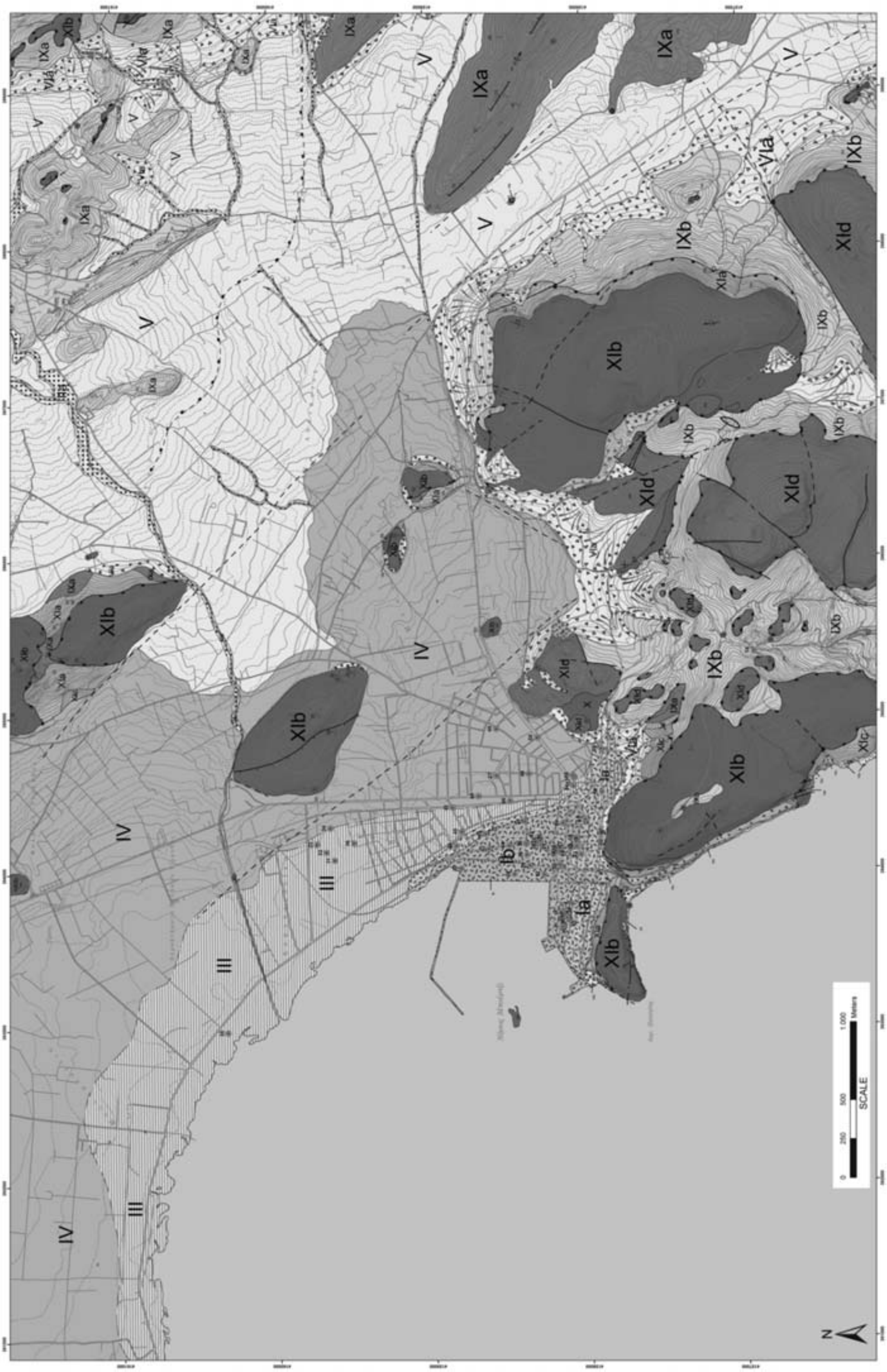

Fig. 2: Engineering geological map of the wider urban and suburban region of Nafplion city, Argolis, Greece.

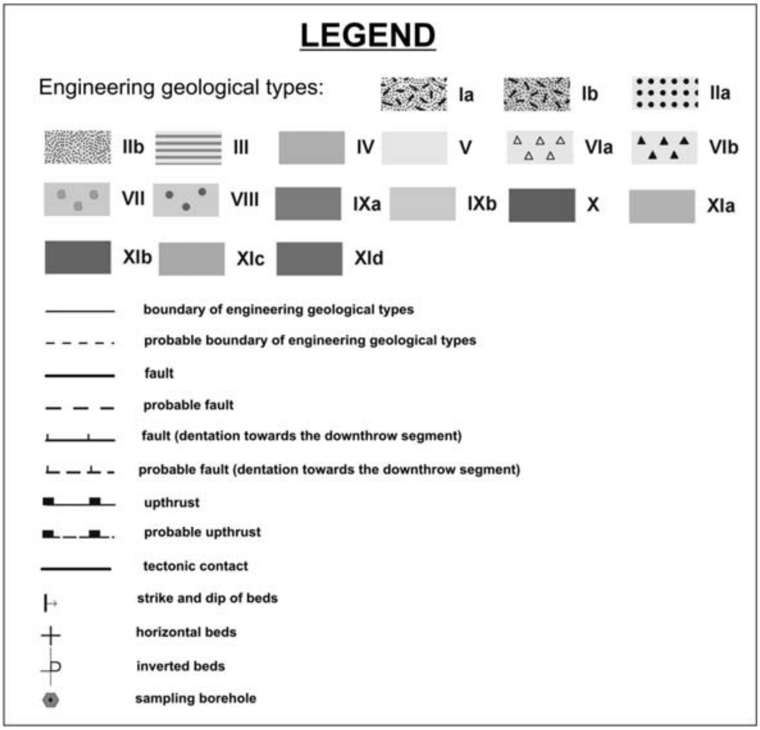

Fig. 3: Legend of engineering geological map (Figure 2).

I_P = 11.0 - 43.0 % $\quad$ q_u = 10 - 201 KPa

w = 17.8 - 65.3 % $\quad$ c_c = 0.041 - 0.46

γ_b = 16.7 - 20.3 kN/m^3 $\quad$ e_o = 0.728 - 1.348

e = 0.62 - 0.74

- Type IV: Clays and silts, brown or red-brown or yellow-brown colour, with small variations in the percentage of sand and small gravels at places. They are characterized by middle to high plasticity and middle to big coherence.

Physical and mechanical properties (usual range of values):

w_L = 20.0 - 65.0 % $\quad$ c = 8 - 155 KPa

I_P = 10.5 - 50.0 % $\quad$ q_u = 26 - 598 KPa

w = 13.0 - 41.4 % $\quad$ c_c = 0.08 - 0.33

γ_b = 18.1 - 21.6 kN/m^3 $\quad$ e_o = 0.499 - 1.045

e = 0.50 - 0.94

- Type V: Loose deposits of mixed phases, brown or red-brown colour. They are composed of silty-clays, sandy-clays, sands, grids, gravels and cobbles of various size and

Photo 1: The formation of engineering-geological type VII, with the characteristic fossils Strombus bubonius.

origin. They are characterized by frequent and rapid changes in their lithological composition and grain size distribution towards their horizontal and vertical development. Their behaviour is controlled by their thickness, their lithological anisotropy and the inclination of the ground (especially in the case of dynamic loading). The strong heterogenelty of these formations results in high anisotropy of their mechanical behaviour, but they usually show satisfactory shear strength parameters, especially in areas with gentle morphology. In general, their geomechanical behaviour is usually controlled by the characteristics and percentage of the fine material.

- Type VIa: Screes and talus cones. Pebbles, cobbles and small fragments of limestones, with sandy-clay materials, constitute them. Usually, they present poor coherence, with decreased geomechanical characteristics.
- Type VIb: Cohessive (usually) to semi-cohessive screes and breccias. They are composed of coarse-grained elements of different origin (mainly from limestones) and various sizes with reddish colour cement (usually red calc-clays). At places, olistholiths of various dimensions are presented. In its entirety, this formation behaves as weak-rock, with decreased geomechanical characteristics.
- Type VII: Coherssive conglomerates in banks, with red clayey cement. At places, the formation has the look of pebbly and encloses the characteristic fossils Strombus bubonius (Photograph 1). In its entirety, this formation behaves as powerful weak-rock, with satisfactory geomechanical behaviour.
- Type VIII: Cohessive conglomerates-microconglomerates, from cobbles of various origin and size and red calc-clay cement, in layers 10-15cm. In its entirety, this formation behaves as weak-rock, with satisfactory geomechanical behaviour.
- Type IXa: Flysch consisted of sandstones, quartzitic sandstones, sandy-marls, siltstones

and conglomerates with intercalations of limestones. They are usually thin-bedded, but often with sandstone layers, 0,50-1,00m thick. The layers present strong traces of horizontal tectonic deformation (folds, wrinkles, inversions, fractures and fragmentations). In macroscale, flysch is considered as an impermeable formation, allowing the occurence of small springs (usually between the fragmentation zone and/or weathering mantle and bedrock). Surface beds usually show a medium to strong weathering and a dense net of discontinuities (bedding planes and joints) causing intense secondary looseness. Flysch, usually, gives a weathering mantle of varying thickness. This formation characterized by an obvious instability, which is usually connected with the numerous heterogeneous layer contacts and the steep bed inclinations, in conjuction with the strong relief and the action of water. Therefore, problems connected with foundation of technical works are very often, usually shown as shear strength problems of the formation. In general, geotechnical behaviour presents a clear anisotropy and rapid changes, controlled by the degree of looseness (weathering-fragmentation), the orientation of discontinuties, the dip of slopes and the action of water. The landslide phenomena usually affecting weathering mantle and upper fragmentation zone.

- Type IXb: Flysch consisted of calcareous schists, sandstones, quartzitic sandstones, conglomerates, reddish marls, sandy-marls, siltstones, with intercalations of limestones in thin layers. At places, usually near upthrusts, flysch is semi-metamorphic with olistholiths of various dimensions (limestones, dolomites, ophiolites, etc). This formation is intensely fractured and multifolded and gives a weathering mantle of varying thickness. They present downgrading geomechanical characteristics and strength parameters, but unfavourable factors such as the intense-multiple fracturing and weathering of the cement, in conjunction with steep slopes and possible base erosion often cause loosening of the rockmass.
- Type X: Formation intensely fractured and multifolded, which is constituted from serpentines, ophiolites, serpentinized peridotites, siltstones, sandstones, conglomerates, limestones, cherts, etc. It is presented as one completely fractionally rockmass with decreased geomechanical characteristics, which at places, due to erosion, is changed in remaining soil.

Physical and mechanical properties (usual range) of values for soil materials of alterated mantle of serpentines:

$w_L = 30{,}3$ %	$c = 67$ KPa
$I_P = 14{,}6$ %	$q_u = 35$ KPa
$w = 20{,}5$ %	$c_c = 0{,}145$
$\gamma_b = 20{,}0$ kN/m^3	$e_o = 0{,}612$

Physical and mechanical properties (usual range) of values for soil materials of decomposed serpentine:

$w_L = 29{,}3 - 46{,}2$ %	$c = 219$ KPa
$I_P = 9{,}4 - 31{,}1$ %	$q_u = 321 - 477$ KPa
$w = 12{,}2 - 15{,}2$ %	$c_c = 0{,}040$
$\gamma_b = 21{,}4 - 24{,}5$ kN/m^3	$e_o = 0{,}266$

- Type XIa: Limestones, white or pinkish or reddish in colour, thin-bedded to thin-slabbed, hard, with nodules or lenticular silica layers at places. The intact rock is characterized by high values of strength parameters, while the rockmass shows medium to high permeability and good geomechanical behaviour for the foundation of technical works.
- Type XIb: Limestones, white-gray or grayish in colour, medium - thick-bedded or unbedded, usually fractured and strongly karstified in the upper beds. In certain cases and in a local scale, limestone rockmass breaks in fragments. Failures are usually observed as rockfalls on steep slopes, where an increased secondary loosening of the rockmass occurs or in cases where disturbances of the natural stability state and dynamic loading have taken place. In its entirety, this formation is characterized by good geomechanical behaviour.
- Type Xic: Cherts, in intercalations with thin-bedded limestones, conglomerates or breccias and few ophiolites in places. Reddish formation, with satisfactory geomechanical behaviour.
- Type Xid: Limestones and dolomites, white-gray or grayish in colour, medium to thick-bedded, compact, fractured and faulted. Underground water is restricted in the fractured zone of limestones, while dolomites are considered practically impermeable or semi-permeable. At places, usually on steep slopes, failures are observed as rockfalls. In its entirety, this formation is characterized by good geomechanical behaviour.

5. Conclusions

From the above analysis, regarding the compilation of the engineering geological map of Nafplion wider area at a scale of 1:5,000, the following remarks can be made:

- For the preparation of the above-mentioned map, which is thought to be a very useful tool for the better land use and planning, both an extended fieldwork and the evaluation of many geotechnical boreholes were used.
- Thus, eighteen (18) engineering geological types (ET) have been distinguished. Special attention was given to those units which structure inhabited zones as well as industrial areas, to avoid problems to the future development of the wider area.
- For every type, the ranges of the values of some main physical and mechanical properties examined, as well as a general description of their geomechanical behaviour, are given.
- As the task of this project was the contribution to the urban development of Nafplion city, this engineering geological map will be a useful tool for engineers, planners, civil authorities, etc.

6. References

Anon., 1972. The preparation of maps and plans in terms of Engineering Geology. Q. Jl. Eng. Geol., Vol. 5, pp 293-381.

Anon., 1979. Report of the Commission of Eng. Geological mapping of the IAEG, Part I.: Rock and Soil materials. Classification of rocks and soils for engineering geological mapping. Bulletin of IAEG, No19, Krefeld, pp 364-371.

Anon., 1981. Rock and Soil description for engineering geological mapping. Report of the Commission of Engineering Geological Mapping. Bulletin of IAEG, No24, Krefeld.

Apostolidis, E. and Koutsouveli An., 2007. Geotechnical study of the wider urban and suburban region of Nafplion city, Argolis. Unpublished study of IGME (T-2587), Athens.

Apostolidis, E. and Koutsouveli An., 2008. Engineering geological map of the wider urban and suburban region of Nafplion city, Argolis. Unpublished study of IGME (T-2588), Athens.

Bell, F.G., 1981. Engineering properties of soils and rocks. Butterworth Co., Ltd., London, 149 pp.

Carter, M.,1983. Geotechnical Engineering Handbook, London, 226pp.

Dearman,W. R. and Matula, M., 1976. Environmental aspects of Engineering Geological Mapping. Bulletin of I.A.E.G., Vol.14, pp 141-146.

E.P.P.O., 2001. Greek Antiseismic Rules 2000 (in Greek), Athens, Greece, pp 257.

Hadzinakos I., Rozos D. and Apostolidis E., 1990: Engineering geological mapping and related geotechnical problems in the wider industrial area of Thessaloniki, Greece. Proceedings of 6th International IAEG Congress, Balkema, Rotterdam, pp. 127-134.

IGME, 1993. Engineering geological map of Greece, scale of 1:500,000, Athens.

Koukis, G., 1980. Geological - Geotechnical maps and their use in technical works. Mining and Metallurgical Annals, Vol. 44, Athens, pp 29-40.

Koukis, G., 1988. Slope deformation phenomena related to the engineering geological conditions in Greece. Proceedings of the 5th International symposium on Landslides, Vol. 2, Laussanne, Balkema Publ, Rotterdam, pp 1187-1192.

Matoula, M., Hrasna, H., Vleko, J., 1986. Regional Engineering geological maps for land use planning documents. Proceedings of 5th International I.A.E.G. Congress, Buenos Aires, Balkema, Rotterdam, pp 1821-1827.

Rozos D., Xatzinakos I and Apostolidis E, 1990. Engineering geological mapping and related geotechnical problems in the wider industrial area of Thessaloniki, Greece. Proc. of the 6th International Congress of Engineering Geology (IAEG), Vol.1, Amsterdam, pp 127-134.

Rozos D., Apostolides E. and Xatzinakos I.†, 2004. Engineering-geological map of the wider Thessaloniki area, Greece. Bulletin of Engineering Geology and the Environment, Volume 63, Number 2, June 2004, pp. 103-108.

Tataris A., Kallergis G.Kounis G., 1970. Geological map of Greece at a scale of 1:50,000, Nafplion sheet, IGME, Athens.

UNESCO/IAEG, 1976. Engineering geological maps. A guide to their preparation. The Unesco Press, Paris, 79p.

Notation

The following symbols were used in this paper:

w_L: liquid limit

c: cohesion (from direct shear test or triaxial shear test – Unconsolidated Undrained)

I_P : plastic index

q_u: uniaxial compressive strength

W : moisture content

c_c: compression index (from consolidation test)

γ_b: bulk density

e_o: initial void ratio (from consolidation test)

e: void ratio

Δελτίο της Ελληνικής Γεωλογικής Εταιρίας, 2010
Πρακτικά 12ου Διεθνούς Συνεδρίου
Πάτρα, Μάιος 2010

Bulletin of the Geological Society of Greece, 2010
Proceedings of the 12th International Congress
Patras, May, 2010

NEOTECTONIC STUDY OF URBAN AND SUBURBAN NAFPLIO AREA (ARGOLIDA-GREECE)

Georgiou Ch., Galanakis D.

Institute of Geology & Mineral Exploration (IGME), 1 Sp. Loui, Acharnae 136.77 Athens, Greece, chgeorgiou@igme.gr & galanakis@igme.gr

Abstract

The wider studied area does not present strong seismic activity, and is characterized however by the existence of active and potentially active faults that were estimated by the fieldwork and the air photographs and satellite images. These faults are located mainly in the boundaries of basins. Some faults are potentially active and have been activated in the Pliocene-Pleistocene under a NE-SW stress field, while some other faults have been activated in the Quaternary under NW-SE stress field, as show the results from the neotectonic analysis. According to the usual seismic magnitudes that were observed in the broader area, they are roughly about 6 Richter maximum vertical displacement expected in the 65 cm and as calculated by the theoretical magnitude. This observed maximum displacement is near the active or seismic fault and is decreasing or increasing depending on the distance from the fault trace.

Particular attention needs in the cases, where the Nauplio urban area, is found in the passage of solid geological formations of the Alpine basement to the unconsolidated Neogene or Quaternary formations.

In this case, a different distribution of seismic waves is observed between the solid rocks and the unconsolidated Neogene or Quaternary formations. In this region the magnitude of vertical displacement is maximum because the strengthened considerably and the dynamic condensation of not cohesive materials.

An also important element is the determination of width zone of both sides of the fault, where surface changes are observed (faults, subsidences etc) during the earthquake activity. The width of this area depends on the geological and tectonic structure.

Key words: *neotectonic fault, slip-vector, fault scarp, Argolikos gulf, Peloponnesus.*

1. Geological setting

The Hellenides consist of NW-SE-trending parallel tectonic belts or "isopic zones" (Aubouin 1959). The Pelagonian zone forms the boundary between the internal and external Hellenides. This zone where includes also the Argolis Peninsula, is represented by Palaeozoic metamorphic basement, with cover of Permo-Triassic clastic sediments bearing rift volcanics, with Triassic-Jurassic metamorphosed and non-metamorphosed platform carbonates (Fotiadis, 2008, Gaitanakis P. & Photiades, 1992, Photiades & Skourtsis – Coroneou, 1994a). This zone upwards is overthrust by ophiolites and melanges (Aubouin et al. 1970, Jacobshagen 1986), and is transgressed by Late Jurassic to Late

Cretaceous carbonate cover sequences and flysch.

The main orogenetic phase of Greek territory was expressed in the late Messozoic- Eocene (Jacobshagen 1986, Bortolotti et al 2003), when was realized the microplate conflict with movement to the noth. The final orogenetic phase was completed in Oligocene and followed by geodynamic movements under an extension stress field in neogene as a result of the creation of many neotectonic basins.

Three main Alpine tectonic phases have affected the Argolida region and present the following characteristics

1st Compression phase: The upper Tithonian characterized by overfolding axies to have a N-S direction and internal overthrusts of the same direction.

2nd Extension phase: The NE-SW direction had affected as mentioned before the N-S tectonic structures. It caused interruption in the sedimentation from NW and led to the deposition of autochthonous limestones of Albian age, which were followed by flysch formation of Ypresian age.

3rd Compression phase: The Eocene age flysch is of an important geodynamic regime (is connected also with the blueschist phase of Cyclades). This compressional phase that reactivated old NE-SW tectonic structures and caused shear zones and the compressional movement to NW.

Two newer extensional phases that followed, from Miocene-Pliocene until upper Quaternary, affected the older geological structures and formed the Argolida peninsula.

Argolikos Gulf is one of the east Peloponnesus neotectonic grabens, that extended south of Nafplio region (fig 1) with a maximum depth of 700 m and is also linked with the Aegean sea. The western coast of Argolikos gulf delimited by a mountainous chain, that is interrupted locally from alluvial fans and in these sites the maximum sea depths are decreased abruptly.

In north Argolikos Gulf a wide submarine horst 8-10 km length characterizes the creation a wedge of sediments of plio-pleistocene age, due to the river depositions and these horst is delimited by the presence of neotectonic faults, (Van Andel et al 1993).

2. Neotectonic regime of Argolikos gulf

The more important neotectonic structure of Argolikos gulf is the system of faults of western margin with NNW-SSE direction and subsidence in the Eastern part (fig. 1). The Eastern margin towards the Nafplio area is affectted by smaller faults and a system of joints which are connected with the margins.

In central Argolida territory in the Karnezaiika region is affected by a shear faults system with sinistral component (Fig. 1). In southern Argolida, the neotectonic fault system affect, the Alpine basement of the region.

The action of this fault system has influenced the Pleistocene sediments of the total region, which subsidies in the Argolikos gulf area in 300-400 m isobaths with a dip of 3° to the south-west.

Along of western side of Argolikos gulf, during Holocene the rate of is of 50cm/kyr (Finke 1988) while to the southern is of 100cm/kyr and tends to zero in the Eastern side near Nauplio city. In the Spetses area the subsidence is approximately 150 cm. /kyr (Flemming & Webb 1986).

According to these data, the Argolikos gulf constitutes a neotectonic structure with half-graben char-

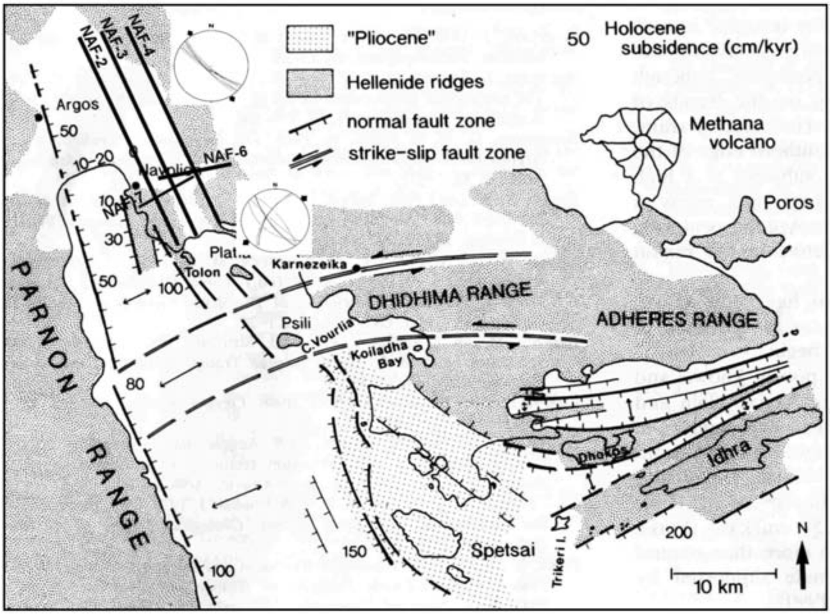

Fig. 1: Neotectonic map of the wider studied area and the rate of subsidence in various places of Argolikos gulf (Van Andel et al 1993) This map is modified with new tectonic data from the Nauplio region which are connected with submarine data.

acteristics. Even though the Argolida region shows very low seismic activity, characteristics features of active tectonics regime are observed.

The Karnezaiika region and the broader are affected by transtentional system faults in a roughly E-W direction which gives an explicit morphology of the active faults, thus creating the narrow and steep Karnezaiika valley. The surfaces of the faults present various generations of tectonic slickensides due to the different reactivations.

According to the seismological and bibliographic data, (Drakopoulos & Makropoulos 1982, Ambraseys, N.N. 1988 and Greek Antiseismic Regulation G.A.R. 2003) as well as from the evaluation of seismotectonic data of Greek territory, the studied area is classified in the (I) category zone of seismic hazard. with seismic territory acceleration A = a x g, where a = 0,16 typical feature of category I.

2.1 Study of Faults

During the fieldwork, seven neotectonic faults were recognized, mapped and measured close to the Nafplio city.

The faults that described below, are normal and are activated under an extensional stress field, that prevailed during the creation of Argolikos gulf, or in a later stage at the duration of Quaternary-Holocene and they are characterized as active or potential active faults.

The stress field analysis of faults and the analysis of tendencies, gave the places and the position of axes σ1, σ2, σ3. The latter (σ3), determines the direction of extension stress field in different geological time.

NAF-1: The NAF-1 fault in the geological map (fig. 2) of the present study, is a normal fault and

LEGEND

Post Alpine Deposits:
Holocene: 1. Swamp deposits, 2. Alluvial deposits, 3. Fluvial terrestrial deposits, 4. Talus scree and cones, Pleistocene : 5. Cohesive talus scree,

Alpine Deposits (Pelagonian Zone):
6. Limestone with charts (Upper Cretaceous), 7. Limestone (Lower-Upper Cretaceous), 8. Tectonic mélange (Jurassic), 9. Tectonic nape of flyschoide mélange (Upper Cretaceous-Eocene), 10. Flysch, 11. Limestone with cherts (Upper Cretaceous-Paleocene), 12. Conglomerate and Breccias carbonate serie(Cretaceous) 13. Limestone and Dolomite (Triassic – Lower Jurassic)

Fig. 2: Geological map of Nafplio area present normal faults

has a NNW-SSE direction and dip 75° - 80° W. The main surface fracture of this fault is located in the submarine region in the west of Nafplio.

This fault has influenced also the early Tyrrhenian sediments, which are found up to 10 meters above the current sea level. Inside these sediments, exist characteristic marine fauna with Strombus Bobonius (Zötl et al 1999) which characterize the Tyrrhenian age (fig. 3). This uplift movement appears clear along the Arvanitia coast south of Nauplio city (fig. 4).

The tectonic and stratigraphic data mean that the fault NAF-1 is an active fault with length that exceeds the 15 kilometres. The expected movement uplift, in the case of a future seismic activity of this fault, can exceed the 40 cm (Bonilla et al 1984, Wells & Coppersmith 1994, Ambraseys & Jackson 1998).

NAF-2: The NAF-2 fault in the geological map (fig.2) is normal and has also a NNW-SSE direction and dips 80° to the west.

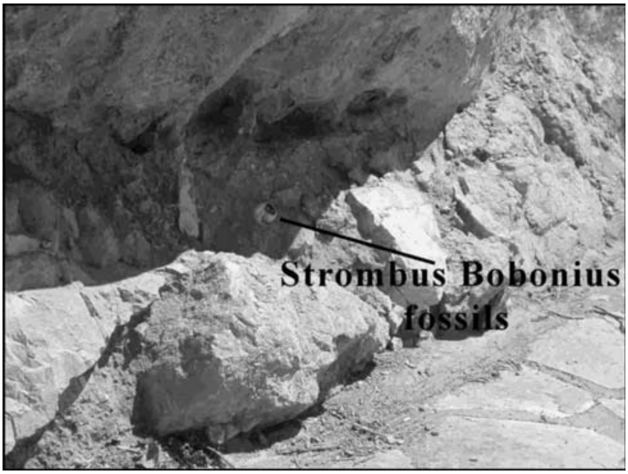

Fig. 3: Marine and terrestrial sediments with characteristic Tyrrhenian fossils with Strombus Bobonius characteristic Tyrrhenian age.

Fig. 4: Characteristic form of uplifting movement of Arvanitia coast (1,5m) from the sea level (a) and 4 m. from the fossil site of the previous picture (b).

This fault has affected the Alpine basement and the Quaternary depositions (Fig. 5). Based on the neotectonic study of the wider area it can be said that the fault NAF-2 is an active fault with length that exceeds the 4,5 kilometres. The expected uplift in an event of seismic activity of this fault, can exceed the 15 cm. (Wells & Coppersmith 1994, Ambraseys & Jackson 1998, Pavlides et al 2000).

The fault planes that are located in the Triassic-Jourassic marbles of the region have oxide depositions and tectonic slickensides. The analysis of measurements show that this system of faults is activated under extension stress field with NW-SE direction that is the same with the present extension stress field, (fig. 6).

Fig. 5: Active fault plane NAF-2 in the marbles with oxides depositions and tectonic slickensides.

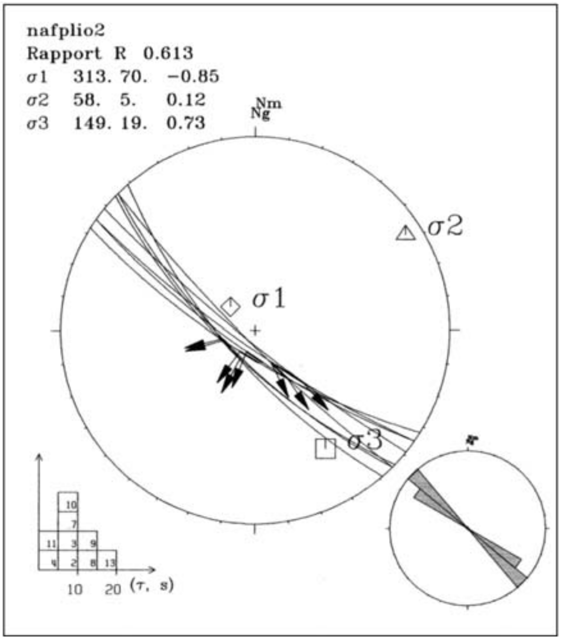

Fig. 6: Tectonic analysis of measurements on the Alpine basement in the region, where the fault plane of NAF-2 are located. In the rosediagram network Schmidt (southern hemisphere) the faults planes, the slickensides, as well as the positions and directions of axes σ1, σ2, σ3 are shown.

NAF-3: The NAF-3 fault in the geological map is normal and it has also a NNW-SSE direction and dips to the East.

This fault has affected the Neogene and Quaternary deposits of the region, as shown by the morphotectonic, satellite and cartographic data because it deforms small streams and form small graben and horst. The tectonic study of the wider region shows that fault NAF-3, is an active with length that exceeds the 21 kilometres. The expected surface displacement in a future seismic activity of this fault can exceed the 48 cm (Wells & Coppersmith 1994, Ambraseys & Jackson 1998, Pavlides et al 2000).

Fig. 7: Fault NAF-7 of ENE-WNW direction affects the marbles and Quaternary sediments, East of Nafplio area.

NAF-4: The NAF-4 fault (fig. 2), is normal and has also a NNW-SSE direction and dips to the West.

This fault affected the Neogene and Quaternary deposits of the region based on morfotectonic, satellite and cartographic data. The tectonic study of the wider region shows, that fault NAF-4 is potentially active, with a length that exceeds the 21 kilometres. The expected displacement in an event of seismic activity of this fault, can exceed 48 cm.

NAF-5: This fault (fig. 2) has also the same NNW-SSE direction and dips to the East. This fault affected the Neogene and Quaternary deposits of the region us shown by morfotectonic data. The neotectonic study of the broader area shows that the NAF-5 fault is potentially active with a length that exceeds the 15 km. The expected displacement during seismic activity can exceed the 41 cm.

NAF-6: This normal fault has an E-W direction and dips to the Noth. This fault affected the Alpine basement and the Neogene sediments of the region. The tectonic study of the wider region reveals that the NAF-6 fault is potentially active with a length that exceeds the 5,6 kilometres. The expected shift in an event of seismic excitation of this fault, can exceed the 16 cm (Wells & Coppersmith 1994, Ambraseys & Jackson 1998).

NAF-7: The normal NAF-7 fault (Fig. 2) has an ENE-WNW direction and dips to the North. The main fault plane is located East of Nafplio city (fig. 7). This fault has influenced the Alpine basement and the neogene sediments. Based on the tectonic study of the wider study area, it can be said that fault NAF-7 is potentially active with a length that exceeds the 2,6 kilometres. The expected shift, in case of seismic activity, can exceed the 10 cm.

The fault affected the Triassic-Jourassic marbles of the region and on the fault plane iron oxides depositions, with slickensides, are observed. The analysis of measurements (fig. 8) shows that this system of faults of this specific direction, is activated under extension stress field with a NE-SW direction which is identified also in the older stress field as shown by the position of axis σ3.

3. CONCLUSIONS

The broader studied area does not present intense seismic activity, however is characterized by the

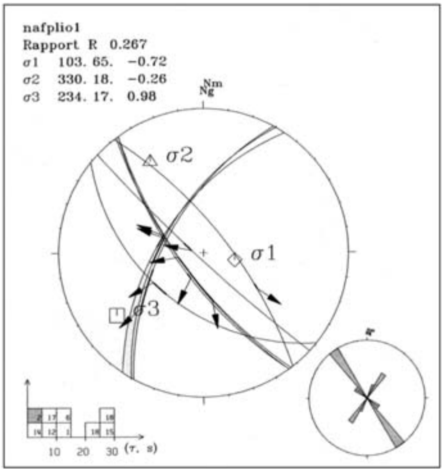

Fig. 8: Stereonet Schmidt, showing slickenside, slip vectors, as measured in the field, with the three principal σ1, σ2, σ3 stress axes and the NE-SW direction of extension stress field (σ3). Data from the area West of Nafplio (NAF-2 fault).

presence of active or potentially active faults where mapped during the fieldwork. These faults are connected with boundaries various basins. The faults show that, the older NAF-4, NAF-5, NAF-6, NAF-7 (table I), are potentially active and have activated during Pliocene-Pleistocene and characterized by extension stress field of NE-SW direction. The newer ones, NAF1, NAF2, NAF3 (table I) have been activated at Quaternary and are controlled by the new extension stress field of NW-SE direction.

Because the usual maximum seismic magnitudes that are observed in the wider region, are around 6 Richter, it is calculated, that the theoretical magnitude of maximum vertical surface displacement, is in the order of 65cm. This maximum displacement is observed near the surface of the active or seismic fault and decreases as the distance from the fault is increasing.

Particular attention must be shown in cases where the urban area of Nauplio extends over the compact Alpine geological formations to the unconsolidated Neogene and Quaternary ones.

In this case, different behaviour of seismic waves that crosses the compact rocks and the unconsolidated geological sediments is observed. In those sites we observe the maximum vertical displacement, due to the dynamic condensation of no cohesive materials caused by seismic vibrations.

An also important element is the determination of the width of the area at both sides of the fault trace, in which surface changes (ruptures, subsidences, liquidations etc) are expected during a future seismic activity. The width of this area depends mainly on the geological and tectonic structure and on the degree of seismic risk of the region, which is crossed by the fault.

For the calculation of the maximum displacement during seismic activity, the existing empiric relations can be used correlating the magnitude of earthquake (Ms) and length of fault (L) and the surface displacement (D). The most recent results that concern Greek territory and Eastern Mediterranean give more reliable magnitudes (Wells & Coppersmith 1994, Ambraseys & Jackson 1998).

With regard to these characteristics, the surface fault plane, the length of the fault and the earthquake magnitude, the maximum seismic surface displacement in the Nafplio area can reach the 48 cm.

Table 1.

FAULT	LENGTH (Km)	EXPECTED SURFACE SHIFT (cm) (Wells D. & Coppersmith 1994)	TYPE OF FAULT
NAF 1	21	48	Normal - Active
NAF 2	4,6	15	Normal - Active
NAF 3	21	48	Normal - Active
NAF 4	21	48	Normal - Potentially Active
NAF 5	15	41	Normal - Potentially Active
NAF 6	5,6	16	Normal - Potentially Active
NAF 7	2,6	10	Normal - Potentially Active

Contrary, the usual seismic magnitudes that were observed in the broader area, are roughly 6 Richter, and the theoretical sizes of maximum vertical displacement is calculated to be around 65 cm.

4. References

Ambraseys, N.N., Jackson, J.A., (1990). Seismicity and associated strain of central Greece between 1890 and 1988. *Geophysical Journal International* 101, 663-708.

Ambraseys, N.N. (1988): Data for investigation of the long-term seismicity of Central Greece. "Proc. European School on the Seismic Hazard Assessment, Athens, 9-16 May 1988"1-7.

Bonilla, M.G., Mark, R.K., & Lienkaemper (1984): Statistical relations among earthquake magnitude, surface rupture length, and surface fault displacement. Bull. Seism. Soc. Am., vol. 74m., No 6, p. 2379-2411.

Bortolotti, V., Carras, N, Chiari, M., Fazzuoli, M., Marcucci, M., Photiades, A. & Principi, G. (2003). The Argolis Peninsula in the palaeogeographic and geodynamic frame of the Hellenides. Ofioliti, 28/2, 79-94.

Drakopoulos, J., & Makropoulos, C., (1982): Seismology, seismotectonics, seismic hazard and earthquake prediction. National report of Greece. Working Group. A Final report, Unesco, A-65, A-98.

Finke E. A. (1988): Landscape evolution and the Argive Plain Greece: Paleoecology, Holocene Depositional History and Coastline Changes. PhD thesis. Stanfotd University. Univ. Microfilms Ann. Arbor, Michigan.

Flemming N.C. & Webb, C. O., (1986): Tectonic and eostatic coastal changes during the last 10.000 years derived from archaeological data Zeitchrift fur Geomorphologie. Newe Folge. Supplement Bahd, 62, 1-29

Fotiadis Ad., (2008): Geological study of the urban and the wider Nafplio area, Argolida Prefecture. *Institute of Geology and Mineral Exploration, Athens*.

Gaitanakis P. & Photiades A.D. (1992): New data on the geology of Southern Argolis (Peloponnesus, Greece). 6th Congress of the Geol. Soc. Greece, Athens, May 1992, Greece, Abstract vol. p. 42-43.

Jacobshagen, V. (1986): Geologie von Griecheenland, 363 s., Berlin, Stuttgart (Gebruder Borntraeger).

Οργανισμός Αντισεισμικού Σχεδιασμού και Προστασίας (ΟΑΣΠ, 2000 & 2004): Ελληνικός Αντισεισμικός Κανονισμός (ΕΑΚ), Αθήνα.

Pavlides, S., Caputo, R., Chatzipetros, A., (2000). Empirical relationships among earthquake magnitude, surface ruptures and maximum displacement in the broader Aegean Region. *Proceedings of the Third*

International Conference on the Geology of the Eastern Mediterranean.

Photiades A.D. (1998). Tectonic evolution of Northern Argolis Peninsula (Greece). The "Third International Conference on the Geology of the Eastern Mediterranean", Nicosia, Cyprus, Sept. 23-26, 1998. Abstracts vol., p.53.

Photiades A.D. & Skourtsis - Coroneou V. (1994a). Stratigraphic and paleogeographic evolution of the Northern Argolis (Greece) during the Cretaceous-Paleogene. 7th Congress of the Geol. Soc. Greece, Thessaloniki, May 1994, Greece. Abstracts vol., p. 65-66.

Tataris, A., Kalergis, A., Kounis, D., (1970): Geological map of Greece – Nafplio Sheet (Scale 1:50.000). *Institute of Geology and Mineral Exploration* I.G.M.E *, Athens*.

Van Andel t. H., Perissoratis C., Rondoyanni T., (1993): Quaternary tectonics of the Argolikos Gulf and adjacent basins, Greece. Journal of the Geological Society, London, Vol 150, pp. 529-539

Wells D. & Coppersmith, (1994): New empirical relationships among magnitude, rupture length, rupture area and surface displacement. Bull. Seism. Soc. Amer., vol. 84, No 4, pp.974-1002.

Zötl, J. G., Geyh, M. A., Riepler, F., Mettos, A., & Ch. Georgiou (1999): Klimaepochen, eustatische Meeresspiegelschwankungen und Strandterrassen im östlichen Mittelmeer (Griechenland). Beiträge zur Hydrogeologie/ 49/50, seiten 5-66, Graz .