Geophys. J. Int. (1989) **98**, 391–394

RESEARCH NOTE

A revised and extended earthquake catalogue for Greece since 1900

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Accepted 1989 January 26. Received 1989 January 26; in original form 1988 March 11

SUMMARY

An earthquake catalogue for Greece is presented covering the period 1900–1985. It is based on a similar effort attempted a few years ago. The present version contains more than double the number of events, i.e. 4310 events compared with 1806 events, than in the previous papers. It also includes another 1711 events which took place in the region in an Appendix. The accuracy and completeness of the parameters of these shocks were insufficient for inclusion in the main catalogue without affecting the catalogue's homogeneity. For the new entries magnitudes are redetermined using Uppsala's reading as before, whereas the other parameters have been rechecked against local macroseismic information. The completeness of this catalogue varies according to the period of observation, but the lower threshold of completely reported magnitudes has been substantially decreased allowing for more detailed seismicity studies to be performed.

Key words: earthquake catalogue, Greece, seismicity

1 INTRODUCTION

Since 1978, when the first earthquake catalogue for Greece containing recalculated source parameters including magnitudes according to a consistent scheme was published by Makropoulos (1978) and further elaborated by Makropoulos & Burton (1981), a continuous effort has been attempted towards the completeness and the accuracy of the parameters involved. Furthermore, earthquake data for the last 8-yr period (1978–1985 inclusive) had to be included in such a way that the catalogue's homogeneity was ensured. However, during the search for additional information which could allow new entries to be included in the main catalogue, it became clear that there was a significant number of events for which, although they did not fulfil the strict requirements for inclusion in the catalogue, there was no doubt about their occurrence. Hence, in this study the procedures leading to the main catalogue are described, and the results are tested for magnitude completeness. Finally, the additional events for the period 1900–1963 are listed in an Appendix.

2 DATA SOURCES

2.1 Hypocentres

Apart from the data sources used in the previous work (Makropoulos 1978), additional information was extracted mainly from the annual bulletins of the National Observatory of Athens (NOA), from the annual bulletins of the Seismological Institute at Uppsala (SIU) for readings at Uppsala (UPP), Unesco's (UNS) catalogue (Shebalin, Karnik & Hadzievski 1974), Papazachos & Comninakis (1982) catalogue (PC) and from the International Seismological Centre bulletins (ISC).

The area of investigation is again limited to latitudes 33°N to 42.5°N and longitudes 19°E to 29°E north of the 38°N parallel and to 30°E south of it, in order to cover the Dodecanese Islands.

For the period 1964–85 all parameters, except magnitudes, are those reported by the ISC.

2.2 Magnitudes

The criteria for including an event prior to 1964 in the main catalogue were (i) the existence of macroseismic information and (ii) that the event was registered by the Uppsala (UPP) and/or Kirouna (KIR) stations with reported ground amplitudes allowing the magnitude to be determined.

The main reasons for choosing these two stations are first because Swedish annual and monthly bulletins reporting ground amplitudes are available from 1908. Secondly, the same stations were used during the compilation of the Makropoulos (1978) catalogue to which the present work is an extension. Thus the use of the same data source coupled with the same magnitude calculation procedure (see below) ensures that the achieved homogeneity and reliability of the previous catalogue will be retained.

The Uppsala Wiechert seismograph was the only instrument in operation for the complete period of investigation. It seldom recorded body phases to justify m_b calculations. For a consistent calculation of magnitude, therefore, the surface-wave magnitude M_s is chosen as the standard magnitude for the whole period. The disadvantage of using only one station, Uppsala, and the deviation that this would cause from any 'true' magnitude is, as it has been pointed out by Alsan, Tezucan & Båth (1975), unlikely to be greater than the error inevitably inherent in most magnitude determinations.

The detailed description of the procedure used for magnitude determination can be found in Alsan *et al.* (1975), Makropoulos (1978) and Makropoulos & Burton (1981). The conversion equations used for magnitude determination are originally due to Alsan *et al.* (1975) and later adopted by Makropoulos (1978). Thus, starting from the basic equations for M_s and m_b, surface and body-wave magnitudes respectively:

$$M_s = \log(A/T) + 1.66 \log \Delta^0 + 3.3 \qquad (1)$$

$$m_b = \log(A/T) + q(\Delta, h) \qquad (2)$$

depending upon the type of seismic waves available (i.e. the period T of the reported ground amplitudes), the magnitudes are determined from the conversion equations (Alsan *et al.* 1975):

$$M_s = 0.95M_{(\mathrm{UPP})} + 0.29, \qquad (3)$$

where $M_{(\mathrm{UPP})}$ is the surface-wave magnitude derived from long period Benioff instruments of the Uppsala station through equation (1), and likewise:

$$M_s = 0.85M_{(\mathrm{W})} + 1.04, \qquad (4)$$

where $M_{(\mathrm{W})}$ is the Wiechert magnitude at the Uppsala station.

When surface-wave records are unavailable, the m_b value is determined from short-period vertical component P-wave records using formula (2). The regression equation of M_s on m_b derived for $h \leq 45$ km (Alsan *et al.* 1975) is:

$$M_s = 1.46m_b - 2.91. \qquad (5)$$

The ISC took over the service from the ISS in 1964 and started to determine body-wave magnitudes m_b with continuously decreasing magnitude threshold. The regression equation of M_s on m_b(ISC) derived in the early publication (Makropoulos 1978)

$$M_s = 1.37m_b(\mathrm{ISC}) - 1.74 \qquad n = 187 \qquad (6)$$

with a standard deviation on M_s of ± 0.27 is used from 1964 onwards.

A comparison between equation (6) and a similar one derived from m_b(ISC) and M_s for the same events reported from all available agencies and for the period 1964–75 [equation (3) in Makropoulos & Burton 1981] shows almost identical results. Thus, any disadvantage caused by using a local network is diminished.

2.3 Depth correction

The M_s calculation through formula (1) is based on shallow-focus earthquakes ($h \leq 50$ km). For deeper events and since the amplitudes of the surface waves generally decrease with depth, M_s values calculated by the same formula (1) are too low and do not represent the true energy of the event (Båth 1985).

In such a case, the M_s values have to be corrected so as to yield the magnitude of the same event, if it were located at shallow depth. However, although the problem is familiar to seismologists only a few attempts can be found in the literature regarding determinations of these corrections. Most of them are due to Båth (1952, 1977, 1984), Alsan *et al.* (1975) and Zatopek & Vanek (1950). Båth in a recent paper (Båth 1985), by evaluating world-wide data, recommended a modification of the Prague formula, equation (1). This consists of an additional term of the form $f(h)$, where the values of $f(h)$ for different ranges of focal depth were tabulated.

In the present study the formula given by Alsan *et al.* (1975), which was derived using 55 events from the same area (i.e. Aegean area),

$$\Delta M = 0.0046(h - 50) \quad \text{for} \quad h \geq 50\,\text{km}, \qquad (7)$$

is adopted. ΔM is the difference between the M_s calculated from equation (5) where h is taken into account, and the M_s from equation (3) without depth correction. We apply this correction to M_s values obtained from surface-wave records.

3 COMPLETENESS

One of the main tasks of this effort is to increase catalogue completeness by including events not previously listed without sacrificing the achieved homogeneity. For the period covered by the previous work (i.e. 1900–1977) the vast majority of the additional events are for a magnitude range of $M = 4$–5, whereas for the period 1978–1985 all events are the ones listed by the ISC and having m_b magnitudes. For the latter, all parameters, except magnitudes, are those reported by the ISC. The magnitudes are converted from m_b ISC magnitudes to M_s magnitudes using equation (6).

However, even for the present catalogue, which contains more than twice the entries of the previous one, incompleteness at the lower magnitudes cannot be prevented. In order to assess the degree of incompleteness, that is to find the magnitude above which the catalogue can be considered as reasonably complete, or alternatively to assign time intervals in which a certain magnitude range is likely to be completely reported, the method introduced by Stepp (1971, 1973) and used in the previous works (Makropoulos 1978; Makropoulos & Burton 1981) and by Drakopoulos (1976) is also applied here. The method, as well as the step-by-step application, is described in Makropoulos & Burton (1981).

Table 1 summarizes the results of the application of the test of completeness on the main catalogue. It can be seen that events with magnitude above 4 are completely reported only during the last 10 yr of the catalogue (1976–1985). This period is the additional one covered for the first time by the present catalogue. The earthquakes half a magnitude unit bigger (i.e. 4.5), are completely reported for about the last 35 yr of the catalogue. The analysis also shows that the present catalogue contains almost all the events with magnitude equal to or greater than 5.0 or 5.5 after 1940 or

Table 1. Results from test of completeness for Greece (1900–1985).

Magnitude	Time required for stable mean recurrence rate (yr)	Period of completely reported events
$M \geq 4.0$	5	1976–1985
$M \geq 4.5$	20	1950–1985
$M \geq 5.0$	25	1940–1985
$M \geq 5.5$	45	1911–1985
$M \geq 6.0$	60	1900–1985

1911, respectively. Finally, no earthquake with magnitude 6 or greater seems to be omitted for the whole period (i.e. 1900–1985). When comparing Table 1 with the corresponding table 4 of Makropoulos & Burton (1981), it is evident that the inclusion of about 1500 more events, mainly of small magnitude, results in lowering the threshold magnitude above which, for the same period, the events are completely reported. Thus, for the period after 1950, for example, the threshold magnitude of completely reported events is $M = 4.5$, while in the previous work it was 5.0. The latter is now the threshold magnitude for the period 1940–1985. For the events of larger magnitudes (i.e. $M \geqslant 5.5$) on the other hand, there is no significant change in the threshold magnitude. This is to be expected since the vast majority of large events was already included in the previous work.

Another important feature of Stepp's method is its ability to determine the time required for stable mean recurrence rate of the magnitudes (see Table 1). This makes it possible to create an artificially homogeneous and complete data sample, thus allowing for statistical studies to be performed.

4 CONCLUSION

The present version of the main catalogue contains 4310 events. Apart from the addition of the earthquakes which occurred after the publication of the first version by Makropoulos (1978), it also contains 903 new entries/events for the period 1900–1977 for which it was possible to reevaluate their parameters, especially their magnitudes. The treatment of both data sets was identical with that of the previously published 1806 events for the period 1900–1977. Hence, it is believed that the catalogue presented here is characterized by an equally high degree of homogeneity and accuracy as the previous one (Båth 1983a,b). Furthermore, the addition of such a large number of events, mainly of small to moderate earthquakes ($M < 5.5$), lowers the threshold magnitude above which the catalogue can be considered to be as complete as possible.

Another contribution of this study towards a more detailed picture of the seismicity of Greece rather than for use in strict statistical studies, is the inclusion of 1770 events for the period 1900–1963 inclusive in the Appendix. The reason for not including these events in the main catalogue is because of insufficient data for the determination of the full set of parameters for these shocks. It is mainly a collection of events from the bulletins of the NOA and the Papazachos & Comninakis (PC, 1982) and Galanopoulos (GAL, 1960) catalogues. None of these events has been registered in the SIU bulletins for UPP readings. Hence, no magnitude could be calculated and consequently the main criterion for inclusion in the main catalogue was not fulfilled.

The parameters listed for each earthquake in both catalogues are (1) date, (2) origin time, (3) latitude, (4) longitude, (5) focal depth, (6) number of reporting station and (7) surface-wave magnitude.

The focal error for the relocated events (1917–1963) is estimated to be less than ±10 km for $h < 50$ km and ±15 km for $h \geq 50$ km (Makropoulos & Burton 1981). For the period 1900–1963 and for the earthquakes which do not permit relocations, the appropriate reference is given instead of the number of reporting stations. This is always the case for the additional earthquakes listed in the Appendix to the catalogue.

Since 1907 the surface wave magnitudes for all earthquakes in the main catalogue have been determined using the Swedish network ground amplitude records. The standard deviation of these magnitudes may be estimated as around ±0.3.

The abbreviations used for references are: UNS earthquake catalogue of Shebalin *et al.* (1974); ATB: earthquake catalogue of Aslan *et al.* (1975); ROT: earthquake catalogue of Rothe (1969); PC: earthquake catalogue of Papazachos & Comninakis (1982); NOA: National Observatory of Athens annual and monthly bulletins and GAL: Galanopoulos (1960) catalogue.

Since the list of both catalogues is lengthy (more than 100 pages) it has been decided not to include them in this paper. However, an IBM-PC diskette copy of the catalogues can be obtained from the first author upon request.

ACKNOWLEDGMENTS

We are grateful to Professor M. Båth and Dr A. R. Ritsema for their constructive criticism.

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