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THE PARNITHA FAULT: A POSSIBLE RELATIONSHIP WITH OTHER NEIGHBORING FAULTS AND CAUSES OF LARGER DAMAGES.

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I. INTRODUCTION

The city of Athens and the region of Attica, considered in general by experts as an area of no major earthquake activity. This hypothesis used to be based on the following assumptions: First, the city itself – at least until the first half of the twentieth century – extended over a relatively small area. Furthermore, it was built on the schist and limestone rock formations of the Attico-Cycladic massif, which do not amplify seismic accelerations. Such layers do not present additional seismic accelerations. Second, the structural integrity of the city of Athens was always far superior to that of other Greek cities. Consequently, Attica has always been capable of escaping earthquakes in neighboring faults with relatively minor damage.

All this changed during the second part of the twentieth century. The city’s population skyrocketed and the result was twofold. The city started expanding over relatively loose layers or unconsolidated sediments, while existing building codes have not always been followed to the letter. Meanwhile, recent microseismic as well as macroseismic studies and observations, indicated that Attica is far from immune to seismic danger. Leading experts, such as Galanopoulos (1956, 1971, 1988), have repeatedly pointed out in their relevant studies the above mentioned. According to these studies, two active rift zones are present: The first one, expanding from Avlona to Marathon through Kapandriti and the second one expanding from Ekali to Kalamis through Kapandriti (figure 1). The two major earthquakes that took place at the Alkionides islands on February 24 and March 4, 1981, with the severe damage they caused to several areas of Attica, confirmed once more the fact that Attica is indeed in some danger from neighboring, as well as from local seismic faults. This indigenous danger was evinced with the reactivation of the relatively old and generally inactive fault of Parnes mountain, which produced the Ms=5.9 Athens earthquake of September 7, 1999, causing some very serious damage in the eastern suburbs of the Greek capital. The purpose of this study is to examine any possible relationship of the Parnes fault zone with other neighboring rift zones. Additionally, the exact causes behind the relatively high percentage of damages to certain areas of Attica will be discussed.
II. REGIONAL GEOLOGICAL AND TECTONIC SETTING

The study area is located on the northwestern margin of the Attico-Cycladic massif. It is mainly centered on the Aspropyrgos plain and it extends from the hills of Egaleo to the mount Parnes. Upper Paleozoic sedimentary layers covered by Triassic sediments, are superimposed to the crystalline basement of the Attico-Cycladic massif (Ktenas, 1923).

The northern end of the Attico-Cycladic massif is a typical example of the metamorphic continuation of the eastern Hellenic zone (Marinos, 1961; Bodechtel and Papadeas, 1986). The crystalline basement commonly underlies all the sedimentary sequences found in eastern Greece. This zone, also known as Subpelagonian zone, extends all under the Attico-Cycladic massif of the Pelagonian zone.

After the main Alpine orogeny period, the topography of the area greatly changed due to rifting and subsidence procedures. Consequently, the Attica basin formed during Miocene to post Miocene due to tectonic dislocations. The formatted structures, such as shallow parts of grabens, rift valleys, fault bounded basins and elongated closed depressions, created by the above mentioned procedures, were filled up with interchanging strata of marly limestone and Miocene marls along with sandstone, Pliocene conglomerates and thick sequences of alternating schist. The tectonic texture of the Subpelagonian zone comprises major normal faults on an E-W direction and minor ones on a NE-SW direction.

The Aspropyrgos plain is covered by alluvial fans and older talus cones scree. The ESE trending rift zone of the trench (figures 1, 2), is parallel to the morphological axis of Parnes mountain then heads in a westerly direction, to end up in the area of Porto Germeno at the gulf of Corinth. To the east, it contacts a NE-SW oriented rift zone, which forms the eastern boundary of the basin. This zone follows the main axis of the hills of Egaleo, ending in the area of Agioi Apostoloi at the southern Evvia gulf.

III. DATA AND INTERPRETATION

The data used in this study refer to the seismic sequences of the large earthquakes that took place on February and March 1981 (Jackson et al, 1982; King et al, 1985), the microseismic activity recorded during the summer of 1993 (Hatzfeld et al, 1999) and the September 7, 1999, earthquake sequence (Papadimitriou et al, 2000, Voulgaris et al, 2000). It concerns reliable data that exhibit extremely small deviations for the calculated focal parameters, mainly due to the large number of seismological stations used and to their efficient azimuthal coverage. Regarding the September 7, 1999, sequence, data are derived from a local network of eight portable seismological stations deployed in the area 24 hours after the main shock and the permanent telemetric CORNET network, both installed by the Geophysics-Geothermal Department.
As already mentioned, the September 7, 1999, earthquake, took place in the running along the southern fringes of the Parnes mountain fault zone, at the northern boundary of the Aspropyrgos basin. This zone evidenced in geological and tectonic maps of the I.G.M.R. and in satellite imaging (figure 2), is connected to the west with a rift zone, to which the Alkionides and Plataies earthquakes are attributed and with the rift zone that ends at Porto Germeno. This zone intersects to the east with the rift zone defined by the eastern boundary of the Thriasian plain – at the hills of Egaleo – and heads off on an ESE direction, towards the bay of Artemis. As shown in figures 1 and 2 the fault of Aegaleo extends to the northeast and ends at the Southern Evoian bay.

By focusing on the microearthquake distribution of the 1993 experiment (Hatzfeld et al, 1999) and that of the aftershocks of the 1981 earthquakes (Jackson et al, 1982), easily can be deducted that the majority of the microseismic events is aligned along the Alkionides-Parnes rift zone (figure 2), while noticeable is the interruption of the spatial continuation of the seismic activity around the area of Villia town. The 1993 microearthquake activity displays similar to the September 7, 1999, aftershock sequence characteristics concerning the Aspropyrgos plain, establishing the seismically active regime of the area and its possible close relation with the western segment of the rift zone. The active regime of the Aspropyrgos basin is additionally reported by the microseismicity recorded from September to December 1996. The cycle of pre and post seismic events that took place between August 1 and September 7, and September 7 to October 24, 1999 respectively, across the under discussion areas, does confirm their interconnection. This assumption is also supported by the epicenter distribution regarding the same period (figures 3 and 4).

The source parameters calculated for the main shock (Papadimitriou et al, 2000), reveal a south dipping (55°) normal faulting in a roughly E-W direction (105°). The focus depth determined at 8 km, in consistent with the range of the aftershock depth distribution between 2 and 10 km (Voulgaris et al, 2000), implying that the major rupture did not reach the surface. Following the assumption that a double pair of opposite forces is present during a rupture process (shear dislocation model), the amplitude of the compressional and surface Rayleigh wave is consequently greater along the direction of the P and T stress axes, while the amplitude of the transverse wave appears to be greater along the A and C kinematics axes.

As in situ field observations indicate, the largest measured intensities (>X of the Mercalli scale) are mainly distributed over an area at a distance between 10-20 km northeast of the main shock and evidence that the energy released during the earthquake was directed mainly to the northeast. Noticeable is that the intensity distribution depends upon a certain number of factors, such as the focal radiation pattern, the soil and finally the construction itself.

Based on the above mentioned, we attempt to interpret the association between the seismic intensities distribution with the focal radiation pattern. In figure 5, the distribution of the
P and T stress axes and the A and C kinematics axes is shown. Those axes are plotted as vectors with lengths being proportional to the pitch. The energy radiation is theoretically expected larger than the observed. Due to the particular way the energy released, the extent of damage should be larger along the A and C axes. A and C axes are NE directed, towards the area that sustained the majority of the damage. In the opposite SW direction the damages were less significant due to the fact that the corresponding axes (P and T) were directed towards the Earth’s interior and additionally for the area above them is sea covered. An additional important factor concerning the energy release along a NE direction, thus increasing the extent of damage to the NE, was the initial focus nucleation at the western edge of the fault and the source propagation towards the east direction (Papadimitriou et al, 2000).

CONCLUSIONS

The study area is of great importance not only from a scientific but also a social point of view, due to the fact that Attica happens to house more than 50% of the total Greek population and is heavily industrialized. Another unique feature of the earthquake of September 7 was its 5.9 Ms magnitude, though Attica is known for earthquakes with magnitudes up to 6.4 of the Richter scale (Comninakis, 1976). However, the September 7, 1999, earthquake was the first and only case in the whole twentieth century when an earthquake of relatively small depth in Attica is characterized by such a significant magnitude.

As the accumulated data concerning the earthquake of September 7, 1999, indicate, the focal depth is about eight kilometers (Papadimitriou et al, 2000; Voulgaris et al, 2000). The main shock event was preceded by a number of smaller earthquakes that took place in the area of the Alkionides islands and in Aspropyrgos basin. In short, the epicenter distribution of the seismic events that recorded in 1981, 1993, 1996 and 1999, confirm the existence of a fault zone extending from the eastern coast of the Corinthian gulf in the area of the Alkionides islands to the west, up to the hills of Egalio to the east, probably terminating at the Artemis bay. This zone is active with a small seismic gap at the area of Oinoi. The focal mechanism of the main shock showed that a 55° south dipping nodal plane with a 105° azimuth is the earthquake fault plane. The fault plane also coincides not only with the existing fault trace as indicated by satellite images and geological maps, but also with the spatial distribution of the aftershock activity (Voulgaris et al, 2000). This particular distribution also showed that the rupture had no surface occurrence but terminated at a depth of two kilometers, as additionally evidenced by in situ field observations.

The focal energy radiation pattern and the directivity effect were the main causes of the major destructions observed at the eastern suburbs of Attica. The emergent topographic relief of Parnes and Egalio probably played a certain role in channeling the seismic energy release towards the NE direction from the main shock.
In conclusion, we point out the existence of a fault zone that extends from Porto Germano to the west, passes through Parnes reaching probably the bay of Artemis to the east. This fault zone should be considered additionally to the two already mentioned ones by Galanopoulos (1971; 1988).

ΠΕΡΙΛΗΨΗ

Η μελέτη της Αττικής παρουσιάζει μεγάλο ενδιαφέρον όχι μόνο από επιστημονικής πλευράς αλλά και καινοτομίας, καθότι το λεκανοπέδιο της Αττικής είναι η πολυπληθέστερη περιοχή της Ελλάδας και έχει τις μεγαλύτερες και πολυπληθέστερες βιομηχανικές μονάδες και βιοτεχνίες. Ένα χαρακτηριστικό του σεισμού της 7ης Σεπτεμβρίου 1999 ήταν το μέγεθος του που έφθασε το 5.9 R, ον και το αναμενόμενο μέγιστο μέγεθος στην περιοχή, βάσει στατιστικών δεδομένων (Κοινηνακίτης, 1976) μπορεί να φθάσει το 6.4. Τέτοιο μέγεθος επιφανειακού σεισμού και προερχόμενο από την περιοχή της Αττικής, δεν έχει συμβεί τον τελευταίο αιώνα.

Όπως προκύπτει από την επεξεργασία και ανάλυση των δεδομένων του σεισμού της 7ης Σεπτεμβρίου 1999, είχε εσωτερικό βάθος 8 km. Τον κοριτσιό σεισμού προηγήθηκε μικρός αριθμός προσέγγισμάν που είχαν επίκεντρα τόσο στην περιοχή των Αλκυνίδων όσο και στο λεκανοπέδιο του Ασπροπύργου. Η διαστορά των επικέντρων της σεισμικής ακολουθεί της 1981, της μικροσεισμικής δράσης του Ιούλιο Αύγουστο του 1993και της πρόσφατης σεισμικής ακολούθα επιβεβαιώνουν την ύπαρξη μιας ρηχαγεννής ζώνης που αρχίζει από τις ανατολικές ακτές του Κορινθιακού κόλπου (περιοχή Αλκυνίδων), φθάνει στη βόρεια πλευρά του όρους Αιγάλεω και παράλληλα καταλήγει στον όρος της Αρτέμιδος. Η ζώνη αυτή είναι ενεργής και έχει ένα μικρό σεισμικό κέντρο στο ύψος της Ουνίδος.

Ο μηχανισμός γέννησης του σεισμού έδειξε ότι το ορικό επίπεδο με N120° και 62° SSW κλίση είναι το επίπεδο διάρρηξης του σεισμού, αφού ταυτίζεται αλήθεια δ όταν μόνο το ήπιο του ρήματος της γεωλογικού και διαφοροφικής χάρτη αλλά και με την χωρική διαστορά των μετασεισμών, όπως υπολογίστηκε από τους Voulgaris et al. (2000). Η χωρική διαστορά έδειξε επίσης ότι η διάρρηξη δεν είχε επιφανειακή εκδήλωση, αλλά σταμάτησε στα 2 km. Η παραστήρεια αυτή διαπιστώθηκε και από επιτύπωτα έρευνες.

Η ακτινοβολία της σεισμικής ενέργειας από την εστία καθώς και το κύμα κρύσσων που δημιουργήθηκε ήταν οι κύριες αττικές των μεγάλων καταστροφών που παρατηρήθηκαν κύρια στα προϊσταμένα Φυλή, Αγω Λύσεια, Αχαρνές, Θρακομακεδόνες. Οι περιοχές αυτές βρίσκονται Α-ΒΑ του επικέντρου.

Στην κατευθυντικότητα αυτή της ενέργειας του σεισμού συνέβαλαν πιθανότατα και οι άξονες των ορεινών όγκων της Πάρνηθας και του Αιγάλεω. Οι δύο αυτοί όγκοι οφθαλμούν την βόρεια και ανατολική πλευρά της λεκάνης του Ασπροπύργου αναηύνονται ένα μικρό χωρίο προς τα A-ΒΑ.
REFERENCES


Figure 1. Structural map of the major region of Attica (Bornovas, 1970).

Figure 2. Seismotectonic map of Attica.
1 AUG - 7 SEP 1999: Seismicity Located by CORNET network

Figure 3. Seismicity located in the study area by the CORNET network, for the period from August 1 to September 7, 1999.

7 SEP - 24 OCT 1999: Seismicity Located by CORNET network

Figure 4. Seismicity located in the study area by the CORNET network, for the period from September 7 to October 24, 1999.
Figure 5. Block diagram illustrating the spatial distribution of the September 7, 1999, Parnes earthquake sequence. Vectors represent the stress and kinematics axes, P, T and A, C respectively with their size being proportional to the pitch of the axes.