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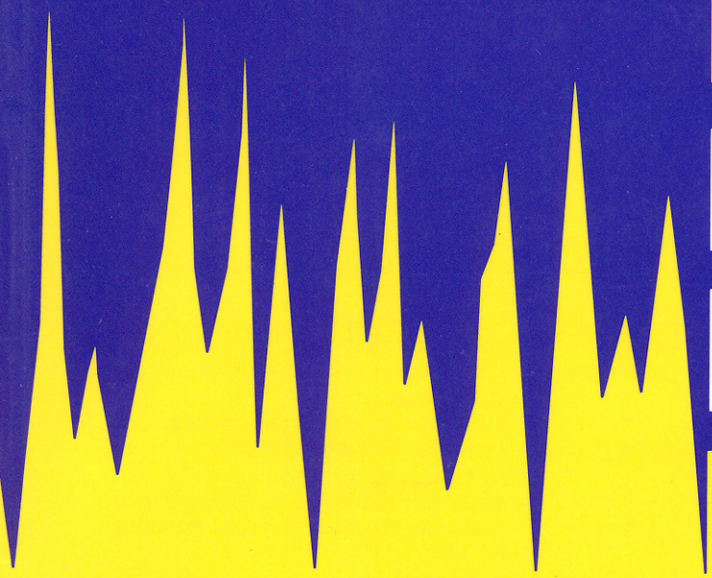

ELSEVIER
APPLIED
SCIENCE

VOLUME 15, NUMBER 2, 1996
ISSN 0267–7261 FEBRUARY

ELSEVIER

0267-7261(95)00034-8

Soil Dynamics and Earthquake Engineering **15** (1996) 61–68

0267-7261/96/$15.00

Pyrgos earthquake damages (based on E.M.S.-1992) in relation with geological and geotechnical conditions

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(Received 26 July 1995; accepted 4 August 1995)

On 26 March 1993 seismic activity at Ilia, West Peloponnesse, Greece resumed to extensive damages. The more severe destruction, with significant differentiation from one locality to another, was observed at the city of Pyrgos. To get a clear picture of the distribution of intensities, recording of damages was conducted according to the E.M.S.-1992. Application of this method at the wider area of Pyrgos showed that the highest intensity was VIII and the minimum was V. Detailed geological mapping and geotechnical investigation at the city of Pyrgos was also conducted and revealed a number of geological formations with special lithological and geotechnical characteristics. Faults that follow an E–W general direction dominate at the area and are part of the same fault zone that gave the earthquakes. Synthesis of the available data showed that there is a clear correlation between the intensities observed and the geological, tectonic and geotechnical conditions.

Key words: earthquake, damages, E.M.S.-1992, Pyrgos (Greece), geology, geotechnical conditions.

INTRODUCTION

Intense and unusual seismic activity took place at the wider area of Pyrgos, Ilia (W. Peloponnessus, Greece) during the first months of 1993. This was the result of the reactivation of fault zones that had been recognised and mapped earlier.[1] The main shock, with its epicentre south-east of the city, took place on 26 March 1993 (Ms = 5·2) and resulted in extended damages within a radius of 15–20 km.

The most significant destruction occurred in the city of Pyrgos (Fig. 1) where, more than 50% of the buildings were damaged according to the official survey data. On site investigation right after the shock, showed that the destruction and accompanying intensities were highly diversified from one locality to another within the urban area of Pyrgos.

In order to investigate the correlation between the observed intensities and their diversification, as well as the prevailing geological–tectonic and geotechnical conditions we conducted (a) detailed survey of the damaged constructions in the city and intensity evaluation according to the European Macroseismic Scale (E.M.S.-1992) and (b) detailed geological tectonic mapping, and geotechnical investigation. The resulting data are presented in this paper.

Paper presented at the Session SC-F3, Microzonation and Site Effects — XXIV General Assembly of European Seismological Commission, Athens, 19–23 September 1994.

RECORDING OF THE DAMAGES — INTENSITY EVALUATION

1 The E.M.S.-1992 and the recording methodology

Recording of damages to the constructions of the urban complex of Pyrgos after the shock of 26 March 1993 was conducted according to the European Macroseismic Scale 1992 (E.M.S.-1992). The E.M.S.-1992 solves some important problems that the use of the M.S.K. and its variations presented.

The main advantages of the use of E.M.S.-1992, especially when dealing with damages in urban complexes, are the following:

— Easier recognition of the type of structure. New types

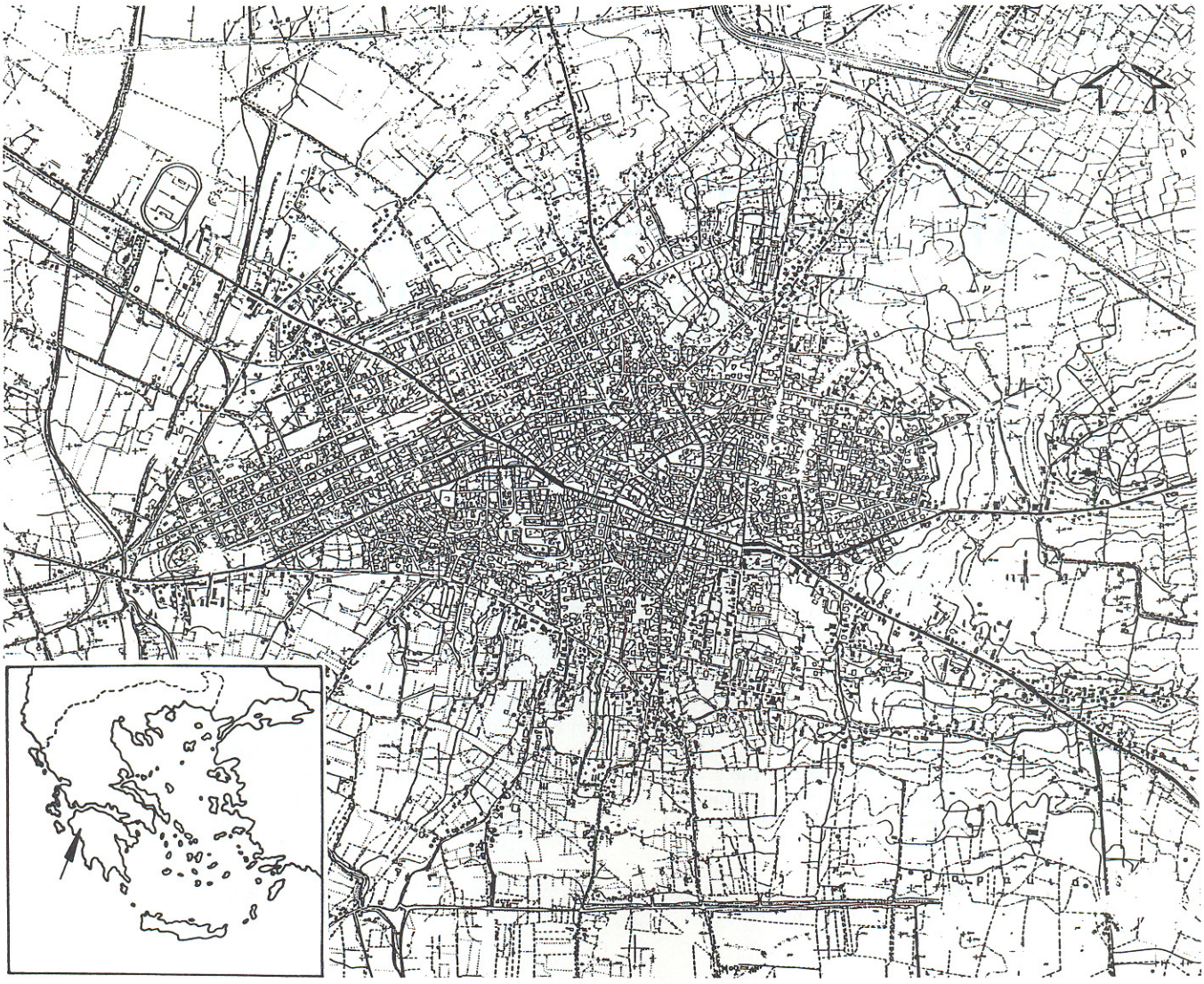

Fig. 1. General use map of Pyrgos.

of buildings, not existing in the previous scales, are included.
— Easier and objective recognition of the vulnerability class of the structure. New types of buildings after antiseismic design are included.
— Precise evaluation of the grade of damage.

Estimation of the intensity per urban unit or per portion of urban unit is made through a clear quantification while effects on objects and on nature are taken into account.

Based on the comprehensive presentation and the guidelines included in the final form of the E.M.S.-1992,[2] we conducted a complete recording of the types of buildings, their vulnerability class and the grade of damage for each construction, just after the earthquake. We also collected data on the effects of the shock on humans, objects and nature. For the facilitation of the procedure, the recording was conducted per block and the data were plotted on detailed 1 : 1000 maps. Finally, with the use of statistical computer software, the intensities for every location gave the isoseismals for the city of Pyrgos.

2 Intensities and their distribution

From the map of Fig. 2 it is concluded that the maximum intensities recorded were VIII on the E.M.S.-1992. These values are observed in the urban area of Pyrgos (Fig. 3). On the contrary, the minimum intensity we thought fit to plot was V and it is observed outside the urban area. Distinction of smaller intensities was not thought purposeful, nor was it totally plausible due to the low density of the structures per unit area, as only isolated country houses exist. A more detailed analysis of the map gives the following:

— The higher (VIII) intensities are observed at Kokkinohoma and Kouvelos, at the northeast of the urban complex. The related coseismals cover an extended

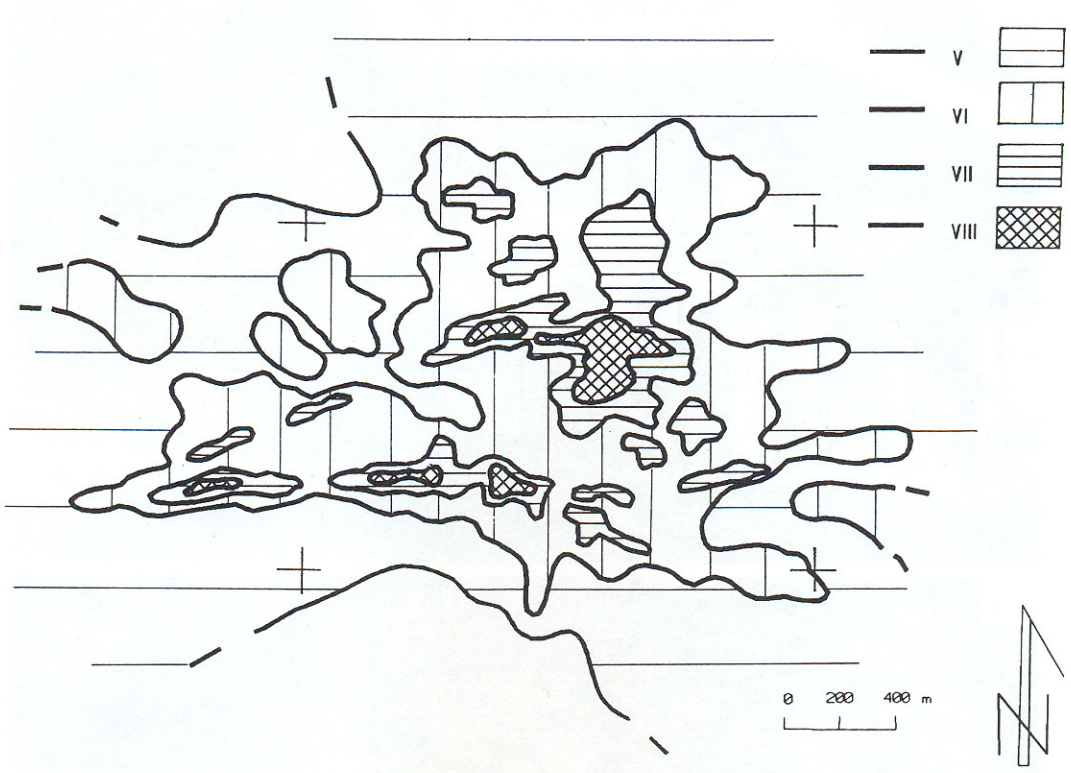

Fig. 2. Distribution of the intensities in the Pyrgos area based on the E.M.S.-1992.

region and this is the part of the city where all the structures were damaged to some degree.

— The same intensities (VIII) are observed at Keramidhaki, Aghios Nikolaos and Aghios Athanasios. At these localities the isoseismals cover a significantly smaller area, but present an impressive E–W elongated form. The VII coseismals that surround the previous ones follow the same pattern.
— The VII coseismals at the area of Aghia Kyriaki present a clear NE–SW elongated form, which continues up to Kouvelos area.
— Large (VII) intensities are observed at the areas of Kokkinohoma and Kouvelos, as well as at Aghioi Pantes cemetery. The area covered by the related coseismals is significant. Some isolated VII coseismals occur at the same area.
— Finally, isolated intensity coseismals in 'islet' form occur north-west and south-east of the city of Pyrgos.
— The minimum intensities VI and V are observed off the main urban unit of Pyrgos, to the north-west and south.

GEOLOGICAL AND GEOTECHNICAL CONDITIONS

The area of Ilia is characterised by intense geodynamical processes which are expressions of the Post-Alpine cycle. The graben of Pyrgos, which extends over a large area is characterised by complex lithostratigraphical structure and byneotectonic deformation which has been particularly intense during Holocene.[1,3]

However, the prevailing conditions at the pleistoseismal area of Pyrgos are relatively simple. Neotectonic structures are covered by recent geological formations (Alluvial, Marshy deposits) which occur in the flat lowland. Approach to the geological and the accompanying geotechnical conditions of the city of Pyrgos has been carried out through the use of existing data of previous extensive researches and mainly the Neotectonic Map of Pyrgos area.[1] This research has formed the source of data and information concerning the nature of the formations that occur in the graben, as well as the active macrostructure, a part of which is at Pyrgos city.

Geological mapping (Fig. 4) in the urban complex of Pyrgos and the surrounding area, where identified the formations (Fig. 5) described later in this paper. For some of these, the determination of their geotechnical parameters was made possible (Fig. 6). More specifically, the outcropping formations, in reverse age order are the following.

Recent marshy deposits

They develop surficially over the other formations at the flat plane part of the area and overlie mainly the alluvial formations, although the contact between them is not very clear. The most important outcrops are north-west of Lapato and east of Aghios Athanasios quarters. They are alternations of brown–greyish-brown clays, grey, blue–grey clayey silts, clayey and silty sands containing

Fig. 3. Damages on new and old structures caused by the 26 March 1993 earthquake at the city of Pyrgos.

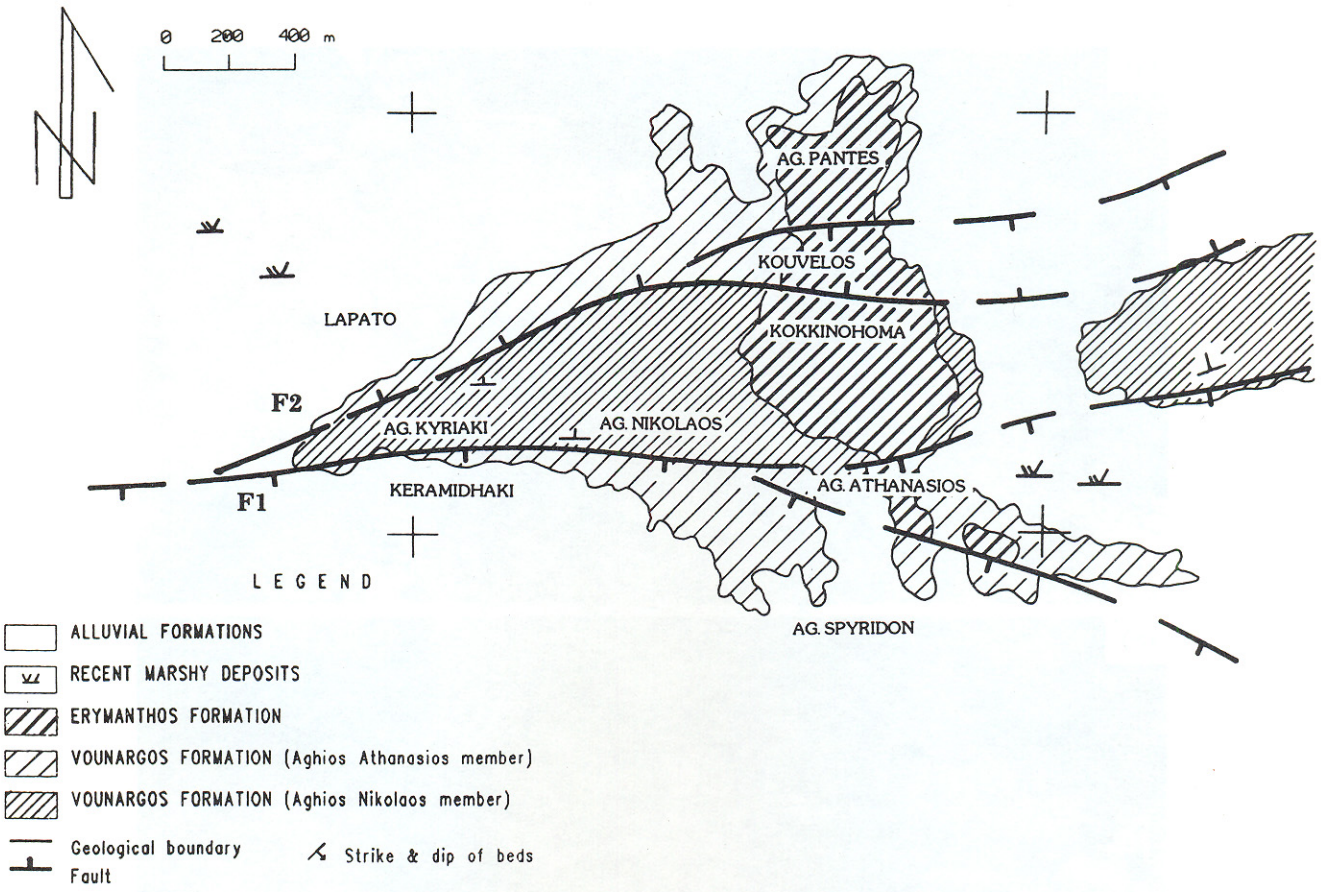

Fig. 4. Geological–tectonic map of Pyrgos area.

abundant organic remnants. Total thickness is up to approx. 5 m. The Standard Penetration Test (S.P.T.) showed that the number of impacts is in no case more than 10.

Alluvial formations

They cover the flat area of the town of Pyrgos and overlie unconformably the older formations. They comprise brown to grey soft clays with irregular (both in vertical and lateral sense) intercalation of brown silt and grey–brown sand. They contain numerous floral remnants as well as coarser material (gravel and pebbles). Their thickness does not exceed 12 m and the SPT test showed that the number of impacts is no more than 15.

Erymanthos formation

It outcrops over a limited area, mainly at Kokkinohoma, Kouvelos and at the Aghioi Pantes cemetery. It is a fossil outcrop of the Pleistocene Erymanthos formation which comprises mainly polygenetic conglomerates of terrestrial origin connected with a red-siliceous fine unconsolidated formation. It corresponds to a huge paleo-talus cone with frequent lateral diversification and covers a large part of the graben of Pyrgos.[1] At the research area in the city of Pyrgos it is represented by red to brown red clays and yellow brown sandy clays, loose horizontal sandy conglomerates and microconglomerates. It overlies unconformably on the Vounargos formations and its thickness varies from 2 to 8 m. The SPT test showed that the number of impacts for a 30 cm penetration is no more than 15.

Vounargos formation

It is perhaps the most characteristic formation that outcrops in the graben of Pyrgos. Its age is Plio-Pleistocene, its thickness is up to 600 m and comprises continuous intercalation of clays, silts, sandstones, sands and marls with constant diversification both in vertical and lateral sense. At the study area it occurs in the urban region and more specifically at the quarters of Aghia Kyriaki, Aghios Nikolaos, and Aghios Athanasios. There can be distinguished; two members of the formation which have both different lithological composition and geotechnical properties.

The upper member (Aghios Athanasios) develops at the quarters of Aghios Athanasios, Keramidhaki, Aghios Spyridon and partially at Lapato and practically covers all the lower parts of the uplands of Pyrgos. It comprises mainly yellow–brown cross-bedded sands and

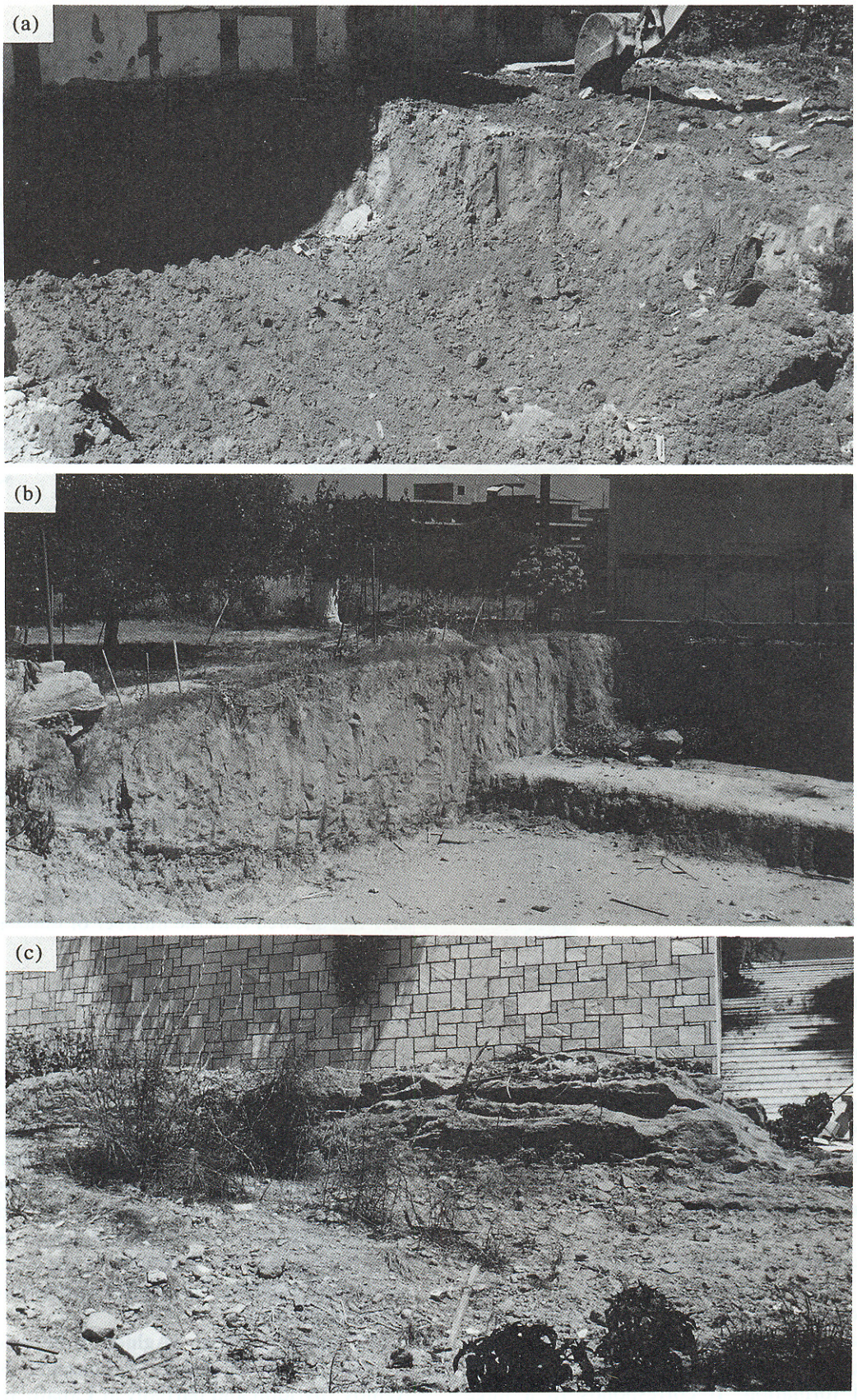

Fig. 5. Representative outcrops of Erymanthos formation red clays (top), Aghios Athanasios sands (middle) and Aghios Nikolaos sandstones (bottom).

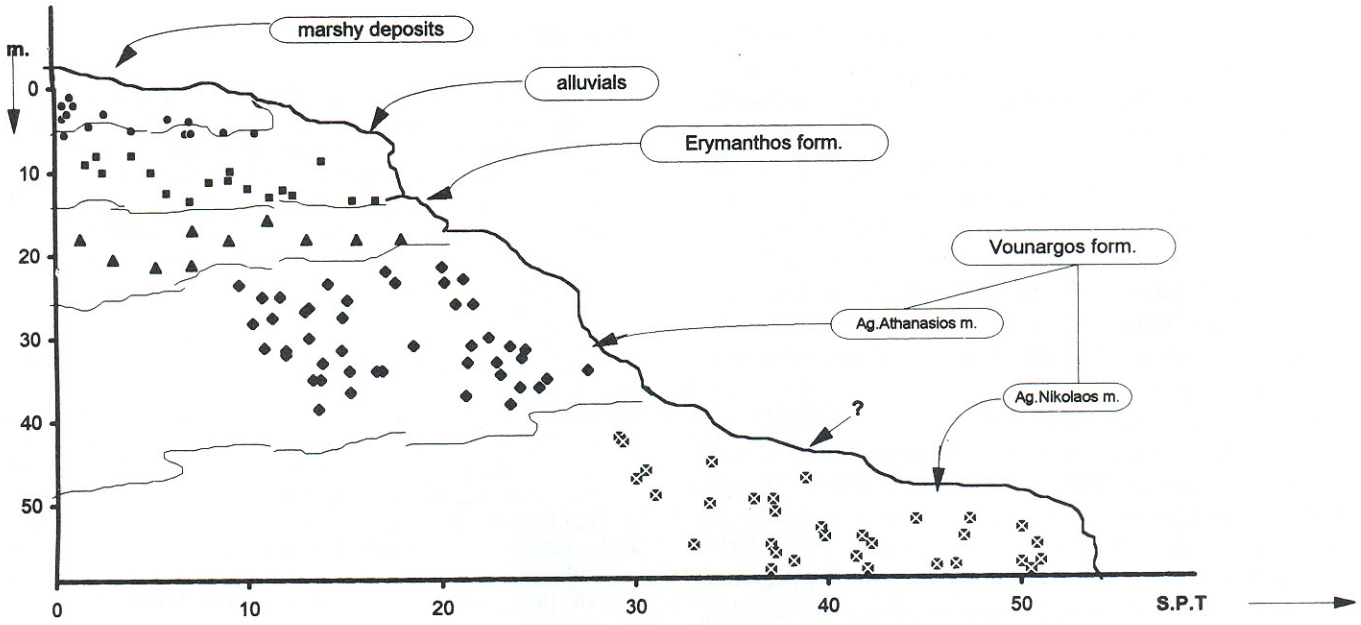

Fig. 6. Schematic lithostratigraphic column of all formations and results of the Standard Penetration Test.

yellow silty sands with certain intercalation of yellow–brown sandy clays. At the SPT test the number of impacts for the clayey sands and the silty sands is 15–30, while for the sandy clays it is 10–20. Its thickness exceeds 30 m.

The lower member (Aghios Nikolaos) occurs at the quarters of Aghios Nikolaos and Aghia Kyriaki and covers most of the uplands of the city of Pyrgos. It comprises fossil bearing grey–blue–greyish marls which alternate with silty, sandy and clayey marls, while locally there are thin intercalation of sand, sandy-silt, lignite horizons and yellow–brown sandstones. In contrast with the upper member, the SPT test showed that the number of impacts for 30 cm penetration exceeds 30, and sometimes they are more than 50. Its thickness is more than 80 m.

The formations that occur at the area of Pyrgos have undergone neotectonic deformation and are crossed by a number of faults of East–West mean direction. These faults are part of the Katakolo–Pyrgos–Epitalio fault zone, according to the existing literature.[1,4] This fault zone was responsible for the earthquakes of 26 March 1993.

More specifically, the elongated outcrop of the lower member of Agios Nikolaos is abruptly terminated by the F1 (E–W bearing) fault, south of which the upper (Aghios Athanasios) member of the Vounargos formations occurs. It is a normal fault, accompanied by a morphological discontinuity (to the south of the city main square), its throw is at least 50 m (estimated from morphotectonic features) and eastwards it branches into two faults. Existence of these faults is also confirmed by small polished surfaces.

To the north there is an identical picture with the occurrence of the F2 fault (av. direction NE–SW), which also branches into two minor faults to the east. The F2 fault brings together the outcrops of Aghios Athanasios and Aghios Nikolaos members, while it also crosses some outcrops of Erymanthos formation. Its throw is smaller (20–30 m), and all along it we recognised seismic fractures caused by the shock of 26 March 1993.

One may distinguish, at the area of Pyrgos, an elongated horst of general East–West direction, which is pronounced by the ridge of the same direction. It consists of the lower (Aghios Nikolaos) member of the Vounargos formation, as well as of a small part of Erymanthos formation. To the north and south of the horst there are the outcrops of the younger formations, which are represented by Aghios Athanasios member (it belongs to the Vounargos formation) and Holocene deposits (Alluvial and Marshy deposits).

DISCUSSION AND CONCLUSIONS

Based on the intensity distribution map and the geological map of the urban complex of Pyrgos, we may propose the following basic correlations and results:

High intensities are observed alongside and on either side of F1 and F2 that cross the geological formations. The VIII isoseismals of the E.M.S.-1992 present an impressive elongated development that also holds for the lower intensity coseismals. As already mentioned, these faults belong to the Katakolo–Pyrgos–Epitalio fault zone,[1] parts of which were reactivated during the 26 March 1993 earthquakes. Along this fault zone, and more precisely along the F2 fault, seismic fractures were observed and those were the locations where the

damages were particularly intense. A similar diversification of the destruction was observed along another fault zone at Kastro village near Pyrgos area during the shock of 16 October 1988.[5]

Particularly high intensities were observed at the areas of Kouvelos and Kokkinohoma, where the fossil outcrops of Erymanthos formation overlie unconformably the Vounargos formation. The low geotechnical properties of these outcrops and their small thickness seem to have been the crucial factors for the magnification of intensities, having created a disadvantageous geodynamic regime.

Some formations or parts of them have caused local isolated 'islets' of high intensity coseismals north-west of Lapato and east of Aghios Athanasios, where Marshy deposits with poor geotechnical properties, occur. In addition are also observed high intensities, west of the Aghioi Pantes cemetery. They coincide with the presence of loose sands that belong to Aghios Athanasios member of Vounargos formation. At this very location, even antiseismic designed buildings (e.g. schools) underwent severe damage.

REFERENCES

1. Lekkas, E., Papanikolaou, D. & Fountoulis, J. Neotectonic map of Greece, Sheet "Pyrgos"-"Tropaia" (scale 1 : 100,000). Project, University of Athens, Dynamic, Tectonic, Applied Geology Div., 1992 (in Greek).
2. Grunthal, G., ed., European Macroseismic Scale 1992 (updated MSK-scale). Conseil de l'Europe, Cahiers du Centre European de Geodynamique et de Seismologie, Vol. 7, p. 79, Luxembourg, 1993.
3. Hatzfeld, D., Pedotti, G., Hatzidimitriou, P. & Makropoulos, K. The strain pattern in the western Hellenic arc form a microearthquake survey. *Geophys. J.*, 1990, **101**(1), 181–202.
4. Lekkas, E., Papanikolaou, D., Fountoulis, J. & Danamos, G. Tectonic analysis of faults at the earthquake-stricken area of Pyrgos. Project, University of Athens, Dynamic, Tectonic, Applied Geology Div., 90 pp, 1994 (in Greek).
5. Lekkas, E. & Danamos, G. Impact of the geological conditions on the distribution of the damages at Kastro village (Killini peninsula) caused by the earthquake of Oct. 16, 1988. *Bull. Geol. Soc. Greece*, 1989, **XXIV** (in press) (in Greek).