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Chapter V

An earthquake catalogue for the Maghreb region 20°-38°N, 10°W-12°E for the period 1900-1990

1. Introduction

Critical structures such as nuclear power plants and dams, as well as the siting of new industry, require earthquake data which are as accurate, homogeneous and complete as possible, so that hidden tectonic features may be revealed and seismic hazard be assessed. Although catalogues or listings of earthquakes are available, they cover different time periods, incomplete at a given region, and are grossly deficient in several respects, particularly in magnitude, depth and location. For some events, especially those prior to 1960, epicentral locations, magnitudes and other pertinent earthquake characteristics are inaccurate or simply not available. A large number of events after 1960 are also incomplete. Great caution must be taken in using published earthquake catalogues uncritically, especially in areas with low seismicity such as the Maghreb region. Also, and constantly, it should be kept in mind that the authors of these catalogues have conceived them according to their needs and personal judgements and certainly not to meet our present needs. The previous catalogues are all biased against the low magnitude range because of the small number and poor azimuthal distribution of seismographic stations or, in the early years of this century, due to the scant densities of the population. This problem has been given special consideration since around 1960 as a consequence of the general improvement in the number, distribution and the sensitivity of the seismographic stations (see Chapter IV). Because of these deficiencies and from the point of view of long term prediction and seismic hazard establishment, it is very important that input data in the Maghreb region catalogues be revised and homogenized.

In this study, an attempt is made to assess the seismicity of the Maghreb region during the period 1900-1990 by reviewing instrumental data and macroseismic information retrieved from various source documentary materials. The first task was to make an inventory of all existing catalogues covering the whole region or parts of it and period under investigation and to compare and combine their entries. The number of estimates inventoried for the Maghreb reached 12447 for 7724 reported earthquakes of which 2061 have surface-wave magnitude equal to or greater than 3.0 and presented in Appendix A. This method has allowed the estimation of the accuracy of the different catalogues and, in particular, the identification of the sources consulted in their compilations as well as the procedures used in the determination of the earthquake parameters. Additional macroseismic information, newly collected from a variety of sources, is used to answer ambiguities among the previous catalogues. Intensities are re-estimated when there are enough data. Surface-wave magnitudes are calculated from amplitude-period readings from station bulletins or converted from various derived semi-empirical formulae (see Chapter IV). The obtained earthquake catalogue for the Maghreb region is, then, tested for completeness using Stepp's method.

This study supersedes all the previous catalogues for references to earthquakes in the Maghreb region during the period 1900-1990.

2. Sources of information

The sources used in the establishment of the Maghreb earthquake data catalogue and the evaluation of the characteristics of the events are discussed in details in the previous chapters. However, in this section, a brief description of the inventoried catalogues of the region and the main bulletins of international seismological organisations, which represent an important source of information, are presented.

2.1. *Previous catalogues*

Cataloguing of earthquakes in the Maghreb region started well before 1900. The earliest known earthquake catalogues are those of Perrey (1848), Chesneau (1892) and Hée (1950) covering respectively the periods before 1840, 1888 and 1911. Also other general catalogues, including references to sources of information about events before 1900, are those of Perrey (1848), Mallet (1850-1857), Fuchs (1886) and Ambraseys and Vogt (1988). A descriptive catalogue of the most important earthquakes in the province of Algiers during the period 1365-1903 has been published by Ambraseys and Vogt (1988). In his seismic catalogue of the world, Montessus de Ballore (1906) included the Maghreb earthquakes. During the twentieth century, about thirty catalogues of earthquakes in different parts of the region under study were published, but most of them were restricted as to areas and time. The better known regional catalogues remain those of Rothé (1950), Roussel (1973) and with other more recent listings, which are mainly copied from earlier compilations. However, it is important for the users of these catalogues to know how they were established, their sources and their limitations. The main earthquake catalogues including events of the region under survey are briefly described and listed below:

A. Hée (1925): a catalogue for earthquakes felt in Algeria during the period 1911-1924. The events are classified in geographical quadrangles. This methodology has the disadvantage of separating within several quadrangles the data of the same event. This listing includes events recorded by the seismograph stations and those felt by people.

A. Hée (1932): it is one of the first published listings of felt earthquakes in the whole of North Africa for the period 1911-1931. It contains the date, the time, the affected sites, the intensity and sometimes the macroseismic coordinates of the epicentre. The methodology used is the same as in Hée (1925). She used the same sources as in 1925.

A. Sieberg (1932): a brief listing of the main Maghreb earthquakes that occurred during the period from 1715 to 1926. This catalogue, which contains inconsistencies, concerns only destructive earthquakes. It contains some isoseismal maps as well as seismicity maps of the region. Sieberg did not quote the sources he used in developing this listing.

J. Galbis Rodriguez (1932 and 1940): this is an important catalogue, published in two volumes, on historical and recent seismicity of the Ibero-Maghreb region limited by 25°-45°N and 5°E-20°W. It describes briefly the extent of damage and contains some isoseismal maps.

G. Roux (1934): it includes the historical as well as recent seismicity of Morocco up to 1933. Roux used as his sources the catalogue of Galbis, to which he added more information collected from Arabic documents.

A. Hée (1950): a catalogue of Algerian earthquakes during the period 1850-1911. The events are also classified in geographical quadrangles. This listing complete all the previous ones for Algeria. Hée used the catalogues of Perrey, the bulletins of the Service Météorologique d'Algérie (1899-1908), the monthly bulletins of the Bureau Central Météorologique de France (1909-1910), and the publications of the Association International de Séismologie (1904-1908).

J.P. Rothé (1950): he presented brief summaries of the main earthquakes in Algeria during the period 1716-1949. This work has always been used as a starting point for Algerian seismicity studies. Rothé used various sources including different macroseismic catalogues and memoirs, instrumental catalogues, field works and press reports.

J. Debrach (1952): this lists a geographical distribution of Moroccan earthquakes during the period 1932-1951.

A. Grandjean (1954): this catalogue presents the earthquakes felt in Algeria during the period 1940-1950 reported either by observers of the IMPGA, the press or by the instrumental data from the seismograph station at Bouzareah. It contains 10 isoseismal maps of the most important events of the period concerned, as well as an epicentral map of the whole country.

B. Gutenberg and C.F. Richter (1954): a listing of large earthquakes in the World during the period 1904-1952. They used various sources around the world.

E. Ben Osman (1962): a listing of Tunisian earthquakes during the period 1892-1955. This listing is incomplete and rich in errors. The author did not use the section «tremblement de terre» of the several annual reports of the Service de Météorologie de Tunisie.

N. Ambraseys (1962): this descriptive catalogue gives major earthquakes in Tunisia for the period 410-1958. He used a variety of sources including press reports, seismological bulletins as well as different existing listings or catalogues covering Tunisia.

J.M. Munuera (1963): this work is based on the Galbis Rodriguez catalogue but added precision of epicentral coordinates for earthquakes before 1933. For the period from 1933 to 1960, data are based on the Spanish seismographic station bulletins and unpublished notes of the Spanish Seismological Survey (Instituto Geografico Nacional). It is presented in table form and gives dates, origin times, epicentral coordinates, magnitudes, maximum intensities and localities. Munuera derived magnitudes from empirical formulae. This listing covers the region delineated by 35°-44°N and 5°E-10°W up to 1960.

J. Duvergé (1969): it includes 360 earthquakes that occurred during the period 1919-1967 in the region comprised between 28°-37°N and 0°-14°W. Numerous epicentres were relocated, particularly those of the ISS, Spanish and macroseismic epicentres. Two isoseismal maps are attached to this catalogue.

J.P. Rothé (1969): this catalogue is the continuation of the seismicity of the Earth by Gutenberg and Richter (1954). It covers the whole World during the period 1953-1965 for magnitudes larger than 5.

V. Karnik (1969): this is the first catalogue with magnitude determinations. Most of the magnitudes are computed from amplitude-period readings and the remaining from semi-empirical formulae. It concerns Europe geographically and all the countries around the Mediterranean sea for the period 1901-1955 with maximum macroseismic intensity I_0 greater than or equal to VI or magnitudes greater than or equal to 4.5.

H. Benhallou and J. Roussel (1971): a catalogue of Algerian earthquakes from 1951 to 1970. This listing is established from the instrumental data of the seismological station at Bouzareah and Alger-University. It contains brief summaries of macroseismic data of destructive earthquakes of that period.

J. Roussel (1973): a catalogue of earthquakes in Algeria for the period 1716-1970. He used different source documentary materials (press reports...), instrumental data from seismological stations at Bouzareah, Alger-University, Setif, Relizane as well as ISS, BCIS, ISC and NOAA bulletins. Seismological bulletins from Moroccan stations were also used.

D. Ben Sari (1978): this catalogue covers the region included between 22°-30°N and 0°-19°W for the period 1901-1980. Magnitudes are often adopted from Munuera (1963) or Karnik (1969).

D. Hatzfeld (1978): this listing covers the area limited by 30°-40°N and 4°E-12°W for the period 1972-1975. All epicentral locations have been determined using the location routine HYPO 71.

M. Frogneux (1980): this catalogue completes that of Hatzfeld (1978) and covers the area delineated by 30°-42°N and 6°E-14°W for the period 1972-1978. Magnitudes are calculated from the signal duration.

J.P. Rothé (1980): this is a descriptive catalogue of Tunisian earthquakes for the period 410-1977. It contains some unspecified magnitudes. He used Sieberg (1932), Ambraseys (1962), instrumental information as well as press reports.

J. Mezcua and J.M. Martinez (1983): this catalogue concerns the Ibero-Maghreb region included between 30°-38°N and 20°W-12°E for the period 500 BC-1980. The events have been completely revised. Magnitudes are determined from L_g phase and reported as m_b.

O. Khemici in EERI (1983): this listing presents some damaging Algerian earthquakes including sometimes intensity and magnitude. The author did not quote the sources used in the establishment of this listing, nor made any critics.

Woodward-Clyde Consultants (1984): a catalogue for the Echeliff region during the period 1846-1981. This listing is incomplete, it contains information reported by various organisations and authors without any revision of the sources.

H. Benhallou (1985): a general survey of various regions in Algeria. The listings concern earthquakes in northern Algeria (1951-1970), Echeliff area (1853-1980), Alger region (1825-1975), northeast of Algeria (1758-1984), east of Alger (1941-1968) and northwest of Algeria (1790-1972). This survey is incomplete and presents many deficiencies, particularly in magnitudes and location. Magnitudes are calculated from macroseismic relations.

T.E. Cherkaoui (1988): a catalogue of earthquakes in Morocco and adjacent areas contained between 21°-38°N and 0°-20°W during the period 1901-1984. A certain number of earthquakes have been relocated. This work is based mainly on that of Mezcua and Martinez (1983). Magnitudes have been calculated from the signal duration.

2.2. *Seismological bulletins*

Monthly bulletins of different seismological stations and international organisations have been used along this study for checking the event itself, completing and/or determining missing characteristics as the magnitude. Moderate earthquakes in the Maghreb region are recorded up to Pasadena (U.S.A.) 90° away, but the most important sources of instrumental information about earthquakes in this region remain in European seismological stations. Also the seismological bulletins of the following international organisations on which the Maghreb catalogue is based are listed:

— International Seismological Summary (ISS), (1918-1963);
— Bureau Central International de Seismologie (BCIS), (1935, 1950-1963);
— International Seismological Centre (ISC), (1964-1982);
— Preliminary Determination of Epicentres (PDE) from the United States;

Table I. Main sources used in the establishment of the Maghreb earthquake catalogue during the twentieth century.

Sources	Time coverage (1900–1990): start	end	
+ Hée (1925)	11	24	I/M
+ Sieberg (1932)		26	I/M
Hée (1932)	11	31	I/M
+ Rodriguez (1932-40)		33	I/M
+ Roux (1934)		33	I/M
+ Hée (1950)		11	I/M
+ Rothe (1950)		49	I/M
Debrach (1952)	32	51	I/M
Grandjean (1954)	40	50	I/M
Gutenberg *et al.* (1954)	04	52	I/M
+ Ben Osman (1960)		55	I/M
+ Ambraseys (1962)		58	I/M
+ Munuera (1963)		60	I/M
+ Rothe (1980)		77	I/M
Duverge (1969)	19	67	I/M
Karnik (1969)	01	55	I/M
Rothe (1969)	53	69	I
Benhallou *et al.* (1971)	51	70	I
+ Roussel (1973)		70	I/M
Ben Sari (1978)	01	80	I/M
Hatzfeld (1978)	72	75	I
Frogneux (1980)	72	78	I
+ Mezcua *et al.* (1983)		80	I/M
+ Woodward-Clyde (1984)		81	I/M
+ Benhallou (1985)		80	I/M
Cherkaoui (1988)	01	84	I/M
ISS (1913-63)	13	63	I
BCIS (1950-63)	50	63	I
ISC (1964-82)	64	82	I
NEIS (1983-90)	83		I

+: catalogue including earthquake data from pre-1900 period; I: instrumental catalogue; M: macroseismic catalogue; I/M: instrumental and macroseismic catalogue.

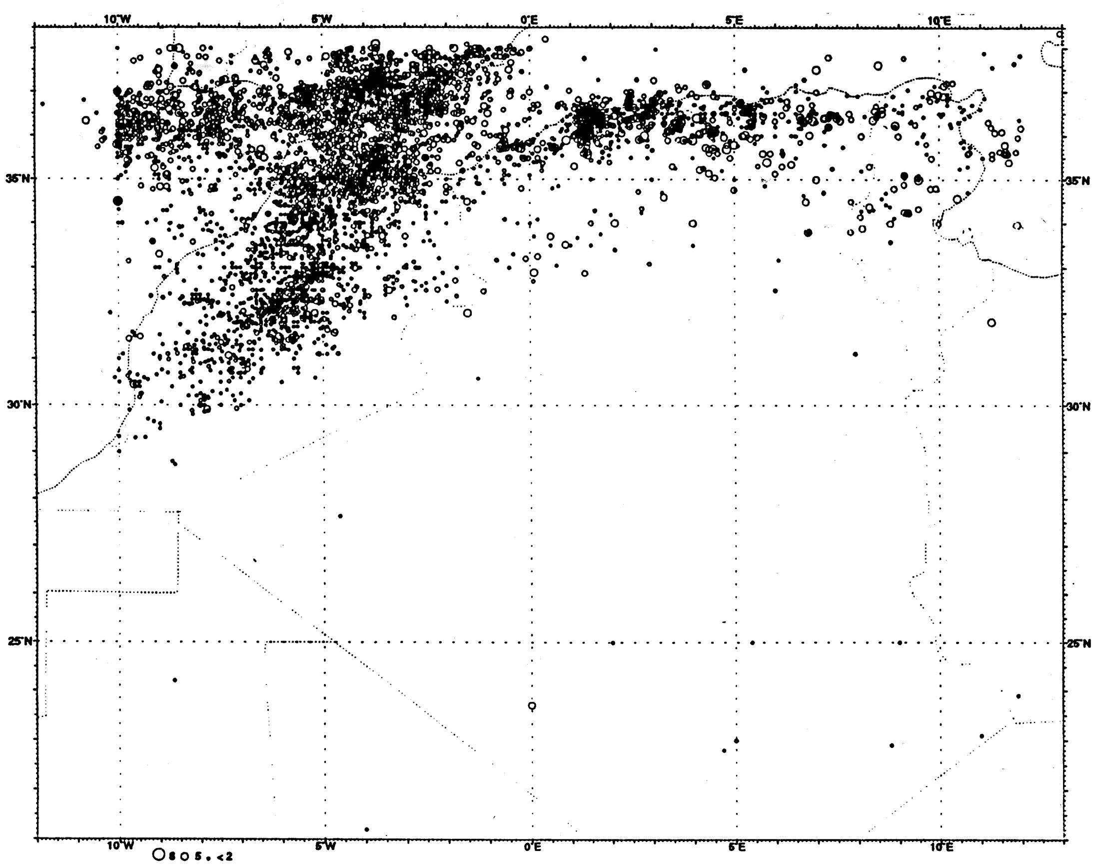
— National Earthquake Information Service (NEIS), (1983-1990).

The main sources used in the establishment of the Maghreb earthquake catalogue presented in sections 2.1. and 2.2. are summarized in table I.

3. Characteristics of the Maghreb catalogue

3.1. *Definition of the area of investigation*

The area under survey, which is defined as the Maghreb, includes Algeria, Mo-

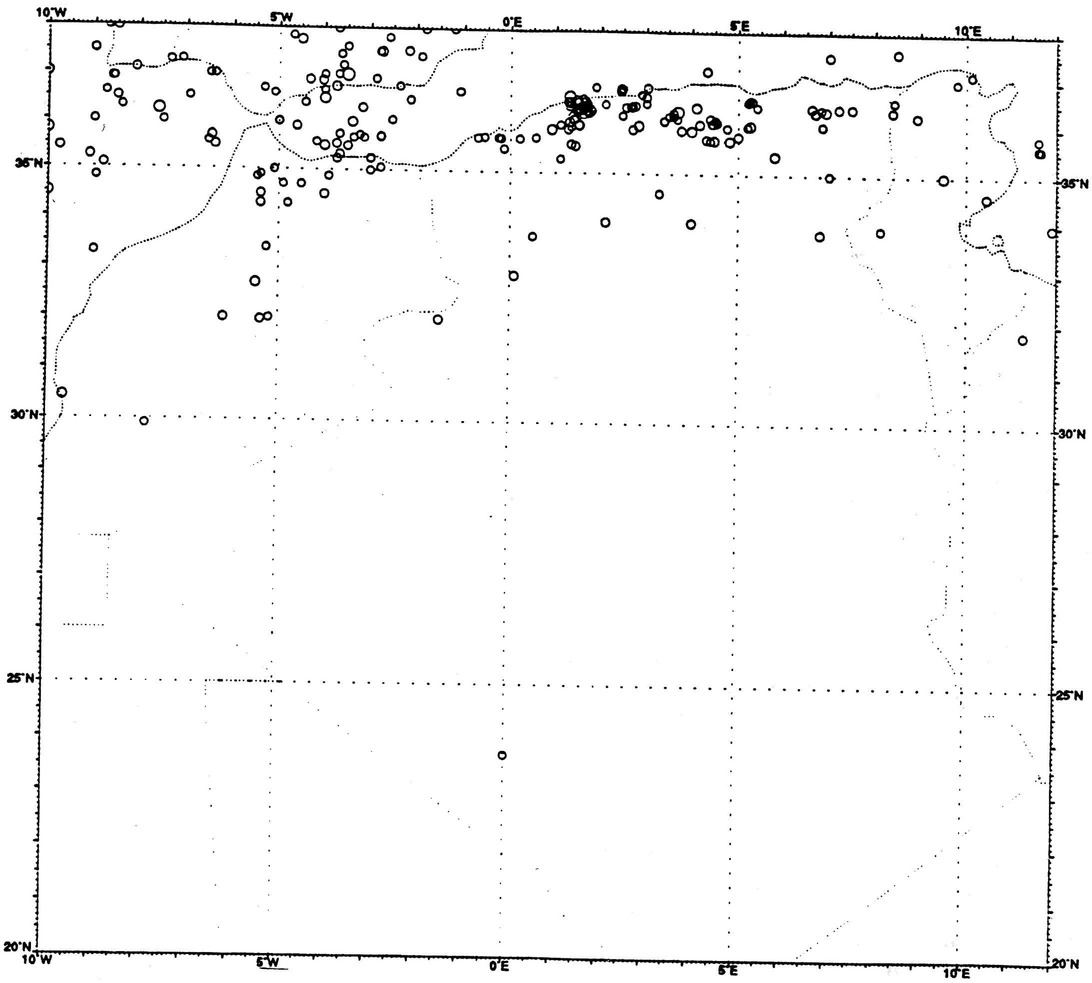


Map 1. The spatial distribution of epicentral locations of all reported earthquakes including foreshocks and aftershocks contained in the Maghreb during the twentieth century.

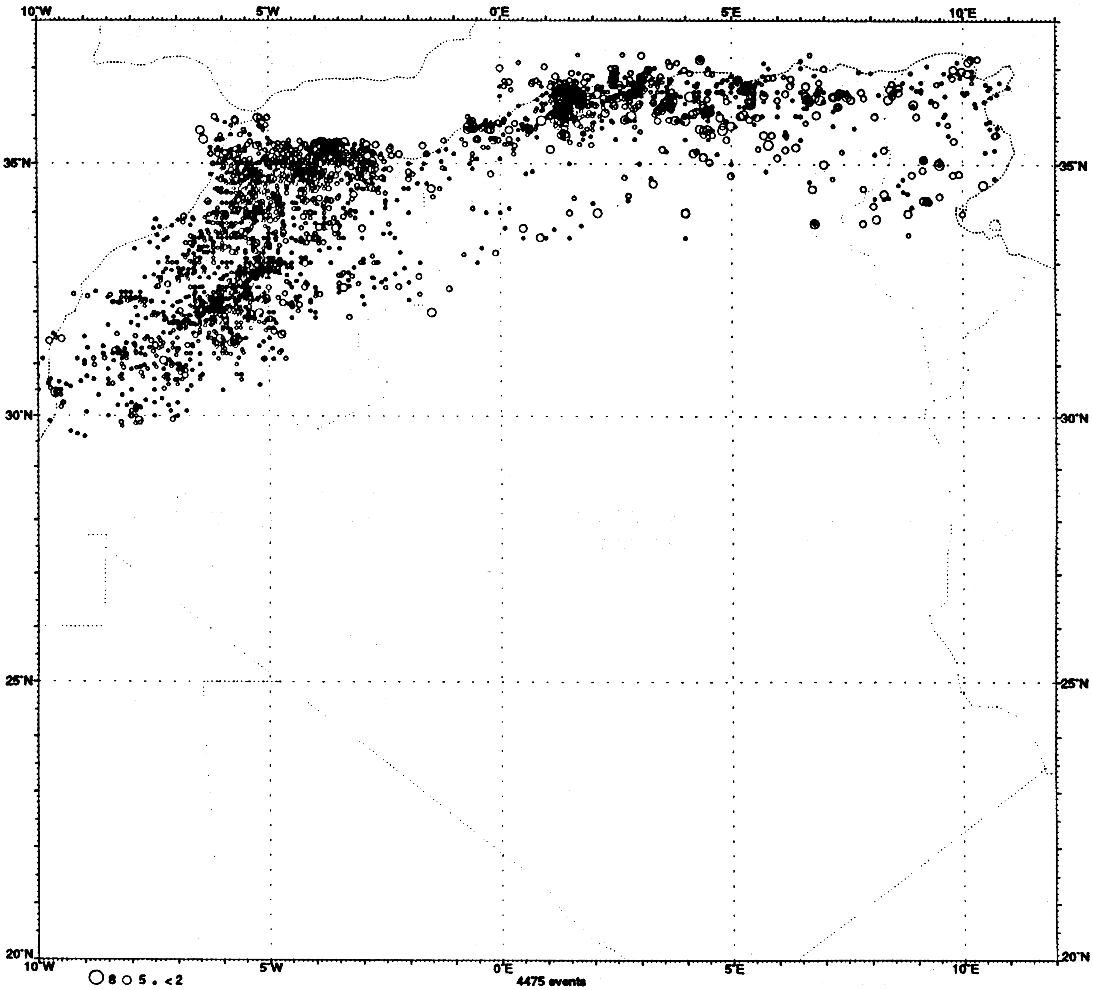
rocco, Tunisia and the Southern Iberian peninsula, is delineated by the 20th and 38th degrees of north latitude and the 10th degree of west and 12th degree of east longitudes (see map 1, page 461). The term «Maghreb» is used to illustrate the area of interest of this study, although Algeria constitutes the main concern. For the Maghreb region, it is imperative to look beyond the boundaries of each country when evaluating seismic hazard, not only because these countries belong to the same geologic process, but also because of their common factors in terms of history and development as well as their building stock characteristics. The selection of this area allows investigation of any earthquake affecting, although not occurring in, a specific country of the Maghreb, which may influence the evaluation of seismic hazard in any particular country or the Maghreb as a whole. The term «Atlas» is used here to define the zone containing the Atlas mountains throughout the Maghreb countries.

3.2. *Structure of the Maghreb catalogue*

The catalogue of the Maghreb region for the period 1900-1990 contains 7724 events (including foreshocks and aftershocks) selected from 12447 estimates retrieved from seismological bulletins and previous catalogues. This catalogue attempts to contain all the earthquakes retrieved from available source documentary materials for the region and time period under study; foreshocks and aftershocks are also included. The catalogue is stored as a computer file for ease of use. The spatial distribution of epicentral locations of all the earthquakes, including foreshocks and aftershocks, contained in the compiled catalogue (7724 events) is presented in map 1. A first selection of earthquakes with surface-wave magnitudes greater than or equal to 4.5 (245 events) is made and the spatial distribution of their epicentres is plotted in map 2. The epicentral distribution of all the Atlas earthquakes contained in this file (4475 events) is presented in map 3. The



Map 2. The spatial distribution of earthquakes with surface-wave magnitude equal to or greater than 4.5 in the Maghreb during the twentieth century.



Map 3. The spatial distribution of all the Atlas reported earthquakes, including foreshocks and aftershocks, during the twentieth century.

Maghreb catalogue presented in Appendix A presents 2061 earthquakes with surface-wave magnitudes M_S equal to or greater than 3.0. The Maghreb catalogues containing all events reported and those having surface-wave magnitudes M equal to or greater than 4.5 will be published separately.

Each event in the catalogue is defined by the following entries as they appear:

Date – Year, month and day. For the events where the month is not known, the month is replaced by «hyphen» and if the day is not available, it is also replaced by «hyphen».

Time – Hours, minutes and seconds (HR-MN-SEC) are given in GMT. The time is that reported by the cited author or seismological station or agency. When a time component is not known, the field is replaced by «hyphen».

Epicentre – It refers to the geographic longitude and latitude position of the epicentre. The latitude (LAT) is given in degrees and terminated with N (north). The longitude is also given in degrees and terminated with W (west) or E (east). The degree of accuracy of the epicentral location is discussed in details in section 4. Chapter II for macroseismic epicentre and in section 2. Chapter IV for instrumental position. Naturally, it is possible to assign to each epicentral location a factor of quality according to the information available. It has been decided to publish separately the Maghreb earthquake catalogue of all reported events during the period 1900-1990 and in which all the factors of quality will be attributed.

Depth – The focal depth is given in kilometres. The depth values reported by the calculating organisation or author are adopted in this catalogue. When the depth is not known, this field is blank.

Magnitudes – The catalogue contains four types of magnitudes:

M_S: surface-wave magnitude. This magnitude is followed by a code indicating its source: () determined from amplitude-period readings; (1) converted from number of reporting seismological stations; (2) converted from body-wave magnitude; (3) converted from local magnitude.
m_b: body-wave magnitude
M: unspecified magnitude
M_L: local magnitude.

If a magnitude is not available, the field is replaced by a hyphen.

Intensity – Maximum intensity reported. The intensity does not necessarily correspond to the epicentral intensity. For offshore events, the intensity is the one felt on land. If intensity is not available, the field is replaced by a hyphen.

Intensity scale – Intensities are re-evaluated according the Medvedev-Sponheuer-Karnik - MSK - (1981) scale. The degree of accuracy of the intensity assigned has also to be determined according to the quality and completeness of the data available. This matter has been discussed in section 3. Chapter II. For earthquakes for which macroseismic data are not sufficient to allow an intensity re-evaluation and for the homogeneity of the catalogue, intensities reported in other intensity scales are converted directly to the MSK scale using the conversion table derived by Levret and Mohammadioun (1984).

Number of stations – NS is the number of seismological stations reporting the event.

Remarks – Eventual remarks concerning the data and the event itself:

M: macroseismic location (if blank: instrumental location)
F: foreshock
A: aftershock (if blank: main shock)
*: complete study with isoseismal map.

Localisation – The site in which the earthquake was most felt.

Country – AL: Algeria; MO: Morocco; PO: Portugal; SP: Spain; TU: Tunisia; LY: Libya; MA: Mauritania.

Agency – A three letter code defining the names of authors, national or international seismological stations or agencies that reported the event. The complete list of these sources is given below:

1) National and International Centres
BCS: Bureau Central International de Séismologie (BCIS)
NES: National Earthquake Information Service (NEIS)
CGS: U.S. Coast and Geodetic Survey (USCGS)
ISS: International Seismological Summary (ISS)
ISC: International Seismological Centre (ISC)
SPG: Service de Physique du Globe du Maroc (SPGM)
CSM: Centre de Séismologie Euro-Méditerranen (CSEM)
NEC: National Earthquake Information Centre (NEIC)
NAO: NORSAR

2) Seismological stations

ALG: Alger-University
MDD: Madrid
EBR: Ebro Roquetas
ABA: Alger-Bouzareah
AVE: Averroes
PAS: Pasadena
CRT: Cartuja
TOL: Toledo
TRI: Trieste
TUN: Tunis
ALI: Alicante
ALM: Almeria
MAL: Malaga
MOS: Moscow
HFS: Hagfors
RBA: Rabat
LIS: Lisbon
ROM: Rome
SET: Setif
LAO: Large Aperture Seismic Array (Centre), U.S.A.
LDG: Laboratoire Français de Détection et de Géophysique

3) Authors

NNA: Ambraseys
CHK: Cherkaoui
ROT: Rothé
HHB: Benhallou
KOO: Khemici
KAR: Karnik
ROS: Roussel
BEN: Benouar
PAY: Payo
YOD: Ouyed
GUT: Gutenberg *et al.*
MEZ: Mezcua *et al.*

4. Completeness of the catalogue

4.1. *Introduction*

One of the main goals of this study is to compile, as completely as possible, a catalogue of earthquakes that have occurred in the Maghreb region during the twentieth century. However, like any other previous catalogue, its completeness is subjected to the data availability which is usually biased against small shocks, particularly in the early years of this century. This means that not all the earthquakes which occurred in the Maghreb region during the period 1900-1990 appear in the compiled catalogue. In order to overcome these difficulties, Stepp

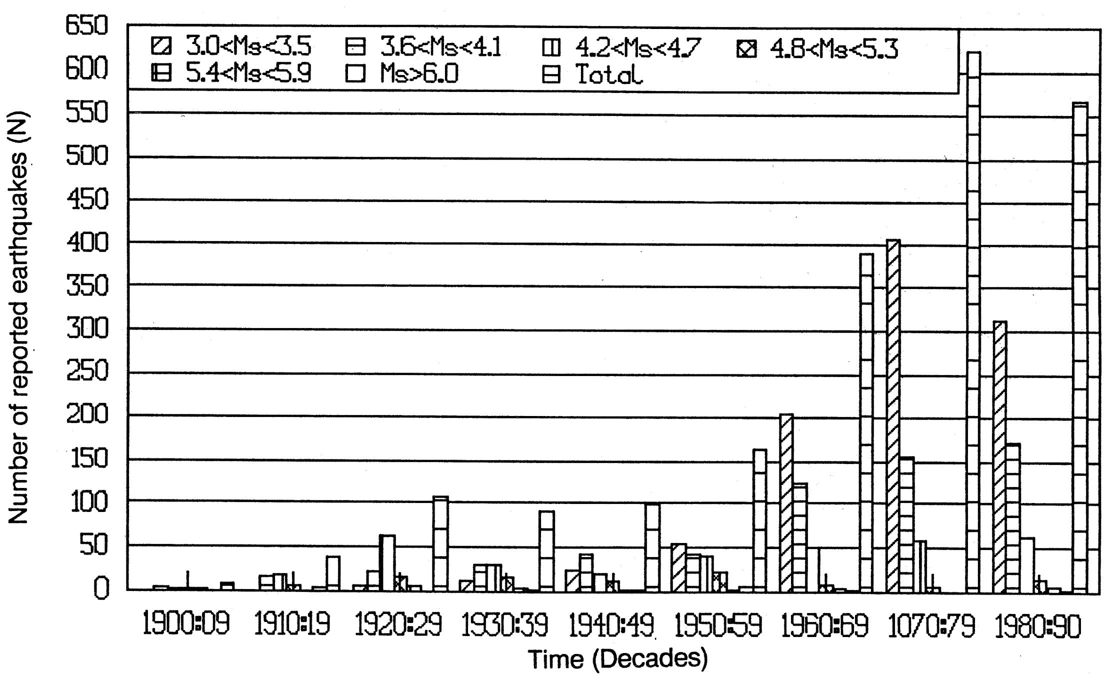


Fig. 1. The number of earthquakes reported per decade in the Maghreb region and grouped into six different classes.

Table II. Number of earthquakes reported in each decade since 1900 in the Maghreb.

Period	$3.0 \leq M_S \leq 3.5$	$3.6 \leq M_S \leq 4.1$	$4.2 \leq M_S \leq 4.7$	$4.8 \leq M_S \leq 5.3$	$5.4 \leq M_S \leq 5.9$	$M_S \geq 6.0$	Total
1900-1909	0	3	2	1	1	0	7
1910-1919	0	14	16	5	0	3	38
1920-1929	5	22	62	15	5	0	109
1930-1939	10	31	31	14	4	1	91
1940-1949	24	43	19	10	2	1	99
1950-1959	54	43	41	20	1	5	164
1960-1969	204	125	49	7	3	1	38
1970-1979	407	155	58	5	0	0	625
1980-1990	312	172	61	12	6	2	565
	1016	608	339	89	22	13	2087

(1971) developed a statistical method to evaluate the completeness of the available earthquake data sample. His method is based on the determination of a time subinterval for which the magnitude recurrence rate is stable. Thus, it allows the assessment of the inhomogeneity and incompleteness by determining the magnitude above which the catalogue can be considered as homogeneous and complete, or by finding subintervals of the 91-year sample in which a particular magnitude range is completely reported.

4.2. *Temporal plot of grouped events*

Figure 1 shows the number of earthquakes per decade in the Maghreb region grouped into six magnitude ranges, $3.0 \leqslant M_S \leqslant 3.5$, $3.6 \leqslant M_S \leqslant 4.1$, $4.2 \leqslant M_S \leqslant 4.7$, $4.8 \leqslant M_S \leqslant 5.3$, $5.4 \leqslant M_S \leqslant 5.9$ and $M_S \geqslant 6.0$. The total number of events per decade is also plotted. Table II lists the numerical magnitude data from the compiled catalogue associated with fig. 1. Examining table II and fig. 1, the first observation to note is the uniformity in the number of reports of large earthquakes per decade with surface-wave magnitude equal to or larger than 4.8 since the beginning of this century, no trend is shown in the 91-year sample. In fact, there is no reason to investigate the completeness of the catalogue for magnitudes $M_S \geqslant 4.8$. Because these earthquakes are generally destructive in the Maghreb region, they are widely experienced. Therefore, it is more likely that these large events have been completely reported during the whole period 1900-1990. Also, earthquakes of magnitudes $M_S \geqslant 4.8$ are generally well recorded in European seismographic stations since the beginning of the instrumental period.

Another interesting feature is the significant increase in the total number of reported shocks in the last three decades (1960-1990). This is due to the considerable contribution of small magnitude events gained from the low detection threshold introduced by the global improvement in the sensitivity, distribution and number of seismographic stations in the Maghreb region since the 1960's (see Chapter IV). About 76 percent of the earthquakes in the compiled catalogue were reported in the last 31-year, interval from 1960 to 1990. This is in contrast to 17 percent in the next oldest 30-year period, from 1930 to 1959, and only 7 percent in the first 30 years of the catalogue. This gives a good idea of the degree of incompleteness of the early earthquake data sample this century. A third important observation, in fig. 1, is the characteristic exponential trend in the distribution of magnitudes in each decade. This exponential behaviour is clearly observed in the last three decades of the catalogue, where all the magnitude ranges have contributed to the shape of the curve. In the first six decades of the catalogue, the exponential trend is not traced. This may be explained by the inadequacy in the early earthquake reports which obviously led to incomplete magnitude classes. A fourth significant feature of fig. 1 is the slow, but constant, rise in the number of intermediate magnitude earthquakes ($4.2 \leq M_S \leq 4.7$) since 1950. The behaviour of this magnitude class may have two possible reasons. A reasonable interpretation is that the completeness of data increases with the increasing sample period. On the other hand, the observed behaviour may be due to statistical fluctuations in activity. Although the uniformity of overall activity suggests the first interpretation, the possibility of a temporal trend in activity cannot be eliminated on the basis of fig. 1 alone.

4.3. *Analysis of the catalogue completeness*

The analysis of fig. 1 indicates that the compiled catalogue is critically incomplete, except for the highest magnitude classes. Using the incomplete compiled file in seismic hazard assessment may seriously affect the magnitude-frequency recurrence formula, and obviously its *b*-parameter, which describes the seismic activity with increasing magnitude, this parameter is fundamental in seismic hazard evaluation. Furthermore, failure to correct the data sample for incompleteness makes the mean recurrence rate of large events overestimated and those of the middle and low magnitude ranges seriously underestimated. To resolve this problem, Stepp's method (1971), which is based on the selection of a subinterval of the 91-year data sample, in which the mean recurrence rate is stable for a particular magnitude range, is used in this study.

The mean rate of earthquake occurrence from the time interval data for each magnitude class is given by:

$$\lambda\,(M_S) = \frac{N(M_S)}{T} \qquad (4.1)$$

where $N(M_S)$ is the total number of earthquakes with magnitudes within the range of magnitude M_S and T is the total time interval.

Stepp (1971) assumed that each magnitude range is an independent point process in time so that it can be modelled by the Poisson distribution:

$$P(T) = \frac{\exp(-\lambda)\lambda^T}{T!} \qquad (4.2)$$

Then, if $k_1, k_2, k_3, ..., k_n$ are the number of events per unit time subinterval and T is the total time interval, an unbiased estimate of the mean recurrence rate $\lambda(M_S)$ is given (Hamilton, 1964) by:

$$\lambda(M_S) = \frac{1}{T}\,\Sigma k_i \qquad (4.3)$$

The variance of the sample mean estimate is given by:

$$\sigma_\lambda^2 = \lambda/T \qquad (4.4)$$

That is, the variance is equal to the mean where T, the unit time interval, is taken to be equal to one year. Thus, it can be written as:

$$\sigma_\lambda = -\lambda_T/-T \qquad (4.5)$$

which is the standard deviation of the mean $\lambda(M_S)$ and T is the total time interval in which the mean is stable.

Then, assuming stationarity, the statistical properties of $\lambda(M_S)$ do not vary with time, which means that σ_λ is expected to behave as $T^{-1/2}$ in the subinterval where the mean recurrence rate is constant in a particular magnitude class. Table III gives the

Table III. Values of mean occurrence rate λ and standard deviation σ_λ for six classes of magnitude and time interval T for the Maghreb region during 1900-1990.

Period	T	$T^{-1/2}$	$3.0 \le M_S \le 3.5$			$3.6 \le M_S \le 4.1$			$4.2 \le M_S \le 4.7$			$4.8 \le M_S \le 5.3$			$5.4 \le M_S \le 5.9$			$M_S \ge 6.0$		
	Years		N	λ-N/T	σ_λ	N	λ-N/T	σ_λ	N	λ-N/T	σ_λ	N	λ-N/T	σ_λ	N	λ-N/T	σ_λ	N	λ-N/T	σ_λ
1990-1986	5	0.45	162	32.4	2.54	72	14.4	1.69	24	4.8	0.97	3	0.6	0.34	3	0.6	0.34	0	0.0	0.00
1990-1981	10	0.32	279	27.9	1.67	135	13.5	1.16	56	5.6	0.74	7	0.7	0.26	5	0.5	0.22	0	0.0	0.00
1990-1976	15	0.26	495	33.0	1.48	242	16.1	1.03	99	6.6	0.66	15	1.0	0.25	7	0.4	0.17	2	0.1	0.09
1990-1971	20	0.22	686	34.3	1.31	305	15.2	0.87	127	6.3	0.56	18	0.9	0.21	7	0.3	0.13	2	0.1	0.07
1990-1966	25	0.20	818	32.7	1.14	381	15.2	0.78	159	6.3	0.50	20	0.8	0.17	7	0.3	0.10	2	0.1	0.05
1990-1961	30	0.18	902	30.0	1.00	438	14.6	0.69	179	5.9	0.44	24	0.8	0.16	9	0.3	0.10	3	0.1	0.05
1990-1956	35	0.17	957	27.3	0.88	466	13.3	0.61	199	5.6	0.40	32	0.9	0.16	10	0.3	0.09	3	0.1	0.05
1990-1951	40	0.16	968	24.2	0.77	481	12.0	0.54	220	5.5	0.37	43	1.0	0.16	11	0.3	0.08	8	0.2	0.07
1990-1946	45	0.15	978	21.7	0.69	500	11.1	0.49	229	5.1	0.33	51	1.1	0.15	13	0.3	0.08	8	0.2	0.06
1990-1941	50	0.14	993	19.8	0.63	525	10.5	0.45	237	4.7	0.30	54	1.1	0.14	13	0.2	0.07	9	0.2	0.06
1990-1936	55	0.13	1000	18.1	0.57	548	9.9	0.42	246	4.4	0.28	62	1.1	0.14	13	0.2	0.06	9	0.1	0.05
1990-1931	60	0.13	1004	16.7	0.52	557	9.2	0.39	270	4.5	0.27	64	1.0	0.13	16	0.2	0.06	10	0.1	0.05
1990-1926	65	0.12	1010	15.5	0.48	571	8.7	0.36	312	4.8	0.27	74	1.1	0.13	19	0.3	0.06	10	0.1	0.04
1990-1921	70	0.12	1010	14.4	0.45	577	8.2	0.34	333	4.7	0.26	83	1.1	0.13	21	0.3	0.06	10	0.1	0.04
1990-1916	75	0.12	1010	13.4	0.42	586	7.8	0.32	341	4.5	0.24	85	1.1	0.12	22	0.3	0.06	10	0.1	0.04
1990-1911	80	0.11	1010	12.6	0.39	598	7.4	0.30	350	4.3	0.23	89	1.1	0.11	22	0.3	0.05	11	0.1	0.04
1990-1906	85	0.11	1010	11.8	0.37	600	7.0	0.28	352	4.1	0.22	90	1.0	0.11	22	0.2	0.05	13	0.1	0.04
1990-1900	91	0.10	1010	11.1	0.35	601	6.6	0.27	353	3.8	0.20	90	0.98	0.10	23	0.2	0.05	13	0.1	0.04

Table IV. Results from analysis of completeness for the Maghreb catalogue (1900-1990).

Magnitude class	Time required for mean rate to reach stability (years)	Period of complete reporting (years)
$3.0 \le M_S \le 3.5$	5-10	30 (1961-1990)
$3.6 \le M_S \le 4.1$	5-10	35 (1956-1990)
$4.2 \le M_S \le 4.7$	10-15	70 (1921-1990)
$4.8 \le M_S \le 5.3$	15-20	91 (1900-1990)
$5.4 \le M_S \le 5.9$	25-30	91 (1900-1990)
$M_S \ge 6.0$	40-45	91 (1900-1990)

values of the mean occurrence rate λ_T as a function of time interval for each of the six selected magnitudes classes ($3.0 \le M_S \le 3.5$, $3.6 \le M_S \le 4.1$, $4.2 \le M_S \le 4.7$, $4.8 \le M_S \le 5.3$, $5.4 \le M_S \le 5.9$ and $M_S \ge 6.0$) and standard deviation of the mean σ_λ. The standard deviation σ_λ is calculated from eq. (4.5) for each mean rate λ (N/T). Then, the values of λ and σ_λ are plotted against time in figs. 2a-f which represent the Maghreb earthquake magnitude completeness plot for six magnitude classes. Figures 2a-f show the expected behaviour of σ_λ over each of the subintervals of the total 91-year period of the Maghreb catalogue. For a particular magnitude class, departure from the standard deviation value from $T^{-1/2}$ line signifies that either the subinterval is not long enough to allow a good estimation of the mean occurrence rate or that the subinterval contains time period in which reports are incomplete. Using this criterion, it is possible to evaluate for each magnitude class the minimum time period required for a stable estimate of the mean occurrence rate. This time interval depends on the magnitude, being successively longer with each higher magnitude class. For earthquakes in the magnitude ranges $3.0 \le M_S \le 3.5$ and $3.6 \le M_S \le 4.1$, 5 to 10 years are sufficient to establish a stable mean occurrence rate, and for a maximum magnitude of 4.7 the minimum observation time period required is between 10 and 15 years. A stable estimate of the mean occurrence rate of maximum magnitude 5.3 is reached in about 15 to 20 years, and for maximum magnitude 5.9 in about 25 to 30 years, while for magnitude greater than or equal to 6.0, a time period of about 40 to 45 years of homogeneous observations is required to establish a stable mean occurrence rate. It is noted that departures of σ_λ values from the expected $T^{-1/2}$ behaviour with increasing sample length occur for all magnitude ranges except those of magnitudes greater than or equal to 4.8. The time of departure of σ_λ from $T^{-1/2}$ behaviour depends on the maximum magnitude. This departure can be explained by incomplete reporting of events, as early data is included in the data sample. On the other hand, it may also be interpreted by a trend of increasing frequency in the data. However, if the latter were adopted, departure from $T^{-1/2}$ behaviour would be expected to occur at the same time in all magnitude ranges. Because this is not observed in figs. 2a-f, it confirms that departure is rather due to incomplete reporting of earthquakes.

As a result of the completeness analysis of the Maghreb catalogue, it is concluded that maximum magnitude 3.5 events have been completely reported only during the last 30 years, events within $3.6 \le M_S \le 4.1$ during the most recent 35 years, events within $4.2 \le M_S \le 4.7$ during the last 70 years, while earthquakes with magnitude greater than or equal to 4.8 are completely reported over the whole 91-year sample interval. The completeness results of the Maghreb earthquake catalogue are summarized in table IV.

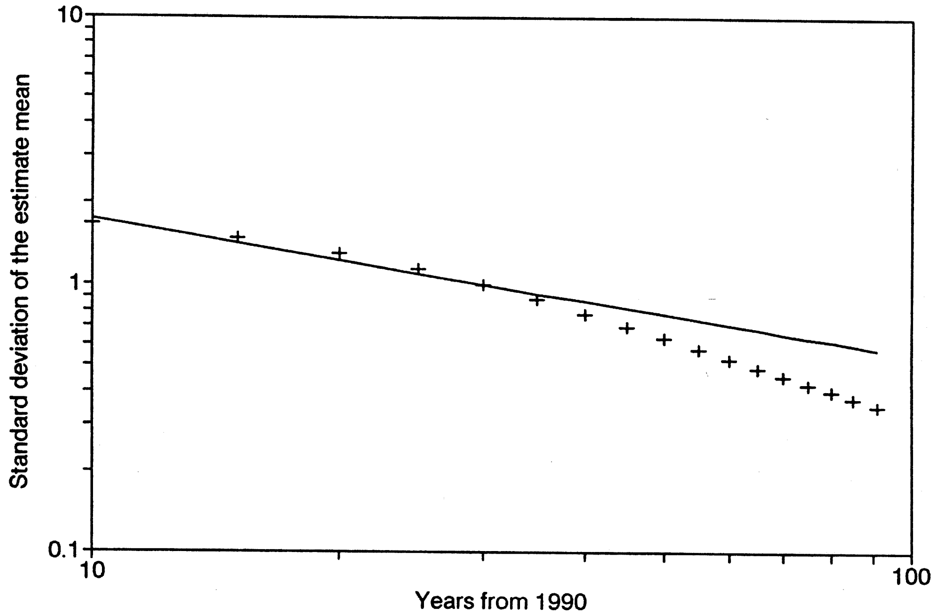


Fig. 2a. Plot of earthquake magnitude completeness in the Maghreb for magnitude class $3.0 \leq M_S \leq 3.5$.

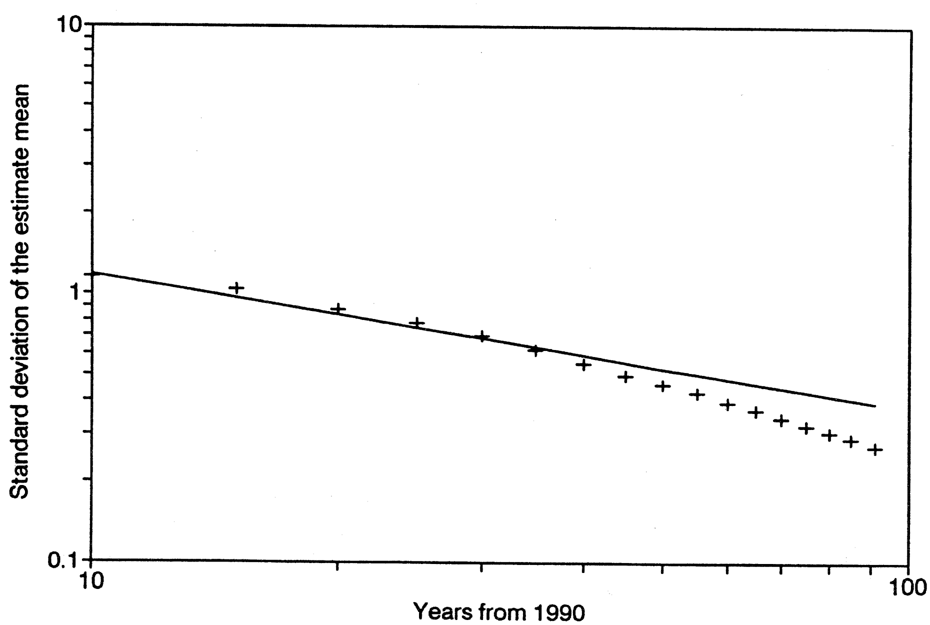


Fig. 2b. Plot of earthquake magnitude completeness in the Maghreb for magnitude class $3.6 \leq M_S \leq 4.1$.

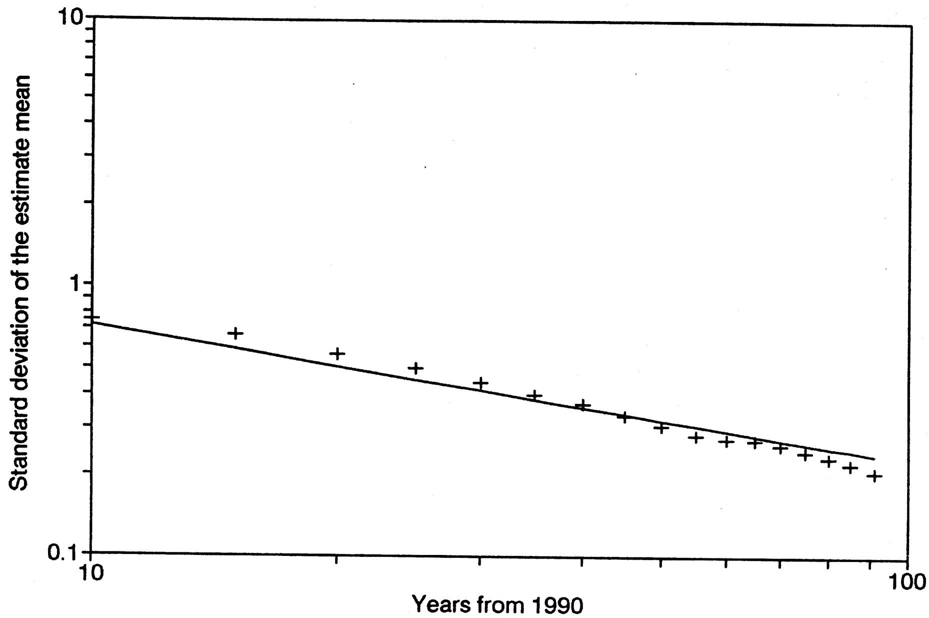


Fig. 2c. Plot of earthquake magnitude completeness in the Maghreb for magnitude class $4.2 \le M_S \le 4.7$.

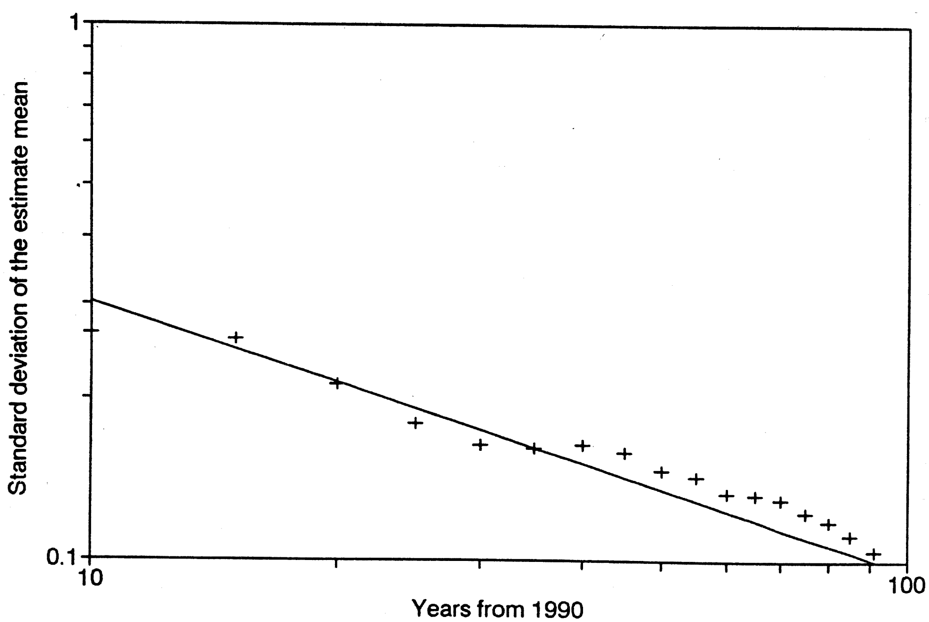


Fig. 2d. Plot of earthquake magnitude completeness in the Maghreb for magnitude class $4.8 \le M_S \le 5.3$.

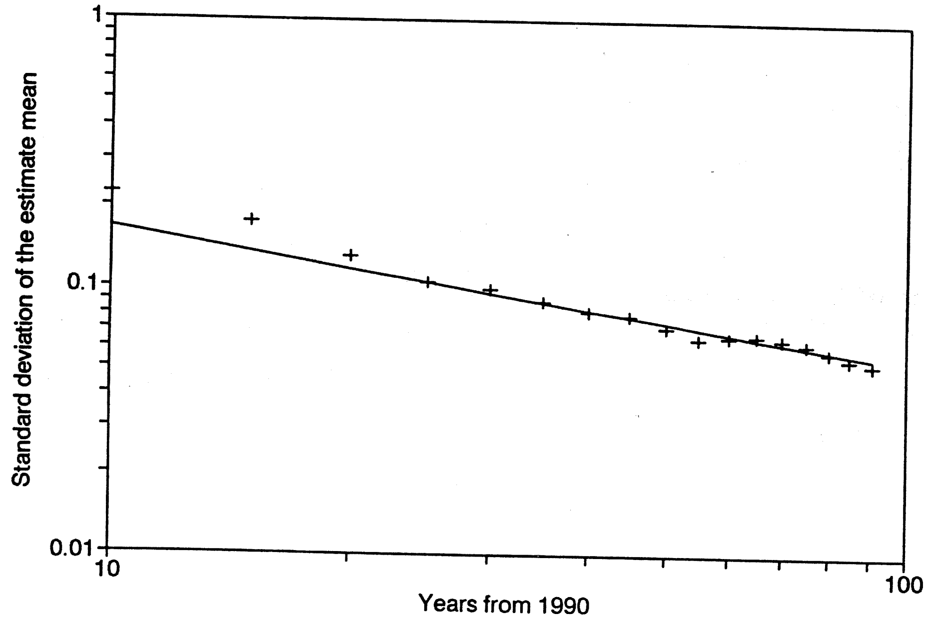


Fig. 2e. Plot of earthquake magnitude completeness in the Maghreb for magnitude class $5.4 \le M_S \le 5.9$.

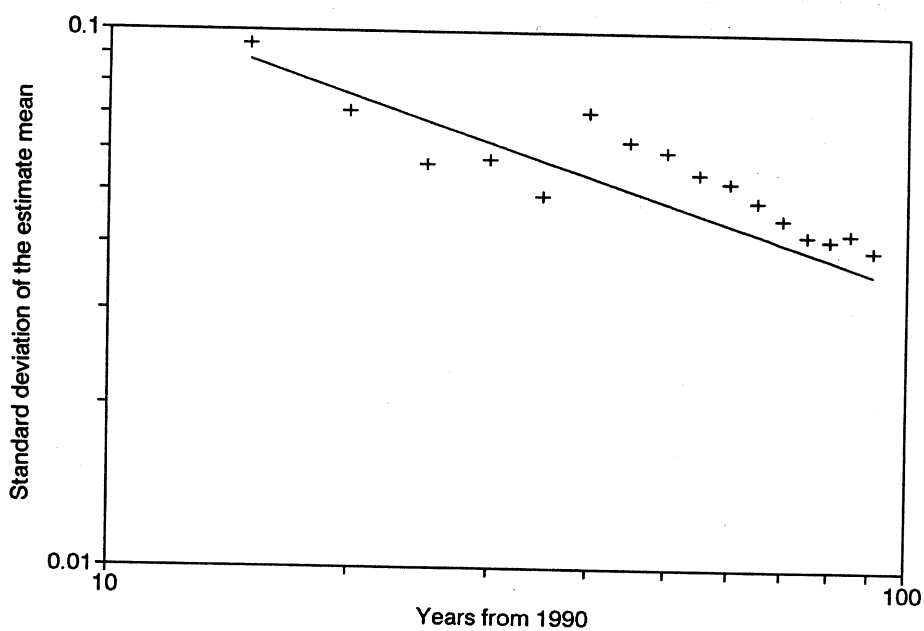


Fig. 2f. Plot of earthquake magnitude completeness in the Maghreb for magnitude class $M_S \ge 6.0$.

5. Conclusions

The completeness of the catalogues remains a problem which attracted many seismologists, as it constitutes the cornerstone for the use of many approaches to the estimation of seismic hazard and thus seismic risk.

The results of the above analysis show that it is possible to create artificially homogeneous earthquake data sample by selecting intervals over which events in different magnitude ranges are completely reported. Thus, it shows that the Maghreb earthquakes are completely reported for surface-wave magnitude 4.8 and greater over the whole period of the catalogue. This also provides an answer to the question of how long the data sample must be to be a good statistic. The answer is that the sample must be long enough to establish a stable estimate of the mean occurrence rate of the largest magnitude class comprised in the analysis. This catalogue is used to derive anew the magnitude-frequency relations in the Maghreb and the Atlas and compare them to those determined from incomplete data (see Chapter VII) in order to compute the effect of the incompleteness on the seismic hazard evaluation.