EARTHQUAKE ARCHAEOLOGY

INQUA PALEOSEISMOLOGY AND ACTIVE TECTONICS

NEOTECTONICS AND COMPARISON OF THE ENVIRONMENTAL SEISMIC INTENSITY SCALE (ESI 2007) AND THE TRADITIONAL SCALES FOR EARTHQUAKE INTENSITIES FOR THE KALAMATA (SW GREECE) EARTHQUAKE (MS=6.2R, 13-09-1986)

Fountoulis, Ioannis (1), Mavroulis, Spyridon (1)

(1) National and Kapodistrian University of Athens, Faculty of Geology and Geoenvironment, Department of Dynamic Tectonic and Applied Geology, Panepistimiopoli, Zografou 15784 Athens, GREECE. Email: fountoulis@geol.uoa.gr , smavroulis@yahoo.gr

Abstract: *The Kalamata (13-09-1986, Ms=6.0R, SW Peloponnese) earthquake can be classified as a medium to small scale event based on the tectonic structures that triggered the earthquake and the effects caused on human, structural and natural environment. The aim of this paper is to present the geotectonic and seismotectonic regime of the earthquake affected region based on field data along the seismic fault zone and an attempt is made towards the: (i) estimation of the intensity values according to the European Macroseismic Scale (EMS 1998) and the Environmental Seismic Intensity Scale (ESI 2007) and the determination of their geographical distribution in a macroscale, (ii) interpretation of the intensity values data and their distribution according to the seismotectonic, geodynamic and geotechnical regime, and (iii) conduction of a comparative evaluation review on the application of both EMS 1998 and ESI 2007. The application of both EMS 1998 and ESI 2007 and the comparative evaluation of the results indicate that the estimated values of EMS 1998 and ESI 2007 were almost in agreement, despite the fact that the geographical locations of assessment data were different suggesting that the application and use of both scales appears to represent a useful and reliable tool for seismic hazard estimation.*

Key words*: Kalamata, earthquake, neotectonics, environmental effects*

INTRODUCTION

Kalamata is located very close (< 70km) to the Hellenic (Ionian) Trench region in which the subduction zone of the African plate beneath the European (Aegean) one exists and thus is one of the most seismically active areas of Europe (Figure 1).
On 13 September 1986, a shallow depth (< 10km) earthquake struck the wider Kalamata area resulting in 20 casualties, extensive damages and many environmental effects. The epicenter of the main earthquake was located about 10km NNE of the city of Kalamata, and its magnitude was Ms=6.2 (Papazachos, et al., 1988). Two days later, a second shock of Ms=5.4R (Papazachos, et al., 1988) occurred closer to the Kalamata city at the same depth. The focal mechanism of the main shock shows an E-W extension (Lyon-Caen et al., 1987; Papazachos, et al., 1988).

Seismological studies of Papazachos et al. (1988), and Lyon-Caen et al. (1988) indicated that aftershocks defined two clusters and an about 450 west-dipping fault plane. The foci depths of the seismic sequence were ranging between 11 and 0.9km. Based on the variety of orientations and dips calculated for the sub-faults activated during the aftershock sequence, since the analysis of the northern cluster indicates the existence of two types of orientation, which are dipping in four different angles and the southern cluster is characterized by an almost uniform behaviour activated later in the sequence, Tselentis et al. (1989) concluded that the area is tectonically very complex which is in agreement with the neotectonic structure described by Mariolakos et al. (1989; 1992, 1993) and Mariolakos & Fountoulis (1998).

Stiros and Kontogianni (2008) applied two first-order leveling traverses crossing the wider Kalamata area and measured subsidence of about 7cm NE of the Kalamata city in epicentral area of the southern cluster. The Kalamata earthquake produced a maximum intensity VIII+ on the IMM or EMS 1992 scale (Elnashai et al., 1987; Gazetas et al., 1990), while Panou et al. (2004) based on building damages estimated the intensity up to IX - X for the city of Kalamata.

The aim of this paper is to present the geotectonic and seismotectonic regime of the earthquake affected region based on field data along the seismic fault zone and an attempt is made towards the: (i) estimation of the intensity values in terms of the European Macroseimic Scale (EMS 1998; Grünthal, 1998) and Environmental Seismic Intensity Scale (ESI 2007; Michetti et al., 2007) and the determination of their geographical distribution in a macroscale, (ii) interpretation of the intensity values data and their distribution according to the seismotectonic, geodynamic and geotechnical regime, and (iii) conduction of a comparative evaluation review on the application of both EMS 1998 and ESI 2007.

GEOLOGY - TECTONICS - NEOTECTONICS - FAULT ZONES - FAULTS

In the broader Kalamata area the following four alpine geotectonic units from the lower to the upper occur (Psonis, 1986; Mariolakos et al., 1993): (a) the Mani unit consisting mainly of marbles, (b) the Arna unit consisting of quartzites and phyllites, (c) the Tripolis unit which consists of neritic carbonates and flysch formation and (d) the Pindos unit consisting of thin-bedded pelagic carbonates and clastic formations. From the structural point of view, the four above-mentioned geotectonic units form a succession of three nappes. The Mani unit (slightly metamorphosed) is considered to be the relatively autochthonous one. The Arna unit overthrusts the Mani unit, the Tripolis unit (second nappe) overthrusts the Arna unit and the Pindos unit (third nappe) overthrusts the Tripolis unit (Figure 2). The Late Pliocene-Early Pleistocene marine deposits consist of marls, sandstone and conglomerates (Marcopoulou-Diacantoni et al. 1989; Mariolakos et al., 1993). The Middle-Late Pleistocene deposits consist mainly of red colored siliceous sands-sandstones and conglomerates. Alluvial deposits, clastic material and talus represent the Holocene.

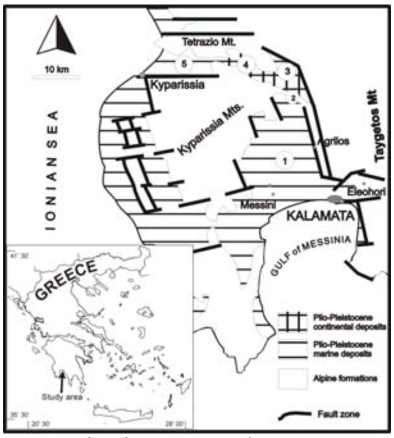

Fig. 1: The second order neotectonic macrostructures within the first order neotectonic macrostructure of the Kalamata-Kyparissia graben. The numbers correspond to the following second order neotectonic macrostructures: 1: Kato Messinia graben, 2: Meligalas horst, 3: Ano Messinia graben, 4: Dorion basin, 5: Kyparissia-Kalo Nero graben

The meizoseismal area is located at the eastern margin of the Kalamata - Kyparissia graben and constitutes the northward prolongation of the Gulf of Messinia (Figure 1). Large and composite fault zones define its margins and second order macrostructures are observed within as well as at the margins representing smaller grabens and horsts (Figure 1) (Mariolakos & Fountoulis, 1998). The E-W striking Dimiova - Perivolakia graben is bounded by the Kato Karveli - Venitsa fault zone to the north, by the Arahova to the east, by the Xerilas fault zone (XFZ) to the south and by the Nedon fault zone (NFZ) to the west (Figure 2). This macrostructure constitutes one of the most interesting minor order neotectonic macrostructures because of the occurrence of the Pindos unit. Mariolakos et al. (1989) interpreted the kinematic regime of this macrostructure suggesting that this graben rotates around an N-S axis located at the area of Arahova westwards. At the western part of the fault zone the total throw is more than 2.000m (Mariolakos et al., 1986; Mariolakos et al., 1989). The most of the environmental effects and damages caused during the seismic activity of September 1986 were observed within this graben. The marginal fault zones consist of many faults, which are not continuous and differ on strike even when they belong to the same fault zone, as they form conjugate fault systems.

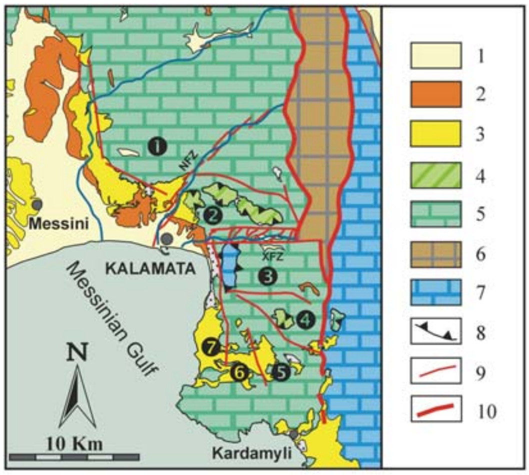

Fig. 2: Simplified geological map showing the four alpine geotectonic units overthrust one on top of the other, as well as the post-alpine sediments of the region of the Kalamata area. 1: Holocene deposits; 2: Continental deposits; 3: Early Pleistocene marine deposits; 4: Pindos unit; 5: Gavrovo-Tripolis unit; 6: Arna unit; 7: Mani unit; 8: Overthrust; 9: Fault; 10: Detachment fault. The numbers in the black circles correspond to the smaller order neotectonic macrostructures of the Kato Messinia sub-graben 1: Asprochoma-Koutalas horst, 2: Dimiova-Perivolakia graben, 3: Kalathion Mt. horst, 4: Altomyra semi-graben, 5: Kambos graben, 6: Vardia-Koka horst, 7: Kitries-Mantinia sub-graben, XFZ:Xerilas Fault zone, NFZ:Nedon Fault Zone.

SPATIAL DISTRIBUTION OF ENVIRONMENTAL EFFECTS

During the above-mentioned seismic activity, fault reactivation (seismic faults), new faulting and seismic fracturing were observed (the latter distinguished by no displacement) (Figure 3). The reactivated faults strike in different directions (N-S, E-W, NNE-SSW) and the throw of the faults due to the reactivation is generally small (max=20cm) and of normal character. The maximum throw has been observed at a seismic fault caused by the main aftershock Ms=5.6 R.

Numerous seismic ruptures trending N-S, NNE-SSW, NE-SW, E-W and NW-SE were mapped in the affected area, in most cases in en echelon arrangement (Mariolakos et al., 1989). These seismic fractures presented a vertical displacement of several mm up to 25-30cm and they often presented a horizontal component showing sinistral or dextral displacement.

The majority of rock falls were observed in several sections along the slopes of the Tzirorema, Karveli and Xerilas streams and the Nedon river valleys as well as in the wider area of Eleochori, Karveli and Ladas villages (Figure 3). They were observed in areas characterized by steep slopes (> 50 per cent) and they were related almost everywhere to small or large faults with some of them reactivated during the earthquake and others not.

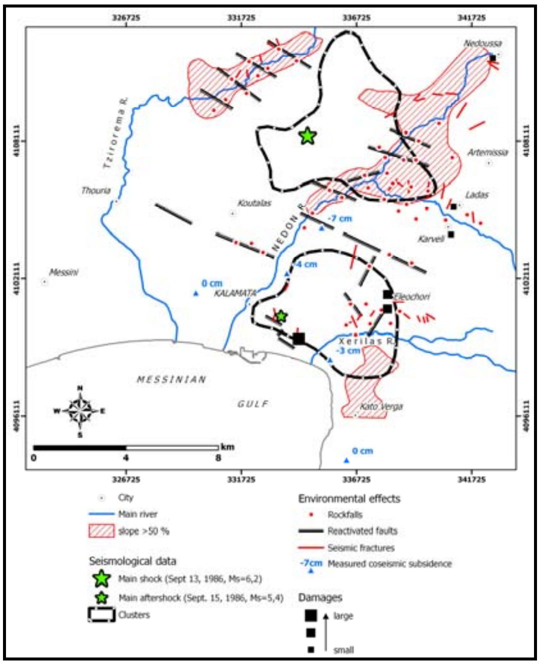

Fig. 3: The spatial distribution of the environmental effects observed during the Kalamata earthquake sequence (based on data from Mariolakos et al., 1992; Gazetas et al., 1990; Fountoulis, 2004; Stiros & Kontogianni, 2008).

SPATIAL DISTRIBUTION OF DAMAGES

The damages were limited to an area of triangular shape, which is defined to the south by the fault zone of the Xerilas River, to the east by the fault zone of Nedousa - Arahova and to the west by the fault zone of the Nedon River (Figure 3). No damages were recorded to the west of the Nedon fault zone and south of the Xerilas fault zone and especially in areas where the geological basement has the same seismo-geological behavior as those in the city of Kalamata and Eleohori village, which caused serious damage. Based on field observations, the damage is not determined only by the age, type, height and other characteristics of buildings. There were cases with two nearly identical constructions in the same area; one remained intact while the other was destroyed. In other cases the building destruction is linked to zones of seismic fracturing that were observed in the construction basement. Of course, this is not the rule. In many other cases the building destruction is linked to zones of seismic fracturing that were observed in the construction basement. Of course, this is not the rule.

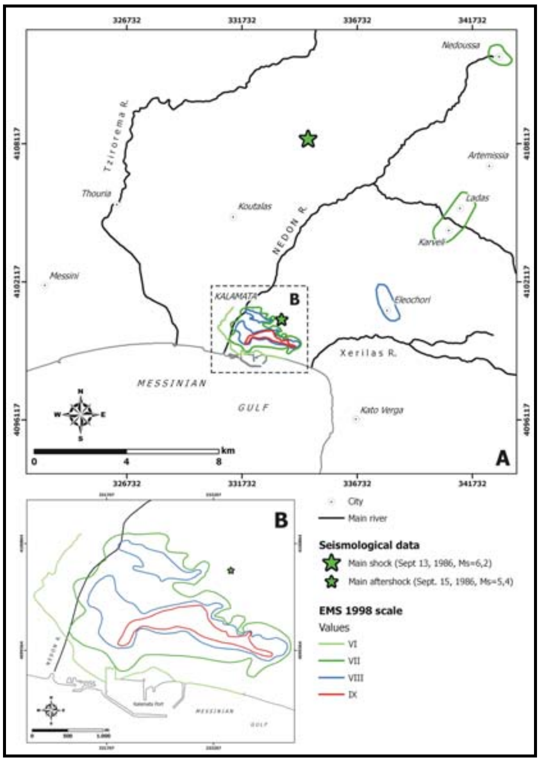

Fig. 4: (A) EMS 1998 intensity distribution of the Kalamata earthquake sequence (based on data from Gazetas et al., 1990; Panou et al., 2004). (B) EMS 1998 intensity distribution of the Kalamata earthquake sequence for Kalamata city (based on data from Panou et al., 2004).

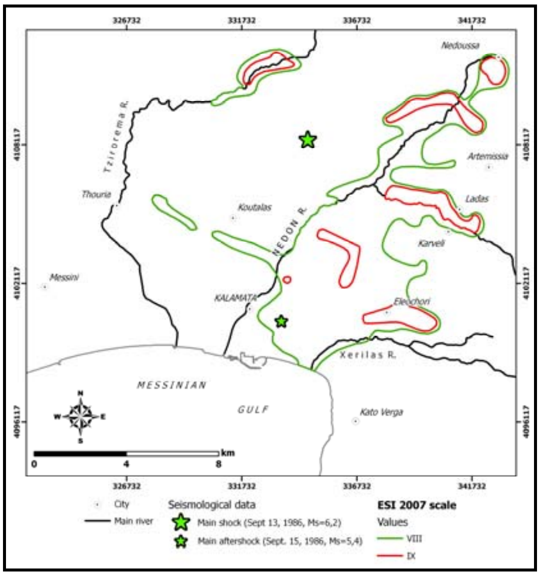

Figure 5: ESI 2007 Intensity distribution based on data of Figure 3.

CONCLUSIONS

Taking into account the aforementioned we can draw the following conclusions:

The damages were limited to the area that can be regarded as a transitional area between the tectonic basin Kalamata - Kyparissia and the tectonic horsts of Asprohoma - Koutala to the north and the Kalathio Mt. to the south. On the contrary, in Messini and in Verga, damages of that size were not observed because those areas belong to different neotectonic macrosturctures that were not reactivated during the earthquakes of 1986 (central region of the tectonic basin of Kato Messinia and tectonic horst of Kalathio Mt respectively).

Rock falls were observed mainly in the tectonic graben that was activated and also north of it, at Tzirorema. On the other hand, on the steep slopes of the Kalathio Mt. that belong to the homonymous neotectonic macrostructure, which was not reactivated, no rock falls were observed.

An important factor in the distribution of the damages and rock falls in the greater area was the reactivation of old faults or the creation of new soil ruptures. In this way, the fact that the destruction of buildings was observed in Giannitsanika (higher intensity in Figure 4) and not near the coast can be explained, although the foundation ground - red siliceous clastic formation - in the first case theoretically presents better geotechnical characteristics in comparison to the loose coastal deposits.

The ESI 2007 scale appears to fit better than the EMS scale in the neotectonic regime of the area as its boundaries coincide better with the boundaries of the activated graben and the observations we have done concerning the distribution of the environmental effects. The application of both EMS 1998 and ESI 2007 and the comparative evaluation of the results indicate that the estimated values of EMS 1998 and ESI 2007 were almost in agreement, despite the fact that the geographical locations of assessment data were different suggesting that the application and use of both scales appears to represent a useful and reliable tool for seismic hazard estimation.

References

Elnashai, A., Pilakoutas, K., Ambraseys, N. & Lefas, I. (1987). Lessons learnt from the Kalamata (Greece) earthquake of 13 September 1986. *European Earthquake Engineering*, 1, 11-19.

Fountoulis, I. 2004. The neotectonic macrostructures and the geological basement, the main factors controlling the spatial distribution of the damage and geodynamic phenomena resulting from the Kalamata (13 September 1986) and Athens (7 September 1999) earthquakes. *WIT Press: In Earthquake Geodynamics: Seismic Case Studies. Edited by: E. L. Lekkas, Series: Advances in Earthquake Engineering*, vol. 12, p. 45-63.

Gazetas, G., Dakoulas, P. & Papageorgiou, A. (1990). Local soil and source-mechanism effects in the 1986 kalamata (Greece) earthquake. *Earthquake Engineering and Structural Dynamics,* vol. 19, 431-456.

Grünthal, G. 1998. (ed.): European Macroseismic Scale 1998 (EMS-98). Cahiers du Centre Européen de Géodynamique et de Séismologie 15, Centre Européen de Géodynamique et de Séismologie, Luxembourg, 99 pp.

Lyon-Caen, H., Armijo, R., Drakopoulos, J., Baskoutas, J., Delibassis, N., Gaulon, R., Kouskouna, V., Latoussakis, J., Makropoulos, K., Papadimitriou, P., Papanastassiou, D. & Pedotti, G. (1988). The 1986 Kalamata (South Peloponnesus) earthquake: Detailed study of a normal fault, evidences for east-west extension in the Hellenic arc, *J. Geophys. Res.* 93, 14.967–15.000.

Marcopoulou-Diacantoni, A., Mirkou, M.R., Mariolakos, I., Logos, E., Lozios, S. & Fountoulis, I. (1989). Stratigraphic observations in the post alpine deposits in Thouria-Ano Amfia area (Messinia Province, Greece) and their neotectonic interpretation. *Bull. Geol Soc. Greece,* XXIII/3, pp. 275-295, (in Greek).

Mariolakos, I., Sabot, V., Alexopoulos, A., Danamos, G., Lekkas, E., Logos, E., Lozios, S., Mertzanis, A. & Fountoulis, I. (1986). Microzonic study of Kalamata (Geology, Tectonics, Neotectonics, Geomorphology). *Report of EPPO (Earth Planning Protection Organization),* (in Greek).

Mariolakos, I., Fountoulis, I., Logos, E. & Lozios, S. (1989). Surface faulting caused by the Kalamata (Greece) earthquakes (13.9.1986). *Tectonophysics*, 163, pp. 197-203.

Mariolakos, I., Fountoulis, I. & Nassopoulou, S. (1992). The influence of the neotectonic macrostructures, fractures and the geological basement in the distribution of the damages in the Kalamata earthquake (13-9-1986). *Proc. 1st Greek Congress on Antiseismic Engineering and Technical Seismology Technical Chamber of Greece*, 1, pp. 55-68, (in Greek).

Mariolakos, I., Schneider, H., Fountoulis, I. & Vouloumanos, N. (1993). Paleogeography, sedimentation and neotectonic implications at the Kambos depression and Kitries Bay area (Messinia, Peloponnese, Greece). *Bull Geol. Soc. Greece*, XXVIII/1, pp. 397-413, 1993.

Mariolakos, I. & Fountoulis, I. (1998). Is it safe to built on fault surfaces in a seismically active area? *Proc. 8th International IAEG Congress*, pp. 665-670, Balkema.

Michetti A.M., Esposito, E., Guerrieri, L., Porfido, S., Serva, L., Tatevossian, R., Vittori, E., Audemard, F., Azuma, T., Clague, J., Comerci, V., Gürpinar, A., Mccalpin, J., Mohammadioun, B., Mörner, N.A., Ota, Y. & Roghozin, E. (2007). Environmental Seismic Intensity Scale 2007 - ESI 2007. In: Guerrieri L. and Vittori E. (Eds.), Memorie Descrittive della Carta Geologica d'Italia, 74, 7-54, Servizio Geologico d'Italia – Dipartimento Difesa del Suolo, APAT, Roma, Italy.

Panou, A., Theodoulidis, N. & Savvaidis, A. (2004). Correlation between (H/V) ratio and seismic damage: The case of the city of Kalamata. In SESAME project, *Report of the WP04, H/V Technique: Empirical Evaluation, Project* No. EVG1-CT-2000-00026.

Papazachos, V., Kiratzi, A., Karacostas, B., Panagiotopoulos, D., Scordilis, E. & Mountrakis, D. (1988). Surface fault traces, fault plane solution and spatial distribution of the aftershocks of the September 13, 1986 earthquake of Kalamata (Southern Greece). *PAGEOPH,* vol. 126, No. 1, 55-68.

Psonis, K. 1986. Geological map of Greece, Kalamata sheet, scale 1/50,000, Geological Survey of Greece: Athens.

Stiros, S. & Kontogianni, V. (2008). Modelling of the Kalamata (SW Greece) earthquake faulting using geodetic data. *Journal of Applied Geodesy,* 2, 179-185; DOI 10.1515/JAG.2008.020