FOURTH INTERNATIONAL SYMPOSIUM

ANALYSIS OF SEISMICITY AND SEISMIC RISK

PROCEEDINGS

I

Czechoslovak Academy of Sciences
Geophysical Institute

Proceedings of the 4th International Symposium on the Analysis of Seismicity and Seismic Risk

Bechyně Castle, Czechoslovakia, September 4-9, 1989

SEISMICITY OF THE AEGEAN AND SURROUNDING AREAS IN RELATION TO TOPOGRAPHY OF THE LITHOSPHERE - ASTHENOSPHERE TRANSITION

J. Plomerová and V. Babuška
Geophysical Institute, Czechoslovak Academy of Sciences
141 31 Prague 4, Czechoslovakia

P. Pajdušák
Geophysical Institute, Slovak Academy of Sciences
842 28 Bratislava, Czechoslovakia

P.M. Hatzidimitriou and D. Panagiotopoulos
Geophysical Laboratory, University of Thessaloniki
540 06 Thessaloniki, Greece

J. Kalogeras and S. Tassos
National Observatory of Athens, Seismological Institute
118 10 Athens, Greece

ABSTRACT

Travel-time residuals are computed from teleseismic P-arrival times recorded at seismological stations in the broader Aegean region. The distribution of the residuals fits well the geometry of the whole Hellenic arc. We use the relative residuals to investigating the deep lithosphere structure in relation to the earthquake distribution in this seismically most active region of the Mediterranean. In our model of the lithosphere, lateral variations of the directionally independent component of the relative residual are transformed into lateral variations of the lithosphere thickness. The mountain ranges of the Dinarides, Hellenides and Anatolian Alpides are characterized by a prominent lithosphere thickening while a lithosphere thinning is observed between the individual ranges, along the south Adriatic and Ionian coasts and beneath the northern Aegean coast. In several regions we observe a correlation between shallow seismicity and great changes in the topography of the lithosphere-asthenosphere transition.

INTRODUCTION

The Aegean region and its surroundings, which include Greece, the Aegean Sea, Albania, south Yugoslavia, western Turkey and the northern part of the eastern Mediterranean, are seismically the most active province in the whole Mediterranean. It is the region, where continental collision (southeastern Turkey), subduction (eastern Mediterranean), transform faulting (northern Anatolia) and extension (Aegean block) take place. All these tectonic activities occur within a rather small area. In this contribution we wish to present a model of the lithosphere thickness and to find out if there is a relation between this model and the seismicity of the Aegean. As we can estimate the lithosphere thickness only beneath the seismological stations, we do not have enough data for the major parts of the Aegean Sea and the Cretan Sea.

In order to study the lithosphere structure of this region we applied a method developed by Babuška et al. (1984, 1987) for central Europe. The method is based on an analysis of teleseismic P-wave residuals, i.e. the delay times of waves arriving from epicentral distances between 10° and 100° observed at a network of seismological stations covering the investigated region (Fig. 1). The main steps of the method are as follows: a) normalization of the absolute residuals of each event (observed minus theoretical times) by subtracting residuals averaged over a system of reference stations, which minimizes effects of deep mantle paths and of source regions, and b) grouping the events by source regions and computing average relative residuals for azimuth - epicentral distance segments to get a better azimuth - distance coverage. The method is applied to the residuals reduced to the M-discontinuity at a reference depth of 33 km by introducing corrections for station elevations, different crustal thicknesses and velocities as well as for sediments. At each station we compute a directionally independent component of the relative residuals, called representative average residual, as an average from steeply inciding waves in each azimuthal window. According to the seismological definition, the lithosphere is a rigid high-velocity outer layer of the Earth which is underlain by a low-velocity asthenosphere (Sacks and Snoke, 1984). Therefore, lateral variations of the representative average residuals can be related to lateral changes of the lithosphere thickness. For an empirical linear relation between representative average residuals and the lithosphere thickness we use the slope derived in central Europe (Babuška et al. 1987; Plomerová and Babuška, 1988). The reference level of the relative residuals depends on the system of reference stations chosen for the normalization. Therefore, we need some overlap at the marginal parts of neighbouring regions, where we model the lithosphere thickness from the residuals computed relative to different reference levels. In the case of the Aegean region we estimated the interception of the linear relation from a comparison of relative residuals averaged over the Thessaloniki local network (THE, LIT, PAIG, SRS, OUR, KNT, SOH and GRG) with our previous study on central Balkan (Plomerová et al., 1988).

Figure 1 shows 67 seismological stations used for the lithosphere study and the 7 stations, finally chosen for the normalization. We investigated 634 teleseismic events from the period between 1979 and 1985, which were divided into 93 source segments of 10° in epicentral distances and 20° in azimuths, computed relative to the centre of the Aegean (38.5°N, 25.0°E).

LITHOSPHERE THICKNESS AND SEISMICITY

Figure 2 shows the representative average residuals (in tenths of a second) computed relative to the 7 reference stations (see Fig 1). Although we observe negative residuals at most of the stations, there are systematic lateral variations from -1.2 sec to 0.9 sec. The most positive residuals were found along the south Adriatic and Ionian coasts, the entire central Aegean region (with the exception of station EZN) and the Crete island exhibited positive residuals, and slightly positive residuals were calculated at some of the stations on the Chalkidiki Peninsula. Other provinces have negative residuals. The most negative values are observed beneath the eastern part of central Greece, from Olympus Mountain southward to the area surrounding the Corinthiakos Gulf. Several places with negative residuals lower than -0.5 sec were found in

Fig. 1. Tectonic sketch-map of the broader Aegean and seismological stations (dots) whose teleseismic P-arrival times recorded between 1979 and 1985 were used for the lithosphere thickness study. Stations used for the normalization are underlined.

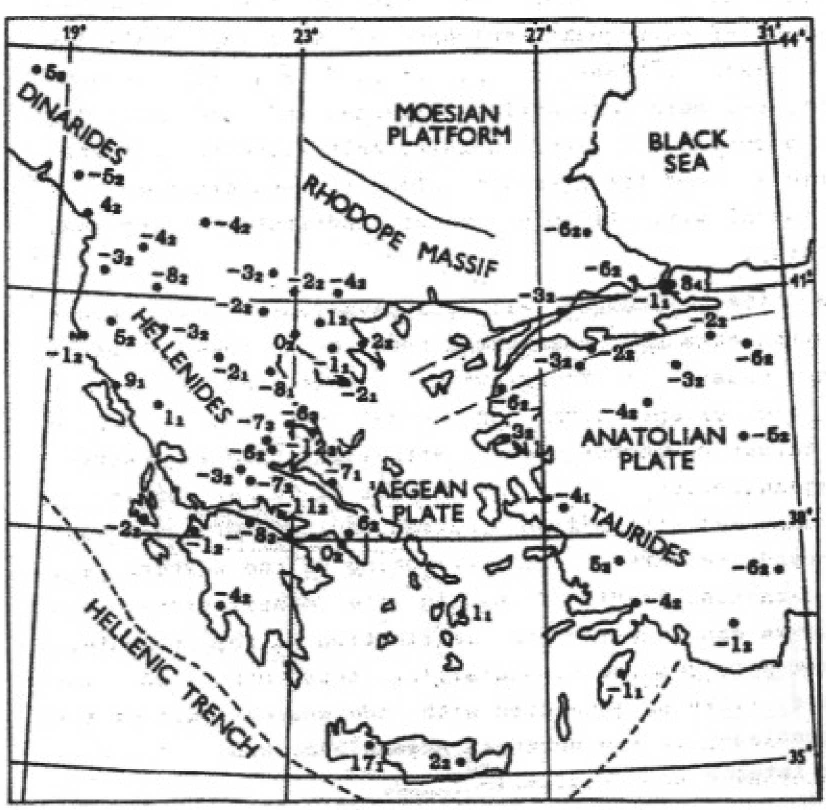

Fig. 2. Representative average residuals (indices denote errors, both in tenths of a second) computed relative to the 7 reference stations (see Fig. 1).

the western part of the Anatolian Plate.

A model of the lithosphere thickness in the broader Aegean region (Fig. 3), derived from the representative average residuals (Fig. 2), depicts the main features which correlate with the large scale tectonics. Since the accuracy of the representative average residuals is only exceptionally better than +/-0.2 sec, in our model we marked regions with a thin lithosphere (h < 100 km), with a normal thickness of the lithosphere (100 < h < 150 km), with a thick lithosphere (150 < h < 200 km) and regions with the deepest sinking of the lithosphere - asthenosphere transition (h > 200 km). The model shows that in general, the lithosphere gets thicker in the direction approximately perpendicular northeast of the western part of the Hellenic Trench. The thinnest lithosphere is observed along the south Adriatic and Ionian coasts, parallel to the trench. The residuals detected the greatest depth of the lithosphere - asthenosphere transition beneath the area of Olympus Mountain down to the Corinthiakos Gulf. The lack of information on the lithosphere thickness beneath the Aegean Sea is due to sparce distribution of the stations. Nevertheless, the residuals indicate quite a normal range for the depths of the lithosphere - asthenosphere transition. However, in region with active subducting slabs, above which a wedge of a very low-velocity asthenospheric material exists, our model of the lithosphere thickness might be underestimated as we derive it from average residuals, i.e. average velocities, beneath stations. The boundary of the Aegean and Anatolian Plates is characterized by undulated lithosphere - asthenosphere transition (Fig. 3). A lithosphere thickening was also found north of the Anatolian Fault as well as beneath the western Taurides.

To examine a connection, if any, between seismicity of the Aegean region and the model of the lithosphere, we compare our map of the lithosphere thickness with the distribution of earthquake epicenters. In a map of shallow seismicity since 600 B.C. (Papazachos, 1988) the epicenters form several seismic zones, which are divided into two main categories: external and internal. The external seismic zones form a continuous large seismic belt along the external (convex) side of the Hellenic arc and its extension along the western coast of central Greece, Albania and Yugoslavia. All other zones constitute the internal seismic zones (Papazachos, 1988).

Papazachos et al. (1984, 1986) studied all the available fault plane solutions of the shallow earthquakes and summarized them as follows: thrust faulting is observed along the coast of Yugoslavia, Albania and along the convex side of the Hellenic arc except from the Cephallonia region, where strike-slip faulting with a thrust component occurs. Normal faulting is observed in the inner part of the Aegean region, but in the NW part of Turkey and in the northernmost part of the Aegean Sea strike-slip dextral faulting with a thrust or normal component is observed, referred to the branching of the western part of the Anatolian Fault (Papazachos, 1988). Combining the observations and conclusions mentioned above, we can classify the distribution of the epicenters of shallow earthquake into three types of clusters: (i) those connected with the external seismic zones, (ii) those connected with the western part of the Anatolian Fault and its continuation in the northern Aegean Sea, and (iii) those connected with the other internal zones (Fig. 4).

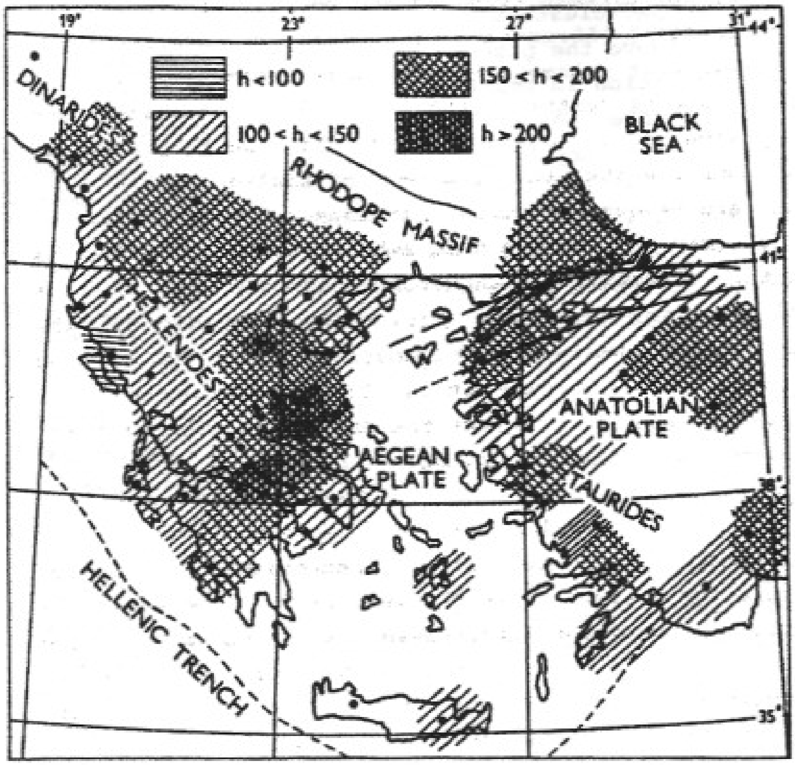

Fig. 3. Model of the lithosphere thickness derived from the representative average residuals (see Fig. 2); dots represent the seismological stations used in the study.

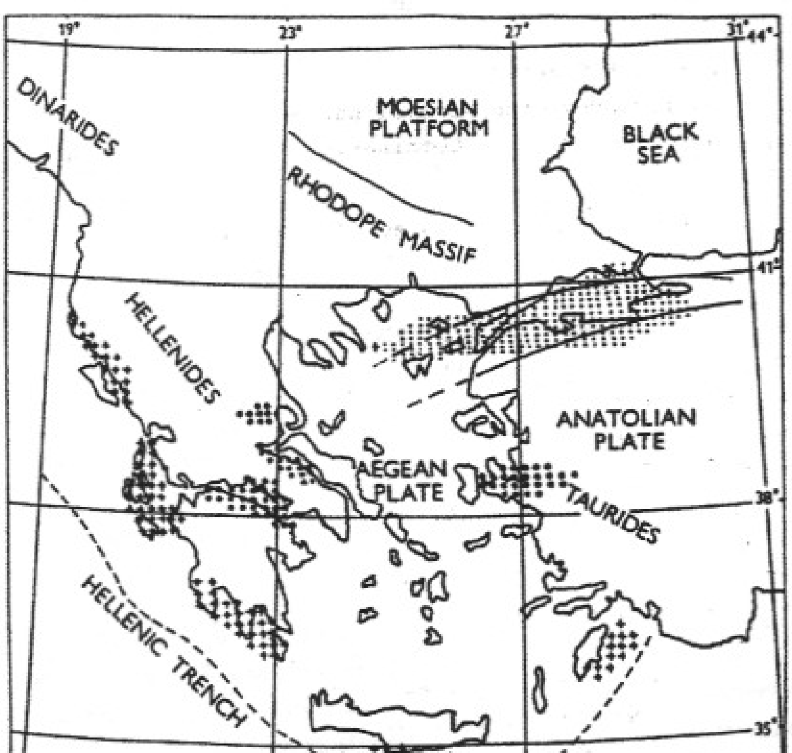

Fig. 4. Clusters of the shallow seismicity in the Aegean region derived from a map by Papazachos (1988), showing the distribution of shallow earthquake epicenters; crosses are for clusters along the external seismic zones, fine dots for clusters of the internal seismic zones typically with strike-slip dextral faulting and heavy dots for clusters of the internal seismic zones typically with normal faulting.

Comparing the maps of the lithosphere thickness (Fig. 3) and the scheme of seismicity (Fig. 4), we can see that clusters of shallow events classified into the third category are situated above the places of the deepest sinking of the lithosphere - asthenosphere transition in central Greece and furthermore in the western Taurides. Similar coincidence between the highest concentration of shallow seismicity and the greatest depth of the lithosphere — asthenosphere transition was found in the area of the eastern Alps - in the Friuli region (Aric et al., 1989). It is possible that the clusters of shallow foci in the inner part of Aegean region are related to deep lithospheric roots which we found beneath them. These roots may represent a cold subducted material which is gradually being heated in the surrounding asthenosphere causing an uplift of the lithosphere. The normal faulting, which is prevailing mechanism of the shallow earthquakes in this region, seems to be compatible with the assumed uplift above the subducted lithospheric roots. It is also proposed by previous authors (Makris, 1978; Horváth et al., 1981) that the pattern of the extension in the centre of the Aegean area indicates its uplift.

CONCLUSION

The Aegean region and its surroundings are mostly characterized by negative relative P-residuals (high-velocity pattern), which indicates a model of a relatively thick lithosphere. The thickest lithosphere was found beneath the eastern part of central Greece, while the thinnest lithosphere was observed along the coasts of the northern Ionian Sea. The clusters of shallow foci in the inner part of the Aegean region, which are characterized by normal faulting, are located above the deepest lithospheric roots. This implies a possible relation of the increased shallow seismicity and the normal faulting with remnants of subducted oceanic lithosphere at depths of about 200 km or more.

ACKNOWLEDGEMENTS

The authors thank Dr. S. Aliaj for providing several parameters of Albanian seismological stations. They also thank Mrs. E. Comninakis for providing many data of the Thessaloniki Network.

The research was partly supported by UNESCO, contract SC/RP 264016.8.

REFERENCES

ARIC,K., GUTDEUTSCH,R., LEICHTER,B., LENHARDT,W., PLOMEROVÁ,J., BABUŠKA,V., PAJDUŠÁK,P. and NIXDORF,U., (1989), Structures of the lithosphere in the Eastern Alps derived from P-residual analysis, Zentralanstalt für Meteorologie und Geodynamik in Wien, Publ. 317 .

BABUŠKA,V., PLOMEROVÁ,J. and ŠÍLENÝ,J., (1984), Large-scale oriented structures in the subcrustal lithosphere of central Europe, Ann. Geophys., B2, pp.649-662.

BABUŠKA,V., PLOMEROVÁ,J. and ŠÍLENÝ,J., (1987), Structural model of the subcrustal lithosphere in central Europe, in "Composition, Structure and Dynamics of the Lithosphere-Asthenosphere System", Geodyn. Ser., 16, edited by K. Fuchs and C. Froidevaux, pp.239-251, AGU, Washington D.C.

HORVÁTH,F., BERCKHEMER,H. and STEGENA,L., (1981), Models of Mediterranean back-arc basin formation., Philos. Trans. R. Soc. London, Ser. A, 300, pp.383-402.

MAKRIS,J., (1978), Some geophysical considerations on the geodynamic situation in Greece, Tectonophysics, 46, pp.251-268.

PAPAZACHOS,B.C., (1988), Active tectonics in the Aegean and surrounding area , in "Seismic Hazard in Mediterranean Regions", Eds. J. Bonnin et al., pp.301-331.

PAPAZACHOS,B.C., KIRATZI,A.A., HATZIDIMITRIOU,P.M. and ROCCA,A.C., (1984), Seismic faults in the Aegean area, Tectonophysics, 106, pp.71-85.

PAPAZACHOS,B.C., KIRATZI,A.A., HATZIDIMITRIOU,P.M. and KARACOSTAS,B.G. (1986), Seismotectonic properties of the Aegean area that restrict valid geodynamic models, 2nd Wegener Conference, Dionysos, Greece, 14-16 May 1986.

PLOMEROVÁ,J. and BABUŠKA,V., (1988), Lithosphere thickness in the contact zone of the Moldanubicum and Saxothuringicum in central Europe, Phys. Earth Planet. Inter., 51, pp.159-165.

PLOMEROVÁ,J., BABUŠKA,V., PAJDUŠÁK,P., HATZIDIMITRIOU,P., PANAGIOTOPOULOS,D., TASSOS,S. and KALOGERAS,J., (1988), Deep lithosphere structure in the Balkans as derived from P-residuals, European Seismological Commission, XXI General Assembly, Sofia, Bulgaria, 23-27 August 1988.

SACKS,I.S. and SNOKE,J.A., (1984), Seismological determinations of the subcrustal continental lithosphere, in "Structure and Evolution of Continental Lithosphere", Eds. H.N.Pollack and V.Rama Murthy, pp.3-89.