Ε Ρ Γ Α Σ Τ Η Ρ Ι Ο   Γ Ε Ω Φ Υ Σ Ι Κ Η Σ
ΑΡΙΣΤΟΤΕΛΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΕΣΣΑΛΟΝΙΚΗΣ

Τ Ε Λ Ι Κ Η
Ε Κ Θ Ε Σ Η   Τ Ο Υ   Π Ρ Ο Γ Ρ Α Μ Μ Α Τ Ο Σ
τ ο υ   Ο. Α. Σ. Π.

" ΜΑΚΡΑΣ ΔΙΑΡΚΕΙΑΣ ΠΡΟΓΝΩΣΗ ΤΩΝ ΣΕΙΣΜΩΝ ΜΕ ΣΕΙΣΜΙΚΕΣ ΜΕΘΟΔΟΥΣ "

(15.12.84 - 15.6.86)

ΘΕΣΣΑΛΟΝΙΚΗ   1986

ΠΕΡΙΕΧΟΜΕΝΑ

1. ΕΙΣΑΓΩΓΗ

Η παρούσα αποτελεί την τρίτη και **τελική έκθεση** η οποία υποβάλλεται στα πλαίσια του προγράμματος **"Μακράς Διάρκειας Πρόγνωση των Σεισμών με Σεισμικές Μεθόδους"**,το οποίο ανατέθηκε από τον Οργανισμό Αντισεισμικού Σχεδιασμού και Προστασίας(ΟΑΣΠ) στο Εργαστήριο Γεωφυσικής του Αριστοτελείου Πανεπιστημίου Θεσσαλονίκης και εκπονήθηκε κατά το δεκαοκτάμηνο χρονικό διάστημα, 15 Δεκεμβρίου 1984-15 Ιουνίου 1986 .

Σκοπός της έκθεσης αυτής,σύμφωνα με τους όρους της σχετικής σύμβασης, είναι ο επιστημονικός απολογισμός του προγράμματος και συγκεκριμένα η παρουσίαση των αποτελεσμάτων του όλου προγράμματος και ο καθορισμός των περιοχών που έχουν αυξημένη πιθανότητα να αποτελέσουν εστίες μεγάλων σεισμών κατά τα επόμενα 10-20 χρόνια.

Οι σημαντικότερες ενέργειες που έγιναν για την επίτευξη των στόχων του προγράμματος έχουν λεπτομερώς περιγραφεί στις προηγούμενες δύο εκθέσεις. Συνοπτικά οι ενέργειες αυτές είναι οι εξής:

α) Συμπλήρωση του υπάρχοντος υλικού παρατήρησης με πρόσθετα στοιχεία,

β) Δοκιμή υπαρχόντων σχετικών προγραμμάτων ηλεκτρονικών υπολογιστών και εκπόνηση νέων,

γ) Επεξεργασία του υλικού παρατήρησης και εξαγωγή των πρώτων αποτελεσμάτων,

δ) Κανονική εβδομαδιαία συνάντηση των μελών της επιστημονικής ομάδας και συζήτηση πάνω στα αποτελέσματα και στην όλη εξέλιξη του προγράμματος,

ε) Παρακολούθηση επιστημονικών συνεδρίων,ανακοίνωση μερικών αποτελεσμάτων και συζήτηση πάνω στο αντικείμενο με ειδικούς επιστήμονες,

στ) Εξαγωγή των τελικών επιστημονικών αποτελεσμάτων,τελική διαμόρφωση του σχετικού υλικού (χάρτες,πίνακες,καμπύλες,κλπ)και συγγραφή των σχετικών δημοσιεύσεων.

Η έκθεση υποδιαιρείται σε οκτώ κεφάλαια για την λεπτομερέστερη παρουσίαση των αποτελεσμάτων και την ικανοποίηση των όρων της σχετικής σύμβασης.

Η εργασία αυτή πρέπει να θεωρηθεί σαν ένα στάδιο, σημαντικό κατά τη γνώμη μας, της όλης προσπάθειας για τη μακράς διάρκειας πρόγνωση των σεισμών και για τη λύση του προβλήματος του σεισμικού κινδύνου στη χώρα μας. Συνεπώς, τα αποτελέσματα της εργασίας αυτής μπορούν με παραπέρα έρευνα να βελτιωθούν ή και να αναθεωρηθούν σ'ορισμένο βαθμό. Το Εργαστήριο Γεωφυσικής έχει προγραμματίσει τη συνέχιση της προσπάθειας αυτής και ασφαλώς νέα οικονομική βοήθεια από τον ΟΑΣΠ ή από άλλον φορέα θα διευκολύνει και θα επιταχύνει το έργο αυτό.

Στο πρόγραμμα αυτό μετείχαν οι Β.Παπαζάχος, Ε.Παπαδημητρίου, Γ.Καρακαΐσης, Α.Κυρατζή, Π.Χατζηδημητρίου, Β.Καρακώστας, Χ. Παπαϊωάννου, Δ.Παναγιωτόπουλος, Ν.Θεοδουλίδης, Μ.Κρημνιανιώτου, Δ.Βλάχου, Α.Ρόκκα και Γρ.Τσόκας.

Η εργασία αυτή βασίστηκε σε σημαντικό βαθμό σε αδημοσίευτο υλικό παρατήρησης για ιστορικούς σεισμούς το οποίο συγκέντρωσε η κ.Παπαζάχου και έθεσε στη διάθεσή μας αφιλοκερδώς.

Ευχαριστούμε θερμά όλους όσους συνέβαλαν στην επιτυχή περάτωση του προγράμματος αυτού και ιδιαίτερα τον Οργανισμό Αντισεισμικού Σχεδιασμού και Προστασίας για τη χρηματοδότηση του προγράμματος. Ευχαριστούμε επίσης την επιτροπή Ερευνητικών προγραμμάτων του Αριστοτελείου Πανεπιστημίου Θεσσαλονίκης και ιδιαίτερα τις κ.Χρ.Μπέστα και Λ.Γεωργιάδη για την βοήθεια που μας προσέφεραν διευκολύνοντας εξαιρετικά την οικονομική διαχείριση του προγράμματος.

Β. Κ. ΠΑΠΑΖΑΧΟΣ

2. ΑΠΟΤΕΛΕΣΜΑΤΑ ΤΟΥ ΠΡΟΓΡΑΜΜΑΤΟΣ

Τα αποτελέσματα του προγράμματος περιλαμβάνονται στις παρακάτω επτά (7) εργασίες οι οποίες αφορούν άμεσα τη μακράς διάρκειας πρόγνωση των σεισμών στον ελληνικό χώρο. Περιλήψεις των εργασιών αυτών περιγράφονται σ'αυτό το κεφάλαιο, ενώ ολόκληρες οι εργασίες αυτές περιλαμβάνονται στο κεφάλαιο (8) της έκθεσης.

1. Papadimitriou,E.E.,Karacostas,B.G.,Karakaisis,G.F. and Papazachos, B.C. Space-Time Patterns of Seismicity in the Aegean and Surrounding Area. "Proceedings of the 3rd International Symposium on the Analysis of Seismicity and Seismic Risk, Liblice Castle,Chechoslovakia, June 17-22, 1985", 1-5, 1985.

2. Papazachos,B.C.,Papadimitriou,E.E.,Karacostas,B.G. and Karakaisis,G.F. Long Term Prediction of Great Intermediate Depth Earthquakes in Greece."12th Seminar on Earthquake Engineering,European Association on Earthquake Engineering , Earthquake Planning and Protection Organization of Greece, Halkidiki,September 16-25,1985", 1-12, 1985.

3. Papadimitriou,E.E.,Kiratzi,A.A. Interrelation of Seismicity between Crete and Ionian Islands (Greece). "Publication of the Geophysical Laboratory,University of Thessaloniki" ,18, 1-17,1985.

4. Papadimitriou,E.E.. Migration of the Intermediate Focal Depth Seismic Activity in the Inner Part of the Hellenic Arc. "Publication of The Geophysical Laboratory,University of Thessaloniki" , 19, 1-5, 1985.

5. Papazachos,B.C.,Hatzidimitriou,P.M.,Karacostas,B.G. .Seismic Fracture Zones in the Aegean and Surrounding Area."Publication of the Geophysical Laboratory,University of Thessaloniki" , 2, 1-10, 1986a.

6. Karakaisis,G.F.,Panagiotopoulos,D.G.,Krimnianiotou,M.Ch.and Papazachos,B.C. Preseismic Quiescence before Large Earthquakes in the Aegean and Surrounding Area. **"Publication of the Geophysical Laboratory,University of Thessaloniki",3 ,** 1986.

7. Papazachos,B.C.,Papadimitriou,E.E.,Kiratzi,A.A., Papaioannou, Ch.A. and Karakaisis,G.F. Probabilities of Occurrence of Large Earthquakes in the Aegean and Surrounding Area during the Period 1986-2006, **"Publication of the Geophysical Laboratory,University of Thessaloniki",4,** 1-23 , 1986b.

Πέρα από τις παραπάνω επτά εργασίες εκπονήθηκαν και οι παρακάτω τρεις των οποίων τα αποτελέσματα επίσης συνέβαλαν στην εκπλήρωση των στόχων του προγράμματος. Οι εργασίες αυτές επίσης περιλαμβάνονται ολόκληρες στο τέλος του προγράμματος.

8. Ch.A.Papaioannou,P.M.Hatzidimitriou,B.C.Papazachos and N.P. Theodulidis. Seismic Hazard Assessment for Southern Balkan Region based on Seismic Sources. **"Proceedings of the 3rd International Symposium on the Analysis of Seismicity and Seismic Risk,Liblice Castle,Czechoslovakia,June 17-22,1985",** 1-6,1985.

9. Ch.A.Papaioannou,A.A.Kiratzi,B.C.Papazachos and N.P. Theodulidis. Regionalization of the Attenuation of Intensities in the Southern Balkan Region. **"Proceedings of the 3rd International Symposium on the Analysis of Seismicity and Seismic Risk,Liblice Castle,Czechoslovakia,June 17-22,1985",** 1-7, 1985.

10. B.C.Papazachos,A.A.Kiratzi,P.M.Hatzidimitriou,Ch.A.Papaioannou and N.P.Theodulidis. Regionalization of Seismic Hazard in Greece." 12th Seminar on Earthquake Engineering , European Association on Earthquake Engineering,Halkidiki , September 16-25, 1985", 1-11,1985.

1. **Χωροχρονικές Κατανομές της Σεισμικής Δράσης στο Αιγαίο και τις γύρω περιοχές.** "Πρακτικά του 3ου Διεθνούς Συμποσίου επί της Ανάλυσης της Σεισμικότητας και της Σεισμικής Επικινδυνότητας, Liblice, Τσεχοσλοβακία, Ιούνιος 17-22, 1985", 1-5, 1985.

Παπαδημητρίου, Ε.Ε., Καρακώστας, Β.Γ., Καρακαΐσης, Γ.Φ., και Παπαζάχος, Β.Κ., Εργαστήριο Γεωφυσικής Αριστοτελείου Πανεπιστημίου Θεσσαλονίκης.

Στην εργασία αυτή εξετάζεται η σχέση μεταξύ της σεισμικότητας στο βόρειο και στο νότιο μέρος του ευρύτερου χώρου του Αιγαίου για τη διαπίστωση πιθανής μετανάστευσης της σεισμικής δράσης μεταξύ των δύο αυτών περιοχών. Διαπιστώνεται ότι κατά τον παρόντα αιώνα οι μεγάλοι σεισμοί ($M \geqslant 7.0$) της περιοχής έγιναν κατά τρεις διακεκριμένες χρονικές περιόδους μετανάστευσης.

Κατά την πρώτη περίοδο (1903-1932) όλοι οι μεγάλοι επιφανειακοί σεισμοί έγιναν στο βόρειο μέρος της περιοχής (βόρεια του 38ου παραλλήλου), ενώ κατά το ίδιο χρονικό διάστημα έγιναν μεγάλοι σεισμοί ενδιαμέσου βάθους στο νότιο Αιγαίο. Κατά την επόμενη περίοδο (1933-1957) η σεισμική δράση ($M \geqslant 7.0$) μετανάστευσε κατά κύριο λόγο στο νότιο τμήμα της περιοχής. Κατά την τρίτη περίοδο (1958-1982) έγιναν μόνο επιφανειακοί μεγάλοι ($M \geqslant 7.0$) σεισμοί οι οποίοι είχαν τα επικεντρά τους στο βόρειο μέρος της περιοχής.

Επειδή κατά την τελευταία χρονική περίοδο κανένας μεγάλος σεισμός ($M \geqslant 7.0$) δεν έγινε στο νότιο χώρο του Αιγαίου, συμπεραίνεται ότι ο χώρος αυτός αποτελεί κενό σεισμικότητας όπου προβλέπεται να αρχίσει περίοδος έντονης σεισμικής δράσης, σε συμφωνία με προηγούμενες ανεξάρτητες έρευνες, και ότι ο σεισμός της 17 Ιανουαρίου 1983 στα Ιόνια νησιά αποτελεί τον πρώτο σεισμό αυτής της περιόδου.

Το συμπέρασμα της εργασίας αυτής ότι το νότιο τμήμα του ευρύτερου χώρου του Αιγαίου βρίσκεται κατά την τελευταία περίοδο σε σεισμική ησυχία ενισχύεται και από το γεγονός ότι ούτε σεισμοί του διαστήματος μεγεθών 6.5 ≤ M ≤ 7.0 έγιναν κατά το χρονικό αυτό διάστημα στο νότιο χώρο του Αιγαίου.

2. **Μακράς Διάρκειας Πρόγνωση Μεγάλων Σεισμών Ενδιαμέσου Βάθους στην Ελλάδα.** "12ο Περιφερειακό Σεμινάριο Σεισμικής Μηχανικής, Ευρωπαϊκής Ένωσης Σεισμικής Μηχανικής, Χαλκιδική, Σεπτέμβριος 16-25, 1985", 1-11, 1985.

Παπαζάχος, Β.Κ., Παπαδημητρίου, Ε.Ε., Καρακώστας, Β.Κ. και Καρακαΐσης, Γ.Φ., Εργαστήριο Γεωφυσικής Αριστοτελείου Πανεπιστημίου Θεσσαλονίκης.

Η περιοχή του νοτίου Αιγαίου έχει αναγνωρισθεί ως κενό σεισμικότητας πρώτου και δευτέρου είδους για σεισμούς ενδιαμέσου βάθους (h ≥ 100Km). Παρατηρήθηκε ότι: α) Δεν έγινε στην περιοχή αυτή ισχυρός σεισμός (M ≥ 6.5) ενδιαμέσου βάθους κατά τα τελευταία 54 χρόνια, ούτε πολύ μεγάλος σεισμός (M ≥ 7.8) κατά τα τελευταία 58 χρόνια, β) Πέντε πολύ μεγάλοι σεισμοί (M ≥ 7.8) ενδιαμέσου βάθους έγιναν στην περιοχή αυτή μεταξύ 1810-1926, γ) Η σεισμική δράση που οφείλεται σε μικρούς σεισμούς ενδιαμέσου βάθους υπήρξε σημαντική τουλάχιστον από το χρόνο της εγκατάστασης του πρώτου αξιόπιστου σεισμομέτρου στον ελληνικό χώρο (1911) μέχρι το 1948, ενώ κατά τα τελευταία 34 χρόνια αυτή η σεισμική δράση ελαττώθηκε σημαντικά. Παρουσιάζονται ισχυρές ενδείξεις ότι η σεισμική δυναμικότητα της περιοχής αυτής για τη γένεση μεγάλων σεισμών είναι υψηλή. Αυτές οι ενδείξεις και το γεγονός ότι οι πολύ μεγάλοι σεισμοί ενδιαμέσου βάθους, οι οποίοι δεν έχουν πλήξει ακόμα νέες υψηλές οικοδομές στην Ελλάδα, προκαλούν μεγάλης περιόδου και μεγάλου πλάτους κύματα μέχρι πολύ μεγάλες αποστάσεις, οδηγούν στο συμπέρασμα ότι τέτοιοι σεισμοί αποτελούν πρώτου μεγέθους σεισμικό κίνδυνο για τις οικοδομές και κυρίως τις υψηλές (Ξενοδοχεία, κλπ) ολόκληρου του νοτιοελλαδικού χώρου κατά τη διάρκεια των επόμενων λίγων δεκαετιών.

3. **Σχέση μεταξύ της Σεισμικής Δράσης της Κρήτης και των Ιονίων Νησιών ".** Δημοσιεύσεις Εργαστηρίου Γεωφυσικής, Πανεπιστημίου Θεσσαλονίκης",18, 1-7,1985.

Παπαδημητρίου,Ε.Ε. και Κυρατζή,Α.Α.,Εργαστήριο Γεωφυσικής Πανεπιστημίου Θεσσαλονίκης.

Δεδομένα τα οποία βασίστηκαν στις σεισμικές αναγραφές της περιόδου 1947-1985 δείχνουν ότι υπάρχει μιά σχέση μεταξύ της σεισμικής δράσης του βορειοδυτικότερου τμήματος του ελληνικού τόξου (Ιόνια νησιά) και του νοτιότερου τμήματος του τόξου αυτού (Κρήτη). Παρατηρήθηκε μία αντιστοιχία στη γένεση των σεισμών οι οποίοι έγιναν στις δύο περιοχές κατά τη χρονική αυτή περιόδο και είχαν μεγέθη M$\geqslant$5.9. Στις περισσότερες των περιπτώσεων παρατηρήθηκε μία-προς-μία εναλλακτική γένεση των σεισμών αυτών στις δύο περιοχές. Η περιοχή η οποία βρίσκεται μεταξύ της δυτικής Κρήτης και των Ιονίων νησιών (νότια Πελοποννήσου) δεν επηρεάστηκε από τη σχέση αυτή της σεισμικής δράσης στα δύο άκρα της και παραμένει άθραυστη από το 1947 από σεισμικές διαρρήξεις με μεγέθη M$\geqslant$6.0.

Η παρατήρηση αυτής της σχέσης μεταξύ της σεισμικής δράσης των δύο περιοχών είναι δύσκολο προς το παρόν να ερμηνευθεί. Όμως, η παρατήρηση αυτή καθεαυτή είναι χρήσιμη για πρακτικούς λόγους γιατί μπορεί να συμβάλει στη λύση του προβλήματος της μακράς διάρκειας πρόγνωσης των σεισμών στην περιοχή.

4. **Μετανάστευση της Σεισμικής Δράσης Ενδιαμέσου Βάθους στο Εσωτερικό Μέρος του Ελληνικού Τόξου.** "Δημοσιεύσεις Εργαστηρίου Γεωφυσικής Αριστοτελείου Πανεπιστημίου Θεσσαλονίκης", 19, 1-5,2985.

Παπαδημητρίου,Ε.Ε.,Εργαστήριο Γεωφυσικής Πανεπιστημίου Θεσσαλονίκης.

Δεδομένα σεισμών ενδιαμέσου βάθους οι οποίοι είχαν μεγέθη M$\geqslant$6.0 και έγιναν κατά τον παρόντα αιώνα στο εσωτερικό μέρος του Ελληνικού τόξου ($35^{o}N-37^{o}N$, $22.7^{o}-28.5^{o}E$)χρησιμοποιήθηκαν για να μελετηθεί η χωροχρονική κατανομή των σεισμών αυτών. Διαπιστώθηκε μιά κανονικότητα στην κατανομή αυτή. Καθορίσθηκε μία ζώνη η οποία έχει διεύθυνση Ανατολή-Δύση κατά μήκος της οποίας παρατηρήθηκε μετανάστευση της σεισμικής δράσης ενδιαμέσου βάθους. Παρατηρήθηκαν τρεις διαδοχικές περίοδοι μετανάστευσης των οποίων οι διάρκειες ήταν 24 χρόνια,19 χρόνια και 18 χρόνια και η τελευταία ακολουθήθηκε από μία περίοδο σεισμικής ησυχίας της οποίας η διάρκεια είναι 20 χρόνια και συνεχίζεται μέχρι σήμερα.

Αν και είναι δύσκολο να δοθεί φυσική ερμηνεία στο φαινόμενο αυτό της μετανάστευσης, η μελέτη της μετανάστευσης αυτής παρουσιάζει εξαιρετικό ενδιαφέρον για τη μακράς διάρκειας πρόγνωση των σεισμών ενδιαμέσου βάθους στο νότιο Αιγαίο, αφού οι σεισμοί αυτοί είναι εξαιρετικά επικίνδυνοι λόγω του μεγάλου μεγέθους τους ($M\sim 8$) και των μεγάλων αποστάσεων στις οποίες μπορούν να προκαλέσουν βλάβες,ιδιαίτερα στις υψηλές κατασκευές.

5. **Σεισμικές ζώνες Διάρρηξης στο Χώρο του Αιγαίου και τις γύρω Περιοχές.** "Δημοσιεύσεις Εργαστηρίου Γεωφυσικής, Αριστοτελείου Πανεπιστημίου Θεσσαλονίκης" , 2, 1- 13 , 1986.

Παπαζάχος,Β.Κ.,Χατζηδημητρίου,Π.Μ.,Καρακώστας,Β.Γ..Εργαστήριο Γεωφυσικής, Αριστοτελείου Πανεπιστημίου Θεσσαλονίκης.

Ως σεισμικές ζώνες διάρρηξης ορίζονται ενεργές τεκτονικά περιοχές οι οποίες έχουν καθορισθεί με σεισμικά στοιχεία κατά κύριο λόγο. Με βάση δημοσιευμένα και αδημοσίευτα ιστορικά στοιχεία (600 π.Χ.-1900) και στοιχεία που βασίζονται σε σεισμικές αναγραφές σεισμομέτρων (1901-1985) και αφορούν τους γνωστούς μεγάλους σεισμούς ($M\geqslant 6.0$) επιφανείας ($h > 70Km$) και ενδιαμέσου ($70Km \leqslant h \leqslant 180Km$) εστιακού βάθους, οι κύριες σεισμικές ζώνες διάρρηξης στο Αιγαίο και στις γύρω περιοχές έχουν καθορισθεί. Ο καθορισμός των ζωνών αυτών , ο οποίος έγινε με το μεγαλύτερο και ακριβέστερο πλήθος στοιχείων που έχουν χρησιμοποιηθεί μέχρι σήμερα για το σκοπό αυτό, έχει πρώτιστη σημασία για προβλήματα που αφορούν την πρόγνωση των σεισμών και τη σεισμική επικινδυνότητα καθώς και για γεωδυναμικά προβλήματα. Όσον αφορά την πρόγνωση των σεισμών οι ζώνες αυτές είναι οι περιοχές όπου κατά κύριο λόγο πρέπει να αναζητηθούν πρόδρομα φαινόμενα και να εστιαστεί η ερευνητική προσπάθεια.

6. **Προσεισμική Ησυχία πριν από Μεγάλους Σεισμούς στο Αιγαίο και τις γύρω Περιοχές.** "Δημοσιεύσεις του Εργαστηρίου Γεωφυσικής Αριστοτελείου Πανεπιστημίου Θεσσαλονίκης", 3, 1 - 13 ,1986.

Καρακαΐσης,Γ.Φ.,Παναγιωτόπουλος,Δ.Γ.,Κρημνιανιώτου,Μ.,Παπαζάχος,Β.Κ. Εργαστήριο Γεωφυσικής,Πανεπιστημίου Θεσσαλονίκης.

Η εργασία αυτή αποτελεί επέκταση άλλων εργασιών οι οποίες εκπονήθηκαν προηγούμενα και αφορούν την σημαντική ελάττωση της συχνότητας των μικρών σεισμών ορισμένα χρόνια πριν από τη γένεση των μεγάλων σεισμών. Δείχνεται ότι υπήρξε σεισμική ησυχία (ελάττωση της συχνότητας των μικρών σεισμών) πριν από τη γένεση όλων των μεγάλων σεισμών ($M \geq 7.0$) οι οποίοι έγιναν στο χώρο του Αιγαίου και τις γύρω περιοχές κατά τα τελευταία 40 χρόνια. Η διάρκεια της προσεισμικής ησυχίας κυμαινόταν από 7 μέχρι 22 χρόνια, ενώ οι διαστάσεις του χώρου τον οποίον επηρέασε η ησυχία αυτή είναι της τάξης των 200Km, δηλαδή, ο χώρος αυτός είναι σημαντικά μεγαλύτερος του σεισμογόνου χώρου των σεισμών.

Έγινε συστηματικός έλεγχος όλων των σεισμικών ζωνών του Ελληνικού χώρου και των γύρω χωρών για τον καθορισμό περιοχών οι οποίες παρουσιάζουν σήμερα σεισμική ησυχία και συνεπώς θεωρούνται επικίνδυνες για τη γένεση μεγάλων σεισμών κατά τα προσεχή χρόνια. Βρέθηκε ότι βρίσκονται σε σεισμική ησυχία οι ζώνες 1C (Δυτικές ακτές Αλβανίας και Ελλάδας), 2N (Λευκάδα),3(ΝΔ της Πελοποννήσου),4(Κρήτη),5(Κάρπαθος , Ρόδος), 8A(Πατραϊκός Κόλπος και δυτικό τμήμα του Κορινθιακού κόλπου), 10 και 11 (Σάμος,Χίος και τμήμα της Δυτικής Τουρκίας), 13(Λέσβος και τμήμα της Δυτ.Τουρκίας) και 14Α(Θάλασσα του Μαρμαρά και τμήμα του Β.Αιγαίου). Οι περισσότερες από τις περιοχές σχετίζονται με αντίστοιχες περιοχές οι οποίες θεωρήθηκαν σεισμικά επικίνδυνες από προηγούμενους ερευνητές.

7. **Πιθανότητες Γένεσης Μεγάλων Σεισμών στο Αιγαίο και τις γύρω Περιοχές κατά τη Διάρκεια της Περιόδου 1986-2006.**"Δημοσιεύσεις Εργαστηρίου Γεωφυσικής,Αριστοτελείου Πανεπιστημίου Θεσσαλονίκης, 4, 1 - 23, 1986.

Παπαζάχος,Β.Κ.,Παπαδημητρίου,Ε.Ε.,Κυρατζή,Α.Α.,Παπαϊωάννου,Χ.Α.,Καρακαΐσης,Γ.Φ..Εργαστήριο Γεωφυσικής Αριστοτελείου Πανεπιστημίου Θεσσαλονίκης.

Με βάση όλα τα διαθέσιμα ιστορικά στοιχεία καθώς και τα στοιχεία του παρόντα αιώνα υπολογίσθηκαν απευθείας από τα δεδομένα παρατήρησης οι μέσες περίοδοι επανάληψης των σεισμών στις διάφορες σεισμικές ζώνες του ελληνικού χώρου σε συνάρτηση με τα μεγέθη τόσο των επιφανειακών όσο και των ενδιαμέσου βάθους σεισμών. Υπολογίσθηκαν επίσης τα σχετικά σφάλματα τα οποία υπεισέρχονται στους υπολογισμούς των μέσων περιόδων επανάληψης.

Με τη χρησιμοποίηση των μέσων περιόδων επανάληψης για διάφορες τάξεις μεγεθών ($M \geqslant 6.0$, $M \geqslant 6.5$, $M \geqslant 7.0$, $M \geqslant 7.5$), του χρόνου ο οποίος πέρασε από τη γένεση του τελευταίου μεγάλου σεισμού και υπό την προϋπόθεση ότι οι χρόνοι επανάληψης των σεισμών ακολουθούν κανονική κατανομή, υπολογίσθηκαν οι πιθανότητες γένεσης σεισμών διαφόρων τάξεων μεγεθών κατά τα επόμενα 20 χρόνια σε κάθε μιά από τις σεισμικές ζώνες. Καθορίσθηκαν έτσι πιθανολογικά οι περιοχές οι οποίες παρουσιάζουν πολύ μεγάλη πιθανότητα, μεγάλη πιθανότητα μέτρια πιθανότητα και μικρή πιθανότητα για τη γένεση επιφανειακών σεισμών μεγέθους, $M \geqslant 6,0$, $M \geqslant 6.5$ και $M \geqslant 7.0$ και εκπονήθηκαν σχετικοί χάρτες. Καθορίστηκαν επίσης οι ζώνες οι οποίες παρουσιάζουν αντίστοιχο πιθανότητες για τη γένεση μεγάλων σεισμών ενδιαμέσου βάθους

3. ΣΧΕΤΙΚΗ ΒΙΒΛΙΟΓΡΑΦΙΑ

Κατά την εκπόνηση του προγράμματος αυτού μελετήθηκε όλη η διαθέσιμη διεθνώς βιβλιογραφία. Το σημαντικότερο μέρος τη βιβλιογραφίας αυτής περιέχεται στο τέλος των εργασιών οι οποίες περιλαμβάνονται αυτούσιες στο όγδοο κεφάλαιο της έκθεσης αυτής. Αναφέρονται παρακάτω δημοσιεύσεις οι οποίες αφορούν κυρίως τη μακράς διάρκειας πρόγνωση των σεισμών στον Ελληνικό χώρο, και τις γύρω περιοχές και αποτέλεσαν τη βάση για την εκπόνηση του παρόντος προγράμματος. Η δημοσίευση (2) αποτελεί κατάλογο των σεισμών του παρόντα αιώνα ο οποίος δημοσιεύτηκε αρχικά το 1982, οπότε περιείχε στοιχεία μέχρι και το 1980, ενώ συμπληρώθηκε με τα στοιχεία της πενταετίας 1981-1985 και επανεκτυπώθηκε στα πλαίσια του παρόντος προγράμματος. Ο κατάλογος αυτός μαζί με τα ιστορικά στοιχεία αποτέλεσαν τη βασική πηγή δεδομένων για το παρόν πρόγραμμα.

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Papadimitriou,E.E.,Karacostas,B.G.,Karakaisis,G.F. and Papazachos,B.C. A seismicity premonitory pattern in the southern Aegean area. **"XIX General Assembly of the European Seismological Commission, October 1-6, 1984,Moscow"**, 1-7, 1984.

Papadimitriou,E.E. and Papazachos,B.C. Evidence for premonitory patterns in the Ionian Islands (Greece).**"Earthq. Pred. Res."**, 3, 95-103, 1985.

Papadimitriou,E.E. and Papazachos,B.C. Seismicity gaps in the Aegean and surrounding area. **"Boll. Geof. Teor. Appl."**,Vol. XXVII, N. 107, 185-195, 1985.

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Papazachos,B.C. and Comninakis,P.E. Long-term earthquake prediction in the Hellenic Trench-Arc System.**"Tectonophysics"**, 86, 3-16, 1982.

Papazachos,B.C. and Comninakis,P.E. A catalogue of historical earthquakes in Greece and surrounding area, 479 B.C.- 1900 A.D. **"Publication Geophysical Laboratory,University of Thessaloniki"**, 6, 1-24, 1982.

Papazachos,B.C.,Tsapanos,T.M.and Panagiotopoulos,D.G. A premonitory pattern of earthquakes in northern Greece.**"Nature"**, 296, 232-235, 1982.

Papazachos,B.C.and Papadimitriou,E.E.Seismicity regularities in Greece as premonitory patterns."Proceedings of the International Symposium on Continental Seismicity and Earthquake Prediction", Beijing, China, 191-197, 1984.

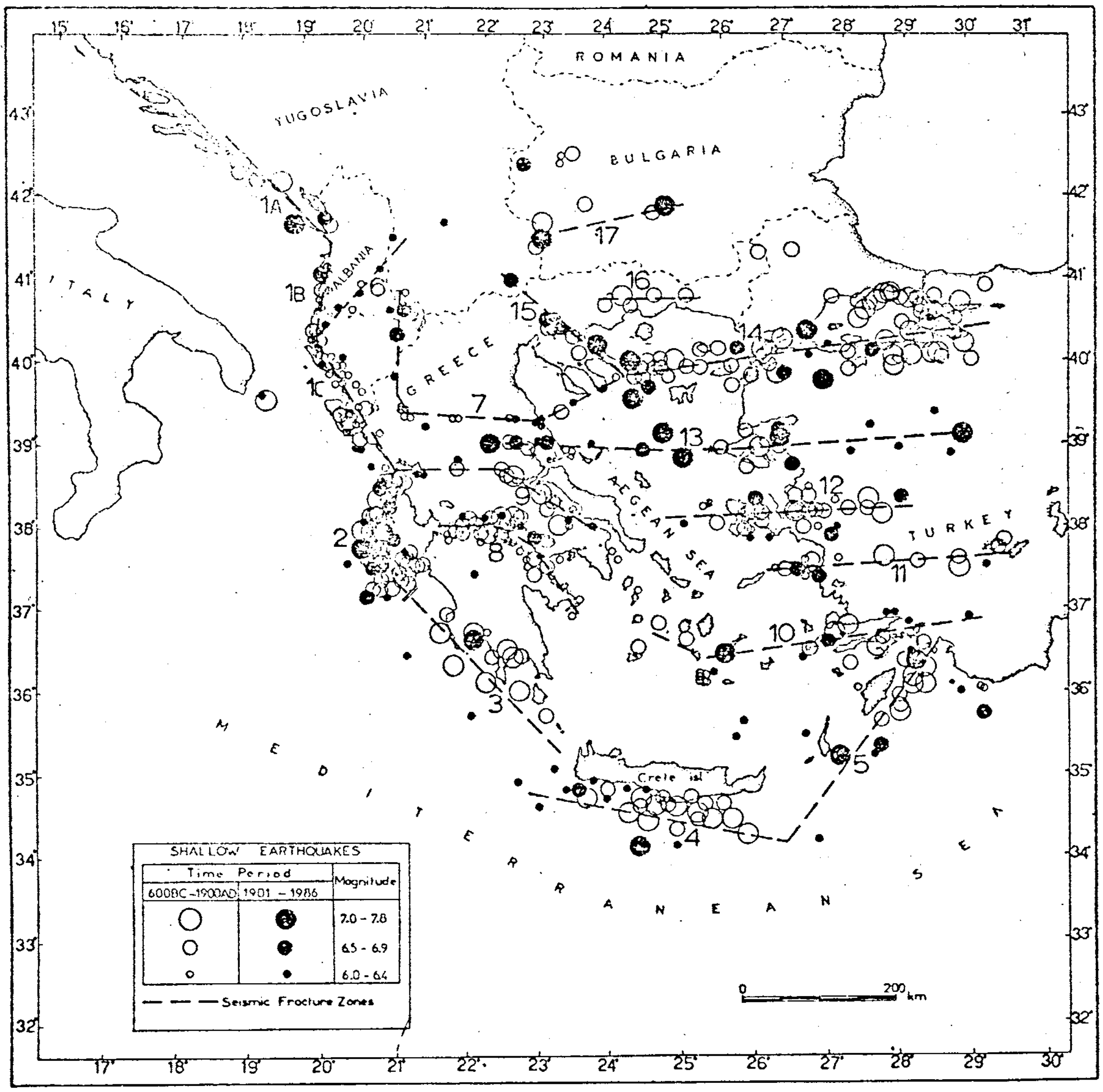
4. ΣΥΝΘΕΣΗ ΤΩΝ ΑΠΟΤΕΛΕΣΜΑΤΩΝ ΤΟΥ ΠΡΟΓΡΑΜΜΑΤΟΣ

Με βάση τις επιστημονικές δημοσιεύσεις του προγράμματος αυτού καταβλήθηκε προσπάθεια σύνθεσης των αποτελεσμάτων των εργασιών αυτών και παρουσίασης της συνθετικής αυτής εργασίας σε δύο μόνο πίνακες και σε δύο μόνο χάρτες, ένα για τους σεισμούς επιφανείας και ένα για τους σεισμούς ενδιαμέσου βάθους, οι οποίοι να δείχνουν όσο το δυνατόν συνοπτικότερα το όλο αποτέλεσμα. Η τέτοια παρουσίαση έχει το πλεονέκτημα ότι δίνει, ακόμα και στους μη ειδικούς άμεσες πληροφορίες και με απλό τρόπο την πιθανότητα γένεσης ισχυρών σεισμών στον ελληνικό χώρο και τις γύρω περιοχές κατά την επόμενη εικοσαετία. Εννοείται βέβαια ότι λεπτομερέστερες πληροφορίες περιέχονται στις αντίστοιχες δημοσιεύσεις.

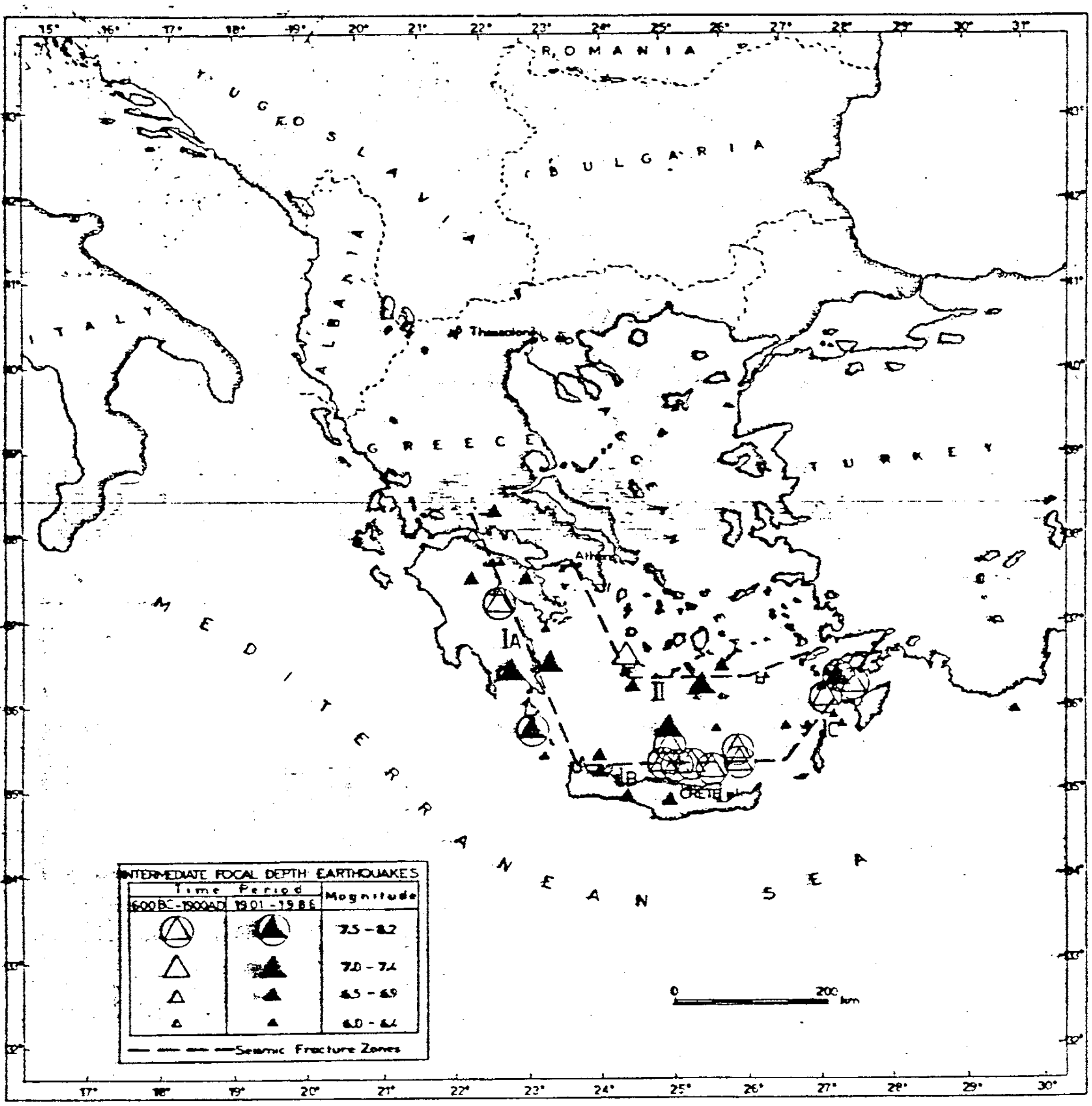
Στο σχήμα (4.1) φαίνονται οι διάφορες σεισμικές ζώνες διάρρηξης των επιφανειακών σεισμών με τους αντίστοιχους κωδικούς τους αριθμούς, ενώ στο σχήμα (4.2) φαίνονται οι σεισμικές ζώνες διάρρηξης για τους σεισμούς ενδιαμέσου βάθους.

Ως βασική εργασία για τη σύνθεση αυτή θεωρήθηκε η εργασία αριθμ. (7) της παρούσας έκθεσης, ενώ ως καταλληλότερο διάστημα μεγεθών σεισμών για την αντιπροσωπευτικότερη συνοπτική παρουσίαση των αποτελεσμάτων επιλέχθηκε το διάστημα $M \geq 6.5$ επειδή βλάβες προκαλούνται συνήθως από σεισμούς αυτού του διαστήματος μεγεθών.

Πέρα από την πιθανότητα, $P(M \geq 6.5)$, για τη γένεση σεισμών $M \geq 6.5$ κατά την επόμενη εικοσαετία που καθορίσθηκε για κάθε μιά ζώνη στην εργασία (7), λήφθηκαν υπόψη, α) το μέγιστο μέγεθος σεισμού, M_{max}, που παρατηρήθηκε σε κάθε ζώνη με βάρος ίσο με $\beta_1 = M_{max}/\overline{M}_{max}$, όπου $\overline{M}_{max}$ είναι το μέσο μέγιστο μέγεθος όλων των ζωνών, β) Στοιχεία ότι άλλες μέθοδοι συνηγορούν ή όχι για την αυξημένη σεισμική δυναμικότητα της ζώνης να δώσει σεισμούς κατά τα επόμενα χρόνια με βάρος β_1 ίσο με 1,0 ή 0,9, αντίστοιχα, γ) Η μέση επικεντρική ένταση κάθε ζώνης για το χρο-



Σχ.4.1. Οι κύριες σεισμικές ζώνες διάρρηξης επιφανειακών σεισμών στον ελληνικό χώρο και τις γύρω περιοχές (Παπαζάχος και συνεργάτες 1986).



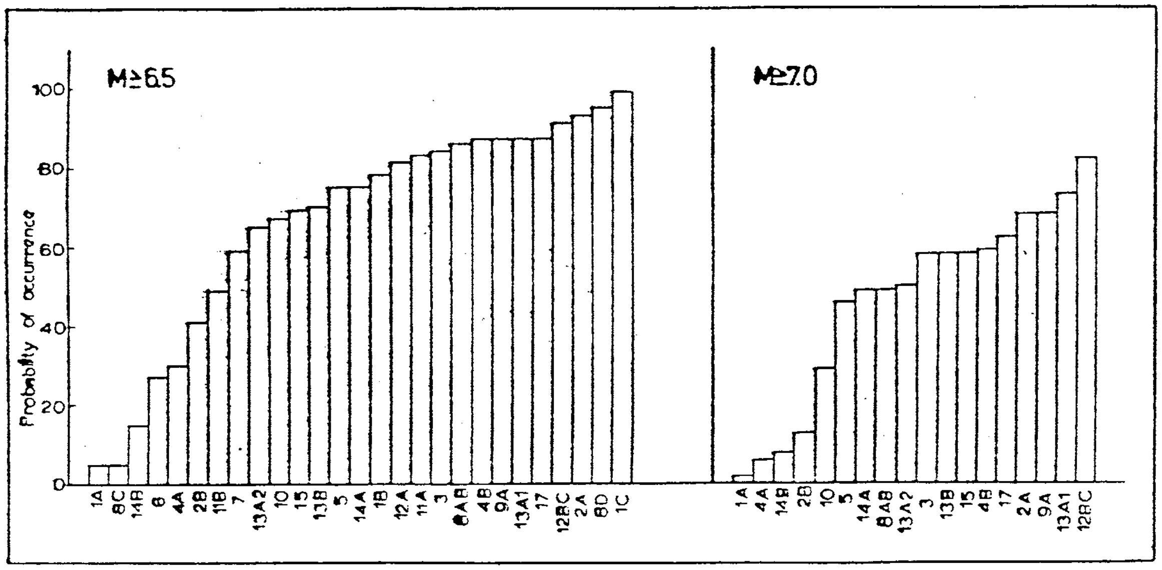
Σχ.4.2. Οι κύριες σεισμικές ζώνες διάρρηξης των σεισμών ενδιαμέσου βάθους στον ελληνικό χώρο και τις γύρω περιοχές (Παπαζάχος και συνεργάτες 1986).

ικό διάστημα πληρότητας του υλικού, I_0, με βάρος $\beta_3 = I_0/\overline{I}_0$, όου $\overline{I}_0$ είναι ο μέσος όρος των μέσων επικεντρικών εντάσεων όων των ζωνών. Έτσι, ως τελικό μέτρο της σεισμικής δυναμικόητας κάθε ζώνης (ή τμημάτων ζωνών) να δώσει ισχυρούς βλαβεούς σεισμούς θεωρήθηκε η ποσότητα

$$P^* = \beta_1 \beta_2 \beta_3 P(M \geqslant 6.5) \qquad (1)$$

Οι τιμές της ποσότητας P^* για τις διάφορες ζώνες που σχηατίζουν οι επιφανειακοί σεισμοί (σχ.4.1) και οι σεισμοί ενιαμέσου βάθους (σχ.4.2) δίνονται για κάθε ζώνη ή τμήμα της τον πίνακα (Ι).

Στο σχήμα (4.3) παρουσιάζονται γραφικά οι τιμές της ποσόητας P^* για τις διάφορες σεισμικές ζώνες.



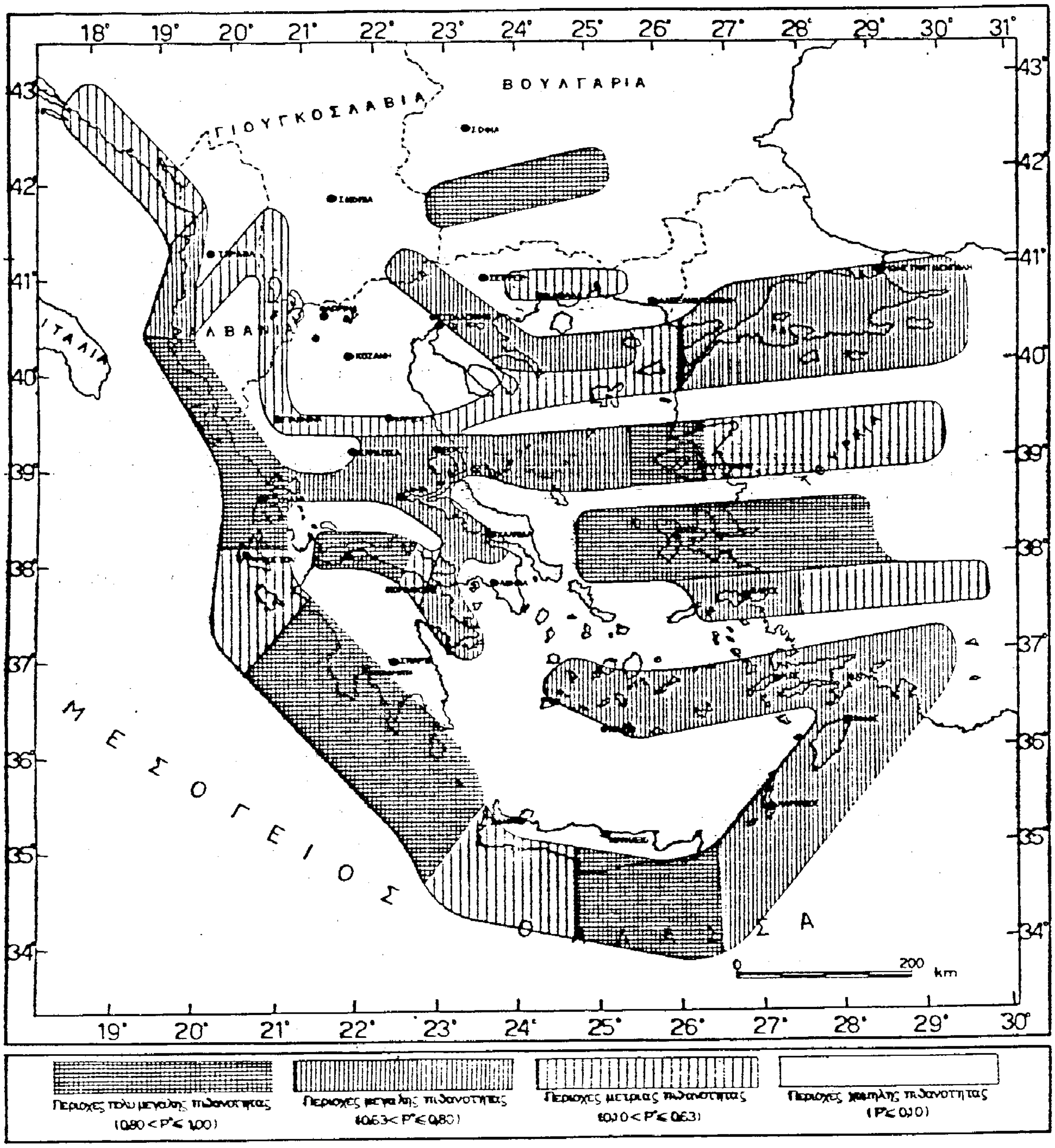
(.4.3. Κατανομή των τιμών τής ποσότητας P^* για τις διάφορες σεισμικές ζώνες.

Πίνακας Ι. Τιμές του μέτρου P^* της σεισμικής δυναμικότητας για τη γένεση ισχυρών βλαβερών σεισμών ($M \geq 6.5$) κατά την εικοσαετία 1986-2006 στις διάφορες σεισμικές ζώνες του ελληνικού χώρου και των γύρω περιοχών.

No	Όνομα περιοχής	Πιθανότητα P^*
2A	Λευκάδα	1,00
1C	ΝΔ Αλβανία	0,93
$13A_1$	Λέσβος	0,93
12BC	Τμήμα ΚΔ. Τουρκίας και Χίος	0,91
4B	Ανατολική Κρήτη	0,89
8AB	Πατραϊκός-Δ.Κορινθιακός Κόλπος	0,89
3	Ν.Ζακύνθου-Ακτές Δ-ΝΔ Πελοποννήσου	0,88
17	Ν.Βουλγαρία	0,87
12A	Χίος	0,82
1B	Δ.Αλβανία	0,79
11A	Σάμος	0,79
8D	Σαρωνικός κόλπος	0,78
9A	Ευβοϊκός	0,78
14A	Θάλασσα Μαρμαρά	0,78
9B	Κ.Ελλάδα	0,73
15	Σερβομακεδονική	0,68
5	Κάρπαθος-Ρόδος	0,66
10	Κώς-Θήρα	0,66
13B	Σποράδες-Μαγνησία	0,66
$13A_2$	Τμήμα δυτ.Τουρκίας	0,57
7	ΝΑ Αλβανία-ΒΔ Μακεδονία-Β.Θεσσαλία-Ν. ακτές Χαλκιδικής	0,56
11B	ΝΔ Τουρκία	0,43
2B	Κεφαλλονιά-Ζάκυνθος	0,38
4A	Δυτική Κρήτη	0,23
6	Κεντρική Αλβανία	0,23
14B	Β.Αιγαίο-Λήμνος	0,14
1A	ΝΔ Γιουγκοσλαβία	0,10
8C	Α.Κορινθιακός	0,10

ΕΡΓΑΣΤΗΡΙΟ ΓΕΩΦΥΣΙΚΗΣ , ΑΡΙΣΤΟΤΕΛΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΕΣΣΑΛΟΝΙΚΗΣ

ΧΑΡΤΗΣ
ΠΙΘΑΝΟΛΟΓΙΚΗΣ ΠΡΟΓΝΩΣΗΣ ΙΣΧΥΡΩΝ ΕΠΙΦΑΝΕΙΑΚΩΝ ΣΕΙΣΜΩΝ ΣΤΟΝ ΕΛΛΗΝΙΚΟ ΧΩΡΟ ΚΑΙ ΤΙΣ ΓΥΡΩ ΠΕΡΙΟΧΕΣ
1986-2006



Σχ.4.4. Χάρτης πιθανολογικής πρόγνωσης των επιφανειακών σεισμών του ελληνικού χώρου και των γύρω περιοχών. Διακρίνονται τέσσερες κατηγορίες ζωνών όπου η πιθανότητα για τη γένεση ισχυρών βλαβερών σεισμών(M≥6.5) κατά το χρονικό διάστημα 1986-2006 είναι πολύ μεγάλη, μεγάλη, μέτρια και μικρή αντίστοιχα.

Τον υπό μελέτη χώρο χωρίσαμε σε πέντε κατηγορίες ανάλογα με την τιμή της ποσότητας P^*, για τους επιφανειακούς σεισμούς. Στην πρώτη κατηγορία υπάγονται οι εννέα πρώτες ζώνες του πίνακα (I) οι οποίες χαρακτηρίζονται ως ζώνες **π ο λ ύ μ ε γ ά λ η ς π ι θ α ν ό τ η τ α ς** ($0,8 < P^* \leq 1.0$), στη δεύτερη κατηγορία (II) υπάγονται οι επόμενες δέκα ζώνες του πίνακα (I) οι οποίες χαρατηρίζονται ως ζώνες **μ ε γ ά λ η ς π ι θ α ν ό τ η τ α ς** ($0,63 < P^* \leq 0,8$), στην τρίτη κατηγορία (III) υπάγονται οι δέκα τελευταίες του πίνακα (I) οι οποίες χαρακτηρίζονται ως ζώνες **μ έ σ η ς π ι θ α ν ό τ η τ α ς** ($0,1 < P^* \leq 0,63$) και στην τέταρτη (IV) κατηγορία υπάγεται ο υπόλοιπος χώρος ο οποίος χαρακτηρίζεται ως χώρος **μ ι κ ρ ή ς π ι θ α ν ό τ η τ α ς** για τη γένεση ισχυρών βλαβερών σεισμών κατά την επόμενη εικοσαετία.

Στο χάρτη του σχήματος (4.4.) παριστάνονται οι ζώνες των τεσσάρων κατηγοριών σεισμικής δυναμικότητας.

Όσο αφορά την σεισμικη δραστηριότητα ενδιαμέσου βάθους, χωρίσαμε το χώρο σε τρεις κατηγορίες ανάλογα με την τιμή της ποσότητας P^* για σεισμούς ενδιαμέσου βάθους.

Πίνακας II. Τιμές του μέτρου P^* της σεισμικής δυναμικότητας γιά τη γένεση ισχυρών βλαβερών σεισμών ($M \geq 7,0$) ενδιαμέσου βάθους κατά την εικοσαετία 1986-2006 στις διάφορες σεισμικές ζώνες του ελληνικού χώρου και των γύρω περιοχών.

No	Όνομα Περιοχής	Πιθανότητα P^*
1A	ΝΔ Πελοπόννησος	1,00
1C	Ρόδος	1,00
1B	Κρήτη	0,93
	Εσωτερική ζώνη	0,74

Στην πρώτη κατηγορία υπάγονται οι τρεις πρώτες ζώνες του πίνακα (II) οι οποίες χαρακτηρίζονται ως ζώνες **π ο λ ύ μ ε-**

γ ά λ η ς π ι θ α ν ό τ η τ α ς $(0,8 < P^{*} \leq 1,0)$, στη δεύτερη κατηγορία υπάγεται η εσωτερική ζώνη $(0,63 < P^{*} < 0,8)$ που χαρακτηρίζεται με τιμή μ ε γ ά λ η ς π ι θ α ν ό τ η τ α ς ενώ στην τρίτη κατηγορία υπάγεται ο υπόλοιπος χώρος ο οποίος χαρακτηρίζεται ως χώρος α σ ή μ α ν τ η ς π ι θ α ν ό τ η τ α ς για τη γένεση ισχυρών βλαβερών σεισμών ενδιαμέσου βάθους κατά την επόμενη εικοσαετία.

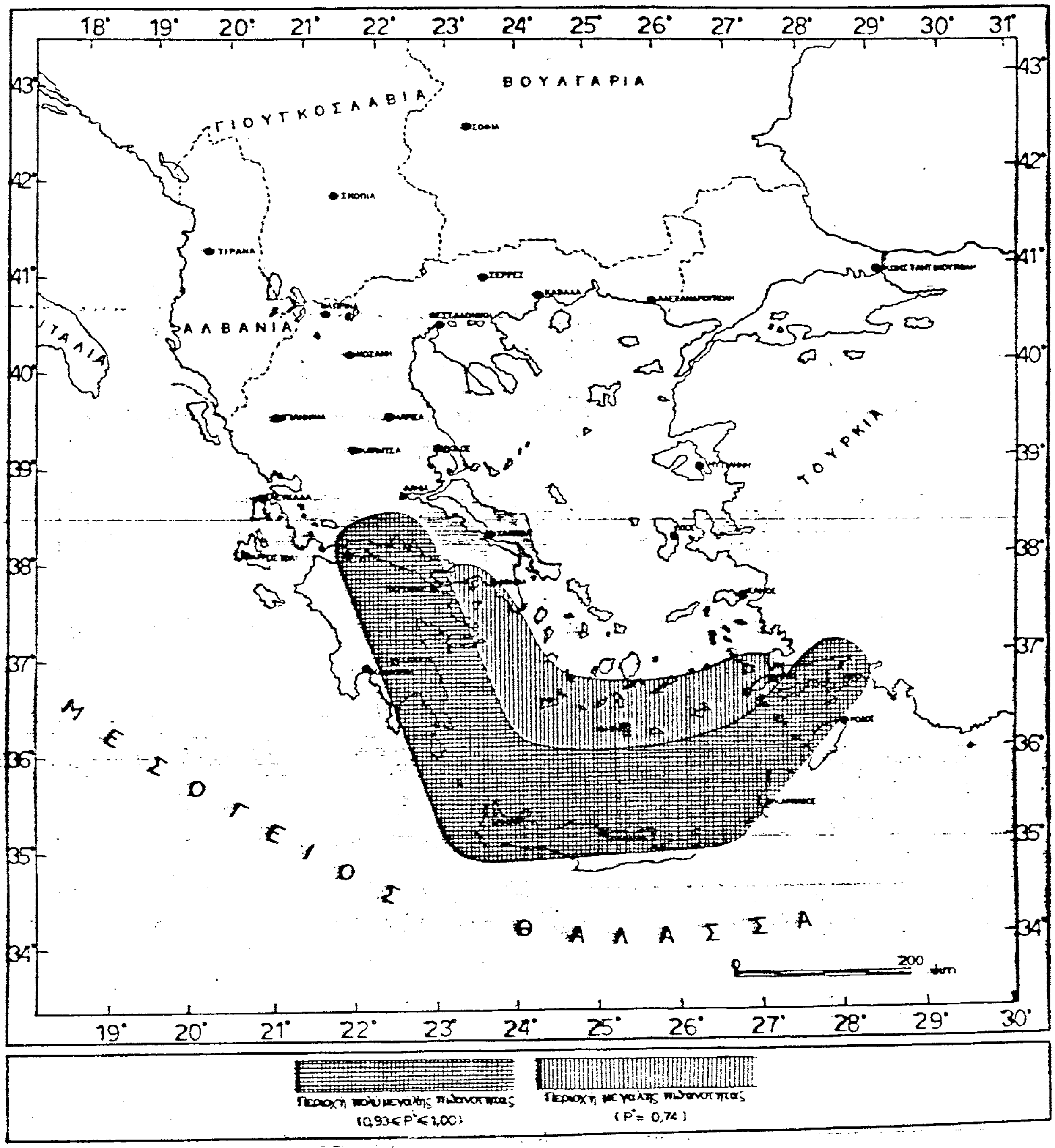
Στο χάρτη του σχήματος (4.5) παριστάνονται οι ζώνες των τριών κατηγοριών σεισμικής δυναμικότητας για σεισμούς ενδιαμέσου βάθους.

ΕΡΓΑΣΤΗΡΙΟ ΓΕΩΦΥΣΙΚΗΣ , ΑΡΙΣΤΟΤΕΛΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΕΣΣΑΛΟΝΙΚΗΣ

ΧΑΡΤΗΣ

ΠΙΘΑΝΟΛΟΓΙΚΗΣ ΠΡΟΓΝΩΣΗΣ ΙΣΧΥΡΩΝ ΕΝΔΙΑΜΕΣΟΥ ΒΑΘΟΥΣ ΣΕΙΣΜΩΝ ΣΤΟΝ ΕΛΛΗΝΙΚΟ ΧΩΡΟ ΚΑΙ ΤΙΣ ΓΥΡΩ ΠΕΡΙΟΧΕΣ

1986-2006



Σχ. 4.5. Χάρτης πιθανολογικής πρόγνωσης των σεισμών ενδιαμέσου βάθους του ελληνικού χώρου και των γύρω περιοχών. Διακρίνονται τρεις κατηγορίες ζωνών όπου η πιθανότητα για τη γένεση ισχυρών βλαβερών σεισμών ενδιαμέσου βάθους ($M \geq 7.0$) κατά το χρονικό διάστημα 1986 - 2006 είναι πολύ μεγάλη, μεγάλη και ασήμαντη αντίστοιχα.

5.ΣΥΝΟΨΙΣΗ ΤΩΝ ΚΥΡΙΩΝ ΕΠΙΣΤΗΜΟΝΙΚΩΝ ΑΠΟΤΕΛΕΣΜΑΤΩΝ ΤΟΥ ΠΡΟΓΡΑΜΜΑΤΟΣ

Βασιζόμενοι στα προηγούμενα μπορούμε να πούμε ότι τα επιστημονικά αποτελέσματα του προγράμματος συνοπτικά είναι τα εξής:

α) Ο καθορισμός των κυρίων σεισμικών ζωνών διάρρηξης του ελληνικού χώρου και των γύρω περιοχών με δείγμα υλικού παρατήρησης (τόσο ιστορικού όσο και ενόργανου) πολύ μεγαλύτερο από ότι προηγούμενα και συνεπώς με μεγαλύτερη ακρίβεια (εργασία 5). Οι ζώνες αυτές καθορίζουν προφανώς τις θέσεις των εστιών μεγάλων μελλοντικών σεισμών.

β) Ο καθορισμός των πιθανοτήτων γένεσης σεισμών με μεγέθη $M \geq 6.0$, $M \geq 6.5$, $M \geq 7.0$, $M \geq 7,5$ κατά την επόμενη εικοσαετία,με πολύ μεγάλο δείγμα υλικού παρατήρησης και με αποτελεσματική μεθοδολογία (εργασία 7) και η κατάταξη των ζωνών σε κατηγορίες διαφόρων βαθμών σεισμικής δυναμικότητας με μεγαλύτερη ακρίβεια από ότι προηγούμενα.

γ) Η διαπίστωση ότι η μεγάλης έκτασης σεισμικη ησυχία (πέρα του σεισμογόνου όγκου) ισχύει για όλους τους μεγάλους σεισμούς ($M \geq 7,0$) οι οποίοι έγιναν κατά τις τελευταίες τέσσερες δεκαετίες στον ελληνικό χώρο και τις γύρω περιοχές και ο ακριβέστερος από προηγούμενες εργασίες προσδιορισμός ζωνών οι οποίες βρίσκονται σε τέτοια ησυχία μεγάλης έκτασης και οι οποίες είναι πιθανώς υποψήφιες για τη γένεση μεγάλων σεισμών (εργασία 6).

δ) Η εκπόνηση συνθετικού χάρτη των κύριων αποτελεσμάτων της έρευνας αυτής στον οποίον οι διάφορες περιοχές του υπό μελέτη χώρου έχουν καταταγεί σε τέσσερες κατηγορίες ανάλογα με το δυναμικό τους για τη γένεση μεγάλων ($M \geq 6.5$) επιφανειακών σεισμών και αντίστοιχου χάρτη για τη γένεση πολύ μεγάλων($M \geq 7,0$) σεισμών ενδιαμέσου βάθους (κεφάλαιο 4).

ε) Η διαπίστωση ότι κατά τον παρόντα αιώνα η σεισμική δράση στο Αιγαίο και στις γύρω περιοχές, η οποία οφείλεται στους μεγάλους επιφανειακούς σεισμούς, παρουσίασε τρεις περιόδους μετανάστευσης κατά τις κατευθύνσεις βορράς-νότος-βορράς και το συμπέρασμα ότι κατά το επόμενο στάδιο η μετανάστευση θα πραγματοποιηθεί προς το νότιο Αιγαίο όπου αναμένονται μεγάλοι σεισμοί(εργασία 1).

στ) Ο εντοπισμός κατά μήκος του κοίλου μέρους του ελληνικού χώρου μιάς ζώνης η οποία παρουσιάζει αυξημένη πιθανότητα γένεσης πολύ μεγάλων σεισμών ($M \geq 7,0$) ενδιαμέσου βάθους κατά τις επόμενες δεκαετίες (εργασία 2).

ζ) Η διαπίστωση σχέσης μεταξύ της σεισμικής δράσης στα Ιόνια νησιά και στη δυτική Κρήτη (εργασία 3) και της μετανάστευσης της σεισμικής δράσης ενδιαμέσου βάθους στο εσωτερικό μέρος του ελληνικού τόξου (εργασίες 3,4).

Σημαντική συμβολή του προγράμματος αποτελεί επίσης το γεγονός ότι δημιούργησε προοπτικές για την παραπέρα θετική εξέλιξη της μακράς διάρκειας πρόγνωσης των σεισμών στην Ελλάδα. Η έρευνα μάλιστα προς ορισμένες κατευθύνσεις, όπως είναι ο υπολογισμός της σεισμικής επικινδυνότητας για τις επόμενες δεκαετίες, άρχισε ήδη κατά τη διάρκεια αυτού του προγράμματος.

Πέρα από τα επιστημονικά αποτελέσματα του προγράμματος υπάρχουν και έμμεσα οφέλη, όπως είναι η συνεργασία μεταξύ ερευνητών και η εκπαίδευση νέων επιστημόνων η προβολή της χώρας με τις επιστημονικές ανακοινώσεις και δημοσιεύσεις,κλπ.

Σύμφωνα με τη σχετική σύμβαση, κύριος στόχος του προγράμματος είναι ο καθορισμός των περιοχών του ελληνικού χώρου οι οποίες παρουσιάζουν αυξημένη πιθανότητα να αποτελέσουν εστίες μεγάλων σεισμών κατά τις επόμενες δύο δεκαετίες.

Είναι φανερό ότι ο στόχος αυτός του προγράμματος επιτεύχθηκε αφού καθορίσθηκαν οι περιοχές αυτές και κατατάχθηκαν με ποσοτικά κριτήρια σε κατηγορίες ανάλογα με το δυναμικό τους για τη γένεση μεγάλων σεισμών κατά τα επόμενα 20 χρόνια.

Για το σκοπό αυτό χρησιμοποιήθηκε εξαιρετικά μεγάλο δείγμα αξιόπιστου υλικού παρατήρησης και σύγχρονη μεθοδολογία. Καταβλήθηκε προσπάθεια, κατά την εκπόνηση του προγράμματος αυτού, ώστε να αξιοποιηθούν όλες οι δυνατότητες που παρέχει σήμερα η επιστήμη για τη λύση του προβλήματος της μακράς διάρκειας πρόγνωσης των σεισμών με σεισμικές μεθόδους.

6. ΠΡΟΤΑΣΕΙΣ ΓΙΑ ΤΟΝ ΤΡΟΠΟ ΑΞΙΟΠΟΙΗΣΗΣ ΤΩΝ ΑΠΟΤΕΛΕΣΜΑΤΩΝ ΤΟΥ ΠΡΟΓΡΑΜΜΑΤΟΣ

Παρά το γεγονός ότι το πρόγραμμα αυτό πρέπει να θεωρηθεί ως ένα μέρος της όλης ερευνητικής προσπάθειας για τη λύση του προβλήματος της μακράς διάρκειας πρόγνωσης των σεισμών και του ευρύτερου προβλήματος της αντισεισμικής προστασίας, τα αποτελέσματά του μπορούν να αξιοποιηθούν οχι μόνο από τους ερευνητές κατά την προσπάθειά τους για τη λύση σημαντικών επιστημονικών προβλημάτων αλλά και από την πολιτεία για αντισεισμικό σχεδιασμό κυρίως μεσοπρόθεσμο. Πιστεύουμε ότι τα αποτελέσματα του προγράμματος αυτού μπορούν να απυτελέσουν οδηγό του ΟΑΣΠ για τον αντισεισμικό σχεδιασμό.

Η αξιοποίηση των αποτελεσμάτων του προγράμματος μπορεί να γίνει κατά πολλούς τρόπους. Θα αναφέρουμε εδώ ορισμένους α- από τους πιό σημαντικούς.

Είναι γνωστό ότι η εγκατάσταση σεισμολογικών οργάνων πρέπει να γίνεται κατά τέτοιο τρόπο ώστε στόχος να είναι η λήψη του μέγιστου δυνατού αριθμού και της υψηλότερης δυνατής ποιότητας επιστημονικών πληροφοριών με το λιγότερο δυνατό κόστος . Αυτό ισχύει ιδιαίτερα για τα δίκτυα επιταχυνσιογράφων. Η γνώση των περιοχών οι οποίες παρουσιάζουν αυξημένη πιθανότητα για τη γένεση μεγάλων σεισμών κατά τις επόμενες δεκαετίες, όπως αυτή προκύπτει από το παρόν πρόγραμμα, είναι πρωταρχικής σημασίας για τη λύση του προβλήματος αυτού. Σχετική μελέτη του Ινστιτούτου Τεχνικής Σεισμολογίας και Αντισεισμικών Κατασκευών για το σχεδιασμό δικτύου επιταχυνσιογράφων στον ελληνικό χώρο,η οποία εκπονείται από τον Δ.Παπασταματίου, βασίζεται σε σημαντικό βαθμό στη σχετική έρευνα του Εργαστηρίου Γεωφυσικής.

SPACE-TIME PATTERNS OF SEISMICITY IN THE AEGEAN AND SURROUNDING AREA

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SPACE - TIME PATTERNS OF SEISMICITY IN THE AEGEAN AND SURROUNDING AREA

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ABSTRACT

The relation in seismicity between the northern and the southern part of the egean and surrounding area, based on the migration concept, which is a fundamental ool for earthquake prediction problems, is examrned in the present study. It is hown that the larger ($M \geq 7.0$) earthquakes of the present century occurred in three uccessive time periods in this area. The main feature of this seismic activity is he north-south migration of shallow shocks, while the intermediate shocks are li- ited in the southern part only. The lack in the occurrence of intermediate shocks ince 1935 and of the shallow ones since 1957 in the southern part suggests that trong shallow as well as intermediate earthquakes are expected in the southern part f this area.

INTRODUCTION

The area surrounding the Aegean sea is very interesting for earthquake predi- tion studies because this area has the largest seismicity in the whole Europe. The nderstanding of the tectonic conditions in this area is of primary importance for arthquake prediction research.

The most characteristic tectonic feature of the area is the Hellenic Arc which xtends along its southern part. This arc has roughly a circular shape. Papazachos nd Comninakis (1969,1970) were the first to suggest that the foci of the interme- iate earthquakes are located in a seismic zone dipping from the Eastern Mediterra- ean to the Aegean. The same authors (1971) determined a Benioff zone with an am- hitheatrical shape.

The seismic activity in the area investigated is concentrated along the Helle- ic Arc in its southern part. Most investigators agree that the seismic activity a- sociated with the Hellenic Arc is a result of convergence between the African and urasian lithospheric plates (Papazachos and Comninakis 1971, McKenzie 1972, Finet- i and Morelli 1972).

The Aegean is a marginal sea and the mode of lithospheric interaction in its orthern part is not known well. Some suggestions have been made on this problem. ccording to McKenzie (1978) the dominated extensive forces in this area result in eplacement of the lower part of the lithosphere with hot mantle, producing high eat flow and the slow thermal subsidence characteristic of sedimentary basins.

An attempt is made here, based on time-space plots, to find the relation in seismicity between the southern and the northern part of the Aegean area. Several investigations of time-space seismicity presented by Fedotov (1965), Kelleher (1970, 1972), Kelleher et al. (1973), Sykes (1971) and Mogi (1968 a,b,c), among others, have demonstrated its significance for establishing areas which run a high risk of future maximal earthquakes. It has been found that if an area is known to have suffered major faulting and associated maximal earthquakes in the past, lies in a seismic zone (i.e., in a plate boundary), and is currently seismically quiet, this area may be preparing for a future maximal seismic activity.

The data used in the present study concern the largest ($M_S \geq 7.0$) earthquakes which occurred during the present century in the area investigated. These data have been taken from the catalogue of Comninakis and Papazachos (1982) and are homogeneous and complete. The errors of this catalogue are less than 30 Km in the epicenter determination and less than 0,3 in the magnitude.

SPACE-TIME DISTRIBUTION OF THE LARGEST (M ≥7.0) EARTHQUAKES

Space-time plots can contribute to the information on the occurrence of earthquakes through the time in a certain area. Such information provides a fundamental tool for earthquake prediction.

The first step was to see in which way the largest earthquakes in the Aegean and surrounding area occur and if there is any relationship between the earthquakes occurred in the south part of the area and those in its northern part. The earthquakes examined had magnitudes larger or equal to 7.0, because the largest amount of seismic energy is released by these earthquakes and because the epicenters as well as the magnitudes of these earthquakes are known more precisely.

Any attempt to detect space-time seismicity patterns is handicapped by the brief period for which instrumental data are available. In this case the data available for the area studied concern earthquakes occurred during the present century, namely for the period 1901-1985. The earthquakes occurred in the south part are shallow as well as intermediate ones since the seismicity in this part is associated with the Hellenic Arc as referrenced above. The earthquakes occurred in northern part are only shallow ones.

A space-time plot of events with M≥7.0 from 1901 to present is shown if figure (1). The epicentral latitude as a function of the year of occurrence is shown. This figure shows that the seismic activity may be examined in three distinct time periods.

The first (1903-1932) was the period in which all large shallow earthquakes occurred in the northern part of the area. During this time period, which lasts thirty (30) years, five large (M ≥ 7.0) intermediate depth earthquakes occurred in the southern part of the area.

During the next period (1933-1957) which lasts twenty five (25) years, the seismic activity was mainly shallow and shifted to the central and southern part of the area.

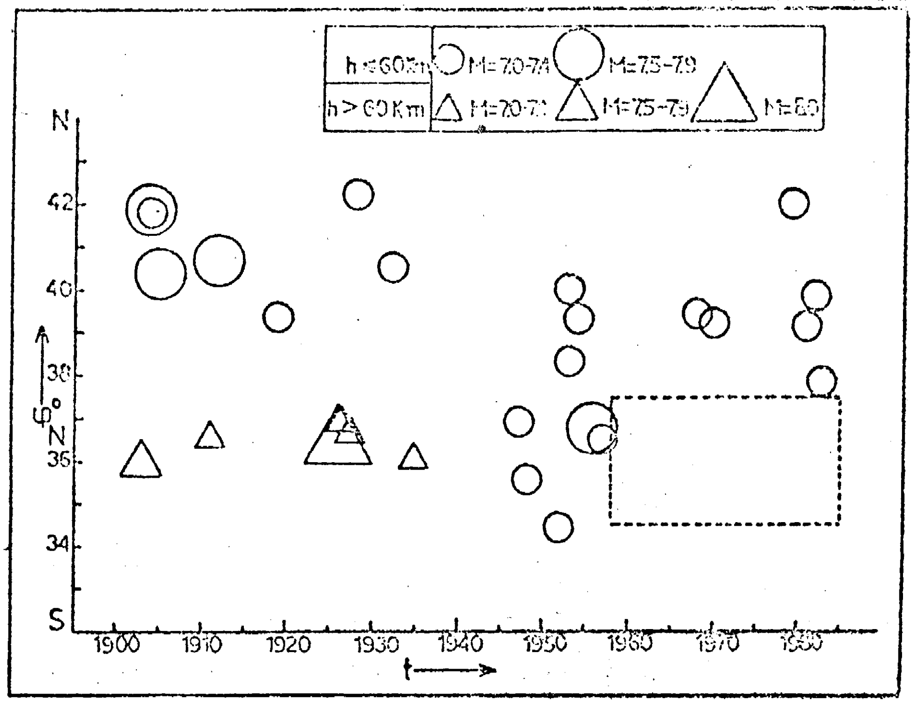

Fig. 1.- Space- time plot of the larger earthquakes (M ≥ 7.0) which occurred in the Aegean and the surrounding area during the present century.

The third period (1958-1982) is characterized by shallow seismic activity lo-ated in the northern part while the southern part remained unbroken. This is a first vidence that the southern part is at quiescence during this time period, that is, or twenty five (25) years.

Figure (2) shows the spatial distribution of the seismogenic volumes of the e-rthquakes mentioned above. The seismogenic volume of an earthquake is shown by a ircle for the shallow shocks or by a triangle for the intermediate ones. The dia-eter of the circle or the side of the triangle were calculated by the following e-uation (Kiratzi et al. 1985)

$$\text{Log L} = 0.61\, M_s - 2.25 \qquad (1)$$

here L is the length of the rupture and M_s is the corresponding surface wave mag-itude.

The upper part of the figure (2) is referred to the first period (1903-1932) , hile the middle and the lower part of this figure are referred to the second (1933 1957) and to the third (1958-1982) periods, respectivelly. The same pattern des-ribed above is shown in this figure too. The shallow seismic activity which was oncentrated in the northern part during the first period (fig. 2a) migrated more outherly during the second period (fig. 2b), while no shallow earthquake occurred n the southern part during the third period (fig. 2c). Additionally, no intermedi-te focal depth earthquake occurred in the southern part since 1935.

DISCUSSION

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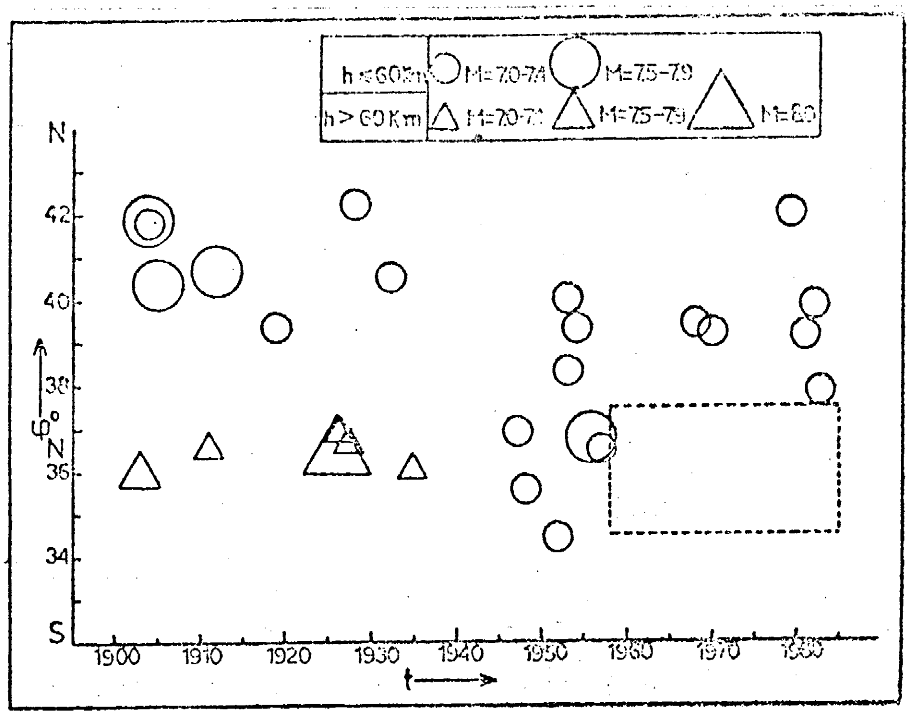

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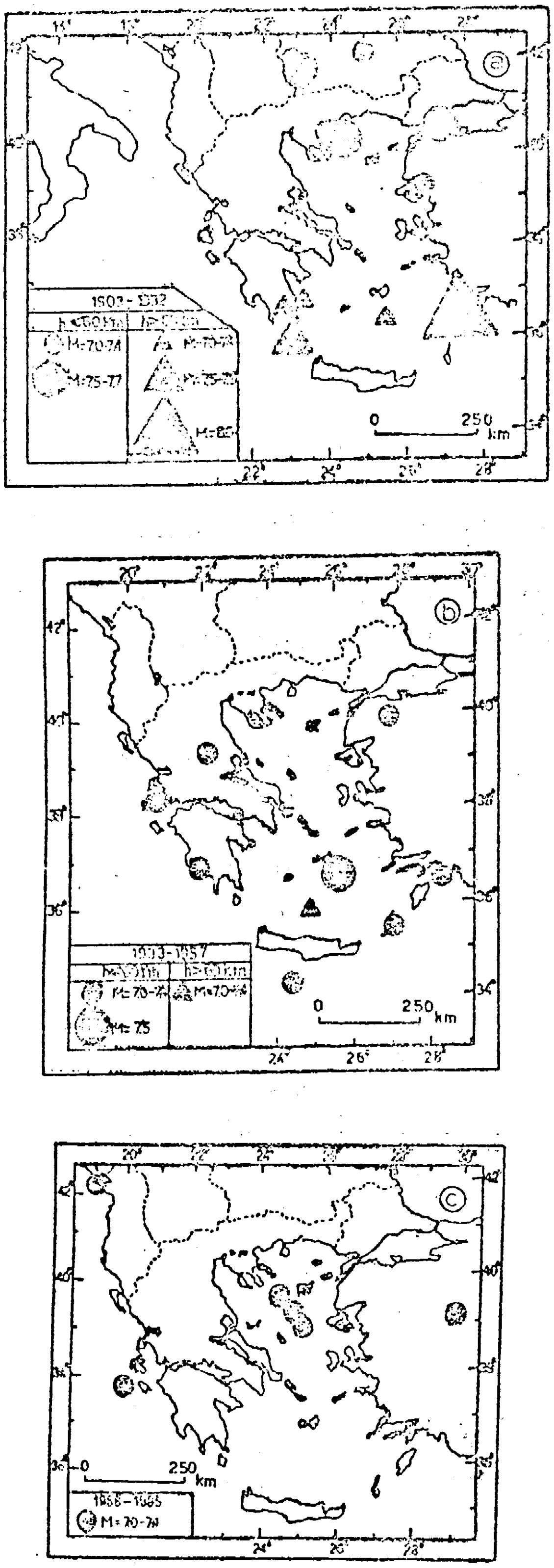

Fig. 2.- Distribution of the seismogenic volumes of the larger earthquakes (M ≥ 7.0) which occurred during the present century.

ate focal depth earthquakes which occurred in the southern part of the Aegean and the surrounding area is associated with the Hellenic Arc. The earthquake occurrence in the northern part of this area, it is difficult to say with which tectonic regime is associated. However, it is obvious from the present investigation that there is a relation in seismicity between the northern and the southern part.

The conclusion that the southern part of this area is a seismic gap in the occurrence of shallow and intermediate earthquakes is in good agreement with previous investigators (Comninakis and Papazachos 1980, Papazachos 1980, Wyss and Baer 1981, Papazachos and Comninakis 1982, Papadimitriou et al. 1984, Papazachos et al. 1984) who concluded that the southern part of the Hellenic Arc will be affected by strong earthquakes during the next few decades. The occurrence of the 1983 earthquake (M_s = 7.0) in the Ionian Islands is probably the first shock of a new cycle of seismic activity in this part. This is in good agreement with Papazachos and Comninakis (1982) who suggested that large earthquakes are expected there between 1983 and 1987. It must be noted that Papadimitriou and Papazachos (1985) predicted the magnitude and the seismogenic volume of the January 17, 1983 Ionian Islands earthquake.

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LONG TERM PREDICTION OF GREAT INTERMEDIATE DEPTH EARTHQUAKES IN GREECE

LONG-TERM PREDICTION OF GREAT INTERMEDIATE DEPTH EARTHQUAKES IN GREECE

By

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ABSTRACT

An area in the southern Aegean has been identified as first and second kind intermediate depth seismicity gap. It is observed: a) no strong ($M_S \geq 6.5$) intermediate focal depth earthquake occurred during the last 54 years and no such great earthquake ($M_S \geq 7.8$) occurred during the last 58 years in this area, b) five great earthquakes ($M_S \geq 7.8$) of intermediate focal depth occurred between 1810 and 1926 in this area, and c) the small intermediate depth activity has been high during the instrumental period (1911-1984) except for the last 34 years (since 1948) when this activity has been seriously reduced. Strong evidence are presented that the seismic potential of this area for the next few decades is high. This evidence and the information that great intermediate depth earthquakes, which have not till now affected modern high structures in Greece, generate relatively long period and very high amplitude seismic waves, lead to the conclusion that such earthquakes constitute a major seismic threat for the buildings and mainly the high ones (hotels etc) in the whole southern Greece during the next few decades.

1. INTRODUCTION

It is well known that earthquakes of magnitude $M_S \geq 7.8$ occur in the southern Aegean (Gutenberg and Richter 1948, Galanopoulos 1953, Karnik 1969, Papazachos and Comninakis 1982a, Comninakis and Papazachos 1982). These earthquakes, which are of intermediate focal depth (~ 90 Km) occur in the well known Benioff zone of southern Aegean (Comninakis and Papazachos 1980) and produce extensive damage in distances up to hundreds of kilometers (Sieberg 1932).

The high modern structures in southern Greece (Rhodos, Crete, Athens, etc) which have been built during the last three decades have not experienced such great earthquakes because the last of these destructive shocks occurred 58 years ago (June 26, 1926, M_S=8.0). Due to their high magnitude and relatively high focal depth, the predominant wave period of these great earthquakes are expected to be higher than the ones of the shallower but smaller shocks which occurred recently in Greece and affected modern structures (Thessaloniki 1978, Athens 1981). Since the accelerograms of these recent shallow earthquakes show a peak acceleration at about 0.4 seconds, the peak accelerations of the great intermediate focal depth earthquakes in southern Aegean must have their peaks at periods of 1.0 seconds or higher which is much closer to the natural periods of modern structures. This is strongly supported by the fact that the accelerograms of the Romanian 1977 intermediate focal depth earthquake (M_S=7.5), which occurred in an area (Vrancea) of very similar tectonic conditions with the southern Aegean, gave a peak accelaration at a period up to 1.5 seconds and produced destruction of high modern buildings in Bucarest in a distance of more than 150 Km from the epicenter (Ambraseys 1977).

The above given information suggests that future intermediate depth earthquakes in southern Aegean will produce extensive damage in a broad area and will affect very seriously modern high structures. For this reason it is of importance to search for possible precursors of these earthquakes. The present paper deals with this subject and investigates some probable seismicity precursory patterns in an area of the southern Aegean where great earthquakes of intermediate focal depths occurred in the past.

Comninakis and Papazachos (1980) as well as Papadimitriou [illegible] (1984) presented evidence for the generation of great intermediate depth earthquakes [illegible] Aegean till the end of the present century or so. In the present paper a more detail study of this problem is attempted and additional evidence to support this idea is presented.

2. A FIRST KIND SEISMICITY GAP FOR INTERMEDIATE FOCAL DEPTH EARTHQUAKES IN THE SOUTHERN AEGEAN

Mogi (1979) suggested two kinds of seismic gaps. Gap of the first kind is that gap in a seismic belt which is later covered by the seismogenic volume (aftershock volume) of a strong earthquake and where strong earthquakes occurred in the past. Such gaps have been first identified in plate boundaries (Fedotov 1965, Kelleher et al. 1973, McCann et al.1979) but have been later identified on other (intraplate areas, etc) areas too (Thatcher et al. 1975,Mogi 1979). Gap of the second kind is a part of a seismic belt where the low magnitude seismicity is at quiescence.

Papadimitriou and Papazachos (1984) modified the definition of the first kind seismic gap in order to make it applicable for the relatively small earthquakes in the Aegean and surrounding area. They used the term " first kind seismicity gap " and defined this gap as a region where: a) No strong earthquake occurred during the last several decades in this region, b) Strong earthquakes occurred in this region several times before this last period of quiescence, and c) The lower magnitude seismicity has been high during the period for which instrumental data are available except probably, for the last several years. In this last case the gap is a " second kind seismicity gap " too.

Based on these definitions we searched for a seismicity gap in the intermediate focal depth earthquakes in the southern Aegean.

Figure (1) shows the epicenters of intermediate focal depth (70 Km $\leq$ h $\leq$ 180 Km) earthquakes which occurred in the southern Aegean during the last two centuries. Seven symbols are used to denote four magnitude ranges ($6.0 \leq M_S \leq 6.4$, $6.5 \leq M_S \leq 6.9$, $7.0 \leq M_S \leq 7.4$, $7.5 \leq M_S \leq 8.3$) and three time periods (1801-1926, 1911-1929, 1930-1980). The errors of e epicenters are less than about 40 Km and of the magnitudes ss than about 0.4.

The polygon in figure (1) includes an area which can be nsidered as a seismicity gap of the first kind for intermeate depth earthquakes because:

a) No strong earthquake with magnitude larger or equal to .5 occurred since 1929, that is for 54 years.

b) Strong intermediate depth earthquakes occurred in this gion several times before 1930. Eight intermediate focal deh earthquakes with $M_s \geq 7.5$ occurred in this area between 1810 d 1926. Five of these shocks have magnitude $M_S \geq 7.8$ and mamum intensities X or more (table 1).

c) The lower magnitude seismicity of the intermediate fo-l depth earthquakes is high since 1911 when the first seiograph was instalied in Athens (Papazachos and Comninakis 71, Comninakis and Papazachos 1980).

ble I. Information for the five intermediate focal depth earthquakes which occurred in the southern Aegean during the last two centuries with $M_S \geq 7.8$.

DATE	TIME	φ_N^o	λ_E^o	h	M_S	I_o
810, Feb. 16	22:15:	35.6	25.0	i	7.8	X
1856, Oct. 12	00:45:	35.5	26.0	i	8.3	XI
1863, Apr. 22	20:30:	36.4	27.7	i	7.8	X
1903, Aug. 11	04:32:54	36.0	23.0	80	7.9	XI
1926, June 26	19:46:34	36.5	27.5	100	8.0	XI

As a measure of the potential of this first kind seismiity gap for the occurrence of an earthquake with magnitude M the ratio, λ, of the time, τ, during which no such earthuake occurred to the mean return period, T, of the earthquaes with such magnitudes in the gap is considered (Papadimitiou and Papazachos 1985). It is therefore necessary to determine the mean return period for the great earthquakes in he southern Aegean. Figure (2) shows the cumulative frequency unction of the magnitudes for the intermediate depth earth-

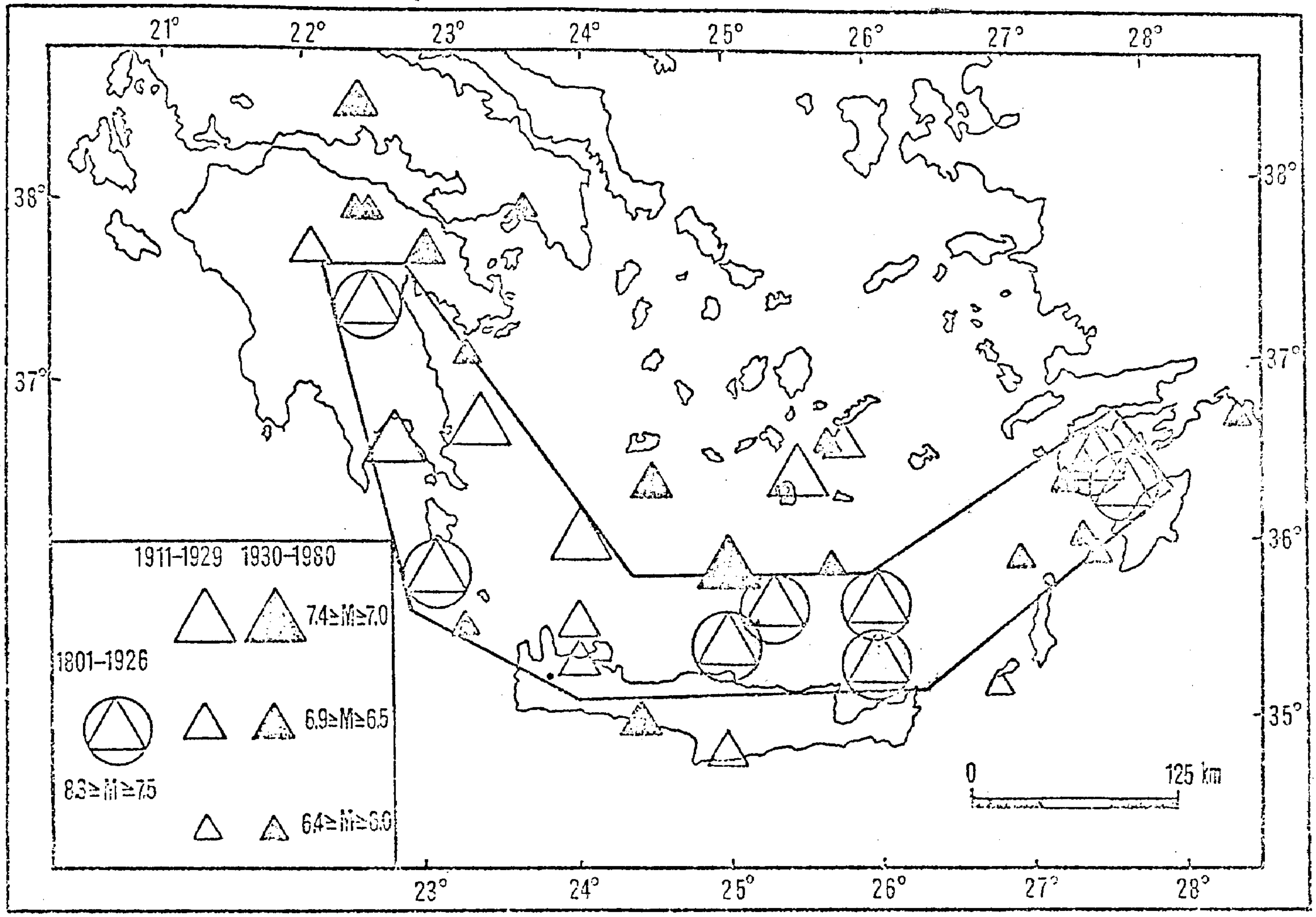

Fig. 1.- Epicenters of the intermediate depth earthquakes in the Aegean and surrounding area. The area included in the polygon is considered as earthquake prone seismic gap.

quakes in the seismicity gap identified in southern Aegean. For this plot, three complete samples of data have been used. These samples cover the periods 1801-1980, 1911-1980, 1964 -1980 with corresponding magnitudes $M_S \geq 7.5$, $M_S \geq 6.0$, $M_S \geq 4.5$. The number of earthquakes in each magnitude step ($M \pm 0.05$) of the last two periods were multiplied by the ratio 180/70 and 180/17, respectively, to get the number of the earthquakes ($4.5 \leq M_S \leq 7.4$) for the whole time period (1801-1980) of 180 years.

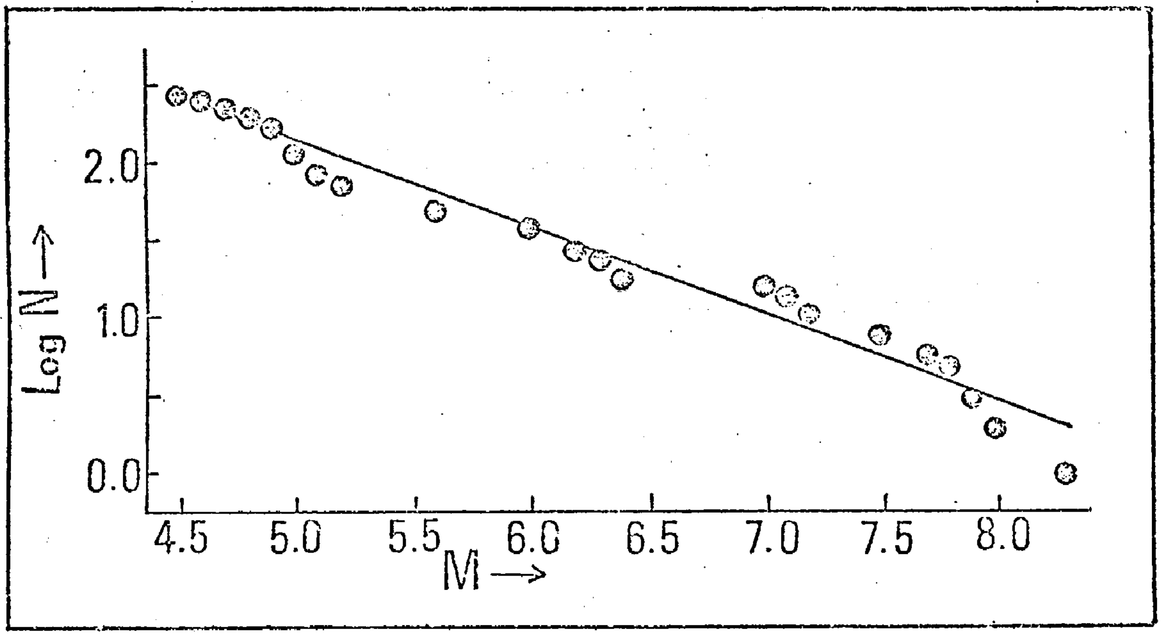

Fig. 2.- Cumulative magnitude destribution for the earthquake prone area shown in figure (1).

The data fit the Gutenberg and Richter (1944) relation:

$$\text{Log } N_k = a_k - bM \quad (1)$$

where N_k is the number of the earthquakes with magnitude M or larger. This relation for one year time period becomes:

$$\text{Log } N = a - bM \quad (2)$$

where $a = a_k - \text{Log}k$, if k is the number of years in the sample period which, in the present case, is k=180. By applying the le-

[illegible] the data we find $a_k = 4.87$ and $b = 0.55$.

Therefore, the parameters a,b of the relation (2) have the values:

$$a = 2.61, \quad b = 0.55 \tag{3}$$

and the mean return period can be determined by the relation:

$$T = 10^{bM}/10^{a} \tag{4}$$

Table (II) shows the mean return periods for great ($M_S \geq 7.8$) earthquakes in the area which has been identified as seismicity gap of intermediate focal depth earthquakes occurred in the southern Aegean. The time since when (June 1926) no such earthquake occurred in the gap is $\tau = 58$ years. Therefore the ratio τ/T varies between 0.6 and 1.2, which indicates a rather high seismic potential for the gap.

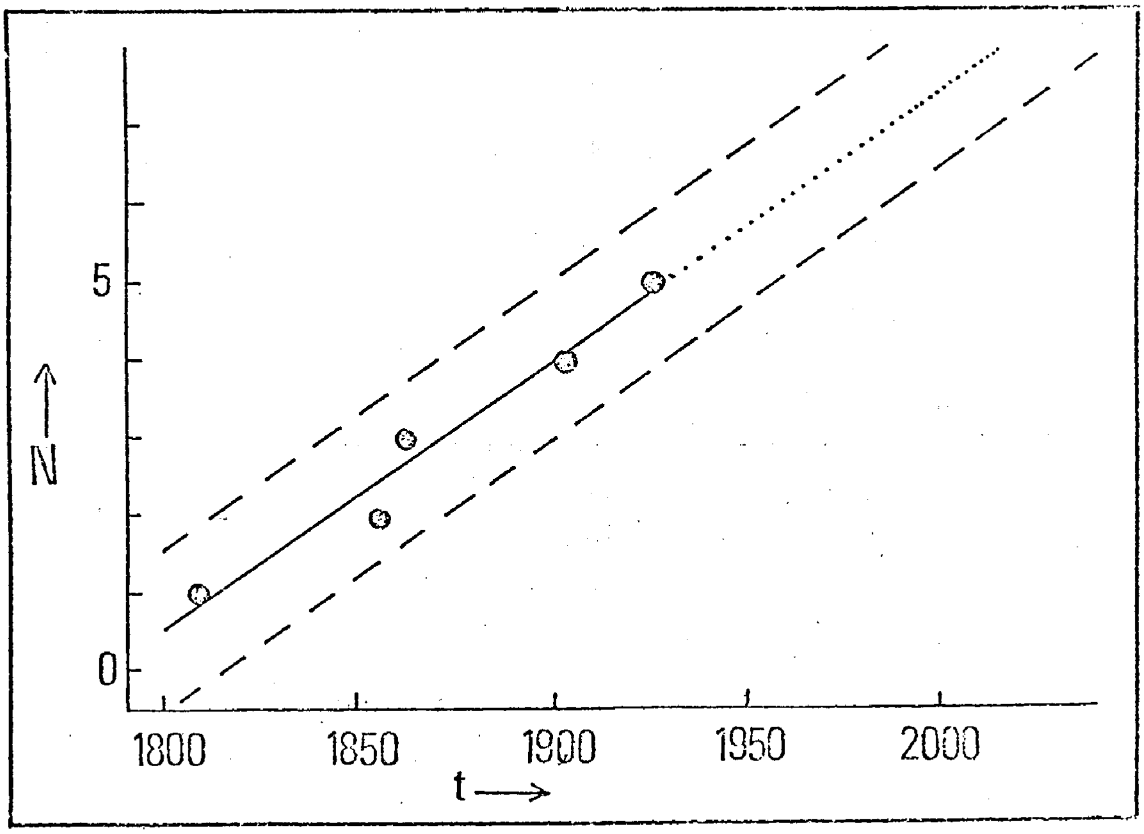

Fig. 3.- Seismicity rate for the great ($M \geq 7.8$) intermediate focal depth earthquakes in the southern Aegean.

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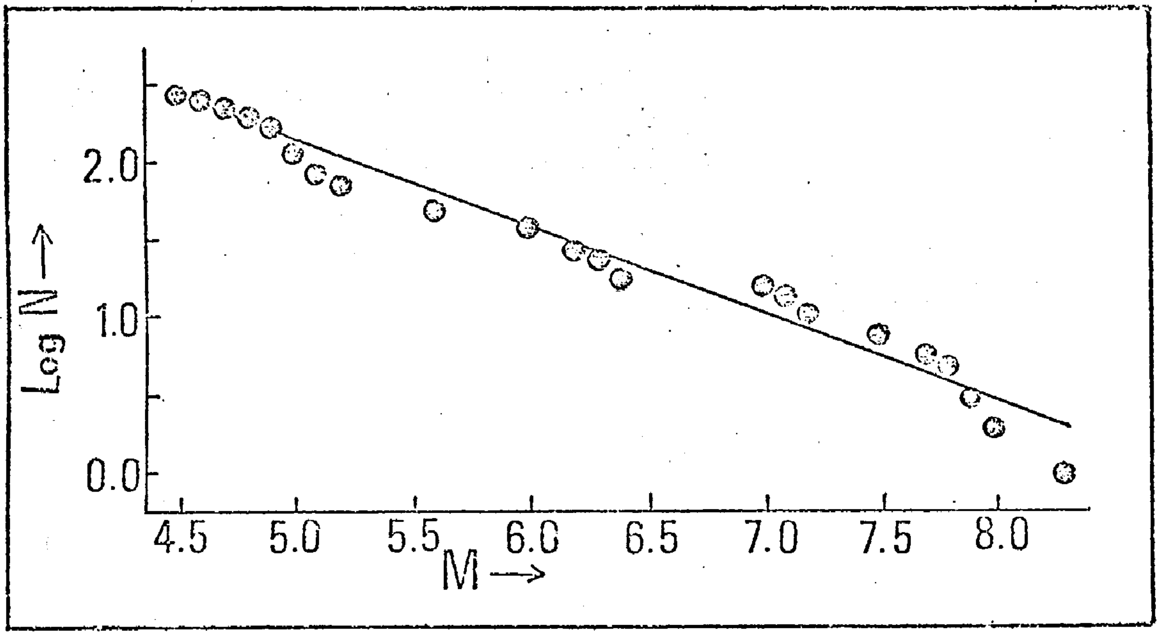

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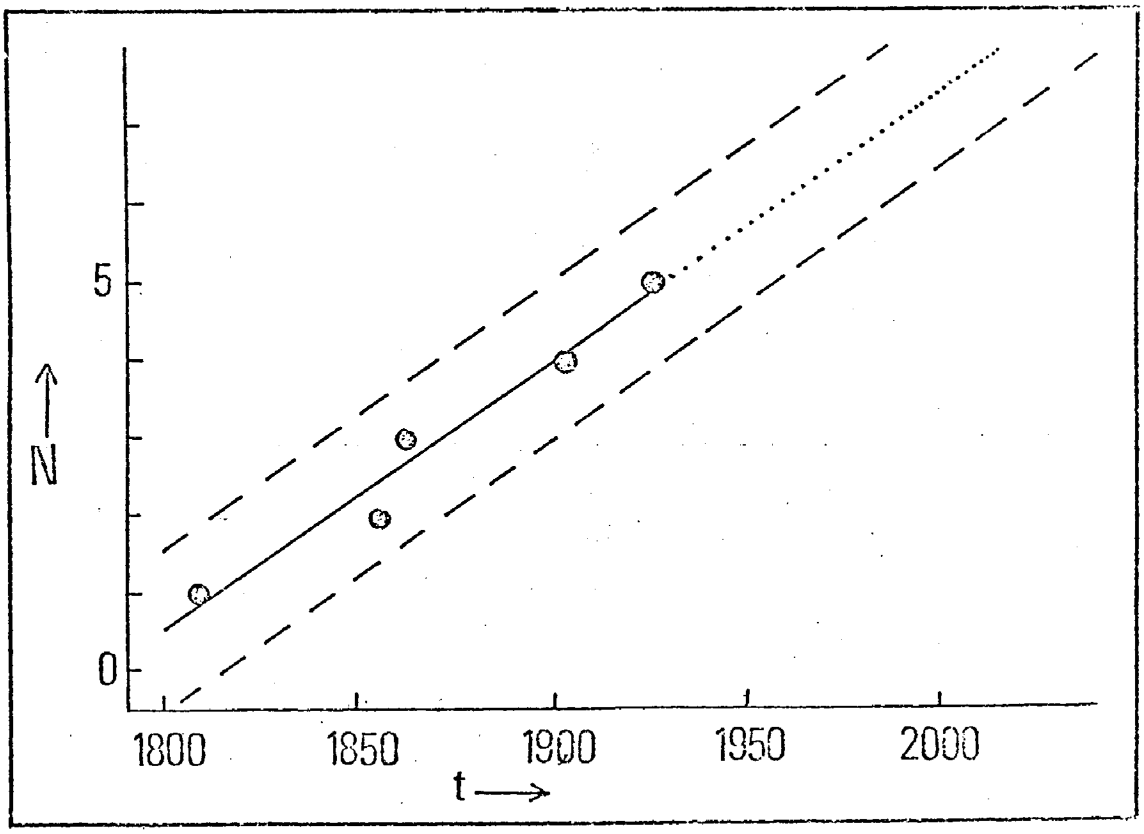

Fig. 3.- Seismicity rate for the great ($M \geq 7.8$) intermediate focal depth earthquakes in the southern Aegean.

Figure (3) shows the cumulative number of the great earthquakes, for which information is given in table (II) as a fun-

Table II. Mean return periods for the great earthquakes of intermediate focal depth in southern Aegean.

M	7.8	7.9	8.0	8.1	8.2	8.3
T years	48	54	62	70	79	90

ction of time. The straight line is the least squares fit and gives a rate of 3.5 great shocks per century, while the two dashed lines are the ninety per cent confidence intervals.This figure shows that,if the seismicity rate for these great shocks continue to be the same in the future, there is a high probability that one up to three great earthquakes will occur till the end of the present century or so in the southern Aegean area.

3. SEISMICITY GAP OF THE SECOND KIND

It is of interest to examine whether the area included in the polygon of figure (1),which has been identified as seismicity gap of the first kind, is also a seismicity gap of the second kind (Papadimitriou and Papazachos 1984). It means that we are going to examine if the small shock activity is at quiescence (seriously reduced) at present. This is usually done by the cumulative number plots which have been used by several investigators (Wyss and Habermann 1979, Wyss and Baer 1981,Papazachos and Comninakis 1982b, Papadimitriou 1984) to identify seismicity quiescence periods which precede strong earthquakes.

The upper part of figure (4) shows the cumulative yearly number of intermediate focal depth earthquakes of $M_S \geq 5.3$, which occurred since 1920 in the area included in the polygon of figure (1), as a function of time, while the lower part of this figure shows the corresponding plot for earthquakes with $M_S \geq 6.1$. It is clear that this area is at quiescence since 1948, that is, for 36 years. During the quiescence period (1948-1984) the seimicity rate (0.09 shocks per year) for shocks with $M_S \geq 5.3$ is reduced in respect to the seismicity rate (0.30

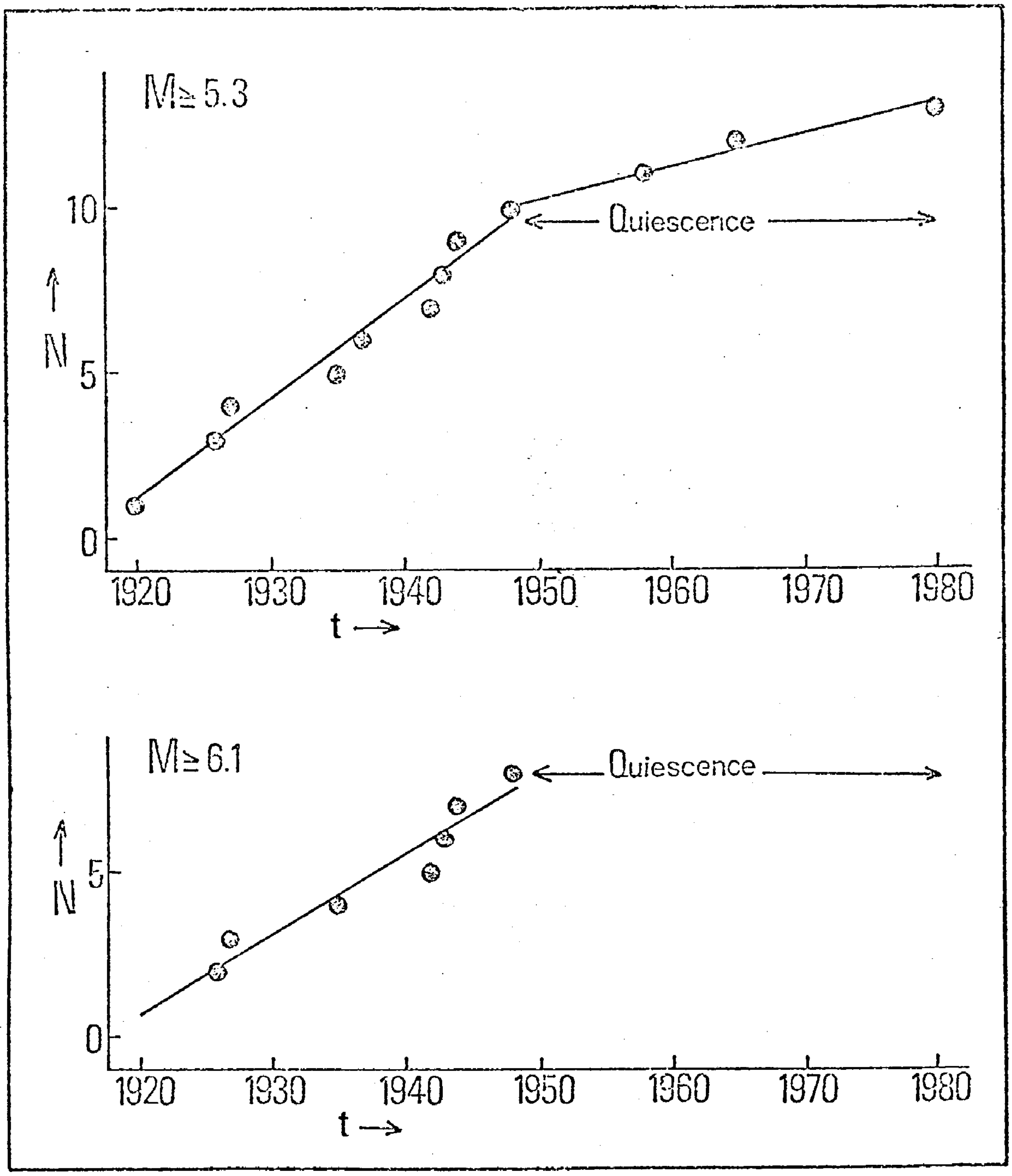

Fig. 4.- Cumulative yearly number of intermediate focal depth earthquakes in the southern Aegean as a function of time.

shocks per year) for such earthquakes during the previous active period (1922-1948) by about 70%. No earthquake with magnitude $M_S \geq 6.1$ occurred in this area during the quiescence period , while the rate for such earthquakes was 0.24 shocks per year during the previous active period. Quiescence in the small intermediate depth earthquake activity during the last decades has been observed for the whole southern Aegean by Comninakis and Papazachos (1980).

It is concluded that the area where great earthquakes of intermediadte focal depth occurred in the past is at quiescence for the small earthquake activity too at present. That is, this area is also a seismicity gap of the second kind.

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INTERRELATION OF SEISMICITY BETWEEN CRETE AND IONIAN ISLANDS (GREECE)

INTERRELATION OF SEISMICITY BETWEEN CRETE AND IONIAN ISLANDS (GREECE)

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ABSTRACT

Instrumental data of the period 1947-1985 revealed an interrelation in the seismicity between the northernmost part (Ionian islands) and the southernmost part (Crete) of the Western Hellenic arc. A correspondence in the occurrence of earthquakes with M≥5.9 in these two areas has been observed. In most of the cases this correspondence was one-to-one. The area between Crete and Ionian , which is the middle part of the western Hellenic arc, has not been affected by this interrelation and remained unbroken since 1947 for earthquakes with M≥6.0.

1. INTRODUCTION

The Hellenic Arc (fig.1) has focused the attention of many geoscientists. Its seismic activity is the result of the interraction between the Eurasian and the African lithospheric plates.

The tectonic regime of this area is fairly well known and this is a helpful tool towards the examination of the occurrence of large earthquakes which follows certain patterns both in time and space.

Studies concerning the long term prediction of large earthquakes along the Hellenic arc have been carried out during recent years. Wyss and Baer (1981), based on the time variation of the seismicity rates, concluded that a sequence of about three earthquakes are expected between 1980 and 1991 along the southwestern part of the Hellenic arc, while in other segments they were not able to clearly define seismicity anomalies. Papazachos and Comninakis (1982) studied the time variation of the difference in magnitude between the main shock and its largest aftershock and suggested that a seismic activity of strong earthquakes is expected between 1983 and 1987 in the Hellenic trench-arc system. Papadimitriou and Papazachos (1985) characterized some parts of the Hellenic arc as seismicity gaps in the occurrence of the larger (M≥6.0) earthquakes and Papadimitriou and her colleagues (1985) suggested that strong earthquakes are expected in the Hellenic arc, on the basis of migration patterns.

The Chinese seismologists were the first who observed an interrelation of seismicity between two areas (Rikitake 1982). In 1978 they noticed a marked tendency of alternate occurrence of large earthquakes between these areas. The tedency of the alternate occurrence was so distinct that a long-term prediction of earthquake occurrence was actually made although no physical mechanism of such tedency was known. Rikitake (1983) examined the interrelation of the seismicity between two areas in Japan. A long-term as well as a short-term tedency of alternate occurrence of earthquakes between the two areas was recognized.

In the present paper, the interrelation of seismicity between two areas of the western part of the Hellenic arc is examined.

2. SEISMIC ACTIVITY IN THE AREA STUDIED

An attempt was made, first, to examine if there is any regularity in the earthquake occurrence along the whole Hellenic arc. For this reason, instrumental data, which in Greece are available since 1911, concerning the shallow (h≤60 km) earthquakes of moderate size were used. However, it was soon found out that during the first four decades of the present century the majority of the seismicity was concentrated in the area of the Ionian islands, while few earthquakes were observed along the rest of the Hellenic arc.

After 1947 the seismicity continued on a regular base in the Ionian islands and another region in Crete revealed considerable seismicity. Out of these two parts no other part of the Hellenic arc seemed to be considerably active. On the basis of this preliminary sorting of the data, the regions of the Ionian islands and western part of Crete were chosen for further investigation.

Table (1) gives information on all earthquakes with M≥5.9 which occurred in the western Hellenic arc between 1947 and 1984. The source for the data was the catalogue of Comninakis and Papa-

Table 1. Information on all earthquakes with M≥5.9 which occurred in the western part of the Hellenic arc since 1947.

DATE	φ^{o}_{N}	λ^{o}_{E}	M	REGION
1947,Aug.30	35.1	23.4	6.3	Crete
1947,Oct. 6	36.9	22.0	7.0	Central part
1948,Apr.22	38.7	20.5	6.5	Ionian
1952,Dec.17	34.4	24.5	7.0	Crete
1953,Aug.12	38.3	20.8	7.2	Ionian
1957,Feb.19	36.2	21.6	5.9	Central part
1958,Aug.27	37.4	20.7	6.4	Ionian
1959,May 14	35.1	24.6	6.3	Crete
1959,Nov.15	37.8	20.5	6.8	Ionian
1962,Jan.26	35.2	22.7	6.2	Crete
1962,Apr.10	37.8	20.1	6.3	Ionian
1963,Dec.16	37.0	21.0	5.9	Central part
1965,Apr. 9	35.1	24.3	6.1	Crete
1968,Mar.28	37.8	20.9	5.9	Ionian
1969,June 12	34.4	25.0	6.1	Crete
1969,July 8	37.5	20.3	5.9	Ionian
1972,May 4	35.1	23.6	6.5	Crete
1972,Sep.17	38.3	20.3	6.3	Ionian
1973,Nov.29	35.2	23.8	6.0	Crete
1976,May 11	37.4	20.4	6.5	Ionian
1977,Sep.11	34.9	23.0	6.3	Crete
1981,June 28	37.8	20.1	6.0	Ionian
1983,Jan.17	37.9	20.2	7.0	"
1984,June 21	35.3	23.2	6.3	Crete

achos (1982). Figure (1) shows the epicenters of the eartrhquakes isted in table (1). It is interesting to note that all epicenters xcept three, are clusterred in two areas, one in the Ionian islands northwest) and the other in the western Crete area. The epicenters n the region between these two areas belong to the earthquakes hich occurred in 1947(M=7.0), 1957(M=5.9) and 1963(M=5.9). This eans that no missed earthquake with M≥5.9 occurred in this region ince 1963.

. INTERRELATION OF SEISMICITY

In order to examine the interrelation of the seismicity between he two areas space-time plots for different magnitude cutoffs were ade. The epicenters of the earthquakes were projected onto a line hich connects the two areas (fig. 1) and the distances from point along the line were measured. These distances are plotted against ime for two data samples (M≥5.9 and M≥6.0) in figure (2). The ashed lines limit the area between Crete and Ionian islands which emained unbroken for earthquakes with M≥6.0 for the whole time peiod during which this examination is made (1947-1984). The same rea also remained unbroken for earthquakes with M≥5.9 since 1963. he length of this area along the line AB is equal to about 300km.

The interrelation of the seismicity of the two areas is obvious fig. 2). In most of the cases the correspondence is one-to-one. amely, each earthquake in the Ionian islands is followed by an erthquake in Crete and vice-versa. In the cases where there is no uch one-to-one relation there is a multiple occurrence in one of he regions. Thus, during the periods 1952-1959 and 1977-1984 no arthquake with M≥6.0 occurred in Crete while two earthquakes in oth periods occurred in the Ionians. During the period 1962-1972 he Ionian were at quiescence while three earthquakes occurred in rete. In this case, we suggest that the observed pattern is: peiod of alteration - multiple occurrence in Ionian - period of aleration - multiple occurrence in Crete - period of alteration - ultiple occurrence in Ionian. It is probable that this pattern will continue and we may expect that after a few earthquakes correlating one-to-one, the seismic activity will be concentrated in Crete while the Ionian will enter a period of quiescence.

In order to further support that actually an interrelation exists the runs test was applied. We assumed that we have a sequence of successive observations arranged in order of occurrence, where the observations are two mutually exclusive categories. The first caregory concerns the earthquakes which occurred in Crete and the second one the earthquakes which occurred in Ionian islands and the earthquakes which occurred in the central part, because the last ones are closer to the Ionian region.

The test statistic Z (Davis 1973) has been calculated for earthquakes with M≥5.8 and M≥5.9 since for larger earthquakes (M≥6.0) the sample is ruther small for such a test. It is found that Z equals to 1.5 and 2.7 for earthquakes with M≥5.8 and M≥5.9 respectively. Using a 5% (a=0.05) level of significance, the last but not the first one of these values is clearly within the critical region. So we would reject the hypothesis that the earthquakes with M≥5.9 contain the number of runs expected in random sequences. This test supports our hypothesis that an interrelation exists between the strong earthquakes (M≥5.9) in Ionian islands and western Crete.

5. DISCUSSION

The present investigation shows that an interrelation between the shallow seismicity in the two ends of the western Hellenic arc exists. In the central part of the western Hellenic arc no earthquake with magnitude M≥6.0, occurred since 1947, although this part should have been the most active since its largest dimension, with a length of about 300 km, is normal to the direction of relative motion between Eurasian and African plates (McKenzie 1978). It is possible that this central part is a seismic gap and big earthquakes are expected there (Wyss and Baer 1981, Papazachos and Comninakis 1982).

However, McKenzie (1978) considers the possibility that the seismic activity of the island arcs to depend on the thickness of the sediments which are found on the top of the plates which are subducted and variation of the thickness of the sediments in different parts of the western Hellenic arc may determine the variation of the level of seismic activity.

Thus, a similarity between the structures of the two ends of the western arc and a difference between these structures and the structure of its central part cannot be excluded as the cause of the behavior of seismicity in this area.

It is difficult at present to explain the observed phenomenon in a satisfactory way but the observed interrelation in seismicity itself is of interest for the earthquake prediction problem.

Acknowledgements

The authors would like to express their deepest appreciation to Prof. Papazachos for the critical reading of the manuscript and his suggestions. This work was financially supported by the Earthquake Protection and Planning Organization (E.P.P.O.) under the Contract 165/7.11.1984.

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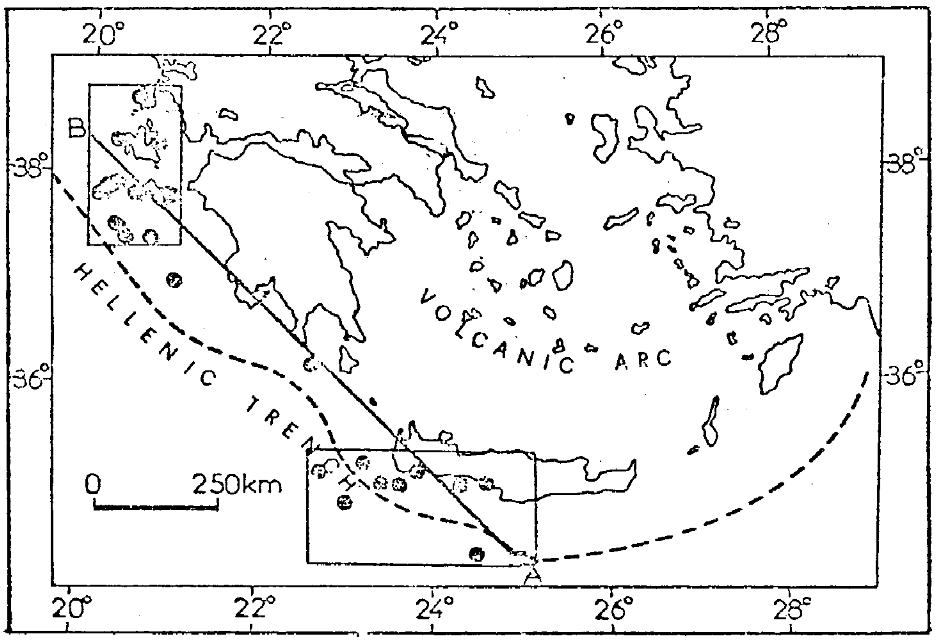

Fig. 1

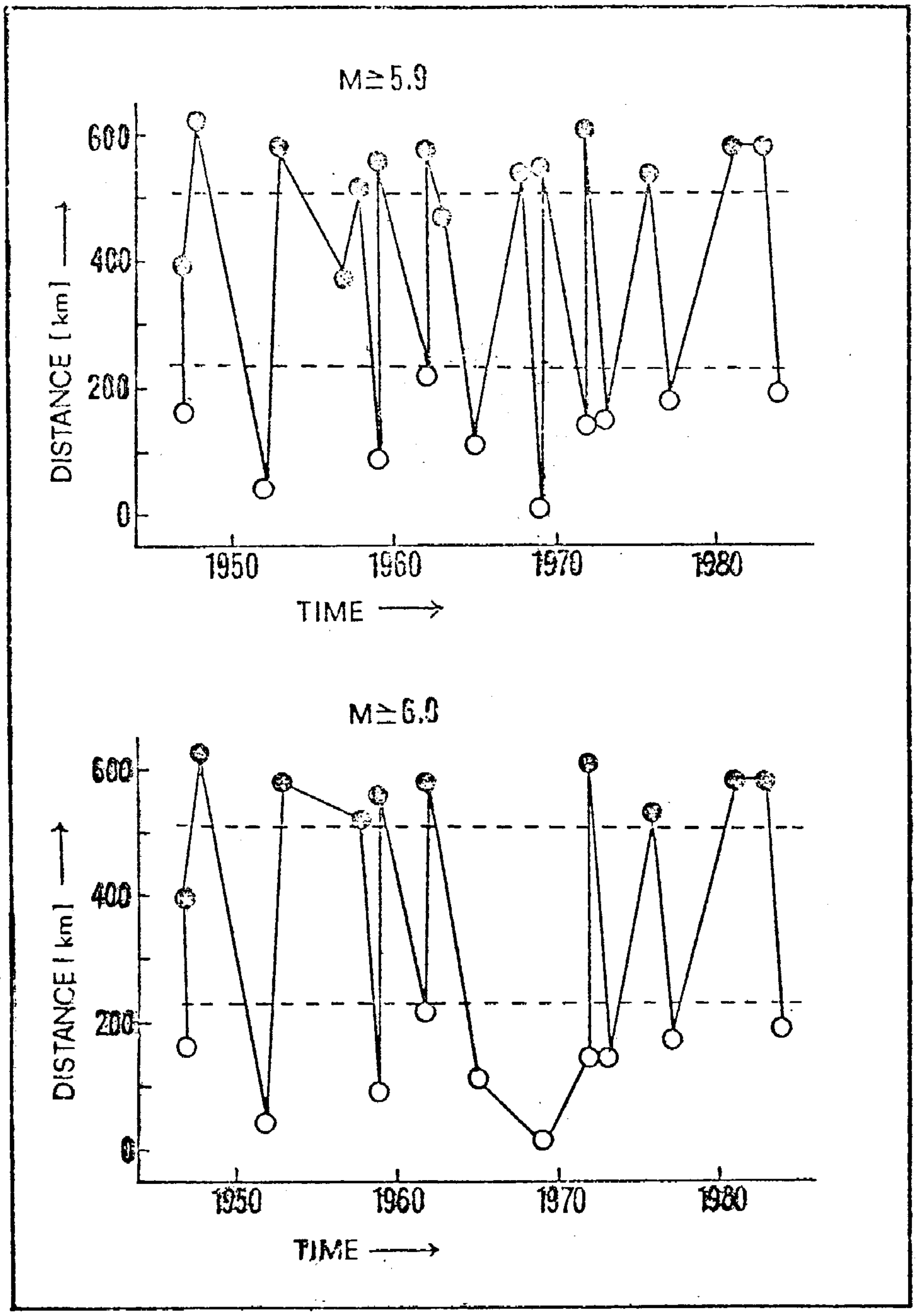
M≥5.9
600
400
200
0
DISTANCE [km]
1950
1960
1970
1980
TIME
M≥6.0
600
400
200
0
DISTANCE [km]
1950
1960
1970
1980
TIME

Fig. 2

MIGRATION OF THE INTERMEDIATE FOCAL DEPTH SEISMIC ACTIVITY IN THE INNER PART OF THE HELLENIC ARC

MIGRATION OF THE INTERMEDIATE FOCAL DEPTH SEISMIC ACTIVITY IN THE INNER PART OF THE HELLENIC ARC

By
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ABSTRACT

A regulatity in the space-time distributions of the intermediate focal depth earthquakes in the inner part of the Hellenic arc has been identified. A belt, trending east-west, where these earthquakes occur and along which tend to migrate has been defined. Three migration periods that lasted 24,19 and 18 years and followed by an aseismic one of 20 years have been observed.

1. INTRODUCTION

The identification of seismicity patterns in the occurrence of intermediate earthquakes in the southern Aegean is of primary importance, because it is well known that such earthquakes have produced severe damages in the past in distances up to hundred kilometers (Sieberg 1932). The foci of these earthquakes are located in a seismic zone dipping from the eastern Mediterranean to the Aegean (Papazachos and Comninakis 1969,1970). Papazachos and Comninakis (1971) determined a Benioff zone with an amphitheatrical shape. These studies showed that the intermediate focal depth earthquakes in the southern Aegean occur in the same seismic zone, where seismicity patterns can be observed.

The seismicity patterns have been grouped in three main types (Keilis-Borok et al. 1980); seismic quiescence, seismic activation and migration of seismic foci. The pattern investigated in the present paper is of the third type.

2. THE DATA

The area examined is bounded by the parallels 35°N, 37°N and the meridians 22.7°E and 28.5°E. This area was selected because the big earthquakes (M>7.5) of intermediate focal depth ($60 \leq h \leq$

200 km) that occurred during the last two centuries along the Hellenic arc, have their epicenters in this area. It is also known that most of the smaller ($M \geq 4.5$) intermediate earthquakes which occurred in the Aegean and surrounding area during the last twenty years, occurred also in this area.

The data which have been used in the present study concern earthquakes with $M \geq 6.0$ that occurred during the present century in the inner part of the Hellenic arc (southern Aegean). The data source is the catalogue of Comninakis and Papazachos (1982). The errors in the epicenters are less than 30 km and the errors in the magnitudes are less than 0.3. Information on these shocks is listed in table (1).

3. MIGRATION OF SEISMIC ACTIVITY

On the purpose to investigate the pattern of the intermediate focal depth earthquakes in the inner part of the Hellenic arc, the epicenters of the earthquakes were plotted on a map. From this plotting it was observed that the seismic activity initiated at the western part of the area studied and then propagated to its eastern part during a certain time period. Just after the last earthquake has occurred in the eastern end of the area, a new seismic activity began in its western end. Three such migration periods were observed during the time intervals 1903-1926, 1926-1944 and 1948-1965.

Since migration pattern has a trend from east to west, it is preferable to plot the longitude of each epicenter versus the time of its occurrence. Such a plot can give information on the process of the migration observed and can be used to estimate the migration rate. Figure (1) illustrates this space-time plotting based on the data listed in table (1).

It is seen that there are three separate migration periods followed by a period of quiescence. The mean migration rate for the three migration periods is 23 km/yr and the dashed lines in figure (1) fit the data in the least squares' sence under the condition that the migration rate is constant. The duration of these three migration periods is 24 years (1903-1926), 19 years (1926-1944) and 18 years (1948-1965), respectively.

Table I. Information on earthquakes with intermediate focal depth which occurred in the south part of the Hellenic arc during the present century.

DATE	h: m: s	λ_E^o	φ_N^o	h	M
1903, Aug. 11	04:32:54	36.0	23.0	80	7.9
1908, May 17	12:30:42	35.5	24.0	80	6.7
1910, Feb. 18	05:09:18	35.7	24.0	90	6.9
1911, Apr. 4	15:43:54	36.5	25.5	140	7.1
1918, Jul. 16	20:03:36	36.7	25.8	150	6.6
1920, Nov. 15	09:20:43	36.0	25.7	120	6.0
1923, Aug. 1	08:16:38	35.0	25.0	90	6.8
1926, June 26	19:46:34	36.5	27.5	100	8.0
1926, Aug. 30	11:38:12	36.8	23.3	100	7.2
1927, Jul. 1	08:18:54	36.7	22.7	80	7.1
1930, Feb. 14	18:38:12	36.5	24.5	130	6.7
1934, Nov. 9	13:40:56	36.7	25.7	150	6.2
1935 Feb. 25	02:51:31	36.0	25.0	100	7.2
1935, Mar. 18	08:40:45	35.3	26.8	70	6.4
1937, Dec. 16	17:35:27	35.7	23.2	100	6.0
1942, Jun. 21	04:38:44	36.0	27.0	90	6.3
1943, Oct. 16	13:08:53	36.5	27.5	110	6.3
1944, May 27	23:52:30	36.0	27.5	100	6.2
1948, Jul. 24	06:03:05	35.2	24.4	80	6.6
1958, Jun. 30	08:42:44	36.4	27.3	109	6.0
1961, May 23	02:45:20	36 7	28.5	70	6.4
1965, Nov. 28	05:26:05	36.1	27.4	73	6.0

After the occurrence of the last shock in 1965, no earthquake with M≥6.0 occurred in the whole area. Therefore this area can be considered as a seismicity gap of the first kind in accordance to the criteria suggested by Papadimitriou and Papazachos (1986). This observation is in agreement with the results of previous investigations in which a broader area had been considered as such gap (Papadimitriou et al. 1984, Papazachos et al. 1985).

Figure (2) shows the spatial distribution of the epicenters during the three migration periods. The numbers in this figure denote the two last digits of the year of occurrence. It is observed that the activity started in 1903 in the western part and ended in 1926 in the eastern part of the area (fig. 2a). Then it started again in the western part and ended in 1944 in the eastern part (fig. 2b). It started again in the western part (1948) and ended in 1965 in the eastern part (fig. 2c). Since then (1965) no earthquake with M≥6.0 occurred.

Although it is difficult to give a physical explanation of this seismicity pattern, these observations can contribute to the long-term earthquake prediction in the southern Aegean.

Acknowledgements

The author would like to express her deepest appreciation to Prof. Papazachos for the critical reading of the manuscript and his suggestions. This work was financially supported by the Earthquake Protection and Planning Organization (E.P.P.O.) under the contract 165/7-11-1984.

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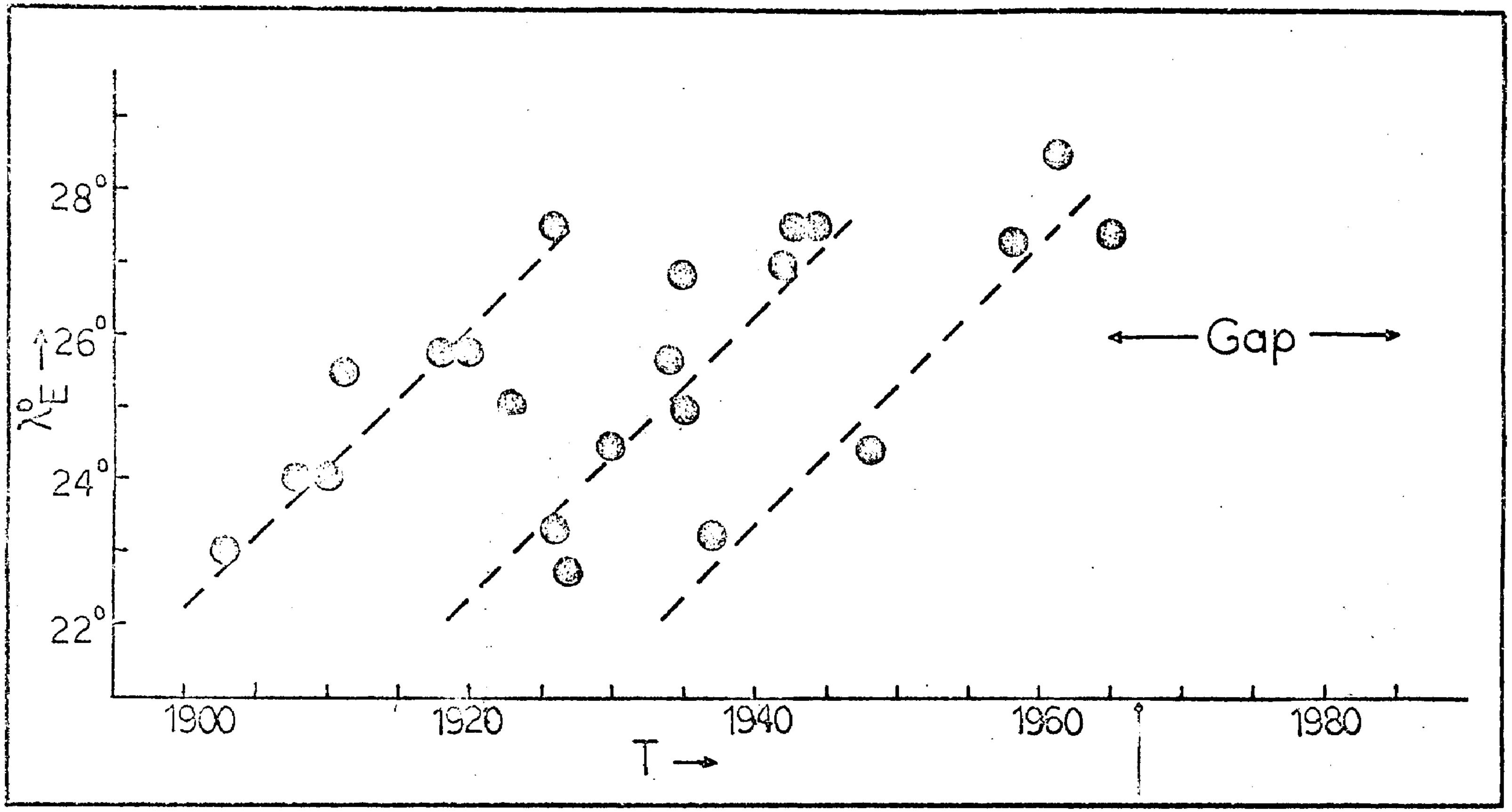

Fig. 1

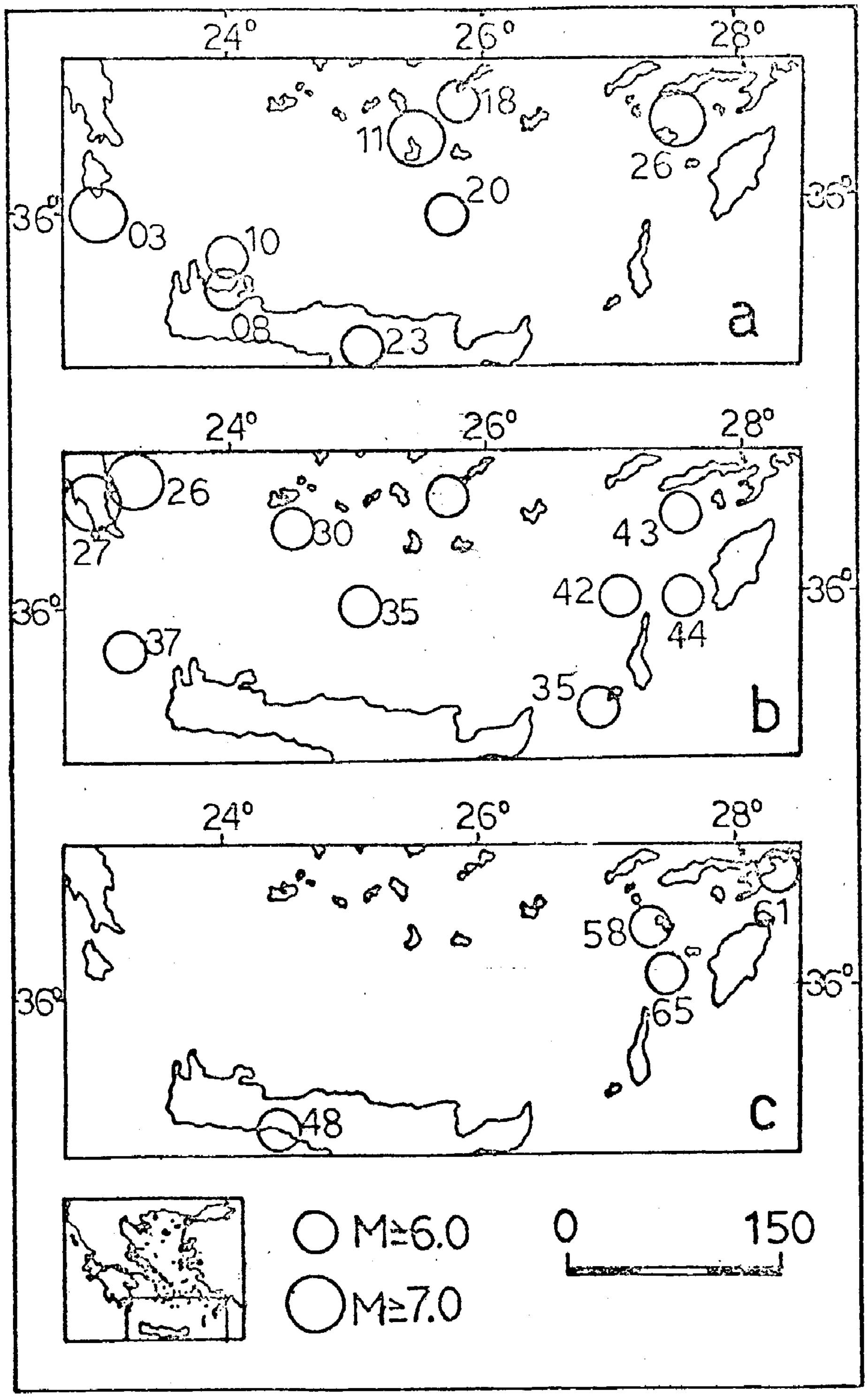
24°
26°
28°
36°
18
11
26
20
03
10
08
23
a
26
27
30
43
35
42
44
37
35
b
58
61
65
48
c
M≥6.0
M≥7.0
0
150

Fig. 2

SEISMIC FRACTURE ZONES IN THE AEGEAN

AND SURROUNDING AREA

SEISMIC FRACTURE ZONES IN THE AEGEAN AND SURROUNDING AREA

By

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ABSTRACT

Seismic fracture zones are defined as active fracture belts of the lithosphere determined mainly by seismic data (delineations of epicenters, etc). On the basis of historical (600BC-1900) and instrumental data (1901-1985) concerning the known major earthquakes ($M \geq 6.0$) of shallow ($h < 70$Km) and of intermediate focal depth, the main seismic fracture zones in the Aegean and surrounding region have been determined. The importance of this zoning for earthquake prediction, seismic hazard and geodynamic problems of this region is emphasized.

1. INTRODUCTION

The problem of the earthquake hazard reduction is becoming more acute with the growth of population and urban and industrial construction. Efforts to solve this problem are based on seismic zoning, seismic research concerning earthquake prediction and other related problems. Seismic zonation contribute also to the solution of the earthquake prediction problem as it gives the long term evaluations of the possible generation of strong shocks on a rather large territory (Nersesov 1982).

So, it becomes clear that one of the primary works one has to do for the earthquake prediction and seismic hazard problem in a region is to define the seismic zones in this region by delineation of areas of earthquake activity and by application of other seismotectonic methods. Such efforts have been made in several regions of the world as well as in the Aegean region.

Papazachos (1980) divided the whole territory of Greece and the surrounding area in 19 seismic zones. The number of these zones was later increased to 21 (Hatzidimitriou et al. 1985). The criteria used in these two works were the distribution of the earthquake foci, the direction of the seismic faults derived from fault plane solutions (Papazachos et al.1984), the orientation of P (maximum compression) and T (maximum tension) axes derived from fault plane solutions (Papazachos et al. 1982, 1984), the type of seismic faults (normal , thrust , strike-slip), the values of the seismicity rates and the values of the parameter b of the recurrence curve. Based on all the above mentioned criteria and also on some additional data(seismicity parameters, seismogenic volumes etc.) the area has been divided into 50 seismic sources by Hatzidimitriou (1984) for earthquake hazard studies.

In the present paper a further effort is made to define the seismic fracture zones in the Aegean and surrounding area on the basis of the data already used for this purpose (Papazachos 1980, Hatzidimitriou et al.1985) as well as on the basis of additional unpublished historical information collected by Catherine Papazachos.

2. FRACTURE ZONES OF SHALLOW SEISMIC ACTIVITY

It is well known that the distribution of epicenters can give valuable information on the determination of major plate boundaries and can identify areas where stress is concentrated in the lithosphere of the earth. This epicenter distribution can also be used for a crude estimation of the seismicity of a region in a quantitative manner. For these reasons, several maps showing the distribution of earthquake epicenters in the Aegean and surrounding area have been compiled in the past for both shallow and intermediate focal depth earthquakes (Galanopoulos 1968, Papazachos 1973, Makropoulos 1978, Papazachos and Comninakis 1982, Hatzidimitriou 1984, Comninakis and Papazachos 1986).

The determination of fracture zones for shallow earthquakes, presented in this paper, is mainly based on an unpublished epicenter map compiled by the senior of the present authors on the basis of published catalogues of historical (Papazachos and Comninakis 1982) and instrumental data (Comninakis and Papazachos 1986) as well as on unpublished newly collected by Catherine Papazachos historical information. This epicenter map is shown on figure (1). It shows the epicenters of all known shallow shocks with $M \geqslant 6.0$ which occurred between 600BC and 1986 in the Aegean and surrounding area (34^{o}N - 43^{o}N, 18^{o}E-30^{o}E) . Three sizes of circles have been used to denote three ranges of magnitude (6.0-6.4, 6.5-6.9, 7.0-7.8) . Black circles represent earthquakes of the present century (1901 -1985) and open circles represent historical earthquakes.

For earthquakes of the present century, the accuracy in the epicenters is within 10-20Km and the accuracy in the magnitude is within 0.1-0.3. For the historical earthquakes, the accuracy of the epicentral coordinates varies between 10Km and 40Km and for the magnitude between 0.2 and 0.5.

The striking characteristic of the map of figure (1) is that the epicenters of these strong earthquakes are clearly delineated and form distinguishable narrow zones of seismic activity. Based on this property of the epicenters as well as on other seismotectonic criteria applied also in previous papers (Papazachos 1980, Hatzidimitriou et al. 1985) the directions of the fracture zones have been drawn on this map(thick dashed lines). To name the zones a number is written close to each of these.

The width of the zones varies considerably and it ranges between 20Km for the most narrow zones 7 and 9 and 100Km for zones 3 and 14. The two small parallel lines between zones 2 and 3 mark the end of zone 2 and the beginning of zone 3.

A major feature of the these zones is that two general trends are observed. One group of zones follows the convex side of the Hellenic arc and extends to western coast of Greece, Albania and Yugoslavia (zones 1A,1B,1C,2,3,4,5). All other zones (from 6 to 17) are in the inner part of the arc and have, more or less, east-west trends, except for zone 6 which has a NE-SW trend, the northern branch of zone 7 which has N-S trend and zone 15 which follows the Servomacedonian geological massif in a NW-SE direction.

Zones 1A,1B and 1C cover the southwestern coast of Yugoslavia, the western coasts of Albania and the southwestern coasts of Albania- western coasts of mainland of Greece,respectively. Zone 2 covers the area of the Ionian islands. This is one of the most active zones of the studied area. Zone 3 covers the area between Ionian islands and west of Crete (south of Peloponnesus), while zones 4 and 5 cover the southern and southeastern part of the external Hellenic arc.

All the other zones lie in the inner part of the Hellenic arc. Zone 6 crosses central Albania in a NE-SW direction and is characterized by low seismicity. Zone 7 starts from southern Albania with a N-S direction up to northwestern Greece where it changes to an E-W direction and it terminates at the southern end of the peninsula of Athos. Zone 8 covers the area of the Patraikos-Corinthiakos-Saronikos gulfs. Zone 9 follows the Evoikos gulf and in its northernmost part (Maliakos gulf) probably changes direction to the west and reaches the intersect of zones 1C and 2.

Zones 10,11,12,13,14 have an E-W trend and cover the Aegean area and the western part of Turkey. Zone 10 starts from the central part of southern Aegean and terminates in the southwestern part of Turkey. Zones 11 and 12 start west of the islands Samos and Chios, respectively, and also terminate in the western part of Turkey. Zone 13 is the longest. It crosses the eastern part of the mainland of Greece and the central Aegean area and through the island of Lesbos terminates in western Turkey. Zone 14 starts from the southern part of Athos peninsula, crosses the northermost part of the Aegean and it continues in the northern Anatolia . This zone is characterized by large earthquakes as it coincides with the north Anatolian fault system and its extension to northern Aegean. Zone 15 has a NW-SE trend and follows the Servomacedonian geological zone. It starts from the southern part of Yugoslavia and terminates in the southern part of the peninsula of Athos at the intersection of the zones 7 and 14. Zone 16 is a small one, covering the northeastern part of Greece with an E-W direction.This zone is characterized by large historical earthquakes but no large earthquake occurred in this zone during the present century. Finally, zone 17 covers the southern part of Bulgaria in an E-W direction.

3. FRACTURE ZONES OF INTERMEDIATE FOCAL DEPTH SEISMIC ACTIVITY

The foci of the intermediate focal depth earthquakes ($h \geqslant 70$Km) in the Hellenic arc form a well developed Benioff zone of amphitheatrical shape which dips from the convex (eastern Mediterranean) to the concave (Aegean Sea) part of the arc (Papazachos and Comninakis 1969, 1971, Papazachos 1973, Comninakis and Papazachos 1980, Panagiotopoulos et al.1984).

There is strong evidence which shows that future intermediate depth earthquakes in southern Aegean will produce extensive damage in a broad area and will affect very seriously modern high structures (Papazachos et al.1985). For this reason, it is of importance to include these intermediate focal depth earthquakes in future studies of seismic hazard and earthquake prediction.

The epicenters of all known major ($M \geq 6.0$) earthquakes of intermediate focal depth ($h \geq 70Km$) in the Aegean region are shown in figure (2). Four symbols have been used to denote earthquakes of four magnitude ranges (6.0-6.4 , 6.5-6.9, 7.0-7.4, 7.5-8.2) . Black triangles represent earthquakes of the present century, while open triangles represent historical earthquakes.

We can distinguish two zones of intermediate focal depth earthquakes in this figure (dashed lines). The outer zone starts from central Greece and following the inner (concave) part of the Hellenic arc terminates north of Rhodos island.This zone follows approximately the isodepth of 100Km and is characterized by earthquakes with big magnitudes. As it can be seen from this map twelve known earthquakes with magnitudes between 7.5 and 8.2 had epicenters in this zone during the period 600 AD-1986. Eight of these earthquakes occurred during the last two centuries.

The second zone of intermediate focal depth earthquakes extends along the innermost part of the Hellenic arc . It is characterized by earthquakes of relatively small magnitude ($M < 7.1$) and follows the isodepth of 150Km and the volcanic arc.

4. DISCUSSION

The maps of figures (1) and (2) are based on a much larger sample of only major shocks in comparison with similar maps so far published. The data used for this map cover also a very large time period. The good delineations of the epicenters of these shocks and the formation of distinguishable narrow belts by these epicenters show that the spatial distribution of these large earthquakes define the main active fracture zones in this area.

All the known seismic faults of the region belong to these fracture zones but each of these faults is not necessarily parallel to the trend of the corresponding zone. For example, most of the known seismic faults in the Servomacedonian zone (15) have an almost east-west strike (Papazachos et al. 1984) and therefore are not parallel to this zone which has a NW- SE trend. On the other hand, the faults along the convex side of the Hellenic arc seem to be parallel to the fracture zones.

We believe that the maps of figures (1) and (2), where the trends of the main fracture zones are shown, are of primary importance for studies concerning earthquake prediction, seismic hazard and geodynamical problems in the Aegean and surrounding area. Attempts to identify seismic precursors(seismicity patterns,etc) must be concentrated mainly along these zones and seismic hazard techniques which are based on seismic zonation can also be based on these maps. On the other hand, the interpretation of some basic properties of these fracture zones (trend directions, etc) is a basic condition for the validity of any proposed geodynamical model for this region.

ACKNOWLEDGEMENTS

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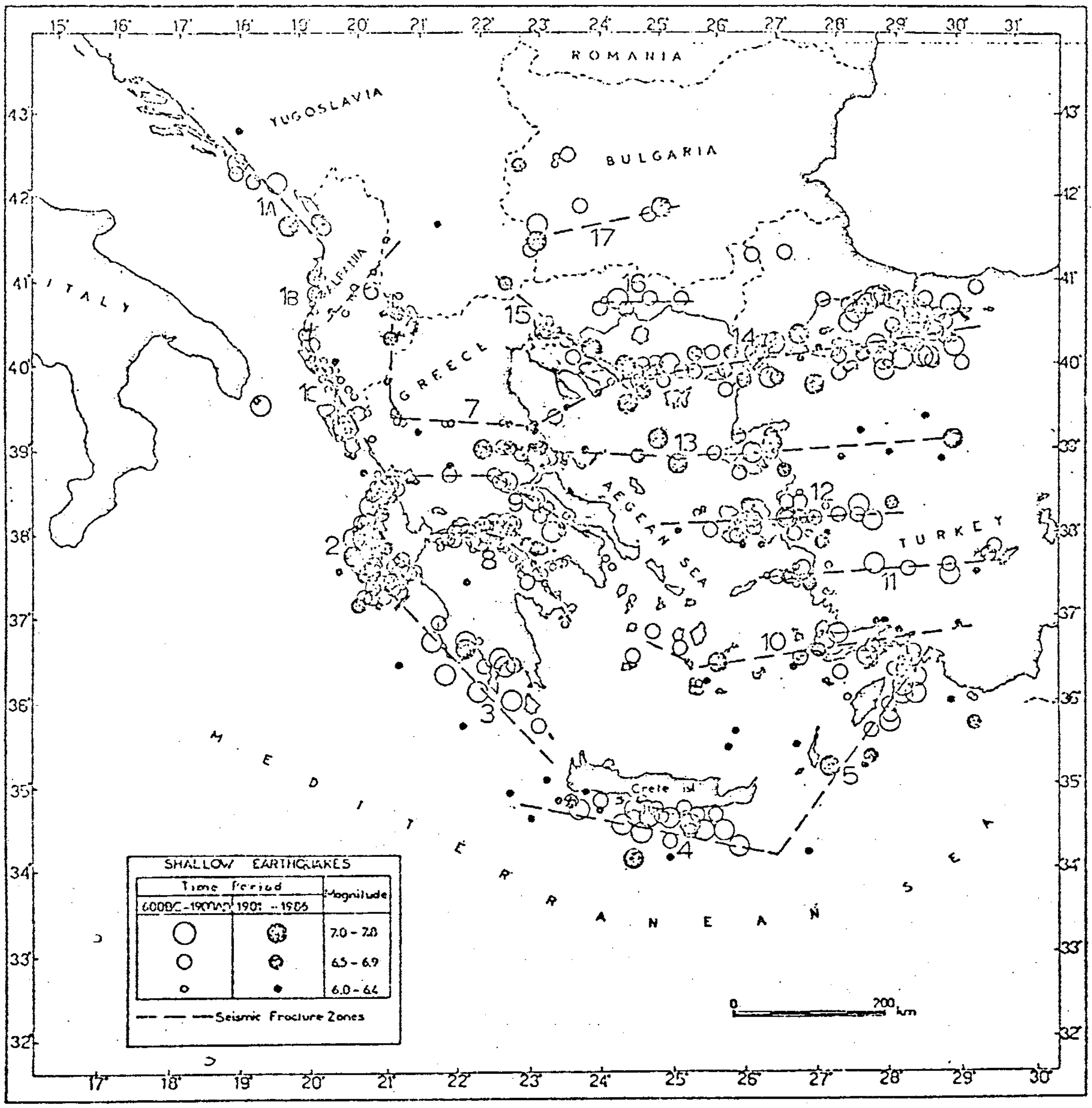
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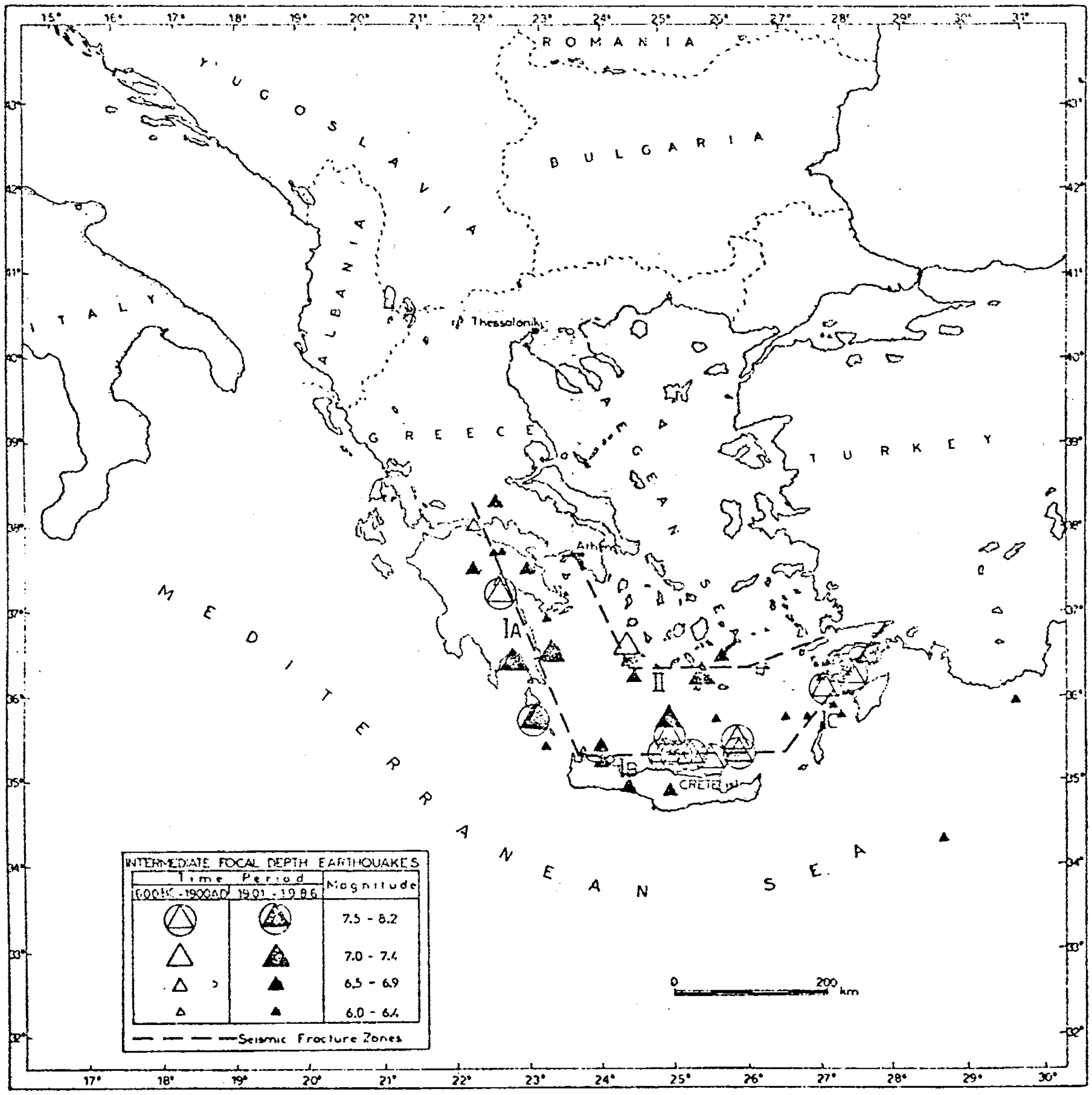
BULGARIA
ALBANIA
ITALY
GREECE
AEGEAN SEA
TURKEY
MEDITERRANEAN SEA
Crete isl
SHALLOW EARTHQUAKES
Time Period
600BC-1900AD
1901-1986
Magnitude
7.0 - 7.8
6.5 - 6.9
6.0 - 6.4
Seismic Fracture Zones
0
200 km

Fig. 1.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GREECE
AEGEAN SEA
TURKEY
Athens
CRETE
MEDITERRANEAN SEA
INTERMEDIATE FOCAL DEPTH EARTHQUAKES
Time Period
600 BC - 1900 AD
1901 - 1986
Magnitude
7.5 - 8.2
7.0 - 7.4
6.5 - 6.9
6.0 - 6.4
Seismic Fracture Zones
0 200 km

fig 2

PRESEISMIC QUIESCENCE BEFORE LARGE EARTHQUAKES IN THE AEGEAN AND SURROUNDING AREA

PRESEISMIC QUIESCENCE BEFORE LARGE EARTHQUAKES IN THE AEGEAN AND SURROUNDING AREA

by

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ABSTRACT

Among the premonitory seismicity patterns investigated so far, decrease of the rate of the low magnitude seismic activity before strong shocks seems to be one of the most promising such patterns for long-term earthquake prediction. Based on the cumulative number of small earthquakes as a function of time, we observed a preseismic quiescence of the small shock seismicity in a broad area around the epicenter of all the large ($M \geq 7.0$) earthquakes wich occurred in the Aegean and surrounding area during the last forty years. Furthermore, additional evidence are presented that some regions of this area are at quiescence now, which indicates that these regions will experience strong earthquakes during the next decade or so.

1. INDTRODUCTION

Regions with high seismicity such Aegean sea and the surrounding areas have attracted much attention from seismologists. Although much work concerning the investigation of prone regions for the generation of large earthquakes in this area has been done, there are still important difficulties concerning this problem and further research is needed.

Various seismicity patterns before strong events which occurred or will probably occur in the area studied, have been reported so far. These patterns concern foreshocks, preseismic quiescence, time variation of the magnitude difference between the main shock and its largest aftershock, migration and doughnut patterns. Among them, preseismic quiescence appears most common.

Wyss and Baer (1980) and Papazachos (1980) based on the drop of the seismicity rate in the area south of Peloponnesus concluded that earthquakes with big magnitudes will probably occur in this area till the end of this decade.

Seeking for seismic gaps along the Hellenic arc, Wyss and Baer (1981) defined four such gaps where they expect strong shocks, while Papazachos (1981) and Papazachos and Comninakis (1982) concluded that strong events will occur along this arc during the next few years.

Papazachos (1980) and Papadimitriou (1984) showed that a broad region is affected during the preparatory stage of large shocks and the seismicity drop is not limited to the seismogenic volume of the coming shock but is extended to a broader zone.

Papadimitriou and Papazachos (1985a) based on the variation of small magnitude seismicity rate in Ionian islands defined two volumes that had remained free of epicenters since 1963. So, the first a- priori prediction in Greece was a fact when a M = 7.0 shock in one (the southern) of these volumes occurred, on January 17, 1983. Another such shock is expected in the second (Leukada island) of these volumes.

Regarding the intermediate depth seismicity, evidence ha been presented that a new cycle of intermediate depth seismi activity will start in southern Greece (Comninakis and Papazachos 1980, Papadimitriou et al.1984, 1985, Papazachos et al.1985)

In the present work, our attention has been focused o the following two subjects: First, to examine whether ther was or not a drop of the low manitude seismicity rate befor all large earthquakes ($M \geq 7.0$) which occurred in Greece an surroundings during the last forty years in a broader are than the seismogenic volume of such earthaquakes, and secon to present further evidence for drop of seismicity rate in some regions for which previous authors presented such evidenc and to identify new such regions, which can be considered a earthquake prone regions . This effort has been stimulated b new information that has been recently attained on the seismi fracture zones (Papazachos et al. 1986) by additional dat concerning historical earthquakes. The search for seismicit drop was thus limited along these fracture zones.

2. DATA AND METHOD

As data source for the present study, the cataloque o Comninakis and Papazachos (1986) has been used. The data o this catalogue are complete for the following time periods an for the corresponding magnitude ranges

1901-1910	$M \geq 6.5$
1911-1949	$M \geq 5.2$
1950-1963	$M \geq 5.0$
1964-1985	$M \geq 4.5$

The method applied is simple and is based on plotting the cumulative number, N, of earthquakes as a function of time, t. By this method it is easy to follow the variations of the seismicity rate and a detect anomalies (Wyss and Habermann 1979). The seismicity rate is given by the slope of the plots, which

$$r = \frac{dN}{dt}$$

corresponds to certain magnitude, M, and to certain surface, S.

If we want to have the rate, r', for the unit surface (e.g. 10.000 Km^2) and for a certain magnitude M′ (e.g. $M \geq 4.5$) we can apply the following relation (Papazachos 1980)

$$r' = \frac{dN}{dt} \cdot \frac{10^{b \cdot \Delta M}}{S}$$

where $\Delta M = M - M'$ and b the well known parameter in the frequency magnitude relation.

We defined as r_2 the seismicity rate during the preseismic quiescence period and r_1 the seismicity rate before this period. So, the ratio r_2/r_1 implies the percentage drop of seismicity during the quiescence period. Both r_1 and r_2 are referred to shocks with $M \geq 5.0$ in this paper.

3. DROP OF SEISMICITY RATE BEFORE STRONG EARTHQUAKES

In this part of our work we determine the preseismic seismicity rate in a broad area around the epicenter of each of all large ($M \geq 7.0$) earthquakes which occurred in this region during the last forty years.

Figure (1) shows the epicenters of all main shocks wit M≥7.0 which occurred in the area studied since 1947, while ta ble (1) includes information on these earthquakes.

We considered all main shocks with M ≥ 4.9 (excluded fo reshocks and aftershocks) which occurred in areas 50 Km ar 100Km around each major shock listed on table (1). The rates r_1 a r_2 have been determined and are also listed on table (1) for the earthqua kes 100km around the epicenter of the main shock.

Figures (2a) and (2b) show the cumulative number of shock which occurred 100Km around each major (M≥7.0) shock as function of time . We can observe that there was preseismi quiescence before all these strong earthquakes. The duratio of the quiescence varies between 7 and 22 years. In many case the earthquake occurred some time after the end of the presei smic quiescence period, when the seismicity rate had alread increased. Note that the area encountered each time (diamete of the circle = 200Km) is much larger that the seismogeni volume of the main shock in each case. This shows that a broa der area is affected before the occurrence of every earthqua ke with M≥7.0. The cumulative plots of the shocks which oc curred 50Km around each main shock showed that in most case the main shock occurred at the end of the quiescence period that is, the quiescence period in these cases lasted till th occurrence of the main shock.

4. FURTHER EVIDENCE FOR QUIESCENCE IN SOME REGIONS IN GREECE

To determine whether any part of the active area unde consideration is in a preparatory stage for the generation o an earthquake we studied the seismicity rate for shocks with M≥4. in seismic zones along all fracture zones determined by Papa zachos and his colleagues (1986) and shown in figure (3). I

Table I. Information on the major shallow earthquakes (M≥7.0) which occurred in Greece and surrounding area between 1947 and 1985.

No	DATE	ORIGIN TIME	φ_N^o	λ_E^o	M	r_1	r_2	r_2/r_1
1.	Oct. 6,1947	19:55:34	36.9	22.0	7.0	0.16	0.05	0.31
2.	Feb. 9,1948	12:58:13	35.5	27.2	7.1	0.21	0.04	0.17
3.	Dec.17,1952	23:03:57	34.4	24.5	7.0	0.25	0.14	0.56
4.	Mar.18,1953	19:06:16	40.0	27.4	7.4	0.16	0.07	0.41
5.	Aug.12,1953	09:23:52	38.3	20.8	7.2	0.63	0.23	0.37
6.	Apr.30,1954	13:02:36	39.3	22.2	7.0	0.18	0.12	0.67
7.	Jul.16,1955	07:07:10	37.6	27.2	7.0	0.11	0.02	0.18
8.	Jul. 9,1956	03:11:40	36.7	25.8	7.5	0.41	0.03	0.07
9.	Apr.25,1957	02:25:42	36.5	28.6	7.2	0.34	0.14	0.41
10.	Oct. 6,1964	14:31:23	40.3	28.2	7.0	0.71	0.03	0.04
11.	Feb.19,1968	22:45:42	39.4	24.9	7.1	0.41	0.12	0.29
12.	Mar.28,1970	21:02:23	39.2	29.5	7.1	0.11	0.02	0.18
13.	Apr.15,1979	06:19:41	42.0	19.0	7.1	0.12	0.04	0.33
14.	Dec.19,1981	14:10:52	39.0	25.2	7.3	0.30	0.04	0.14
15.	Jan.18,1982	19:27:24	39.8	24.4	7.0	0.31	0.05	0.16
16.	Jan.17,1983	12:41:29	38.0	20.2	7.0	0.83	0.38	0.46

has been found that eleven of these zones are now at quiescence. The cumulative plots for these eleven zones are shown in figures (4a) and (4b) while information the seismicity rates during the present quiescence period and the preceded active one are listed on table (II).

Zone 1c includes parts of the southwestern coast of Albania and western coast of mainland of Greece. This zone is in quiescence since 1974, while Papadimitriou (1984) considered a broader area and detected a quiescence since 1969.

Table II. Information on the seismicity rates in the regions (see fig. 3) considered as prone for the generation of large earthquakes.

ZONE	r_1	r_2	r_2/r_1	ZONE	r_1	r_2	r_2/r_1
1C	0.52	0.36	0.69	10	0.28	0.04	0.16
2N	1.23	0.64	0.52	11	0.94	0.00	0.00
3	0.59	0.16	0.27	12	0.20	0.00	0.00
4	0.91	0.46	0.51	13A	0.09	0.06	0.67
5	0.56	0.09	0.16	14A	0.15	0.05	0.30
8	0.90	0.29	0.32				

Zone 2N is the northern part of zone 2 which includes Leukada island. It is well known that this island has experienced large earthquakes in the past (Papazachos and Comninakis 1982). This zone is in quiescence since 1948. Zone 3 covers the area south of Peloponnesus, and has been reported as the area with a major likelihood for the occurrence of large shocks in the next few years by several seismologists (Wyss and Baer 1980, 1981, Papazachos 1980, 1981, Papazachos and Comninakis 1982, Papadimitriou 1984, Papadimitriou and Papazachos 1985b). As we can see in figure (4a), this zone is in quiescence since 1963.

Zone 4 is located at the southernmost part of the Hellenic arc and includes Crete island. This is also an area that has attracted much attention from seismologists. As previous scientists concluded (Wyss and Baer 1980, 1981, Papazachos 1981, Papazachos and Comninakis 1982, Papadimitriou and Papazachos 1985b) this zone is a prone area for the generation of large earthquakes. Figure (4a) shows that this area is in quiescence since 1973.

The eastern part of the Hellenic arc is terminated . at Rhodos island and is designated as zone 5. During the present century three large events occurred in this zone (M = 6.8, 1922 , M = 7.1, 1948, M = 7.2, 1957) and several seismologists (Wyss and Baer 1980, Papazachos 1981, Papazachos and Comninakis 1982, Papadimitriou 1984, Papadimitriou and Papazachos 1985b) considered this area as a prone one for the generation of large events. We can see in figure (4a) that this zone is in quiescence since 1974.

Zone 8A is the western part of zone 8A and includes Patraikos gulf and the western part of Corinthiakos gulf. As it is shown in figure (4a), this zone is in quiescence since 1975. Similar results have been reported by Papadimitriou and Papazachos (1985b).

A part of the back-arc region forms zone 10 which includes Amorgos and Kos islands and part of southwestern Turkey . The largest shallow event in the whole area of Greece occurred in this zone (1956, M = 7.5), which is now in quiescence since 1968.

Zones 11 and 12 include Samos and Chios islands and a part of W.Turkey. They are in quiescence since 1977. Papadimitriou and Papazachos (1985b) arrived at a similar conclusion.

Zone 13 includes Lesvos island and a part of W. Turkey . It is in quiescence since 1944 when an earthquake with magnitude M = 7.0 occurred there .

Zone 14 occupies Marmara sea and a part of Northern Aegean sea. As we can see, this zone is in quiescence since 1969 . This area has been characterized as a prone one for the generation of a strong shock by Papadimitriou (1984).

Intermediate depth seismic activity in the area studied is concentrated in the two zones, A and B, shown in figure (5). Several seismologists concluded that high intermediate seismic activity is expected in this area (Comninakis and Papazachos

1980, Papadimitriou et al. 1984, 1985, Papazachos et al.1985)

The cumulative number of intermediate depth shocks as a function of time are shown in figure (6) while information on the seismicity rates r_1 and r_2 are listed on Table (III). We observed that zone A is at quiescence since 1936 while zone B since 1948.

Table III. Information on the seismicity rates in zones A and B of figure (5), which are considered as prone for the generation of large intermediate depth earthquakes.

ZONE	r_1	r_2	r_2/r_1
A	0.18	0.08	0.44
B	0.14	0.08	0.57

5. DISCUSSION AND CONCLUSIONS

This work deals with the determination of preseismic quiescence in Aegean and surroundings using seismicity rates, and several interesting results for the long term earthquake prediction have been obtained.

In all cases of strong events (M≥7.0) which occurred in this area since 1947, the main shock was preceded by a seismicity quiescence period varying between 7 and 22 years, 100 Km around each main shock epicenter. This is in agreement with observations made by Papadimitriou and Papazachos (1985b), that a broader area around the seismogenic volume is affected. In some cases, the preseismic quiescence period did not lasted up to the time of occurrence of the main shock, as Wyss and his collaborators (1984) also noticed, but in the cumulative plots of the shocks located in the area 50Km around the main shock epicenters we observed that the quiescence was lasting up to the time of the main shock.

We presented further evidence for some parts of the area studied that are in quiescence now and large earthquakes are expected to occur there.

Since our work was of a rather qualitative character, we believe that further and more detailed study may result to a quantitative form, e.g. a relation between quiescence period and the magnitude of the main shock. This can be facilitated by the establishment of a dense telemetric seismograph network for a continuous monitoring of the small magnitude seismicity in Greece.

ACKNOWLEDGEMENTS

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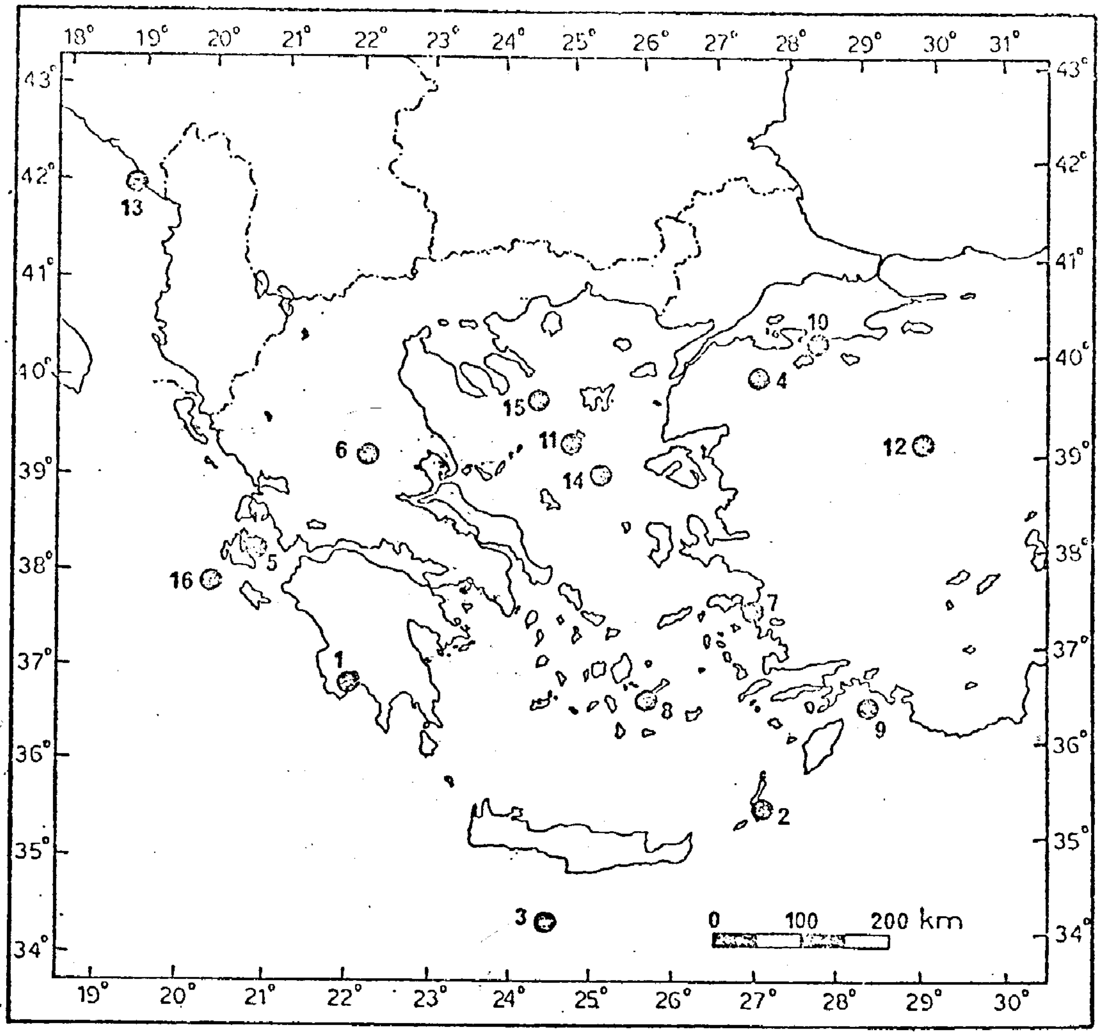
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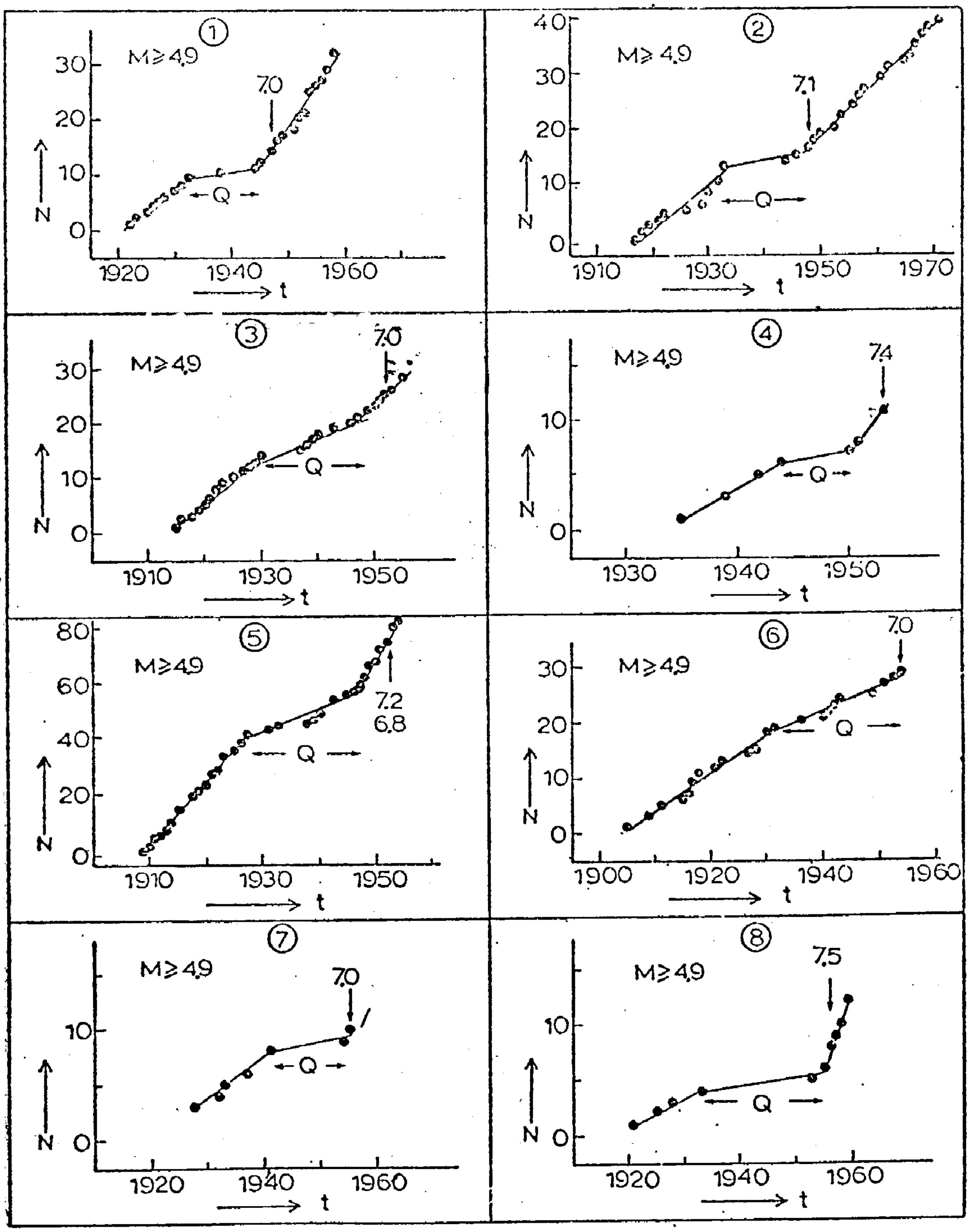
0 100 200 km

fig. 1.



①
M≥4.9
7.0
Q
N
t
1920
1940
1960
②
M≥4.9
7.1
Q
1910
1930
1950
1970
③
M≥4.9
7.0
④
M≥4.9
7.4
⑤
M≥4.9
7.2
6.8
⑥
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⑦
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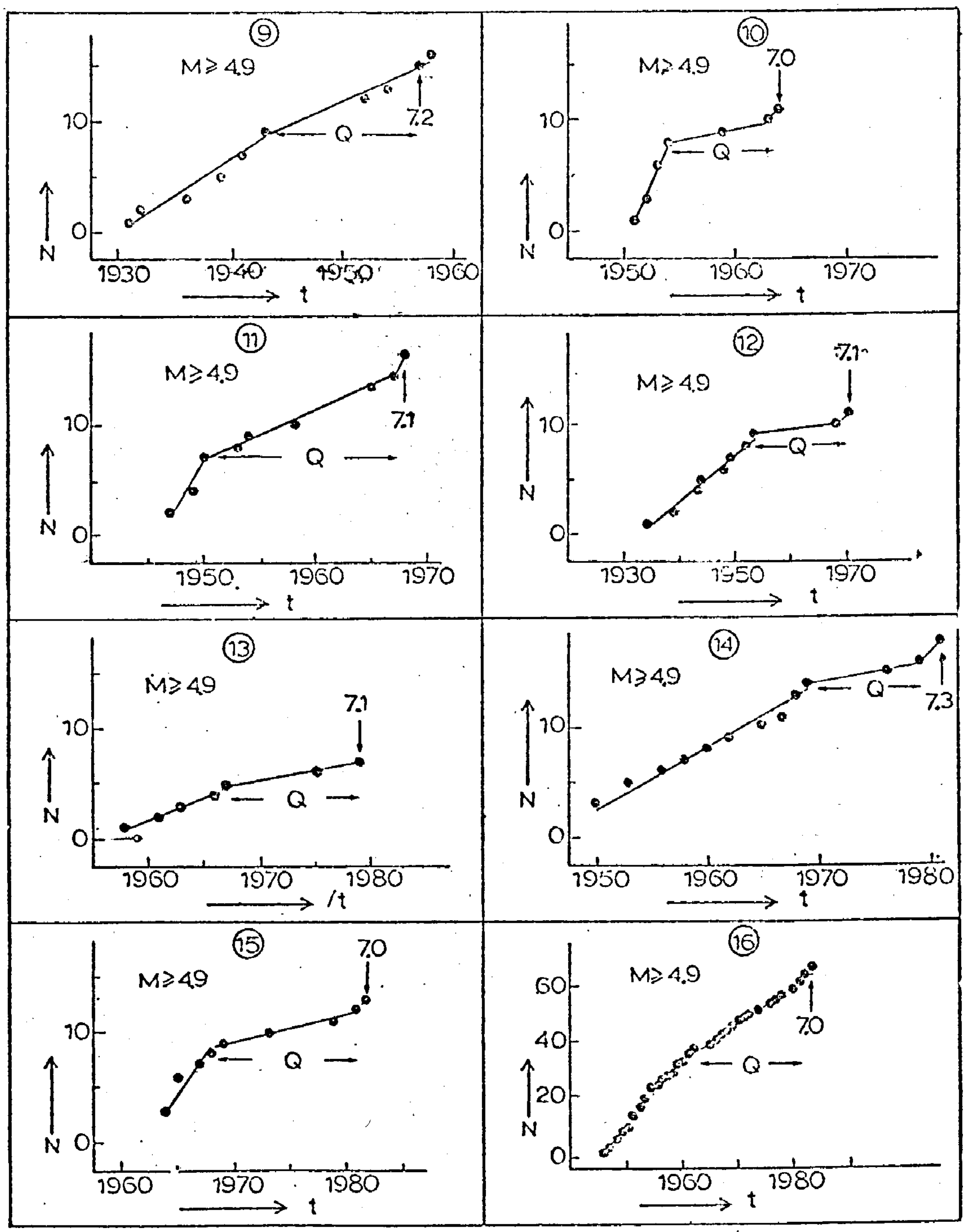
7.0
⑧
M≥4.9
7.5

fig. 2a.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7.2
Q
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N
1930
1940
1950
1960
t
10
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7.0
Q
10
0
N
1950
1960
1970
t
11
M≥4.9
7.1
Q
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0
N
1950
1960
1970
t
12
M≥4.9
7.1
Q
10
0
N
1930
1950
1970
t
13
M≥4.9
7.1
Q
10
0
N
1960
1970
1980
t
14
M≥4.9
7.3
Q
10
0
N
1950
1960
1970
1980
t
15
M≥4.9
7.0
Q
10
0
N
1960
1970
1980
t
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Q
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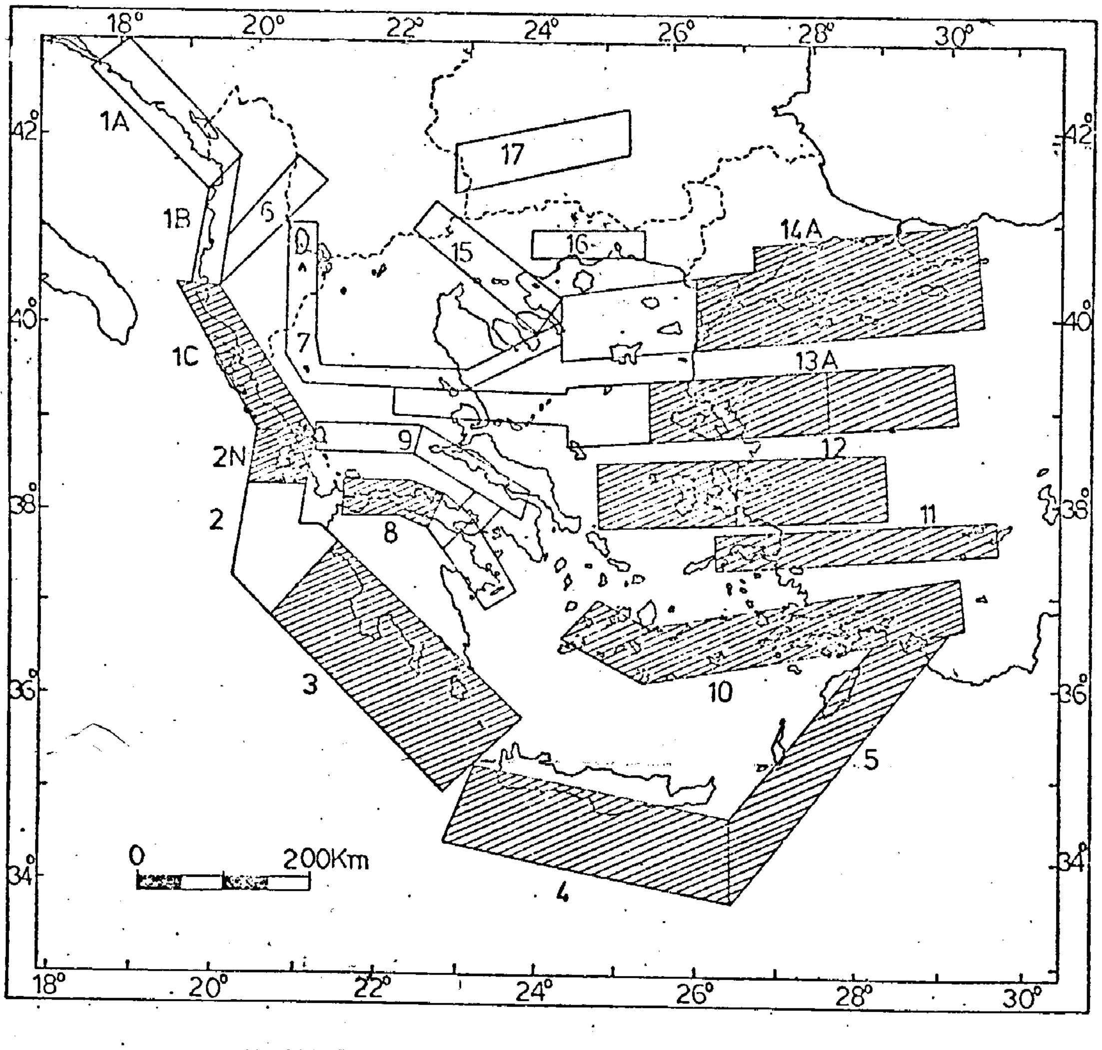
1960
1980
t

fig. 2b.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2N
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3
4
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11
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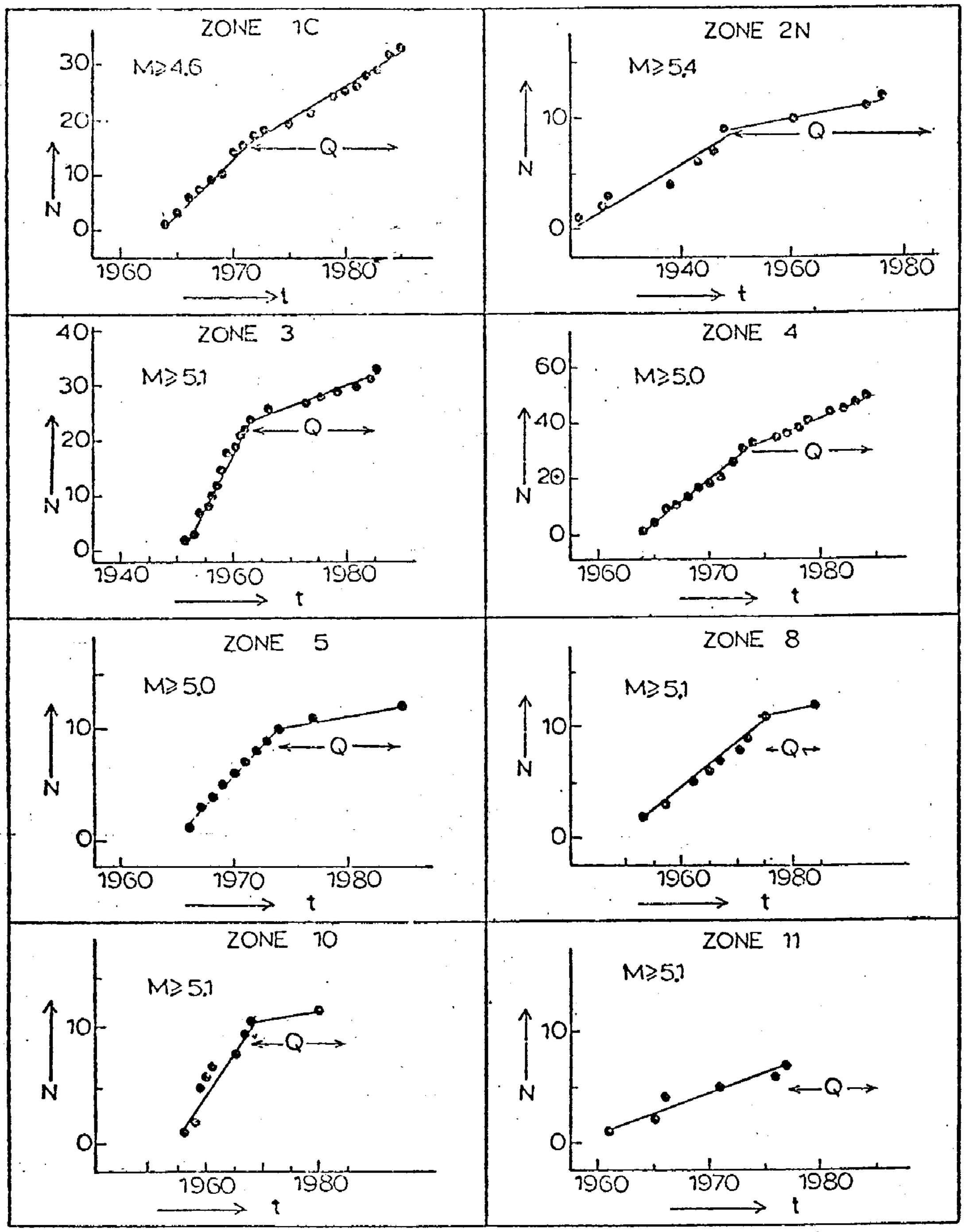
13A
14A
15
16
17
0
200Km

fig. 3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1980
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ZONE 3
M≥5.1
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ZONE 8
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1980
t
ZONE 10
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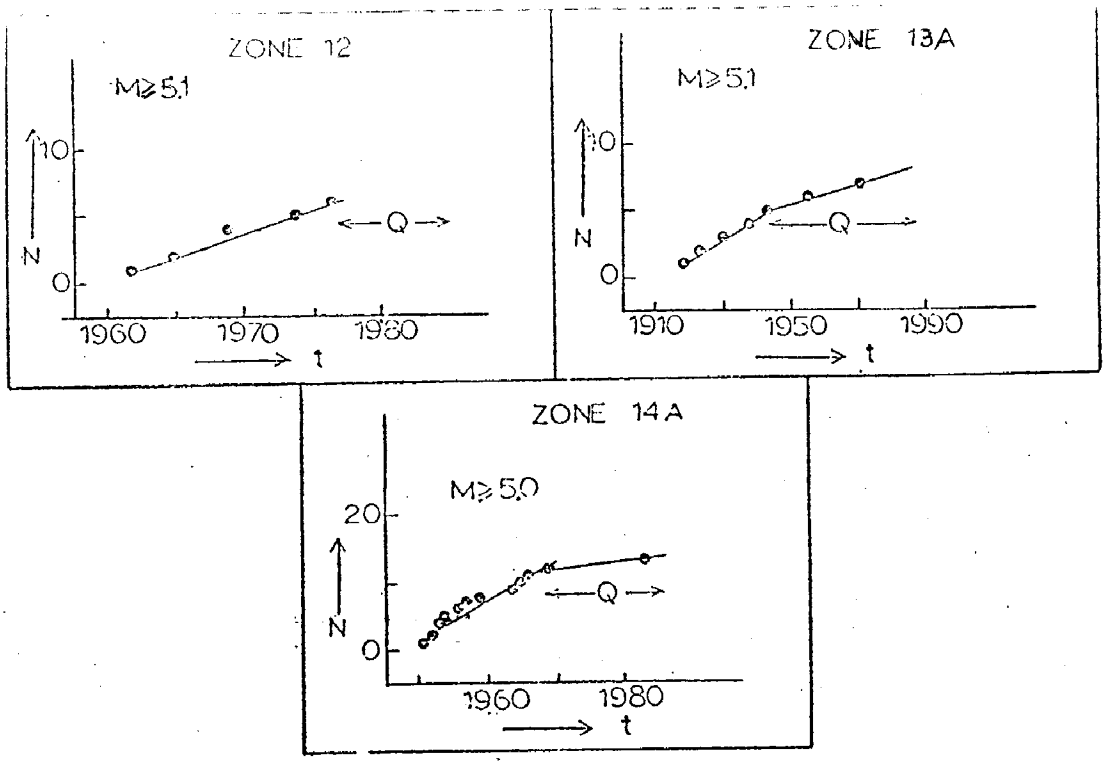
fig. 4a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1970
1980
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Q
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1910
1950
1990
t
Q
ZONE 14A
M≥5.0
20
N
0
1960
1980
t
Q

fig. 4b.

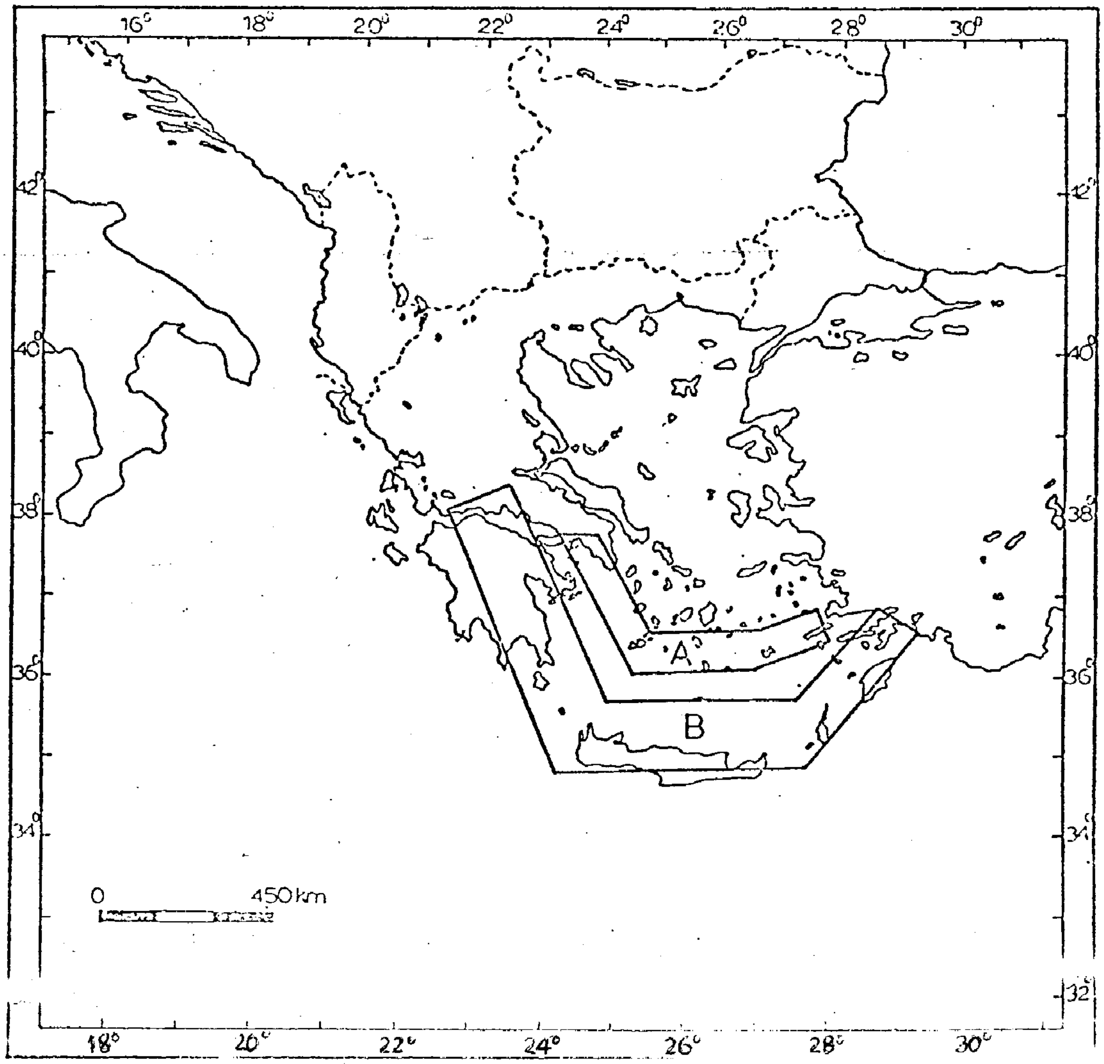
16°
18°
20°
22°
24°
26°
28°
30°
42°
40°
38°
36°
34°
32°
A
B
0
450 km

fig. 5.

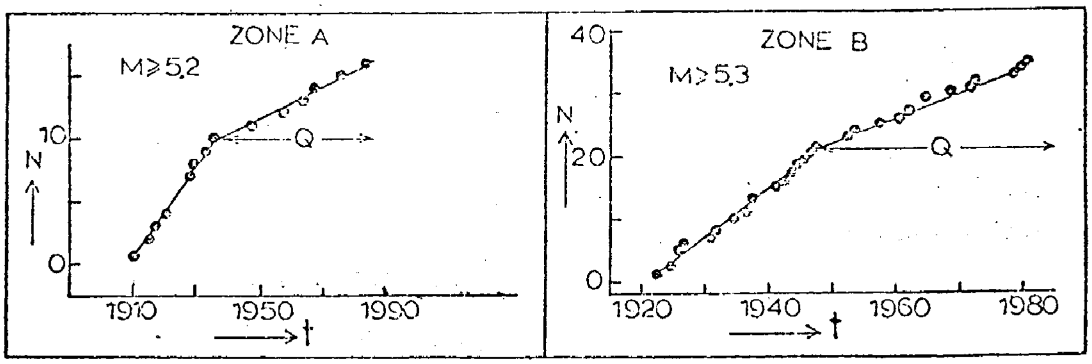
ZONE A
M≥5.2
N
10
0
1910
1950
1990
Q
t
ZONE B
M≥5.3
40
N
20
0
1920
1940
1960
1980
Q
t

fig. 6

PROBABILITIES OF OCCURRENCE OF LARGE EARTHQUAKES IN THE AEGEAN AND SURROUNDING AREA DURING THE PERIOD 1986-2006

PROBABILITIES OF OCCURRENCE OF LARGE EARTHQUAKES IN THE AEGEAN AND SURROUNDING AREA DURING THE PERIOD 1986-2006

By

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ABSTRACT

Repeat times of large shocks are obtained for 17 seismic fracture zones of the Aegean and surrounding area, from times of historic and present century earthquakes. The mean standard deviation of the repeat times is aproximately 50% of any one observation.

A probabilistic approach is then used to forecast the likelihood of large future earthquakes in each fracture zone using as input the time of the last large shock, the average repeat time and its standard deviation. Shallow and intermediate depth earthquakes are examined separately. The calculated probabilities are high for the entire Hellenic arc, both for shallow and intermediate depth seismicity, for the area of Leucas island (Ionian), of Lesbos island (Aegean), for Patraikos-west Corinthiakos Gulfs, for Evoikos Gulf as well as for southern Bulgaria.

The probability estimates based on the most recent large earthquake, involve a number of basic physical assumptions and we would think that they provide a semi-stochastic approach

to the problem of earthquake prediction in Greece.

1. INTRODUCTION

The demand for earthquake prediction is prominent in the Aegean area which is very often struck by large earthquakes. The tectonic setting of this area is complex and this makes earthquake prediction research difficult, since the starting point for such research should be an understanding of the tectonic process causing the earthquakes.

The most clearly defined tectonic features of the area are the Hellenic arc-trench system, a subduction zone of about 1000Km length and the Aegean Sea, which is a back – arc marginal sea (Papazachos and Comninakis 1969,1971). Many of the large ($M \sim 7.0$) shallow earthquakes of the area occur by low angle thrust fault movement along the convex side of the Hellenic arc, while other even larger ($M \sim 7.5$) shallow shocks are produced by normal or strike slip faulting in the back-arc broad Aegean area. Great ($M \sim 8.0$) intermediate focal depth earthquakes ($h \gtrsim 100$Km) occur by thrust faulting in the Benioff zone which is associated with the subduction along the arc.

The present paper uses information on repeat times to identify regions of special interest to earthquake prediction and to seismic hazard assessment. It includes a probabilistic approach so as to allow for variations in repeat time. The probabilities of occurrence of large shocks in the next 20 years were calculated on the basis of the time that has elapsed since the last earthquake, the mean repeat time and estimates of the variation (standard deviation) of the repeat time for the different seismic fracture zones examined.

No recurrence model of large earthquakes is assumed a priori in this analysis, and to our knowledge our investigation is the first in which repeat times have been calculated directly from observations for various regions of the entire Aegean and surrounding area.

2. THE DATA SET

The data source for this work was basically two catalogues published by the Geophysical Laboratory of the University of Thessaloniki. The first one covers the period 1901- 1985 (Comninakis and Papazachos 1986). The second catalogue covers the historical seismicity in Greece for the period 473 B.C. - 1900A.C. (Papazachos and Comninakis 1982). This last catalogue, recently improved with new information collected by Mrs. Catherine Papazachos, prooved to be our most valuable source of data.

Figure (1) shows the epicenters of all known shallow($h < 70$Km) shocks which occurred in Greece in the periods 600 B.C.-1900A.C. (open circles), 1901-1986 (black circles)with $M_S \geq 6.0$ (Papazachos et al. 1986a). It is observed that there are certain lines along which the seismic activity seems to delineate. These lines, 17 altogether, which are called seismic fracture zones, are represented by broken lines in this figure. Apart from these fracture zones the earthquake activity in the Aegean seems to be rather random. The broken lines of figure (1) were drawn based not only on the seismicity but also on the tectonic features of the region. A lot of work preceded this fracture zone separation (Papazachos 1980, Hatzidimitriou et al. 1985).

Figure (2) shows the epicenters of the intermediate depth shocks ($h \leq 70$Km) (Papazachos et al. 1986a). Two zones can be identified, namely the outer one following the inner (concave) part of the Hellenic arc and the inner one which extends along the innermost part of the Hellenic arc.

3. ESTIMATION OF REPEAT TIMES

A computer program (POLYGON) was used to depict all the earthquakes which occurred in a polygon which was drawn around each fracture zone, in such a way that it included information on all the observed shocks. Thus, for each fracture zone a catalogue of the earthquakes which ruptured the whole zone or part of it over a certain period of time was compiled. Each fracture zone was separately examined and for each one the data set used was complete over a certain magnitude threshold. Foreshocks and aftershocks were excluded and only the independent events were included in the analysis.

For our calculations we divided some of the zones into more segments because parts of them have not ruptured for a very long time, or their dimensions were considerably large, or they exhibited different tectonic complexity, or they had different strike. The exact number of segments and their boundaries are, of course, somewhat arbitrary.

For each fracture zone or its segments the observed repeat time, T, in years, for all earthquakes of each magnitude class (differing by 0.1 magnitude values) was calculated.

Figure (3) shows plots of the logarithm of the mean repeat time T_m in years, as derived directly from the observations, versus the surface wave magnitude, M_S, for the shallow earthquakes which occurred in two fracture zones (2B and 14A) Such plots were produced for all shallow earthquakes of eac fracture zone and in all plots the linear trend was evident The same was done for the zones of intermediate focal dept seismicity.

Straight lines drawn through the observations in figur (3) were determined in the least squares´ sense since the fol lowing linear relation is assumed to hold between the repea time T_m and the magnitude , M_S

$$\log T_m = a + bM_S \qquad (1$$

where a and b are constants. The lowest magnitude threshold i.(M = 5.0 or 6.0 was chosen on the basis of the goodness of fi of the least squares´ solution. Table I summarizes the value of the constants a and b for each fracture line, for the shal low and intermediate depth earthquakes.

The repeat times of the earthquakes along the subductio belt (zones 1C to 5) may be related to , among other factors the rate of plate convergence between Africa and the Aegea plate (Acharya 1979). The fact that other factors are envolve besides the rate of convergence is indicated by the variatio of repeat time among regions with relative plate velocitie that are compared. Also, even for a particular point along a given plate boundary repeat times may vary by at least a factor of 1.5 to 2.0 (Sykes and Quittmeyer 1981).

The logarithms of the observed standard deviations fo each observation of repeat time were plotted as a function o magnitude for the shallow and intermediate depth earthquakes separately. Although the scatter was considerable, the linea trend was evident . We decided to include all the observation in the plots and calculate a mean standard deviation of repeat

Table I. Calculated values of the parameters a and b of the relation (1) for the shallow and intermediate depth earthquakes

No of fracture line	b	a
SHALLOW EARTHQUAKES		
1A	0.71	-2.66
1B	1.05	-4.97
1C	0.70	-3.01
2A	1.36	-7.52
2B	1.15	-6.25
3	0.67	-3.07
4A	1.56	-8.23
4B	1.56	-8.05
5	0.72	-3.37
6	0.97	-4.43
7	1.49	-8.16
8AB	0.88	-4.20
8C	0.83	-3.47
8D	1.20	-5.83
9A	0.60	-2.27
9B	0.41	-1.02
10	1.04	-5.45
11A	0.23	-0.02
11B	0.73	-2.76
12A	0.49	-1.60
12BC	0.60	-2.20
$13A_1$	0.37	-1.06
$13A_2$	0.40	-1.27
13B	0.31	-1.16
14A	0.45	-1.65
14B	0.57	-2.07
15	0.27	-0.46
16	-	-
17	0.68	-3.04

No of fracture line	b	a
INTERMEDIATE-DEPTH EARTHQUAKES		
IA	0.63	-3.04
IB	0.63	-2.93
IC	0.63	-2.98
Inner zone of the Hellenic arc	0.48	-1.72

time for each magnitude . So, the following relations were determined in the least squers' sense

$$\log\sigma = 0.44M_S - 1.59 \quad \text{shallow} \qquad (2)$$

$$\log\sigma = 0.54M_S - 2.54 \quad \text{intermediate-depth} \qquad (3)$$

It is observed that for a shallow earthquake with $M \geqslant 6.0$ the mean standard deviation is 11 years or 50% of the average repeat time. For an intermediate depth event with $M \geqslant 7.0$ the mean standard deviation is 17 years or 50% of the average repeat time. It is our belief that the use of equations (2) and (3) for the calculation of the errors in the estimation of repeat times , which are input in the probability estimates, is averaging out any individual errors.

4. PROBABILISTIC ESTIMATES

The probabilities of occurrence of large shocks at each fracture zone, for a time interval of 20 years are estimated. The time interval of 20 years was chosen on the basis that probability calculations are often more stable than they are for shorter intervals. Moreover, this period is long enough for various planning purposes such as engineer design and possible modification of structures.

The probability of occurrence of large shocks along each of the fracture zones is estimated using as input for each one the date of the last large earthquake, the average repeat time and its standard deviation as calculated from equations (2) or (3). The probabilities, thus estimated, have many analogies to those of the human mortality, i.e., an individual 100 years old (or a very old seismic gap) is very likely to die (to be the site of an earthquake) in , say, the next 20 years compared to one that is 20 years old (a young seismic gap).

Given the uncertainties in the input data and in models for earthquake recurrence, it is our belief that a probabilistic analysis is more useful than estimates of actual dates of future events. Proper attention, of course, must be given to the uncertainties of estimates.

To calculate the probability, P, that the repeat time T of an earthquake of certain magnitude interval will occur in a fracture zone during the next Δt years, conditional to the t years that have elapsed since the last earthquake of this magnitude in this zone, the following formula has been applied:

$$P\ (t \leq T < t+\Delta t / T > t) = \frac{\int_t^{t+\Delta t} n(t)\,dt}{\int_t^{\infty} n(t)\,dt} \qquad (4)$$

under the assumption that Gaussian distribution of repeat time is appropriate, that is,

$$n(t) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{t-T_m}{\sigma}\right)^2\right] \qquad (5)$$

where σ is the standard deviation (Wesnousky et al.1984).

Using formula (4), the probabilities of occurrence of shallow earthquakes with $M \geq 6.0$, $M \geq 6.5$ and $M \geq 7.0$ in each zone shown in figure (1) during the next 20 years were calculated. The same was done for the zones of intermediate focal depth earthquakes shown in figure (2) but in the case of these zones (IA, IB, IC) the probabilities for $M \geq 7.5$ were also calculated.

In the case of Poisson distribution, the probability of occurrence of earthquakes of a certain magnitude range in a certain seismic zone during the next Δt years is given by the formula

$$P = 1 - \exp\left(-\frac{\Delta t}{T_m}\right) \qquad (6)$$

This probability is independent of the time t elapsed since the last earthquake of this magnitude range and therefore is the same before and after the occurrence of an earthquake. If, however, $t+\Delta t$ is used instead of Δt this formula gives reasonable results comparable with the results of formula (4). We made all calculations of probabilities using formula (6) too and we found a linear correlation between these probabilities and the corresponding probabilities calculated by formula (6) with a correlation coefficient equal to 0.95. The linear relation is of the form:

$$P\ (\text{Poisson}) = 0.13 + 0.78\ P\ (\text{Gauss}) \qquad (7)$$

If the probability for the occurrence of an earthquake of $M \geq M_1$ during the next Δt years is P_1 and the probability for the occurrence of an earthquake of $M \geq M_2$ during the same period is P_2, then, according to (6), the following relation holds between these two probabilities

$$\frac{\ln(1-P_1)}{\ln(1-P_2)} = \frac{T_2}{T_1} \tag{8}$$

where T_1, T_2 are the corresponding mean return periods. This formula can be used to calculate easily the probability for a certain magnitude range (e.g. $M \geq 6.5$) if we know this probability for another magnitude range (e.g. $M \geq 7.0$).

In addition to the probability determined by applying formula (4) for each of the magnitude ranges (e.g. for $M \geq 6.0$) for which data are available, this probability was also calculated by formula (8) and the use of values determined by formula (4) for other magnitude ranges (e.g. $M \geq 6.5$, $M \geq 7.0$) for which data are available. The average of these values was finally adopted as a more representative probability believing that by this procedure the influence of random errors is reduced . No probability was calculated for magnitudes larger than the maximum observed magnitude in each zone.

Table (II) summarizes for each zone the mean repeat time in years, the date of the last large shock, the probability of occurrence of large shocks, the range of completeness of the data and the magnitude of the maximum earthquake ever occurred. All the results listed in Table (II) correspond to shallow ($h < 70$Km) events.

Figure (4) shows the estimated probabilities for the occurrence of shallow earthquakes with $M \geq 6.5$. On the basis of this figure we divided the fracture zones to three categories. To those having the highest probability values ($\geq$ 80%), to those of high probability values (63% to 79%) and to those exhibiting low probability values (<63%) .

It is understood that the area out of these zones has e ven lower probability for the occurrence of large events . Tl probabilistic map of figure (5) was constructed on the basi of this division. It represents the probability that a certai zone will be the site of an earthquake with $M \geq 6.5$ during tl next 20 years. At the discussion a qualitative approach to the se results is attempted.

Table (III) summarizes the corresponding results for tl fracture zones where intermediate depth seismicity is observec We decided to follow the same division into three probabili classes as before. The map of figure (6) shows the probabili ties of occurrence of an earthquake of intermediate depth wi $M \geq 7.5$.

An immediate striking point from the results of tabl (II) and (III) is, as expected, that the probability for a fu ture event is small immediately following the previous shoc and increases with increasing time since the last earthquake This time dependent behavior of the probability is especiall appropriate to the seismic gap or periodic recurrence model.

5. DISCUSSION

Our calculated probabilities for large shocks are bett constrained when a long record of historic earthquakes is ava lable.

The probabilities of occurrence of earthquakes with $M \geq$ 6.0 are very high for practically all of the fracture zones.S the following discussion mainly deals with the occurrence earthquakes with $M \geq 6.5$, 7.0 and 7.5.

Fracture zone IA exhibits low probabilities due to tl large earthquakes which occurred there in 1979 (Karakaisis e al. 1985). The historical record is long for line 1A and probabilities are well constrained.

Zone 1B which runs the west coast of Albania exhibits high probability for the occurrence of large shocks. The time lapse since the last shocks with M $\geq$6.0 and $\geq$6.5 (1962 and 1866, respectively) is more than the mean repeat time estimated, so an earthquake of magnitude around 6.0 is likely to occur in the region.

Fracture zone 1C exhibits very high probabilities, since the last large event occurred in 1872 and the region has a long historical record. Although the whole zone could produce an earthquake of the class 8 (Kiratzi et al.1985), no earthquake with M $\geq$ 7.0 has occurred in the area.

The segment A of fracture zone 2 is one of the regions that a strong earthquake is almost definite to occur. This zone has been recognized as a seismic gap (Papadimitriou 1984, Papadimitriou and Papazachos 1985a). Segment 2B was a well known seismic gap (Papadimitriou and Papazachos 1985b) which ruptured with the 1983 (M = 7.0). Cephalonian event (Scordilis et al.1985).

Fracture zone 3 exhibits high probabilities since the region has historical seismicity but only one eartqhuake with M $\geq$ 7.0 has occurred in the present century.

The segment 4A (Western Crete) and the 4B (eastern Crete) have the largest repeat times for M$\geq$7.0 in the whole Aegean area. Stress build up is performed through plate convergence and the large repeat times observed may be attributed to the fact that stress is also taken up by aseismic creep. Probability is very low for the western part of Crete (4A)while it is very high for the eastern (4B) since the last large shock occurred there in 1780.

Fracture zone 5 which includes Rhodos island has a high probability for the occurrence of a large earthquake, and it is our belief looking at the distribution of historical seismicity that high seismic activity is to break out soon.

Wyss and Baer (1981) say that the entire plate boundary of the Hellenic arc can be considered to be a seismic gap.

Looking at the probabilities of the intermediate depth earthquakes (figure 6) one can see that they are all very high . This is in agreement with the results of previous authors (Comninakis and Papazachos 1980,Papadimitriou et al.1984,1985, Papazachos et al 1985) According to them, the southern Aegean has all the characteristics of a seismicity gap in the occurrence of shallow and intermediate depth earthquakes. The probabilities calculated in the present study support this conclusion. The occurrence of such an event could strongly affect the surrounding islands and especially the high buildings of Rhodes and Crete (for an intermediate depth shock).

The fracture zones of the mainland Greece reveal different probability levels. Zone 7 shows high probability only for a moderate size event (M $\sim$6.0) while the probabities are low for the occurrence of larger events. Zone 8 shows very high probability especially in its segments which run the Patraikos Gulf and West Corinthiakos Gulf. The segment 8C has recently ruptured by the Alkyonides 1981 sequence (Papazachos et al. 1984a) and exhibits very low probability levels. The eastern segment of zone 9 (9A) which has ruptured by a sequence of historical earthquakes (many of which had a well described surface expression) is considered to be a dangerous region for the occurrence of a large event, in the sense that is very close to the metropolitan city of Athens. Zone 10 has a high probability for an earthquake of the class 6.0, In this zone a large shallow earthquake (M = 7.5) on July 9,1956 occurred, which caused a great tsunamis. From zone 11 only its western segment has high probability for the occurrence of a moderate size event (M$\sim$6.0).Zone 12 has very high probability for the occurrence of a M $\geq$ 7.0

event especially in its segment in Turkey. Zone 13 which runs the Sporades trough passes through Lesbos island and terminates in Turkey, reveals the highest probability for segment A_1 of Lesbos island.

Zone 14 was divided into two segments, and its segment in Turkey has the longest record of historical seismicity (1564, M ≥ 6.6). Segment 14B has ruptured by two earthquake sequences in 1982 (Papazachos et al.1984b) and 1983 (Rocca et al.1985). The region in Northern Aegean is very complex in the sence that strike-slip, and dip-slip focal mechanisms are observed with either normal or thrust component (Papazachos et al.1984C, 1986b). Probability levels are high to low for the whole zone.

Zone 15 part of which ruptured with the Thessaloniki 1978 earthquakes it is very likely to break near the triple junction in connection with lines 14 and 7. The Assiros 1902 and Ierissos 1932 earthquakes ruptured the south segment of line 15, the 1982 and 1983 earthquakes occurred at the triple junction, which is somewhat a geometrical barrier, and activity is expected to migrate eastwards to the region over Limnos island when a seismic gap has been identified (Karacostas et al 1985).

Finally, fracture zone 16 has not experienced any earthquakes in the present century, while line 17 in Bulgaria is very likely to break since no large earthquake since 1928 has occurred there.

We must stress here that is more important to look at the relative levels of probability with respect to adjacent zones, than the absolute level in any single zone.

As a general comment, for the present paper, we would like to say that in many instances the definition of the particular fracture zones was fairly obvious and based on the distribution of historical earthquakes. The definition of the various segments was less straightforward. It is our belief that the areas which were assigned high probability deserve high priority to any microearthquake monitoring seismic hazard or level of ground shaking studies. Another step that could be taken is to test whether the slip or time predictable models (Shimazaki and Nakata, 1980) can be applied.

ACKNOWLEDGEMENTS

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fracture zones of figure (1) during the period 1986-2[illegible]6, etc.

FRACTURE ZONE	CALCULATED MEAN REPEAT TIME (YEARS)				LAST EARTHQUAKE WITH				PROBABILITY OF OCCURRENCE 1986-2006 (%)				COMPLETENESS OF DATA	M_{max}
	M≥6.0	M≥6.5	M≥7.0	M≥7.5	M≥6.0	M≥6.5	M≥7.0	M≥7.5	M≥6.0	M≥6.5	M≥7.0	M≥7.5		
1A	40	90	204	-	1979	1979	1979	-	12	5	2	-	1563,M≥6.6	7.2
1B	21	72	-	-	1962	1866	-	-	97	78	-	-	1816,M≥6.0	6.6
1C	15	35	-	-	1930	1872	-	-	99	99	-	-	1773,M≥6.3	6.6
2A	4	21	100	-	1948	1948	1783	-	99	93	68	-	1612,M≥6.5	7.1
2B	4	17	63	-	1983	1983	1983	-	83	41	13	-	" "	7.2
3	9	19	42	90	1962	1947	1947	1886	98	84	58	33	1846,M≥7.0	7.5
4A	4	24	145	-	1984	1972	1952	-	64	30	6	-	1494,M≥7.0	7.2
4B	13	40	120	-	1969	1780	1780	-	98	87	59	-	" "	7.8
5	9	20	47	-	1968	1957	1957	-	94	75	46	-	1851,M≥6.8	7.2
6	25	60	-	-	1967	1959	-	-	52	27	-	-	1843,M≥6.1	6.5
7	6	35	-	-	1967	1960	-	-	99	59	-	-	1858,M≥6.2	6.7
8(A+B)	12	34	93	-	1970	1889	1870	-	98	86	49	-	1748,M≥6.2	7.1
8C	32	84	-	-	1981	1981	1981	-	13	5	-	-	" "	6.7
8D	24	95	-	-	1928	1828	-	-	99	95	-	-	" "	6.8
9A	27	43	68	-	1938	1894	1894	-	98	87	68	-	1853,M≥6.0	7.1
9B	29	-	-	-	1921	-	-	-	100	-	-	-	1901,M≥6.0	6.5
10	6	20	65	-	1968	1956	1956	1956	96	67	29	-	1869,M≥6.6	7.5
11A	24	31	-	-	1955	1955	-	-	89	83	-	-	1831,M≥6.2	7.0
11B	43	100	-	-	1971	1875	-	-	63	49	-	-	" "	6.7
12A	19	43	-	-	1949	1949	-	-	93	81	-	-	1668,M≥6.5	6.7
12(B+C)	24	47	94	-	1969	1969	1688	-	97	91	82	-	" "	7.1
$13A_1$	15	23	33	-	1944	1944	1919	-	96	87	73	-	1845,M≥6.6	7.0
$13A_2$	13	20	32	-	1970	1970	1970	-	80	65	50	-	" "	7.1
13B	3	6	12	-	1981	1981	1981	-	81	70	58	-	1901,M≥6.0	7.3
14A	11	19	32	53	1983	1964	1953	1912	81	75	49	38	1855,M≥6.7	7.7
14B	22	43	83	-	1983	1983	1982	-	25	15	8	-	1564,M≥6.6	7.5
15	14	20	27	-	1978	1978	1932	-	79	69	58	-	1901,M≥6.0	7.0
16	Not	enough	data										1784,M≥6.0	7.3
17	11	25	55	-	1928	1928	1928	-	98	87	62	-	1750,M≥6.8	7.7

Table III. Information on the probabilities of occurrence of large intermediate focal depth earthquakes in the fracture zones of figure (2) during the period 1986-2006, etc.

FRACTURE ZONE	CALCULATED MEAN REPEAT TIME (YEARS)				LAST EARTHQUAKE WITH				PROBABILITY OF OCCURRENCE % 1986-2006				COMPLETENESS OF DATA	M_{max}
	M ≥ 6.0	M ≥ 6.5	M ≥ 7.0	M ≥ 7.5	M ≥ 6.0	M ≥ 6.5	M ≥ 7.0	M ≥ 7.5	M ≥ 6.0	M ≥ 6.5	M ≥ 7.0	M ≥ 7.5		
IA	5	11	22	45	1972	1965	1927	1903	100	99	92	70	1809, M ≥ 7.5	7.9
IB	7	14	29	59	1948	1948	1935	1887	100	100	92	70	1809, M ≥ 7.5	8.2
IC	6	12	25	53	1958	1926	1926	1926	100	97	86	64	1807, M ≥ 7.5	8.0
Inner Zone of the Hellenic arc	14	24	42	-	1964	1930	1911	-	100	100	96	-	1901, M ≥ 6.0	7.1

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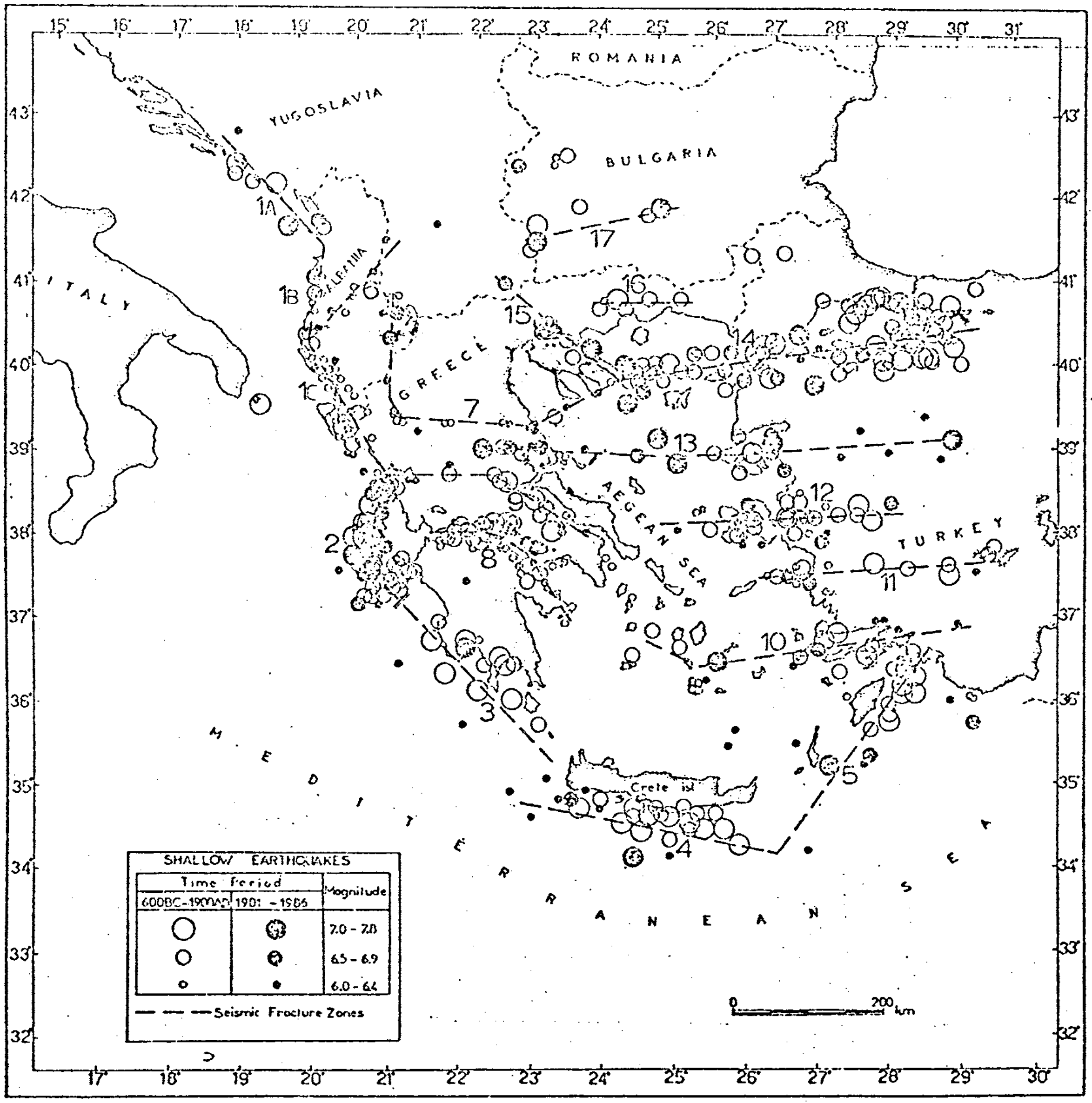
LIST OF FIGURES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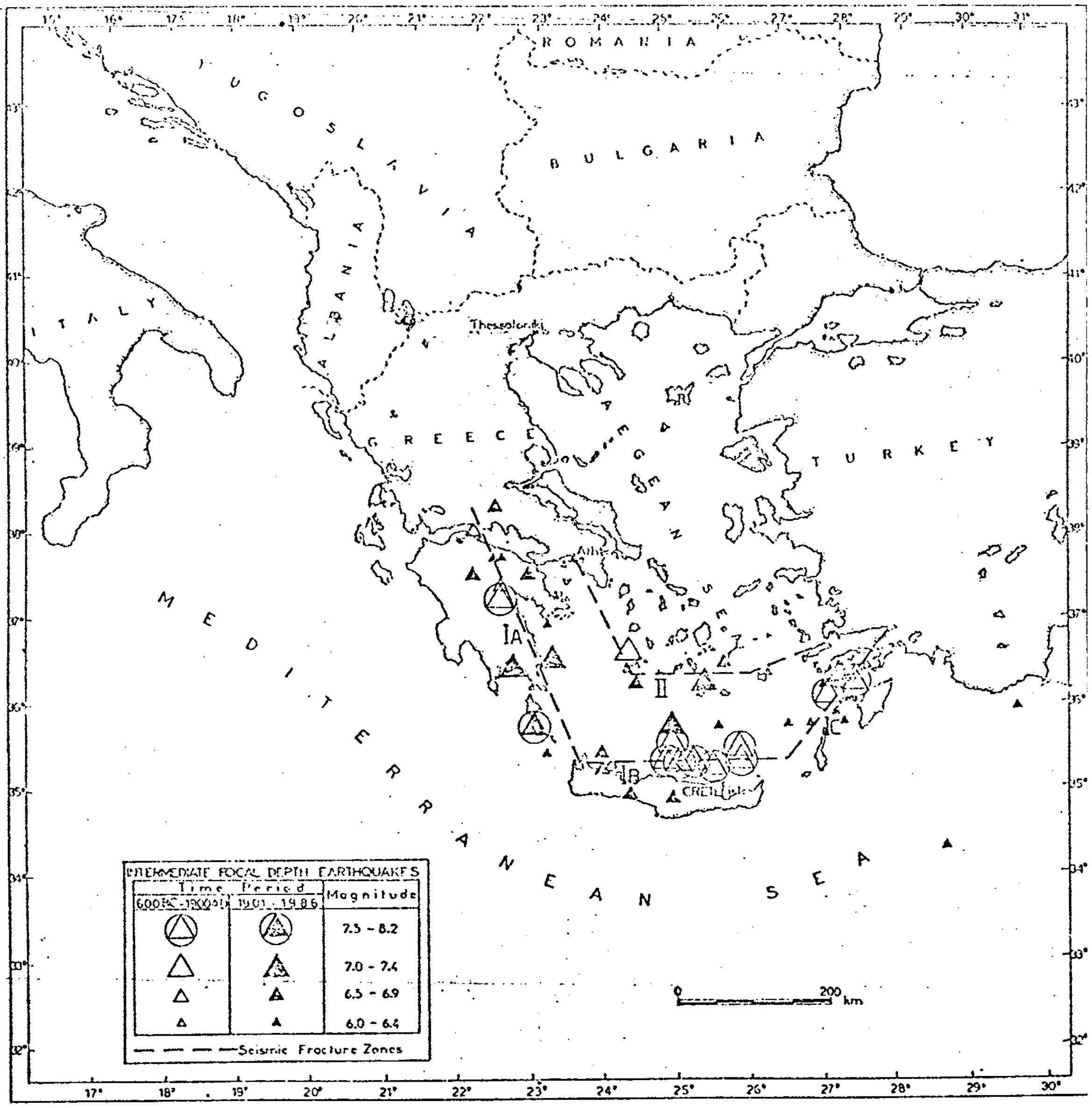
BULGARIA
ITALY
ALBANIA
GREECE
AEGEAN SEA
TURKEY
Crete isl
MEDITERRANEAN SEA
SHALLOW EARTHQUAKES
Time Period
600BC-1900AD
1901 - 1986
Magnitude
7.0 - 7.8
6.5 - 6.9
6.0 - 6.4
Seismic Fracture Zones
0
200 km

Fig. 1.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IA
IB
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CRETE
INTERMEDIATE FOCAL DEPTH EARTHQUAKES
Time Period
600BC-1900
1901-1986
Magnitude
7.5 - 8.2
7.0 - 7.4
6.5 - 6.9
6.0 - 6.4
Seismic Fracture Zones
0
200 km

Fig. 2

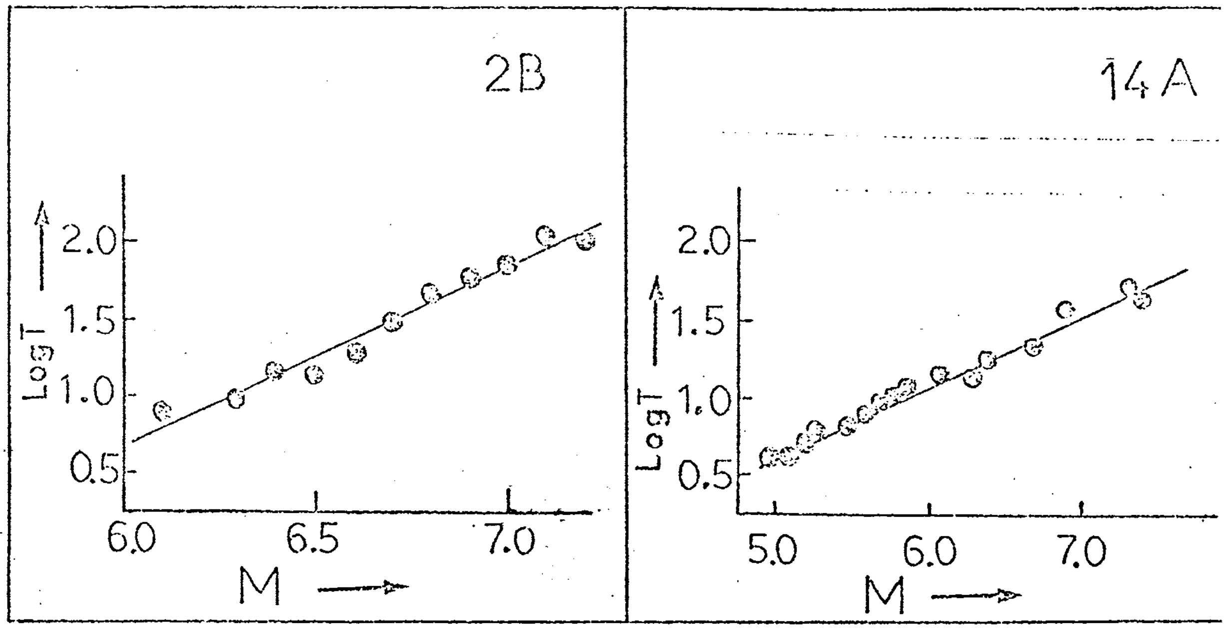

2B
14A
LogT
2.0
1.5
1.0
0.5
6.0
6.5
7.0
5.0
M

Fig. 3

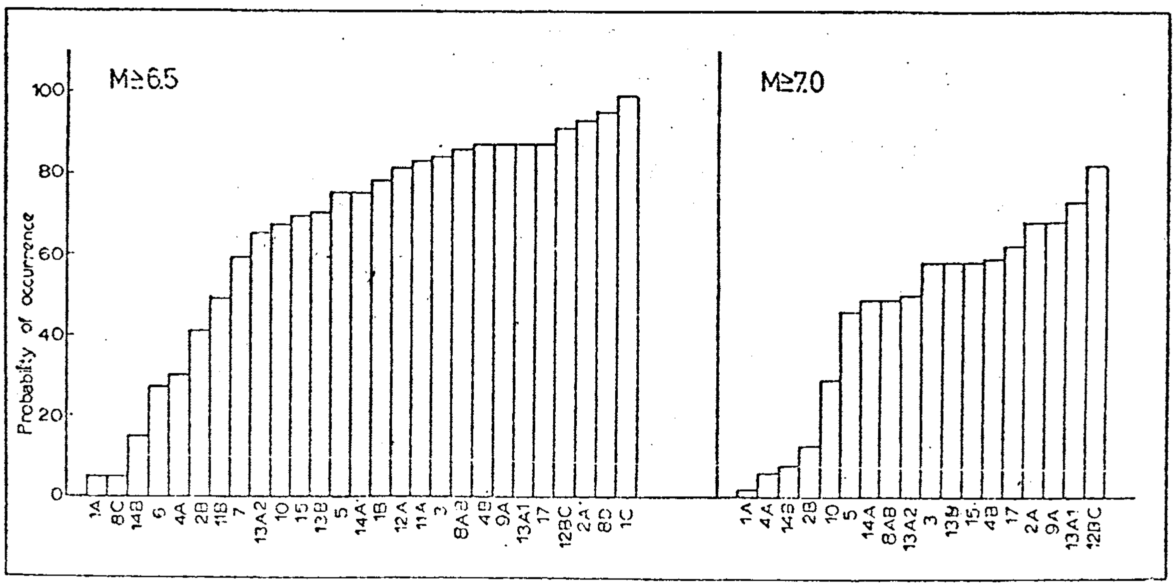
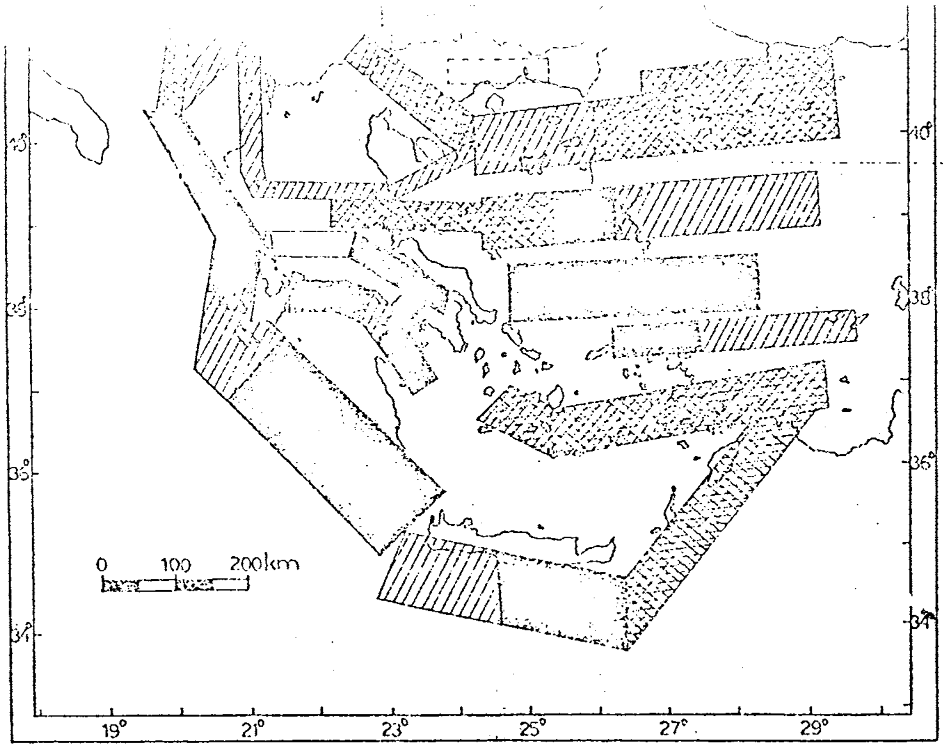

M≥6.5
M≥7.0
Probability of occurrence
100
80
60
40
20
0
1A 8C 14B 6 4A 2B 11B 7 13A2 10 15 13B 5 14A 1B 12A 11A 3 8AB 4B 9A 13A1 17 12BC 2A 8D 1C
1A 4A 14B 2B 10 5 14A 8AB 13A2 3 13B 15 4B 17 2A 9A 13A1 12BC

Fig. 4


0 100 200km
19°
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23°
25°
27°
29°
40°
38°
36°
34°

Fig. 5.

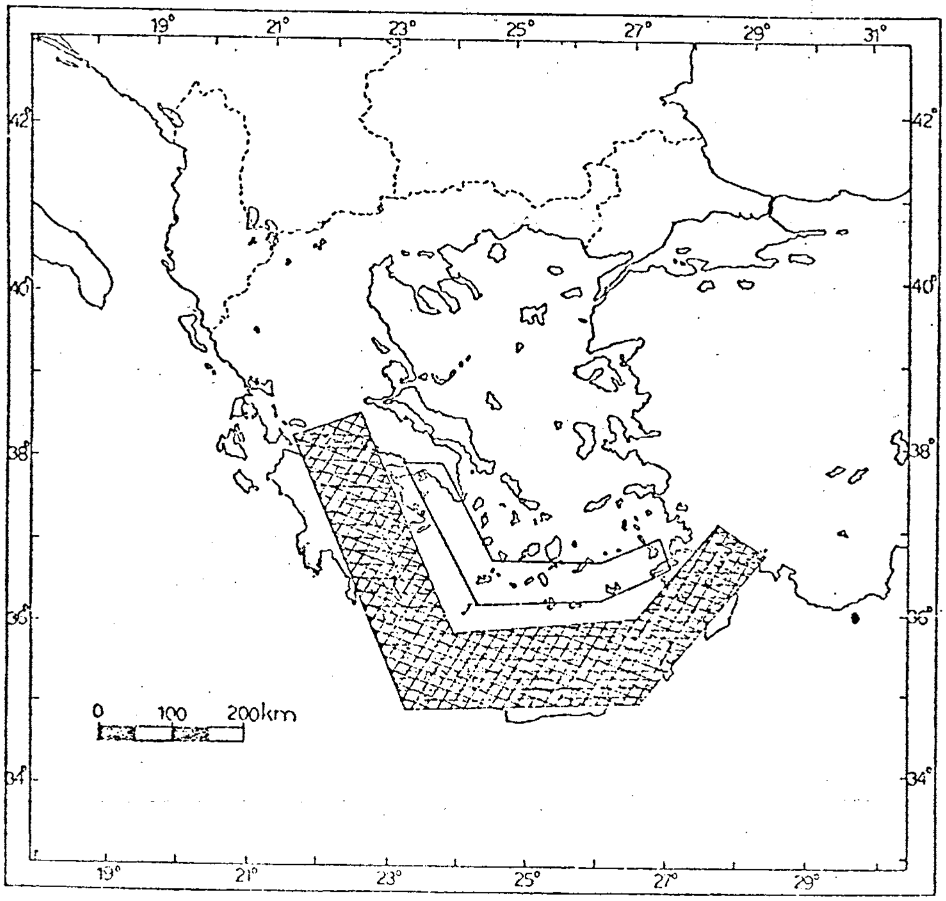
19°
21°
23°
25°
27°
29°
31°
42°
40°
38°
36°
34°
0 100 200km

Fig. 6

SEISMIC HAZARD ASSESSMENT FOR SOUTHERN BALKAN REGION

BASED ON SEISMIC SOURCES

Proceedings of the 3rd International Symposium on the Analysis of Seismicity and Seismic Risk
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SEISMIC HAZARD ASSESSMENT FOR SOUTHERN BALKAN REGION BASED ON SEISMIC SOURCES

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ABSTRACT

A semi-deterministic approach to the seismic hazard assessment of the southern Balkan region is presented. For this reason 50 seismic sources were defined in the Aegean and surrounding area and the seismicity parameters were estimated for each one based on data of 180 years. The attenuation formulae used in the present study are those proposed by Papaioannou (1984) based on macroseismic and instrumental data of the southern Balkan region.

For the evaluation of the seismic hazard the computer program EQRISK, written by McGuire (1976) has been used. The theory on which this program is based has been developed by Cornell (1968) and Cornell and Merz (1973).

A grid of points, with distance 25 Km has been made and the seismic hazard was estimated for each point. Finally, a seismic hazard map of the Aegean and the surrounding area has been constructed by means of the most probable maximum seismic intensity in 80 years.

INTRODUCTION

The southern Balkan region is considered to be a region with high seismic hazard. Several attempts have been made in the past for the seismic hazard assessment of this region based mainly on the probabilistic methods of mean values and Gumbell's asymptotic distributions.

The first attempt to estimate the seismic hazard in the area of Greece was made by Galanopoulos and Delibasis (1972) who compiled maps of the maximum observed intensities during the period 1800-1970. Algermissen et al. (1976), compiled seismic hazard maps of the Balkan region in terms of peak ground velocity and acceleration with 70% probability of not being exceeded in 25 and 200 years. They based their results on the catalogue of earthquakes by Shebalin et al. (1974) and the attenuation curves of acceleration proposed by Schnabel and Seed (1973). Shebalin et al. (1976) presented maps of maximum expected intensity for return periods of 50,100,200,500 and ∞ years using various geological, geomorphological, tectonic and seismological data.

Makropoulos (1978) proposed a new "averaged" attenuation curve of acceleration, based on world- data and compiled maps, using the first-type asymptotic distribution, depicting acceleration with 70% probability of not being exceeded in 50,100 and 200 years.

Hattori (1979), using Gumbell's third type asymptotic distribution, studied the seismic hazard of the Balkan region in terms of peak-ground acceleration.

Michailov (1980) studied the seismic hazard of southern Yogoslavia and central Macedonia compiling maps of the maximum peak ground acceleration with return periods of 50 and 100 years.

Galanopoulos (1981) compiled a map which gives information on the maximum expected most probable earthquake magnitude, intensity and acceleration.

Drakopoulos and Makropoulos (1983) presented maps which depict the peak ground acceleration with 90% probability of not being exceed in 25 and 50 years, following Gumbell's first type asymptotic method.

Papaioannou (1984), using the mean value method and the first asymptotic distribution of Gumbell compiled maps which depict the most probable maximum intensity and peak ground acceleration with 63% probability of not being exceeded in 86 years.

In the present paper a semi-deterministic approach for the seismic hazard assessment of the Aegean and surrounding area is presented. The methodology applied is the one developed by Cornell (1968) which is based on the consideration of seismic sources.

METHOD APPLIED AND DATA USED

There are two general and different approaches that may be followed in the estimation of design seismic ground motions, namely, the deterministic and the probabilistic. Cornell (1968) has developed an approach to this problem which can be considered a combination of the two previous ones. According to it, with the use of all the available geophysical, geological and tectonic information, as well as of the historical seismicity the region of study is devided into seismic sources within which the occurrence of future events is considered to be very probable at any one location. For each seimic source, the rate of occurrence of events above a chosen threshold is estimated, using the observed frequency of historical events. The sizes of events in each source are assumed to be independent and exponentially distributed following the Gutenberg-Richter's law. The b value of this law is determined either for each seismic source individually or for all sources in the region. Finally, the maximum possible size, of events for each source is determined, using personal judjement and the historical record.

The next step is to find the correlation between magnitude M, peak ground accelation or maximum intensity Y at the site and distance R from the site to the epicenter, of the following form

$$Y=b_1 . e^{b_2 M} . R^{-b_3} \qquad (1)$$

where b_1, b_2, b_3 are constants.

Finally, the total annual probability that a chosen MM intensity or peak ground acceleration is equaled or exceeded at each site is calculated by summing the probabilities of this occurrence due to all event which can affect the postulated site.

The data used in the present paper come from the project which the Geophysical Laboratory of the University of Thessaloniki has developed in the last years with the aim to evaluate the seismic hazard in the area of Greece.

Hatzidimitriou (1984), based on various seismological and seismotectonic data divided the Aegean and surrounding area into 50 seismic sources (fig. 1). For each one the parameters a and b of the frequency-magnitude relation as well as the maximum observed earthquake magnitude were defined. For this purpose seismic data from the period 1800-1982 were used. The source of data has been the catalogues of earthquakes by Papazachos and Comninakis (1982) for earthquakes in the period 479 B.C. - 1900 A.C. an by Comninakis and Papazachos (1982) for the period 1901-1980.

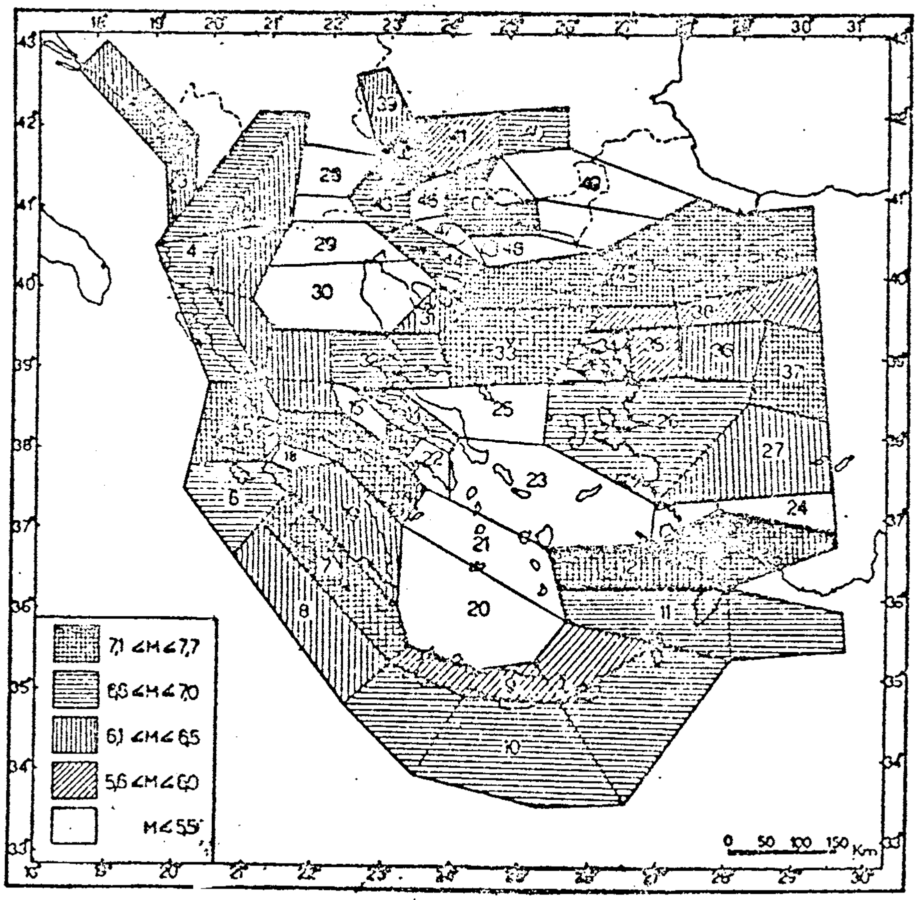

Fig.1.- Seismic sources of the Aegean and surrounding area (Hatzidimitriou 1984).

The attenuation formulae for seismic intensities and peak ground accelerations used in the present study were these proposed by Papaioannou (1984). For the attenuation of seismic intensity with distance and magnitude Papaioannou (1984) proposed the following empirical formula

$$I_i = 6.59 + 1.18M_S - 4.50\log(\Delta + 17) \quad (2)$$

where I_i is the seismic intensity (MM scale), M_S is the surface-wave magnitude a
Δ is the epicentral distance. The above mentioned relation holds only for shallow
arthquakes (h≤60 Km). The data used for the derivation of this relation were t
Atlas of isoseismal maps published by the Geophysical Laboratory of the Universit
of Thessaloniki (Papazachos et al. 1982) and the Atlas of isoseismal maps publish
by Unesko (Shebalin 1974).

The attenuation of peak ground acceleration was studied also by Papaioann (1984), based entirely on published data from accelerograms of Greek earthquakes. formula proposed, which holds for shallow shocks and medium type soils, is

$$\log a = 3.78 + 0.39M_S - 2.37\log(\Delta+23) \quad (3$$

were a is the peak ground acceleration ($cm.sec^{-2}$), M_S is the surface wave magnitu and Δ is the epicentral distance.

For the computation of seismic hazard the computer program EQRISK written McGuire (1976) was used. The theory on which this seismic-hazard analysis program is based is that developed by Cornell (1968,1971) and Merz and Cornell (1973). Th program needs as input the coordinates of the seismic sources as well as the ra of earthquake activity, the seismic parameter b and the maximum earthquake magni de in each one.

The output of the program is the intensity or peak ground acceleration with given probability of exceedance.

SEISMIC HAZARD MAP

The area included between 19°-30°E and 34°-43°N was divided into a grid c points at equal distances of 25 Km. For each point the seismic hazard was estimate in terms of the most probable maxiumum seismic intensity (in the MM scale) in 8 years.

The seimic hazard map of the Aegean and surrounding area divided into fi groups of probable seismic intensity (5.5-6.0, 6.0-6.5, 6.5-7.0, 7.0-7.5, 7.5-8.0 is shown in figure (2).

The estimation of the corresponding peak ground accelerations can be made u sing the following relation which was proposed by Papaioannou (1984)

$$\log a = -0.04 + 0.32\ I \quad (4$$

As it can be seen from the map in figure (2), areas with the highest seism hazard are located in the northwestern Albania-southeastern Yugoslavia, the Ionia islands in western Greece, south of Peloponnesus, east of Crete island and west c Rhodos island. Areas of such seismic hazard are also observed at the eastern pa of central Greece, at the eastern part of Chalkidiki in northern Greece and i southwestern Bulgaria.

Most of the other part of continental Greece, northern Aegean sea, western Turkey and Albania belong to the intensity interval 7.0-7.5.

Zones with the lowest seismic hazard are observed in the northern part of cer

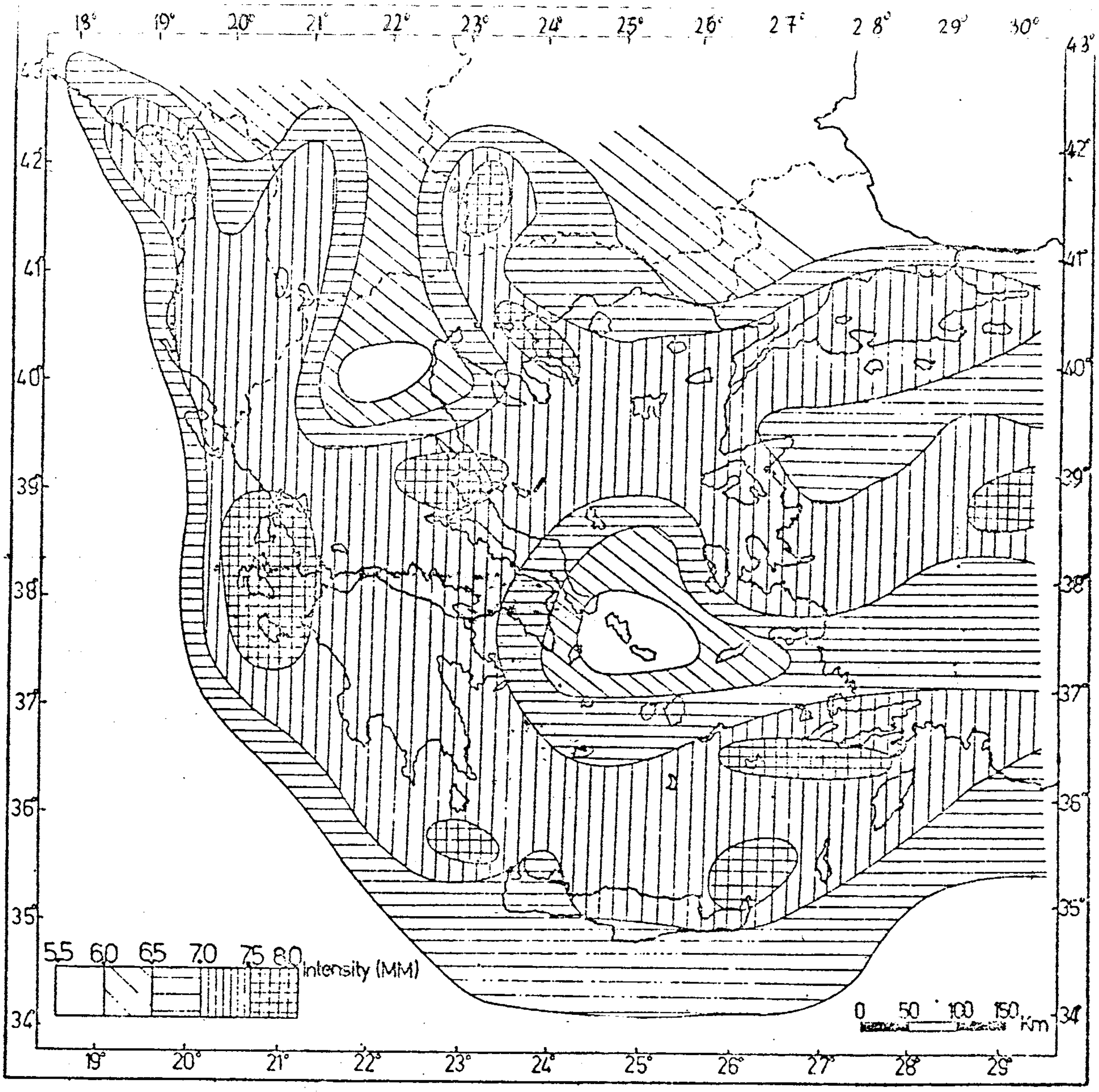

Fig.2.- Seismic hazard map of the Aegean and surrounding area.

tral Greece and in the central Aegean.

ACKNOWLEDGMENTS

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REGIONALIZATION OF THE ATTENUATION OF INTENSITIES IN THE SOUTHERN BALKAN REGION

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REGIONALIZATION OF THE ATTENUATION OF INTENSITIES IN THE SOUTHERN BALKAN REGION

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ABSTRACT

A data set of the most reliable isoseismals of 60 shallow earthquakes,of the time period 1902-1981 is used to infer empirical relations describing the variation of the intensity attenuation coefficient,v, as obtained by the Blake formula, with the magnitude, M_s , and the hypocentral distance, D. This empirical relation derived from 1616 observations, using the regression analysis procedure, has the form:

$$v = 0.42M_S + 0.01D + 0.39$$

The attenuation coefficient, v, is considered to represent the rate of the attenuation of the macroseismic intensities.

A pattern of areas with low and high intensity attenuation was recognized. The spatial variation of v, calculated at various azimuths from the source , up to a distance of 100 Km, showed that the area along western Albania and the western coast of central Greece is characterized by less rapid attenuation ($v \leq 3.3$) than the area of the mainland of Greece, the Aegean, southern Bulgaria and southern Yugoslavia ($v \geq 3.4$).

Finally, the following empirical relation between the maximum macroseismic intensity, I_o ,theoretically calculated, and surface wave magnitude ,M_s , was defined:

$$I_o = (1.15 \pm 0.04)M_S + (1.29 \pm 0.23)$$

INTRODUCTION

Attenuation of strong ground motion is an important consideration in the seismic design of critical facilities. Attenuation characteristics vary from region to region, and in Greece, an area of high seismicity the problem has focused the attention of many scientists. Among others, Galanopoulos(1968), Drakopoulos (1978), Macropoulos (1978), Papaioannou(1984) and Tassos(1984) have published various relations and maps describing the attenuation of strong ground motion in the Aegean and the surrounding area.

In the present paper, the variation of the intensity attenuation coefficient with magnitude and distance is parameterized and a pattern with high and low rate of attenuation is recognized. Moreover, an empirical relation between the maximum epicentral intensity, I_o and magnitude, M_s , is de-

THE DATA

Isoseismal maps for several damaging earthquakes in Greece have been compiled by UNESCO/UNDP , (...in,1974) and by the staff of the Geophysical Laboratory of the University of Thessaloniki , (... et al.1982) using data obtained by intensity surveys. These two publications were the ... source of information for the present study. After a very careful examination of the quality ... published isoseismal maps (selecting those based on dense observations), the earthquakes listed in Table (1) were considered suitable for the present study. All earthquakes are shallow(maximum focal depth less than 15 Km) and their M_s magnitudes range from 5.7 to 7.5.

The radius of every isoseismal from the macroseismic epicenter was measured, for different azimuths, starting from 0^{o} and going clockwise with a step of 30^{o}. In most of the cases, for the shallow earthquakes used here, the difference between the macroseismic and microseismic epicenter was negligible.

Table(1). Information on the earthquakes used in the present study

No	DATE	ORIGIN TIME	EPICENTER		M_S	h (Km)	No	DATE	ORIGIN TIME	EPICENTER		M_S	h (Km)
1.	July 5,1902	14:56:30	40.8	23.1	6.6	5	31.	Oct. 2,1961	07:21:44	37.2	22.0	5.7	5
2.	Apr. 4,1904	10:02:34	41.9	23.0	7.1	10	32.	Mar. 18,1962	15:30:30	40.7	19.6	6.0	6
3.	June 1,1905	04:42:15	42.0	19.5	6.6	4	33.	July,26,1963	04:17:12	42.0	21.1	6.1	7
4.	Oct. 8,1905	07:27:30	42.0	23.1	6.5	14	34.	Sept.18,1963	16:58:08	40.8	29.1	6.3	10
5.	Nov. 8,1905	22:06:30	40.3	24.4	7.5	7	35.	Oct. 6,1964	14:31:23	40.3	28.2	6.9	12
6.	May,30,1909	06:14:30	38.3	22.1	6.2	4	36.	Mar. 9,1965	17:57:54	39.3	23.8	6.1	6
7.	Febr.18,1911	21:35:12	40.9	20.8	6.7	6	37.	Apr. 5,1965	03:12:55	37.5	21.9	6.1	7
8.	Jan. 27,1915	01:09:56	38.5	20.5	6.6	10	38.	Apr. 9,1965	23:57:02	35.0	24.3	6.1	10
9.	Mar. 30,1921	15:05:30	41.7	20.5	5.8	6	39.	July, 6,1965	03:18:42	38.3	22.2	6.3	7
10.	Aug. 10,1921	14:10:32	42.3	21.4	5.8	12	40.	Febr. 5,1966	02:01:45	39.0	21.7	6.2	7
11.	Dec. 7,1922	16:22:10	41.8	20.5	6.1	4	41.	Sept. 1,1966	14:22:57	37.4	22.1	5.9	3
12.	Apr. 14,1928	09:00:01	42.2	25.3	6.8	18	42.	Oct. 29,1966	02:39:25	38.9	21.1	6.1	2
13.	" 18,1928	19:22:48	42.2	25.0	7.0	15	43.	Febr. 9,1967	14:08:18	39.9	20.3	5.8	10
14.	" 22,1928	20:13:46	38.0	23.1	6.3	10	44.	May, 1,1967	07:09:02	39.6	21.2	6.4	9
15.	" 17,1930	20:06:39	37.7	23.2	5.9	6	45.	Nov. 30,1967	07:23:50	41.4	20.5	6.4	6
16.	Mar. 7,1931	00:16:52	41.3	22.3	6.0	4	46.	Feb. 19,1968	22:45:42	39.7	25.1	7.1	14
17.	" 8,1931	01:50:28	41.3	22.5	6.7	7	47.	Jan. 14,1969	23:12:06	36.1	29.6	6.2	10
18.	Sept.26,1932	19:20:42	40.5	23.9	7.0	6	48.	Mar. 23,1969	21:08:42	39.1	28.5	6.1	10
19.	" 22,1939	00:36:32	39.1	26.8	6.6	9	49.	Mar. 28,1969	01:48:29	38.3	28.6	6.6	10
20.	Mar. 1,1941	03:52:47	39.7	22.4	6.3	9	50.	Apr. 3,1969	22:12:22	40.7	20.0	5.8	4
21.	Aug. 27,1942	06:14:15	41.6	20.4	5.9	9	51.	Oct. 13,1969	01:02:31	39.8	20.6	5.8	5
22.	Oct. 6,1947	19:55:34	36.9	22.0	7.0	3	52.	Mar. 28,1970	21:02:23	39.2	29.3	7.1	10
23.	July 23,1949	15:03:30	38.5	26,3	6.7	12	53.	Apr. 8,1970	13:50:28	38.5	22.3	6.2	8
24.	Apr. 30,1954	13:02:36	39.3	22.3	7.0	5	54.	Dec. 31,1975	09:45:47	38.6	21.6	5.7	6
25.	Apr. 13,1955	20:45:46	37.3	22.3	5.9	2	55.	May, 23,1978	23:34:11	40.7	23.2	5.8	2
26.	" 19,1955	16:47:19	39.4	23.0	6.2	4	56.	June,20,1978	20:03:21	40.7	23.2	6.5	4
27.	July, 9,1956	03:11:40	36.6	26.0	7.5	10	57.	Apr. 15,1979	06:19:41	42.0	19.0	7.1	7
28.	Mar. 8,1957	12:21:13	39.5	22.6	6.8	10	58.	July, 9,1980	02:11:53	39.2	22.8	6.5	5
29.	Apr. 25,1957	02:25:42	36.5	28.8	7.2	20	59.	Febr.24,1981	20:53:37	38.2	23.2	6.7	14
30.	May, 14,1959	06:36:56	35.0	24.7	6.3	6	60.	Dec. 19,1981	14:10:52	39.1	25.7	7.3	20

DATA ANALYSIS AND RESULTS

The decrease of intensity with distance has the general form:

$$I_o - I_i = C_1 + C_2 \; f_1(\Delta_i) + C_3 \; f_2(\mathrm{Log}\Delta_i) \qquad (1)$$

ere I_o is the maximum epicentral intensity, I is the intensity at distance Δ and C_1, C_2, C_3 are stants. C_2 is the absorption factor usually included in the earthquake energy propagation formu- and C_3 takes care of the geometrical spreading. A relevant formula proposed by Blake (1941)

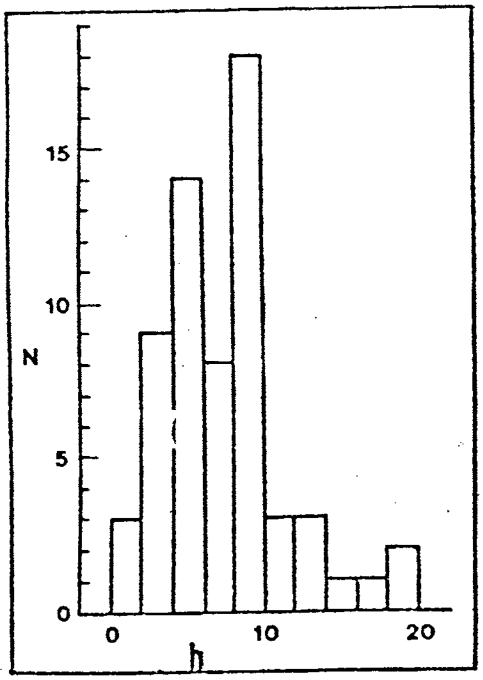
$$I_o - I_i = v_i \; \mathrm{Log}\sqrt{1 + \Delta_i^2/h_i^2} \qquad (2)$$

equivalent to (1) and is here adopted to represent best the attenuation of intensities in Gre- (Papaioannou, 1984). The attenuation coefficient, v, was calculated for each pair of successive lines by the formula (as infered from the Blake formula):

$$v = \frac{1}{\mathrm{Log}(D_{i+1}/D_i)} \qquad (3)$$

re D_i is the mean hypocentral distance, i is the number of isoseismal counted from the epi- ter. Thus, different values of the attenuation coefficient v, were calculated for any given azi- Great caution was taken which isoline to be chosen as the first one to start the calculations order to avoid the strong source effect at distances very close to the focus. Thus, a set of 16 observations of calculated v values and corresponding distances was compiled. The variation the mean radii in different azimuths is supposed to reflect the anomalies in the propagation of smic energy.

Figure (1) represents the frequency function of the focal depths of the earthquakes used in present study. These depths are calculated from macroseismic observations. It is observed that most earthquakes are very shallow ($h \leq 15$ Km). On these grounds, focal depth was considered as rather constant and was taken into consideration in formula(3) as far as the calculation of slant distances was concerned.



).1.-Frequency function of the focal depths of the earthquakes listed in Table(I).

Empirical plots of the attenuation coefficient, v, versus magnitude, M_s and distance, D, in Km revealed a linear dependence on both parameters. Distance, D is the average distance of any two successive isolines. The regression analysis performed to the data resulted in the following equation:

$$v = 0.42M_s + 0.01D + 0.39 \quad [RMS=1.25] \qquad (4)$$

The regression analysis was performed by the computer program MINUIT (James and Roos, 1977) of the CERN (Centre Europeene des Researches Nuclaires) library. Equation (4) shows by a very simple numerical example, that the distance effect on parameter v is much stronger than that of magnitude as one might expect.

Figure (2) represents a plot of the attenuation coefficient, v, versus distance D. This figuit was constructed by using a moving average prosedure. Initially average values of v were obtained for three distinct magnitude ranges. However as expected from the results of equation (4) these values for each magnitude range were approximately the same. Therefore, magnitude was not taken into consideration. Error bars in figure (2) represent the standard deviation(= 2σ). It is

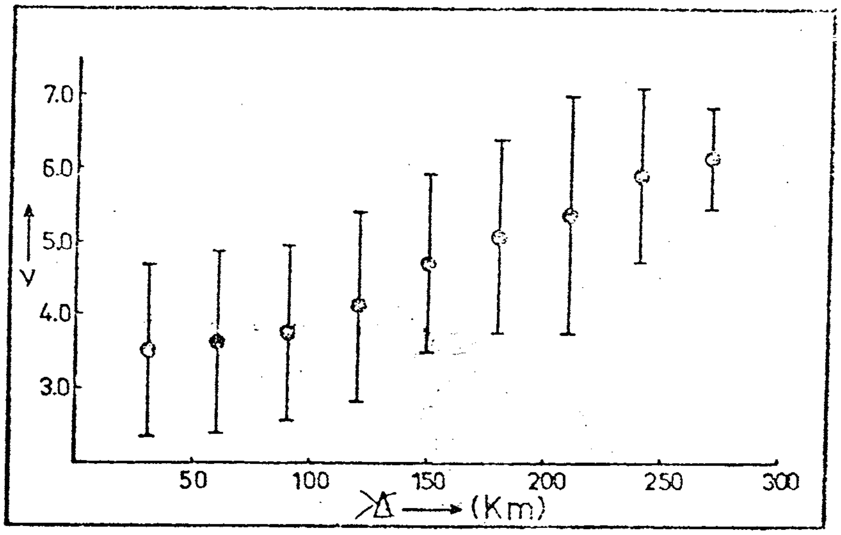


Fig.2.-Average values of v versus distance,D, calculated by a moving average procedure with an overlapping step of 30 Km.Error bars represent standard deviation (2σ) .

observed that the rate of attenuation is rather constant for distances up to 100 Km and rapidly increases for larger distances.

REGIONALIZATION OF THE RATE OF ATTENUATION OF SEISMIC INTENSITIES

For each earthquake of those listed in Table (I) an average value of parameter v was calculated. Namely, the values of v determined for the different azimuths (by equation 3) were averaged. All the numerical calculations were performed for distances D, less than 100 Km, on the basis to keep to distances which have engineering interest.

Figure (3) represents the frequency function of the average v values which vary from 2.0 to 4.8. These values were plotted at the site of the epicenter at the map of figure (4). Two symbols

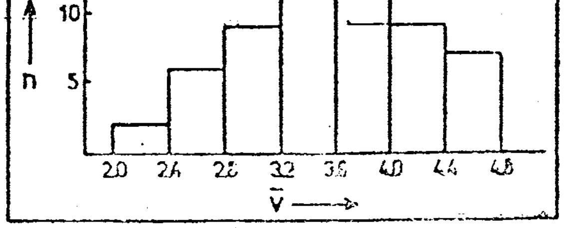


Fig.3.- Frequency function of the average values of the attenuation coefficient v,of the earthquakes listed in Table(I),calculated for distances less than 100 Km.

ed black circles to denote $\bar{v} \leq 3.3$ and to Table I).

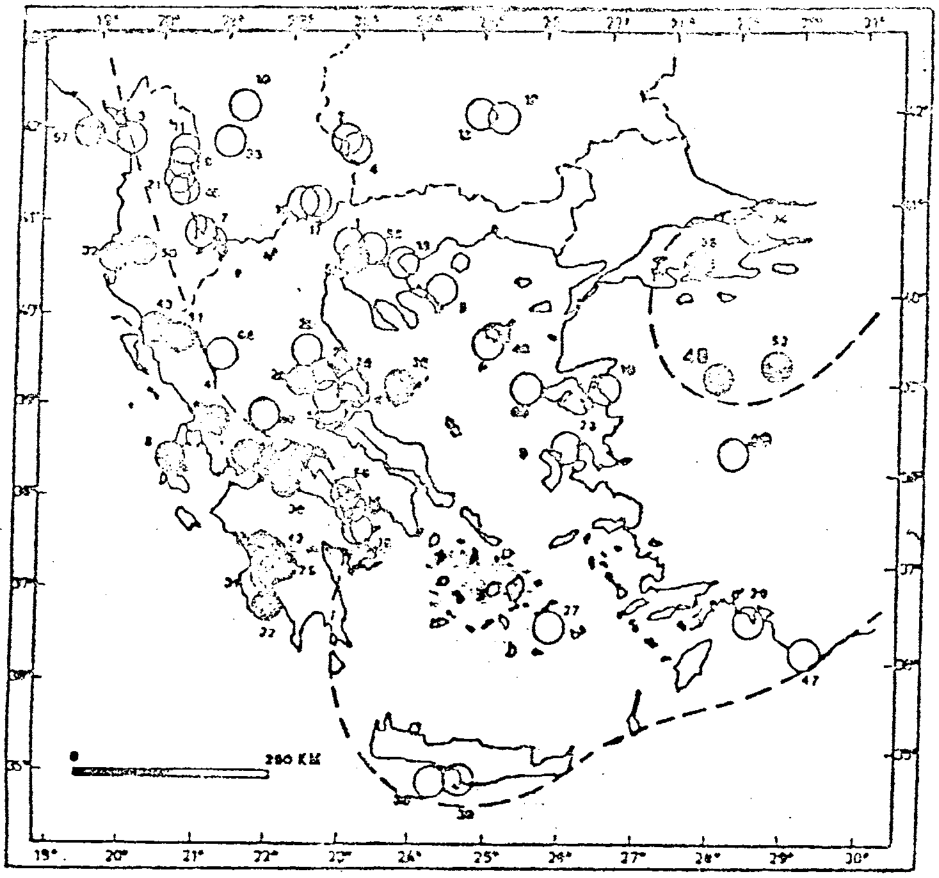


Fig.4.- Map showing the areas of high and low rate of intensity attenuation. Black circles denote average $\bar{v} \leq 3.3$, while open circles denote average $\bar{v} \geq 3.4$ (Numbers correspond to Table I).

Areas with rapid and less rapid rate of attenuation can be recognized. The region covered by western Albania, western coast of central Greece, Peloponese and an area in northwestern coast of Turkey is characterized by low rate of intensity attenuation. However, the mainland of Greece, the Aegean and southwestern Turkey are characterized by a rapid rate. An interpretation of the pattern is given in the discussion.

RELATION OF MAXIMUM EPICENTRAL INTENSITY I_o TO MAGNITUDE M_S

Papaioannou (1984) has made a detailed study of the isoseismal maps of major earthquakes which occurred in the broader area of Greece. He developed intensity attenuation relations for each of the 20 out of 21 seismic zones of Greece, as they were originally defined by Papazachos (1980) and later slightly modified by Hatzidimitriou et al. (1985).

A graphical method for the estimation of an initial set of epicentral intensities, I_o from the intensity distance plot for earthquakes of different magnitudes was used (Papaioannou, 1984), thus avoiding the need to equate the maximum reported or mapped intensity with I_o. The attenuation relations for each of the seismic zones were derived using an iterative least-squares fit procedure, wherein an initial approximate estimate of I_o for each event is successively improved. As a by-product, the analysis yielded improved estimates of I_o for each event.

[illegible] Ioannou (1984) has noted a linear trend between the [illegible] intensity, I_o and [illegible], M_S for the data of each of the 21 seismic zones of Greece. In the present study, a re-[illegible] between I_o and M_S applicable to the whole Greece is determined. Figure (5) represents a plot [illegible] 432 observations. Least squares analysis performed to the data resulted in the following re-[illegible]:

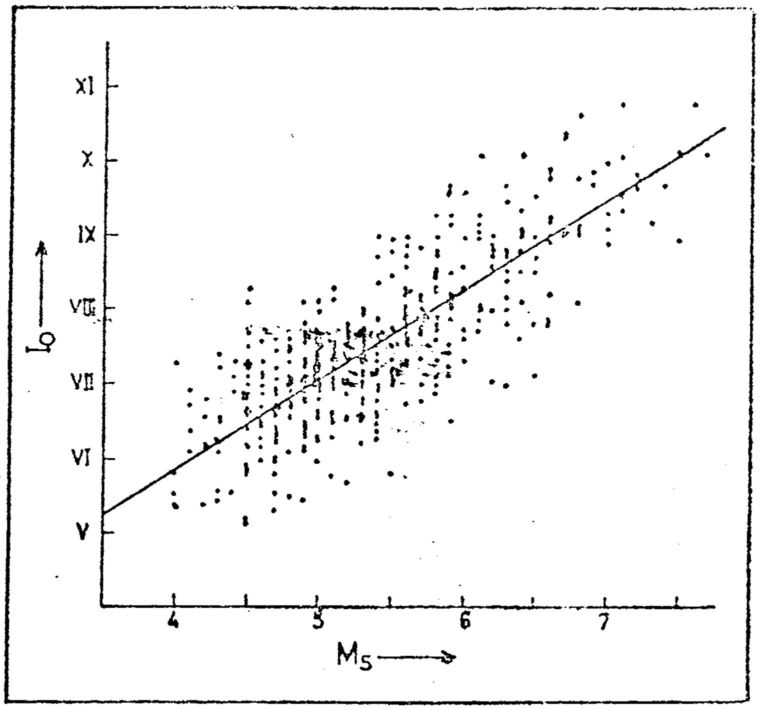


Fig.5.- Revised estimates of maximum epicentral intensity I_o versus magnitude, M_S. The straight line represents the linear approximation to the data.

$$I_o = (1.15 \pm 0.04)M_S + (1.29 \pm 0.23) \qquad \text{(RMS= .65)} \qquad (7)$$

which is represented by the straight line of figure (5).

DISCUSSION

A strong distance dependence of the attenuation coefficient v for distances greater than 100 Km was found. Although, one might expect earthquake magnitude to have a stronger effect, this is not the case. This may be attributed to the natural periods of most structures in Greece which are considered to be less than 0.5 sec. Taking into account that the predominant period of strong ground motion increases significantly for distances greater than 40 Km (Seed et al.1968), it is obvious that these very structures at some considerable distance from the source, where lower frequencies are observed, are not severely vibrated. As a result lower intensity values are observed.

It is well known that the Aegean sea is a back-arc region and has all the characteristics of a marginal sea. Intense gravity and magnetic anomalies are observed. The strong attenuation is connected to the thermal condition (high heat flow) and the degree of partial melting of the lithosphere and asthenosphere (Papazachos and Comninakis, 1971; Tassos, 1984).

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REGIONALIZATION OF SEISMIC HAZARD IN GREECE

REGIONALIZATION OF SEISMIC HAZARD IN GREECE

By

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ABSTRACT

Greece is located in one of the most active seismic belts of the Earth. Therefore , its seismic hazard is high.Several attempts have been made in the past for seismic hazard assessment in this area, on the basis of the mean value and the extreme value methods.

In the present study, based on the theory developed by Cornell (1968) which considers the seismic sources of a region, we estimated the seismic hazard of the most important cities of Greece. The seismic hazard is expressed in terms of the most probable maximum intensity calculated for different time periods. According to these values, the cities are separated into nine classes of seismic hazard.

1. INTRODUCTION

Several attempts have been made in the past to estimate the seismic hazard in the area of Greece (Galanopoulos and Delibasis 1972, Schnabel and Seed 1973, Algermissen et al. 1976, Shebalin et al. 1976, Hattori 1979), on the basis of the mean value and extreme value method.

Makropoulos (1978) proposed an average attenuation curve of acceleration, based on world-wide data and he compiled maps using the first-type asymptotic distribution depicting acceleration with 70% probability of not being exceeded in 50, 100 and 200 years.

Galanopoulos (1981) compiled a map which gives information on the most probable maximum expected magnitude, intensity and peak ground acceleration.

Drakopoulos and Makropoulos (1983) presented maps which depict the peak ground acceleration with 10% probability of exceedance in 25 and 50 years, following Gumbell's first type asymptotic method.

Papaioannou (1984), using the mean value method and Gumbell's first asymptotic distribution compiled maps which depict the most probable maximum intensity and peak ground acceleration with 63% probability of exceedance in 80 years.

Papaioannou et al. (1985) based on the theory developed by Cornell (1968) compiled a map for a period of 80 years.

In the present paper, the seismic hazard for the largest cities in the area of Greece is estimated in terms of the most probable maximum intenti.sy in different periods of time with the aim to contribute to the regionalization of the seismic hazard in Greece which will serve as a basis for the building construction code.

2. METHOD APPLIED AND DATA USED

The method applied in the present paper for seismic harard assessment is a semi-deterministic one based on the theory which was developed by Cornell (1968,1971) and Merz and Cornell (1973). According to this theory, the seismic sources of the region are defined on the basis of all the available seismological, seismotectonic and geological criteria. For each source, the rate of earthquake occurrence , the seismic parameter b of the frequency-magnitude relation as well as the maximum earthquake magnitude which can occur are estimated. Then, with the aid of a relation between the seismic intensities (or peak ground accelerations), the distance and the earthquake magnitude , the total probability that a chosen MM intensity (or peak ground ... or exceeded at each site is calculaed by summing the probabilities of this occurrence due to all vents affecting the site from all the neighbouring seismic sources.

The division of the broad Aegean area into the seismic sources and the estimation of their characteristic seismicity parameters determined by Hatzidimitriou (1984) is shown in figure 1).

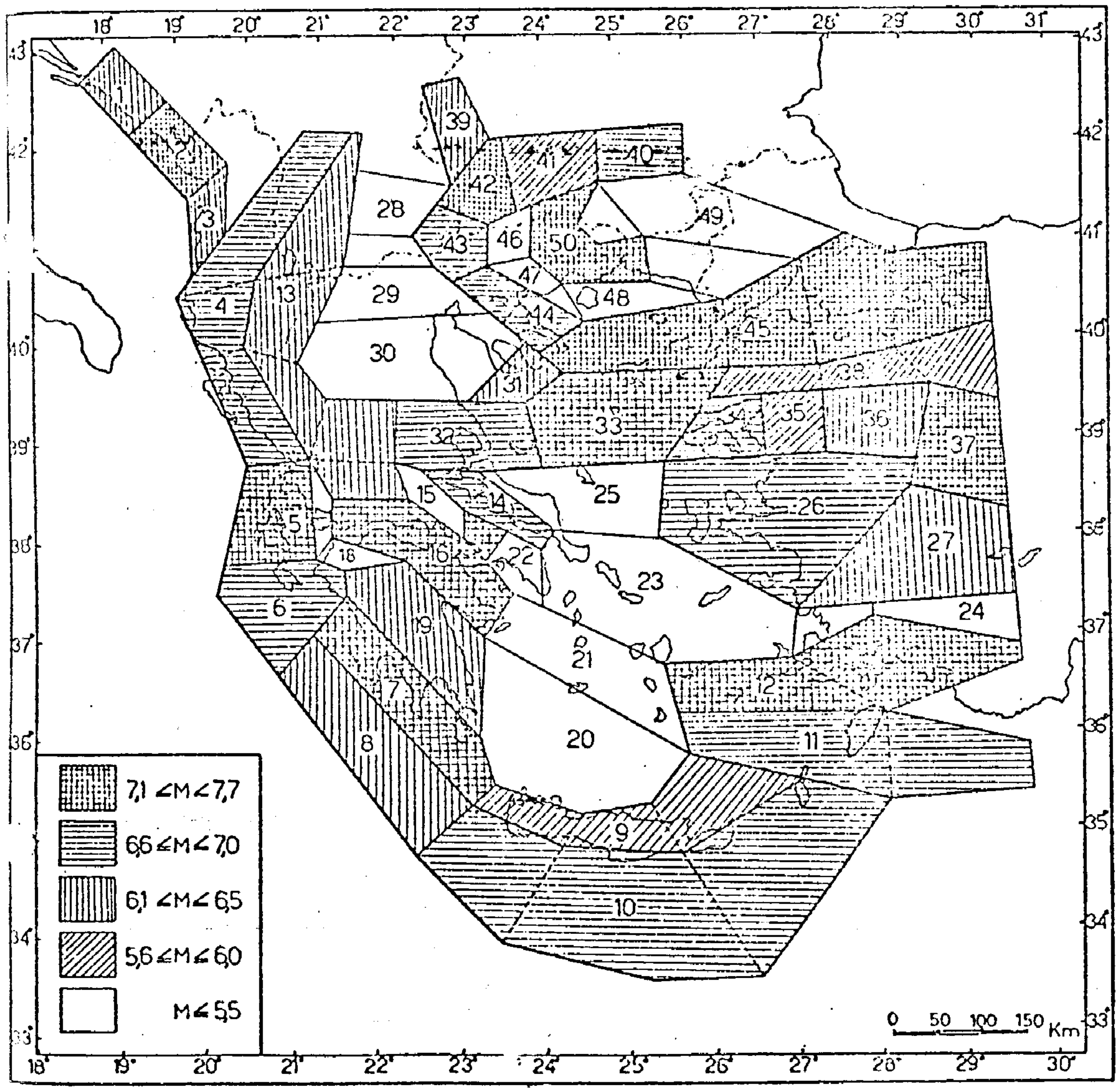

Fig. 1.- Seismic sources of the Aegean and surrounding area (Hatzidimitriou 1984).

The attenuation formula of seismic intensities used, is the following one which was proposed by Papaioannou (1984)

$$I = 6.59 + 1.18M \ldots 4.50 \log(\ldots) \quad (1)$$

where I_i is the seismic intensity, M_S is the surface-wave magnitude and Δ is the epicentral distance, in Km.

The computer program EQRISK (McGuire 1976) has been used for the calculations. The input required for the program is the characteristic seismicity parameters of the seismic sources of the region, their coordinates and the annual probabilities of exceedance R_A, for which the corresponding intensities are sought. The output is the values of the intensities which have annual probabilities of exceedance equal to R_A.

3. REGIONALIZATION OF THE SEISMIC HAZARD

The area of Greece has been divided into quadrilaterals with sides equal to 0.5° geographical latitude and longitude and the biggest population center observed in each one of these has been chosen. For each city, following the method and using the computer program described above, the most probable maximum seismic intensity (with 63% probability of exceedance) in a time period of 3,10,20,40,60,80,100 and 180 years has been estimated.

For each site, the graph of the seismic intensity I(in MM) versus time T (in years) was made. The curves have been compared with each other and according to their level and shape the cities were grouped into nine classes. Class (1) which represents the highest seismic hazard and class (9) represents the lowest seismic hazard. For each class the average curve has been constructed. These nine average curves are shown in figure (2). The vertical lines represent the standard deviation of the mean.

The results for each site (city) are given in table (1). The index numbers and the names of the cities are given in the first and second columns, respectively. The seismic intensities (in MM) with 63% probability of exceedance in 3,10,20,40,60, 100 and 180 years for each city are given in the next eight columns while the class number of each city is given in the last column.

In figure (3) the sites (cities) for which the seismic hazard was estimated are shown. Nine different symbols have been used for the nine different classes into which they were grouped. Black circles represent the highest seismic hazard (clas

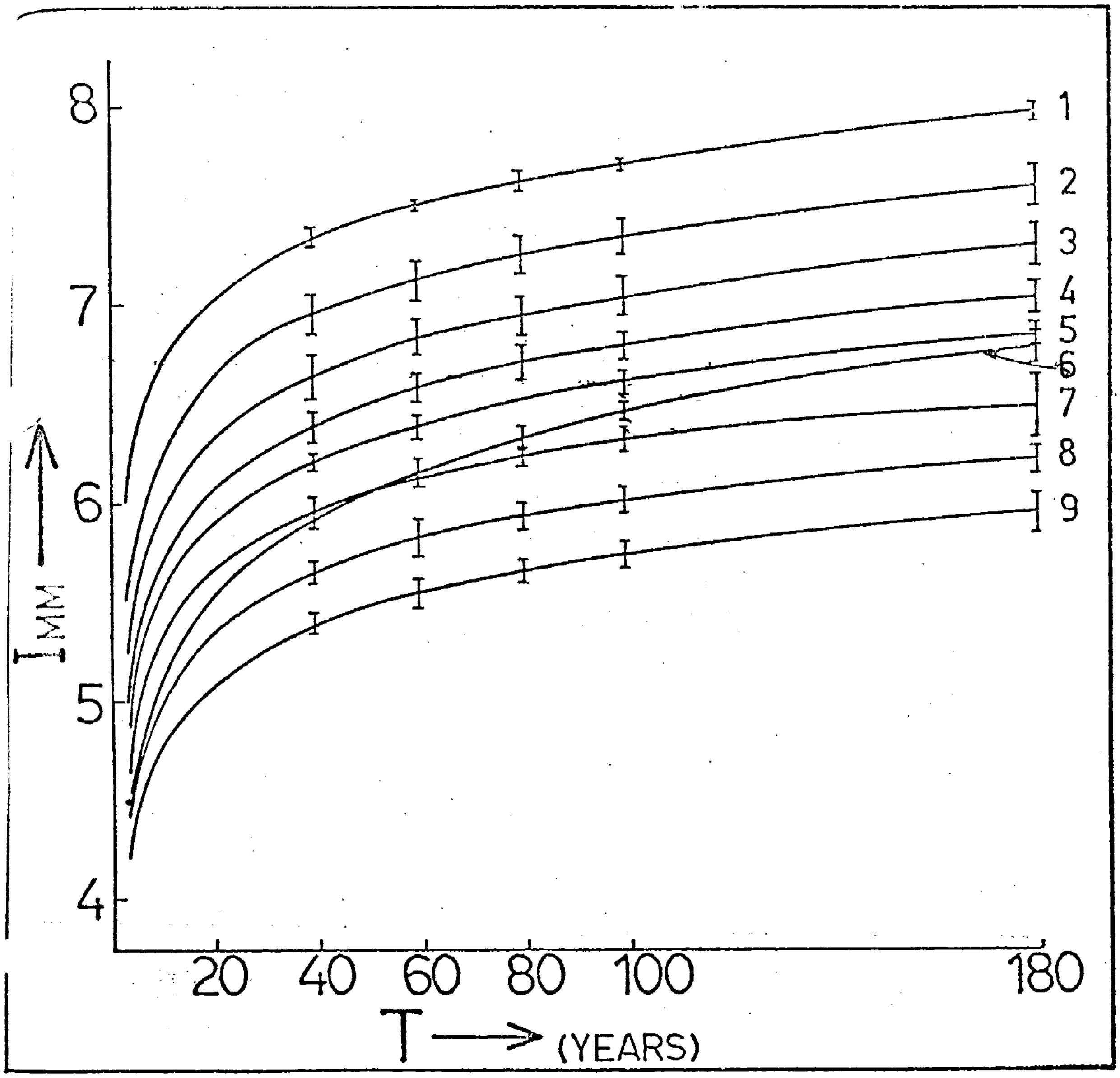

Fig. 2.- Average curves of the most probable seismic intensity I (in MM) versus the period T (in years) for the nine (9) classes of seismic hazard.

1) while the white circles represent the lowest seismic hazard (class 9). The number at each site corresponds to the number of the first column of table (1).

As it can be seen from this map, areas of high seismic hazard are the Ionian islands in western Greece and generally the whole part along the convex side of the Hellenic arc as

TABLE I. Seismic hazard of selected cities in the area of Greece, in terms of the most probable maximum intensity (in MM) in 3,10,20, 40, 60,80,100 and 180 years.

No.	City	Period (years)								Class
		3	10	20	40	60	80	100	180	
1.	NOTIA	4.2	4.8	5.1	5.4	5.6	5.7	5.8	6.0	9
2.	PETRITSI	4.8	5.6	6.0	6.4	6.6	6.7	6.8	7.1	4
3.	SERRES	5.0	5.7	6.0	6.2	6.4	6.5	6.6	6.8	5
4.	DRAMA	4.4	5.2	5.6	6.0	6.2	6.4	6.5	6.9	6
5.	XANTHI	4.1	4.9	5.4	5.8	6.1	6.2	6.4	6.7	6
6.	KOMOTINI	-	4.7	5.2	5.6	5.8	6.0	6.1	6.4	8
7.	SAPPES	-	4.6	4.9	5.3	5.5	5.6	5.7	6.0	9
8.	DIDYMOTIHO	-	4.6	4.9	5.3	5.4	5.6	5.7	5.9	9
9.	FLORINA	5.0	5.6	5.9	6.2	6.4	6.5	6.6	6.8	5
10.	KASTORIA	4.8	5.4	5.7	6.0	6.1	6.2	6.3	6.5	7
11.	PTOLEMAIDA	4.5	5.1	5.4	5.7	5.8	5.9	6.0	6.2	8
12.	EDESSA	4.5	5.1	5.4	5.7	5.8	5.9	6.0	6.2	8
13.	VERIA	4.4	5.0	5.3	5.6	5.8	5.9	5.9	6.1	8
14.	KILKIS	4.6	5.5	5.9	6.3	6.5	6.7	6.8	7.1	4
15.	THESSALONIKI	4.7	5.5	5.9	6.2	6.4	6.6	6.6	6.9	5
16.	LAGADAS	4.8	5.7	6.1	6.5	6.7	6.9	7.0	7.3	3
17.	MAYROTHALASSA	4.9	5.8	6.2	6.6	6.8	6.9	7.0	7.3	3
18.	KAVALA	4.4	5.2	5.6	6.0	6.2	6.4	6.5	6.8	6
19.	THASSOS	4.5	5.4	5.7	6.0	6.2	6.4	6.4	6.7	7
20.	ALEXANDROUPOLIS	-	4.8	5.1	5.5	5.7	5.8	5.9	6.2	9
21.	FERRES	-	4.7	5.1	5.5	5.7	5.8	5.9	6.2	9
22.	KONITSA	5.2	5.8	6.1	6.4	6.6	6.7	6.8	7.0	4
23.	GREVENA	4.4	5.0	5.2	5.5	5.6	5.7	5.7	5.9	9
24.	KOZANI	4.3	4.9	5.1	5.4	5.5	5.6	5.7	5.9	9
25.	SERVIA	4.4	5.0	5.2	5.5	5.6	5.7	5.8	6.0	9
26.	KATERINI	4.5	5.1	5.4	5.7	5.8	5.9	6.0	6.1	8
27.	POLIGIROS	4.8	5.5	5.9	5.2	6.4	6.6	6.6	6.9	5
28.	IERISSOS	5.1	6.0	6.4	6.8	7.0	7.2	7.3	7.5	2
29.	KARYES	5.0	5.9	6.4	6.8	7.0	7.2	7.3	7.5	2
30.	SAMOTHRAKI	4.5	5.3	5.8	6.2	6.5	6.7	6.8	7.1	4
31.	KERKIRA	5.5	6.1	6.4	6.7	6.9	7.0	7.1	7.3	3
32.	IGOUMENITSA	5.5	6.2	6.5	6.8	7.0	7.1	7.2	7.4	3

	City	Period (years)								Class
		3	10	20	40	60	80	100	180	
33.	IOANNINA	5.3	5.9	6.2	6.5	6.7	6.8	6.9	7.1	4
34.	METSOVO	4.8	5.4	5.7	6.0	6.1	6.2	6.3	6.5	7
35.	TRIKALA	5.1	5.8	6.1	6.4	6.6	6.7	6.7	7.0	4
36.	LARISA	5.2	6.0	6.4	6.7	6.9	7.1	7.2	7.4	3
37.	AGYA	4.9	5.6	6.0	6.3	6.5	6.6	6.7	6.9	4
38.	KALANDRA	4.9	5.6	5.9	6.2	6.4	6.5	6.5	6.7	5
39.	PALIOURI	5.2	5.9	6.2	6.5	6.7	6.8	6.9	7.1	4
40.	MYRINA	4.9	5.7	6.1	6.5	6.7	6.9	7.0	7.3	3
41.	ARGIRADES	5.3	5.9	6.2	6.6	6.7	6.8	6.9	7.2	4
42.	MARGARITI	5.6	6.2	6.5	6.8	7.0	7.1	7.2	7.4	3
43.	ARTA	5.5	6.1	6.4	6.7	6.9	7.0	7.0	7.3	3
44.	TETRAKOMO	5.3	5.9	6.2	6.5	6.7	6.8	6.8	7.1	4
45.	KARDITSA	5.3	6.0	6.3	6.6	6.8	6.9	7.0	7.2	3
46.	FARSALA	5.5	6.2	6.6	7.0	7.2	7.3	7.4	7.6	2
47.	VOLOS	5.6	6.3	6.7	7.0	7.2	7.4	7.4	7.7	2
48.	SKIATHOS	5.6	6.3	6.7	7.1	7.2	7.4	7.5	7.7	2
49.	SKOPELOS	5.5	6.3	6.7	7.0	7.2	7.3	7.4	7.7	2
50.	SIGRI	5.1	5.8	6.2	6.6	6.8	6.9	7.1	7.3	3
51.	KALLONI	5.1	5.9	6.3	6.6	6.8	7.0	7.1	7.3	3
52.	MYTILINI	5.1	5.9	6.2	6.6	6.8	7.0	7.1	7.3	3
53.	LEYKADA	6.1	6.7	7.0	7.3	7.5	7.6	7.7	7.9	1
54.	AGRINIO	5.5	6.1	6.5	6.8	6.9	7.0	7.1	7.3	3
55.	KARPENISI	5.3	5.9	6.2	6.5	6.7	6.8	6.9	7.1	4
56.	LAMIA	5.3	6.0	6.3	6.6	6.8	6.9	7.0	7.2	3
57.	KAMENA VURLA	5.1	5.8	6.1	6.4	6.5	6.7	6.7	7.0	4
58.	ATALANDI	5.1	5.8	6.1	6.4	6.6	6.7	6.8	7.1	3
59.	ISTIEA	5.4	6.1	6.5	6.8	7.0	7.1	7.2	7.5	3
60.	PYLIO (EVIA)	5.0	5.7	6.0	6.3	6.5	6.6	6.7	6.9	4
61.	KYMI	4.8	5.4	5.8	6.0	6.2	6.3	6.4	6.6	7
62.	SKYROS	4.8	5.5	5.8	6.2	6.4	6.5	6.6	6.9	5
63.	PSARA	4.7	5.5	5.8	6.1	6.3	6.5	6.6	6.8	5
64.	KARDAMILA	4.8	5.6	6.0	6.4	6.6	6.7	6.8	7.1	4
65.	ARGOSTOLI	6.0	6.7	7.0	7.3	7.5	7.6	7.7	8.0	1
66.	ITHAKI	6.0	6.7	7.0	7.4	7.5	7.6	7.7	8.0	1
67.	MESOLOGI	5.6	6.2	6.6	6.9	7.0	7.2	7.3	7.5	3
68.	PATRA	5.3	5.9	6.2	6.5	6.7	6.9	7.0	7.2	3

No	City	3	10	20	40	60	80	100	180	Class
		Period (years)								
69.	EGHIO	5.3	5.9	6.2	6.6	6.8	6.9	7.0	7.2	3
70.	XYLOKASTRO	5.3	6.0	6.3	6.6	6.8	6.9	7.0	7.3	3
71.	THIVA	6.0	6.7	7.0	7.4	7.5	7.7	7.7	8.0	1
72.	HALKIDA	5.4	6.1	6.5	6.8	7.0	7.1	7.2	7.5	2
73.	KAPANDRITI	5.2	5.9	6.3	6.6	6.8	6.9	7.0	7.3	3
74.	KARYSTOS	4.3	4.9	5.2	5.5	5.6	5.7	5.8	6.0	9
75.	MESTA (CHIOS)	4.8	5.5	5.9	6.3	6.5	6.7	6.8	7.1	4
76.	CHIOS	4.8	5.6	6.0	6.4	6.6	6.7	6.8	7.1	4
77.	ZAKYNTHOS	5.8	6.4	6.7	7.0	7.2	7.3	7.4	7.6	2
78.	PYRGOS	5.6	6.3	6.6	6.9	7.1	7.2	7.3	7.5	2
79.	MONASTIRAKI	5.4	6.0	6.3	6.7	6.9	7.0	7.1	7.4	3
80.	VLAHERNA	5.4	6.0	6.4	6.7	6.9	7.0	7.1	7.4	3
81.	KORINTHOS	5.4	6.0	6.3	6.7	6.8	6.9	7.0	7.3	3
82.	EGINA	5.3	5.8	6.2	6.5	6.7	6.8	6.9	7.1	4
83.	ATHINA	5.2	5.9	6.2	6.5	6.7	6.8	6.9	7.1	4
84.	KEA	4.2	4.9	5.2	5.4	5.6	5.7	5.8	6.0	9
85.	ANDROS	4.1	4.7	5.0	5.3	5.4	5.5	5.6	5.8	9
86.	TINOS	4.1	4.7	5.0	5.3	5.5	5.6	5.6	5.9	9
87.	AG.KIRIKOS(IKARIA)	4.3	5.0	5.4	5.7	5.9	6.0	6.1	6.3	8
88.	SAMOS	4.8	5.5	5.9	6.3	6.5	6.7	6.8	7.0	4
89.	TRIPOLI	5.4	6.0	6.4	6.7	6.9	7.0	7.2	7.4	3
90.	FILIATRA	5.2	5.8	6.2	6.5	6.7	6.8	6.9	7.2	3
91.	KALAMATA	5.2	5.9	6.2	6.6	6.8	6.9	7.0	7.3	3
92.	LEONIDI	5.4	6.0	6.4	6.7	6.9	7.1	7.2	7.4	3
93.	ERMIONI	5.3	6.0	6.3	6.6	6.8	6.9	7.0	7.3	3
94.	KYTNHOS	4.4	4.9	5.3	5.6	5.8	5.9	6.0	6.2	8
95.	SYROS	4.1	4.7	5.0	5.3	5.5	5.6	5.7	5.9	9
96.	MYKONOS	4.1	4.8	5.1	5.4	5.5	5.6	5.7	5.9	9
97.	PAROS	4.4	5.1	5.4	5.8	5.9	6.0	6.1	6.4	7
98.	NAXOS	4.6	5.3	5.6	5.9	6.1	6.2	6.3	6.5	7
99.	PATMOS	4.4	5.1	5.4	5.7	5.9	6.0	6.1	6.3	8
100.	AG.MARINA(LEROS)	4.7	5.3	5.7	6.0	6.2	6.3	6.4	6.6	7
101.	PYLOS	5.2	5.8	6.1	6.5	6.7	6.8	6.9	7.2	3
102.	AG.NIKOLAOS(MESSINIA)	5.2	5.8	6.2	6.5	6.7	6.8	6.9	7.2	3
103.	GITHIO	5.3	5.9	6.3	6.6	6.8	6.9	7.0	7.3	3
104.	MONEMVASIA	5.3	6.0	6.4	6.7	6.9	7.0	7.1	7.4	3

No	City	Period (years)								Class
		3	10	20	40	60	80	100	180	
105.	MYLOS	4.9	5.6	5.9	6.2	6.4	6.5	6.6	6.9	5
106.	SIFNOS	4.7	5.3	5.7	6.0	6.2	6.3	6.4	6.7	7
107.	IOS	4.8	5.5	5.8	6.2	6.3	6.5	6.6	6.8	5
108.	KATAPOLA (AMORGOS)	5.5	6.2	6.5	6.9	7.1	7.2	7.3	7.6	2
109.	ASTIPALEA	5.7	6.3	6.7	7.0	7.2	7.3	7.4	7.7	2
110.	KYTHIRA	5.3	6.0	6.4	6.7	6.9	7.0	7.1	7.4	3
111.	THIRA	4.9	5.6	6.0	6.3	6.5	6.6	6.7	7.0	4
112.	ANAFI	5.3	6.0	6.3	6.7	6.9	7.0	7.1	7.4	3
113.	GALAMIANOS (ANTIKITHYRA)	5.7	6.4	6.7	7.1	7.3	7.4	7.5	7.8	2
114.	KISSAMOS	5.0	5.7	6.0	6.4	6.5	6.7	6.8	7.0	4
115.	CHANIA	5.0	5.6	6.0	6.3	6.5	6.6	6.7	7.0	5
116.	STOMIO(CHANIA)	4.9	5.6	5.9	6.3	6.4	6.6	6.7	6.9	5
117.	RETHYMNO	5.0	5.7	6.0	6.4	6.5	6.7	6.8	7.0	4
118.	TYBAKIO	5.0	5.6	6.0	6.3	6.5	6.6	6.7	6.9	4
119.	IRAKLIO	5.1	5.7	6.1	6.4	6.6	6.7	6.8	7.1	4
120.	AG.NIKOLAOS	5.3	6.0	6.3	6.7	6.9	7.0	7.1	7.4	3
121.	IERAPETRA	5.2	5.9	6.3	6.6	6.8	6.9	7.0	7.3	3
122.	SITIA	5.3	6.0	6.3	6.7	6.9	7.0	7.1	7.4	3
123.	VATHI (SAMOS)	4.8	5.5	5.9	6.3	6.5	6.6	6.8	7.0	4
124.	KALYMNOS	5.5	6.1	6.5	6.8	7.0	7.1	7.2	7.5	2
125.	KOS	5.7	6.4	6.8	7.1	7.3	7.4	7.5	7.8	2
126.	HALKI	5.1	5.8	6.2	6.5	6.7	6.8	6.9	7.2	3
127.	GENADIO	4.9	5.6	5.9	6.2	6.4	6.6	6.7	6.9	5
128.	RODOS	5.5	6.2	6.6	6.9	7.1	7.2	7.3	7.6	2
129.	KARPATHOS	4.9	5.6	5.9	6.2	6.4	6.5	6.6	6.9	5
130.	LIVADIA	5.6	6.2	6.6	6.9	7.0	7.1	7.2	7.4	2
131.	AMFISSA	5.7	6.3	6.6	7.0	7.1	7.3	7.4	7.6	2

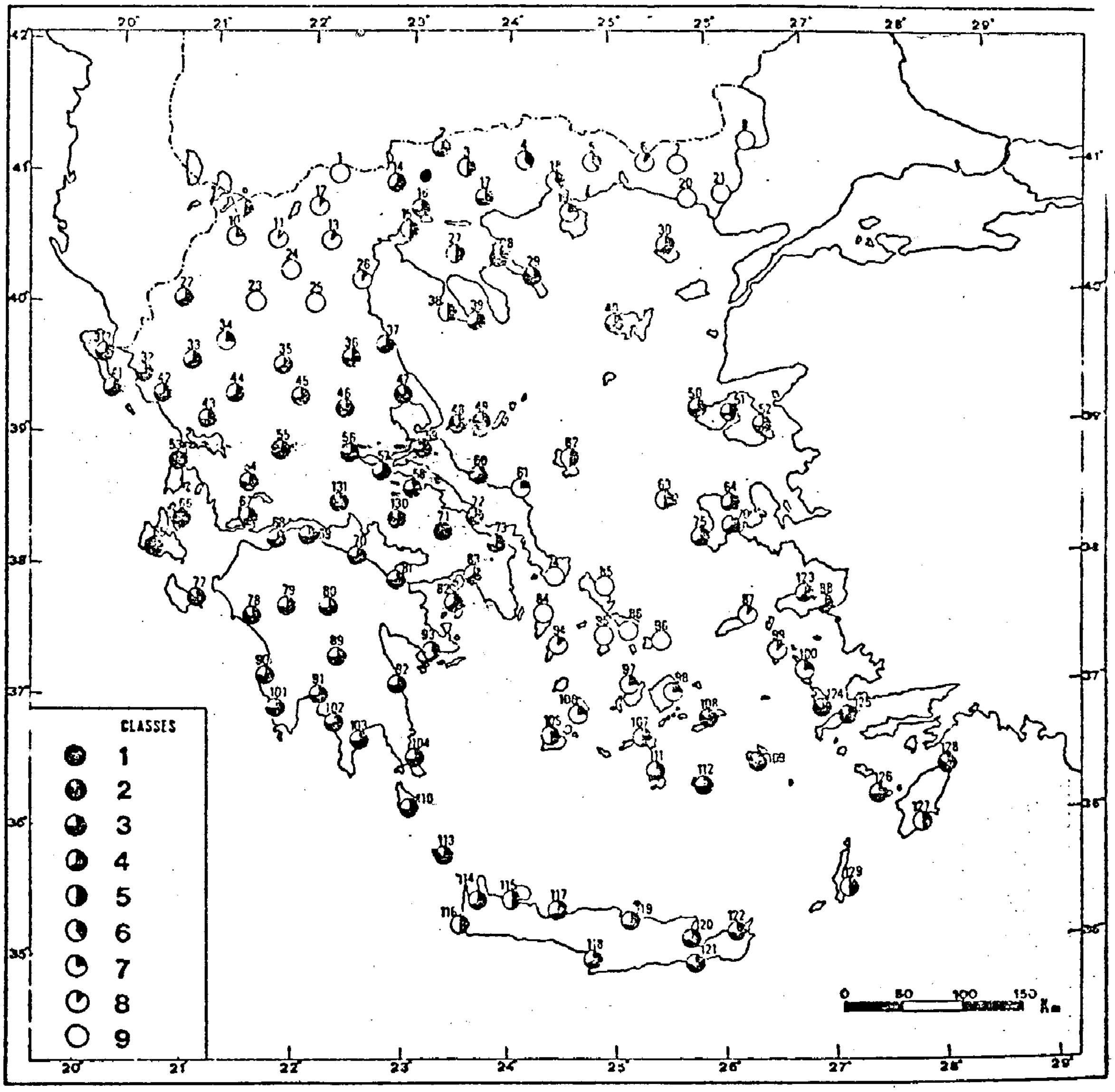

Fig. 3.- Sites for which the seismic hazard was determined. The graduation from high seismic hazard to low seismic hazard goes from black circles (class 1) to white circles (class 9).

well as a zone with E-W trend in central Greece. Peloponnesus, the eastern part of central Greeece as well as parts of northern Greece along the Servomacedonian massif can be also considered as areas of high seismic hazard.

Areas of low seismic hazard are those in the central part of southern Aegean sea, northern part of central Greece and also the northeasternmost part of Greece.

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