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-

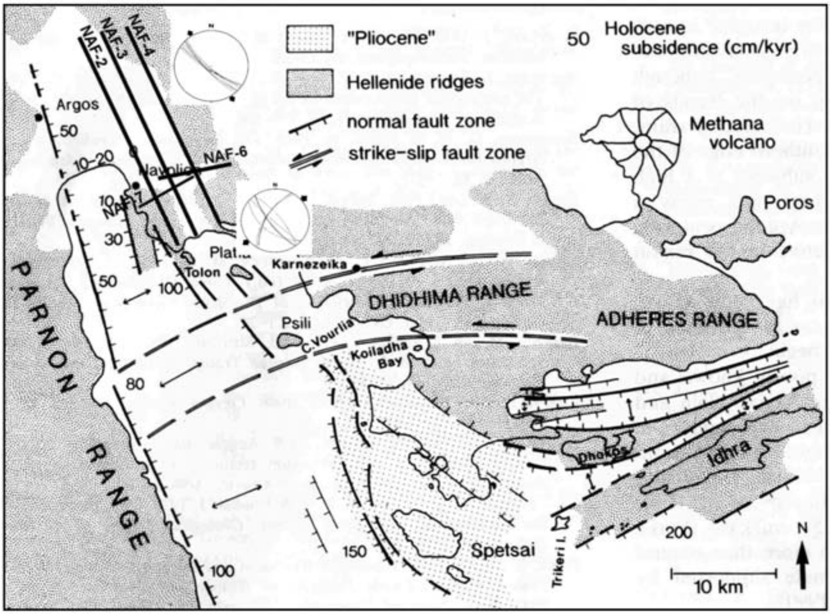

Fig. 1: Neotectonic map of the wider studied area and the rate of subsidence in various places of Argolikos gulf (Van Andel et al 1993) This map is modified with new tectonic data from the Nauplio region which are connected with submarine data.

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.

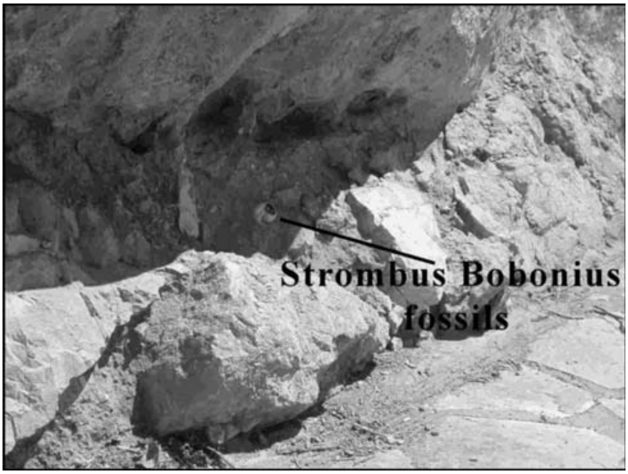

Fig. 3: Marine and terrestrial sediments with characteristic Tyrrhenian fossils with Strombus Bobonius characteristic Tyrrhenian age.

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.

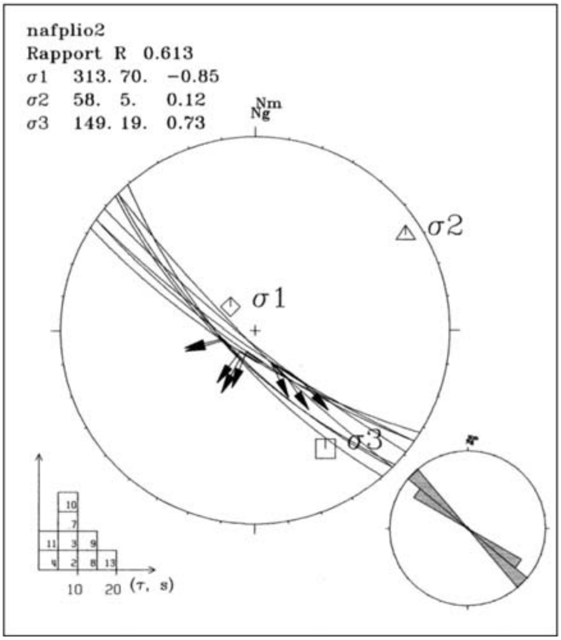

Fig. 6: Tectonic analysis of measurements on the Alpine basement in the region, where the fault plane of NAF-2 are located. In the rosediagram network Schmidt (southern hemisphere) the faults planes, the slickensides, as well as the positions and directions of axes σ1, σ2, σ3 are shown.

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

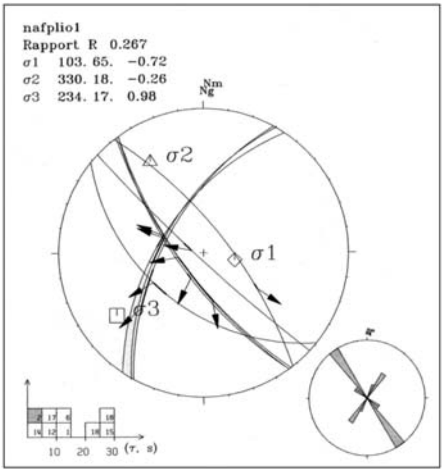

Fig. 8: Stereonet Schmidt, showing slickenside, slip vectors, as measured in the field, with the three principal σ1, σ2, σ3 stress axes and the NE-SW direction of extension stress field (σ3). Data from the area West of Nafplio (NAF-2 fault).

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 .