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Chapter IV

Instrumental information

1. Network of seismograph stations

Earthquake instrumental recordings in the region under study started late in the last century with instruments which were very limited by today's standards. The first instrument in the Maghreb was installed in Alger-Bouzareah by 1917. Most of the seismographic stations covering the Maghreb countries were operating in southern Europe, thus all to the north, resulting in a narrow range of azimuthal distribution of stations around the epicentre and contributing to east-west positioning uncertainty. Stations such as those at Cairo (Egypt) and Ksara (Lebanon) give some additional east-west control. The distribution of seismograph stations that operated in the Maghreb countries and neighbouring regions before 1955 are shown in fig. 1.

During the period 1899-1919, the first instruments installed were Milne seismographs, most of them undamped, short period (10-20 s), low-magnification (10-20), photograph recorders which were set up for the recording of local events. These instruments had no precise timing, and with the uncertain knowledge of earthquake travel times then in existence, make solutions very poor. The Milne instruments mainly recorded surface waves and were unable to report consistent pairs of *P* and *S* phases, which prevents the estimation of origin times and thus reliable north-south location. In the early bulletins the onset of the surface-waves and the time of maximum amplitude are reported and used to determine equivalent surface-wave magnitude for earthquakes in this period (Ambraseys and Melville, 1982). For some major events, instrumental locations seem to be correct to a few tens of kilometres, which is enough to estimate the overall area of an event, but sufficiently gross to be adopted over macroseismic epicentres of good quality. For example, the Aumale earthquake of 24 June 1910, of which the first instrumental study was made in 1913, when the epicentral position was calculated by Milne (1913) at 36°N, 4°E. The relocation of this event using the present location procedure at the ISC gives an epicentral location at 36.3°N, 3.7°E which is in agreement with the previous position within an error of about 50 km. Comparison of the macroseismic epicentral position (36.23°N, 3.44°E) with the ISS and ISC epicentral locations shows that the error values attain respectively about 70 and 30 km which represent about 4 and 3 times the average radius of the meizoseismal zone.

During the period 1920-1960 and particularly in the early years, the undamped Milne pendulums were gradually replaced by a growing number of shorter-period damped instruments with higher sensitivity which give more reliable readings of *P* and *S* phases and thus more precise calculations of origin time and distances. This period had seen an improvement of the aptitudes of the seismograph station network in the region, particularly the installation of local stations in Tamanrasset (1948), Relizane (1955) and Setif (1957) in Algeria, Averroes (1937) in Morocco and Tunis (1937) in Tunisia. However, despite this increase in the number of stations, the azimuthal distribution and number of stations around the Maghreb region were still very poor for an adequate earthquake recording and obviously for a reliable epicentral location. For some earthquakes in the Maghreb region that occurred during this period, there are reliable instrumental data to relocate them by using the actual ISC location routine, but still inaccuracies of locations cannot be eliminated due to the poor azimuthal distribution of recording stations. For instance, the Carnot earthquake of 7 September 1934 was given an epicentral position at 36°N, 2°E (Gutenberg and Richter, 1965) and at 36.0°N, 1.1°E (ISS). A relocation of this event using the ISC location procedure suggests a position at 36.2°N, 1.6°E; this agrees with the macroseismic epicentre (36.3°N, 1.7°E) with errors of about 10 km in longitude and 10 km in latitude. From late 1940s onward, some major events as those of Berhoum of 12 February 1946 and Kherrata 17 February 1949 are relatively well located. A small sample of location errors for earthquakes in Algeria is given in table I. Instrumental locations started to be calculated on a routine basis by the ISS, which operated from 1913 to 1963, since 1957. Magnitude determinations in this period can be made from amplitude-period readings from numerous station bulletins. It is of interest to mention that the overall recording capability of many seismographic stations in and around the region under survey was considerably altered for long periods of time during the unstable years between 1914-1922 and also between 1940-1947 (Ambraseys and Melville, 1982).

Since 1960, with the installation of the World-Wide Standard Seismograph Network (WWSSN), the quality of the data, both in accuracy and in the number of earthquakes recorded, improved remarkably. The introduction of advanced instruments and the improvement of location

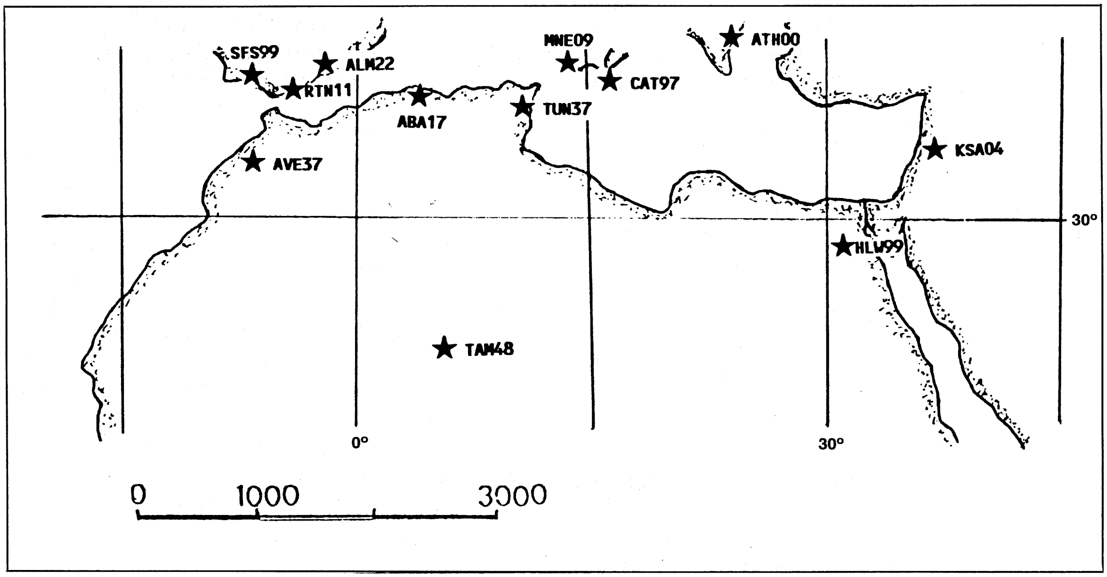

Fig. 1. The distribution of seismograph stations in the Maghreb and adjacent areas before 1955. Seismograph stations are illustrated by open stars followed by the last two digits of the year of installation.

Table I. Comparison of original ISS, relocated and macroseismic epicentres for some Algerian earthquakes.

Date	ISS (1)	Relocated (2)	Macroseismic (3)	(1-2) (km)	(2-3) (km)
1910 June 24	36.0°N 4.0°E	36.3°N 3.7°E	36.23°N 3.43°E	47	30
1922 Aug. 25	36.5°N 1.5°E	36.4°N 1.3°E	36.42°N 1.20°E	25	11
1924 March16	35.0°N 6.0°E	35.4°N 5.8°E	35.42°N 5.90°E	50	11
1924 Nov. 5	35.3°N 3.5°E	36.6°N 3.0°E	36.64°N 2.91°E	154	11
1928 Aug. 24	34.3°N 1.3°E	35.9°N 0.9°E	35.94°N 0.88°E	183	5
1934 Sept. 7	36.0°N 1.1°E	36.2°N 1.6°E	36.30°N 1.70°E	60	16
1937 Febr. 10	36.6°N 7.5°E	36.4°N 7.2°E	36.38°N 7.52°E	40	35
1943 April 16	36.1°N 4.6°E	35.9°N 4.0°E	36.09°N 4.48°E	70	57
1946 Febr. 12	35.7°N 4.8°E	35.7°N 4.8°E	35.70°N 5.00°E	2	20
1959 Nov. 7	36.4°N 2.5°E	36.4°N 2.5°E	36.41°N 2.48°E	6	8

(1-2) Location error between ISS and relocated epicentres; (2-3) location error between relocated and macroseismic epicentres.

techniques, particularly computer determinations, are clearly exhibited by the number of earthquakes reported, by the good agreement in the epicentral positions given by different agencies or seismological stations for the same event and also by the increasing number of source parameters made available. The continuation of earthquake data collection and location determinations by the ISC in 1964, which coincided with a substantial development in the number and sensitivity of seismographic stations in the world, characterize a particular amelioration in the earthquake data reports. The ISC file includes different estimates of each recorded event from other major agencies. This period had also been marked by the development of national seismographic networks in the Maghreb countries, where the number of operating stations increased from one station in 1917, to two in 1948, to four in 1957 and to nine in 1990 in Algeria, from one station in 1937, to two in 1964, to four in 1968 and to 14 in 1990 in Morocco, and one station in 1937 to six in 1990 in Tunisia. The distribution of seismographic stations operating at the present time in the Maghreb countries is shown in fig. 2. A detailed analysis of the world instrumental data development has been made by Ambraseys and Melville (1982).

It is noteworthy that after the catastrophic earthquake of El-Asnam 1980, Algeria launched, in 1982, a project for the installation of a national telemetry seismograph network in Northern Algeria. The installation of the instruments, which were received by 1986, has been in progress since then by the Centre of Research in Astronomy, Astrophysics and Geophysics (CRAAG) which is also in charge of exploitation of the network. This national network is subdivided into four regional networks: Oran, Cheliff, Alger and Constantine. Each of these regional networks has the following configuration:

1) one tricomponent central recording station: one vertical seismometer and two horizontal;

2) seven stations of only one vertical component are connected to the central station by radio-electric links.

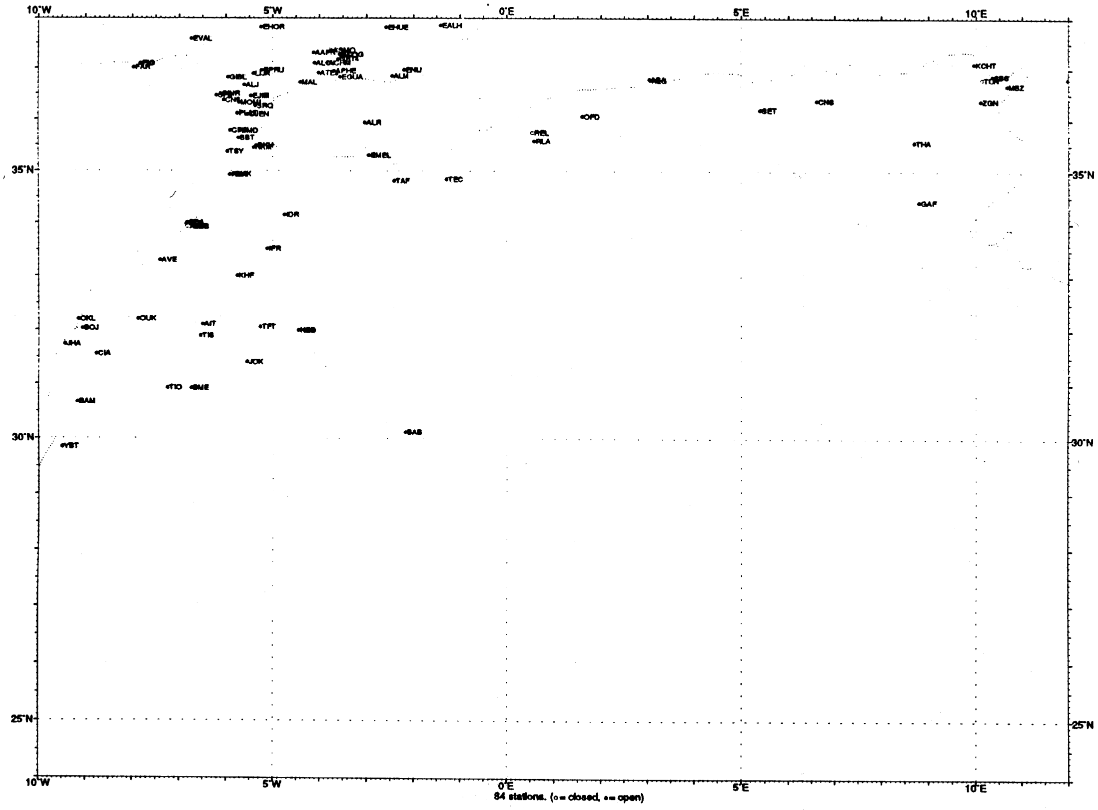

Fig. 2. The present distribution of seismograph stations in the Maghreb and adjacent areas.

The four regional networks are linked to the main seismographic station at Alger-Bouzareah by telephone lines. A total of 32 seismographic stations will cover Northern Algeria in the very next future (CRAAG, 1990).

2. Instrumental epicentres

The location of earthquake epicentres is a fundamental problem in seismological observations and research. It is well connected to the investigation of the structure of the Earth and particularly to the Earth crust. In regions well covered with seismographic stations, it is believed that instrumental locations are more precise than macroseismic epicentres. However, this is not the case in the Maghreb countries where neither the quality of the data nor the azimuthal distribution and number of stations is suitable for an accurate epicentral location, especially before 1960s. Instrumental locations during the period 1899-1917 were determined by the British Association for the Advancement of Science (BAAS). During the ISS period (1918-1963), epicentres were computed with procedures that are similar to those in practice today at the ISC, using the least-square method which was worked out by mechanical calculators up to the introduction of electronic computers in 1957. Quite often, the ISS kept old locations without any calculation for the latest sets of arrivals, in order to reduce the laborious amount of work (Ambraseys and Melville, 1982). The deficiency of the travel-time tables then existing with the procedure of «adopting» old locations made the ISS determined epicentres very uncertain. To show the degree of accuracy of the ISS epicentral locations in the Maghreb region, some Algerian earthquakes have been relocated using the present location ISC procedure and, with macroseismic epicentres, are compared to those originally determined by the ISS. Table I presents original ISS, relocated and macroseismic epicentres for some Algerian earthquakes. As a result of the comparison between the relocated epicentral positions and macroseismic epicentres, it is found that the location error reaches values about an average of 16 km, but it still remains important at about 2 to 3 times the radius of the meizoseismal area. Also, relocated positions of these same events are found to be at locations somewhat different from those computed originally by ISS, with an average shift of about 165 km, which represents a significant improvement. But it remains clear that, for the pre-1960 events in areas such as the Maghreb, the best approach for correcting or confirming instrumental locations is to attempt to achieve a correlation with macroseismic information. From 1964 onward, the ISC gives, in addition to the number of source parameters, standard deviations for origin times and coordinates and focal depth determinations which is an indication of the quality and accuracy of the solution. Since then, the location errors have decreased considerably, but they are still around 10 km, which is just in the limit of the meizoseismal zone.

3. Determination of magnitudes

The idea of a magnitude scale arose out of the need to classify earthquakes objectively and independently of local ground conditions and environment.

Wadati (1931) was the first to use the term «magnitude» to compare the size of Japanese earthquakes. They defined this value by the logarithm of the earthquake maximum ground amplitude instrumentally recorded, thus indirectly related to the energy released. This may have influenced, in 1935, Richter (1935) to conceive the well known Richter magnitude scale in California. Richter designated the local magnitude M_L for shallow shocks as $M_L = \log (A/A_0)$ where A is the maximum amplitude in microns recorded by a wood-Anderson seismograph and A_0 is an amplitude of one micron which represents the correction factor for a distance of 100 km from the source. Gutenberg and Richter (1942 and 1956b) extended this measurement of earthquake size to more general distances and recording instruments. He defined the surface-wave magnitude M_S determined from surface-waves of periods between 17 and 23 s. The surface-wave magnitude is given by:

$$M_S = \log (A) + 1.656 \log (D) + 1.818 + S \tag{3.1}$$

where A is the combined maximum ground horizontal amplitude in microns, D the focal distance in degrees and S is the station correction. Gutenberg and Richter (1956) revised the first definition of the body-wave magnitude m_b computed from body waves (PZ, PH, PPZ and SH). The revised body-wave magnitude is given by:

$$m_b = \log (A/T)_{\max} + Q(D,h) + S \tag{3.2}$$

where $(A/T)_{\max}$ is the maximum amplitude-period ratio in the wave classes (PV, PH, PPH and SH) and $Q(D,h)$ is a calibrating function which depends on epicentral distance (D), focal depth (h) and wave type.

The idea of magnitude as a quantitative measure of the size of earthquakes began to be accepted only after the publication in 1949 of the Seismicity of the Earth and

Associated Phenomena (Gutenberg and Richter, 1965). In 1950s, many stations and authors started to calculate their own magnitudes using methods very close to that derived by Gutenberg and Richter. The surface-wave magnitudes were determined using maximum ground amplitude in microns for wave periods comprised between 17 and 23 s and the body-wave magnitudes calculated according to eq. (3.2). Soloviev in 1955 eased the wave period restraint by substituting the ground amplitude in the magnitude relation by the ground velocity in terms of the amplitude-period ratio (A/T) (Ambraseys and Melville, 1982), a method used in the U.S.S.R. since about 1953. By 1960, numerous formulae to determine the surface – and body-wave magnitudes were used which lead obviously to inhomogeneity and confusion between different scales. The main shortcoming of this is that comparison of the magnitude values determined for the same event was often impossible. At this time, it became clear that a standardization of magnitude scales was necessary. Vanek *et al.* (1962) proposed the so-called standard Prague formula for international use. It was in 1967, at the Magnitude Symposium during the General Assembly of the International Union of Geodesy and Geophysics (IUGG) in Zurich, that the concept of unifying the determination of magnitudes was approved. It was decided that magnitudes, of all type of waves for which calibrating functions exist, must be calculated from maximum amplitude-period ratio and that two types of magnitudes should be used: surface – and body-waves magnitudes respectively M_S and m_b. It has also been agreed that for m_b the Q-values (Gutenberg and Richter, 1956a) should be used and for M_S the most suitable formula for epicentral distance between 2 and 160° and period between 10-60 s is:

$$M_S = \log (A/T)_{\max} + 1.66 \log (D) + 3.3 + S \tag{3.3}$$

where $(A/T)_{\max}$ is the maximum value of the ratio of the ground displacement amplitude in microns, T is the corresponding period in seconds, D is the focal distance in degrees and S is the station correction. The station correction S_i is defined as:

$$S_i = \Sigma(M_n - M_i)/n \tag{3.4}$$

where M_i is the magnitude of a certain earthquake at the station (i) and M_n is the mean value of the magnitude, of the same event, determined from the number of station n in which M_n and M_i are already computed.

The ISS had made no magnitude evaluations during its whole period (1918-1963). It was in 1963 that the USCGS started the determination of body-wave magnitudes m_b with the Preliminary Determination of Epicentres (PDE) according to the methodology described by Gutenberg and Richter. Surface-wave magnitudes M_S were calculated for the larger events only. The ISC, successor of the ISS, began in 1964 a systematic magnitude determination of body-wave magnitudes m_b as the USCGS. The ISC evaluate the surface-wave magnitude M_S from eq. (3.1) in the distance range 20-160°. However, M_S in the distance range between 5 and 20° are not used in the calculation of the average but their values are reported only with the individual station reading.

4. Revision of magnitudes

Magnitudes in the Maghreb region prior to 1963 are either not assigned, non-homogeneous or it is not known by which method they were determined. Rothé (1950) used the class magnitude method defined by Gutenberg and Richter (1956a), which is based on recording distance, to compare the earthquakes reported in his descriptive Algerian seismic catalogue for the period 1908-1949; the same method was followed by Benhallou and Roussel (1971) between 1951 and 1970. Rothé (1950) had also tried to assign «local» magnitudes for some important Algerian events, using extrapolation techniques. Benhallou (1985) used the (M – I_0) Gutenberg and Richter empirical formula ($M = 1 + 2/3\ (I_0)$) to assign magnitudes for earthquakes in the Cheliff region (1853-1979) as well as in other regions of the country and for which epicentral intensities exist. Instrumental data are not sufficient to determine all the earthquake magnitudes in the Maghreb; however, some data exist but no attempt was made to use them until recently. In 1969, Karnik, in the Seismicity of the European Area, presented the first earthquake catalogue with magnitude determinations. He calculated numerous surface-wave magnitudes and when the data are insufficient (magnitude in brackets), he estimated the magnitude from the macroseismic parameter I_0. Ambraseys and Vogt (1988), Ambraseys *et al.* (1990, 1991 a,b) in different studies, have determined for the region under study several surface – and body-wave magnitudes. Mezcua *et al.* (1983) estimated body-waves magnitudes for some events in the Ibero-Maghreb region from the L_g phase from 1908 to 1980. De Miguel and Payo (1980, 1983) determined body-wave magnitudes for earthquakes that occurred in the Iberian peninsula and adjacent areas between 1948 and 1975, using the L_g phase.

The idea of determining anew or revising and unifying existing magnitudes is carried out. The main goal is to produce a file of reliable data which reflect, as homogeneously and completely as possible, the seismicity of the region, and that could be used with a certain degree of confidence for the evaluation of seismic hazard and risk. Using non-homogeneous and incomplete magnitude estimations will lead, obviously, to significant bias in magnitude-frequency recurrence formula, which is fundamental in seismic hazard evaluation. The determinations of surface-wave magnitudes, without station corrections, have been made for all the events for which it was possible to collect instrumental data (amplitude and period readings), using the standard Prague formula (3.3). For the early years of this century, when most instruments were undamped and with a low magnification, as was the Milne seismograph which was widely operating in Europe, Asia, America and Africa, some events in the Maghreb region show both the trace maximum amplitude for the Milne seismograph, as well as ground displacement amplitude and period data for more advanced instruments. For the latter, the surface-wave magnitude is determined from the standard Prague formula (3.3), but the number of reporting stations is too small to give a reliable average of the magnitude value. For the trace maximum amplitude recorded in the Milne seismograph, the equivalent surface-wave magnitude was calculated using the calibration formula derived by Ambraseys and Melville (1982):

$$M_S = \log(2At) + 1.25 \log(D) + 4.06 \quad (4.1)$$

where ($2At$) is the double trace ground displacement amplitude (peak-to-peak) in millimetres and D is the focal distance in degrees.

For a variety of reasons, many remaining events are without surface-wave magnitudes or simply without any type of magnitude. To solve this problem, surface-wave magnitudes are estimated when possible from semi-empirical relationships between M_S and m_b or M_S and M_L. Another empirical method to assess a surface-wave magnitude of a particular earthquake is by using the number of stations that reported it to the ISS or ISC.

5. Semi-empirical estimation of magnitude

The teleseismic data retrieved from the sources available are still insufficient to evaluate the surface-wave magnitudes for all events reported in the regional catalogues. M_S, from amplitude-period data, can be estimated for only 218 earthquakes in the Maghreb zone and for 319 in the whole region under study. This incompleteness of data reduces considerably the size of the sample used to analyze the seismicity of the considered regions, which inspired the derivation of empirical relations between different scales to help to complete the data.

The derivation of an empirical relationship between surface-wave magnitude M_S and body-wave magnitude m_b is sought in the form of $M_S = a + b\,(m_b)$. This equation is fitted to 193 sets of values of M_S and m_b for shallow events in the Maghreb zone and adjacent areas during the period 1900-1990. For the region under study, the regression gives:

$$M_S = 0.47 + 0.86\,(m_b) \qquad (5.1)$$

with a standard deviation of 0.48.

Figure 3 shows a plot of surface-wave magnitude M_S versus body-wave magnitude m_b for shallow earthquakes in the Maghreb and adjacent areas. Also the derivation of another empirical relationship is made, for the Maghreb region and adjacent areas, between surface-wave magnitude M_S and local magnitude M_L. Assuming this relation is linear, the regression for 17 pairs of M_S-M_L values gives:

$$M_S = 1.40 + 0.76\,(M_L) \qquad (5.2)$$

with a standard deviation equal to 0.37. This relationship is in fairly good agreement with the one developed for Europe by Ambraseys (1990). Figure 4 shows a plot of surface-wave magnitude M_S versus local magnitude M_L for the region under study.

Another empirical method to estimate the magnitude of an earthquake is the use of the number of stations (NS) that reported the event to the ISS or ISC. Many authors have already used the number of stations to assess magnitudes (Karnik, 1969; Rothé, 1969; Ambraseys and Melville, 1982). The steady improvements in technology and the increasing number of seismograph stations during the twentieth century make the derivation of a formula between M_S and NS for the whole period (1900-1990) meaningless; thus, the period should be divided according to the different stages of the development of the world seismographic station network. As a result of a detailed analysis of the changes that occurred to the instrumental seismology, Ambraseys and Melville (1982) subdivided the period into five time intervals. The empirical relationship is assumed to be in the form:

$$M_S = a + b \log(\mathrm{NS}) \qquad (5.3)$$

where M_S is the surface-wave magnitude determined from amplitude-period readings, and NS the number of reporting stations are taken from the ISS/ISC bulletins. The determination of the constants a and b in eq. (5.3) is made for four different time intervals for the region under survey:

$a = 3.69$, $b = 0.86$ – period 1919-1930
$a = 2.77$, $b = 1.50$ – period 1931-1949
$a = 2.59$, $b = 1.41$ – period 1950-1963
$a = 1.35$, $b = 1.44$ – period 1964-1990

The results of the analysis show that the value of M_S may be evaluated from NS, but with an average precision of not less than 0.45 units of magnitude which is in good agreement with the one achieved by Ambraseys and Melville (1982) for Persia.

Figures 5 to 8 show the comparison between determined magnitude M from eq. (5.3) and estimated surface-wave magnitude M_S from amplitude-period data.

6. Evaluation of magnitudes of historical earthquakes

Magnitudes of early events could be estimated from the radius of perceptibility (r_3) which is defined as the mean epicentral distance of an area within which the shaking was felt with an intensity equal to, or greater than III (MSK). This procedure has been used for Persia (Ambraseys and Melville, 1982) and for West Africa (Am-

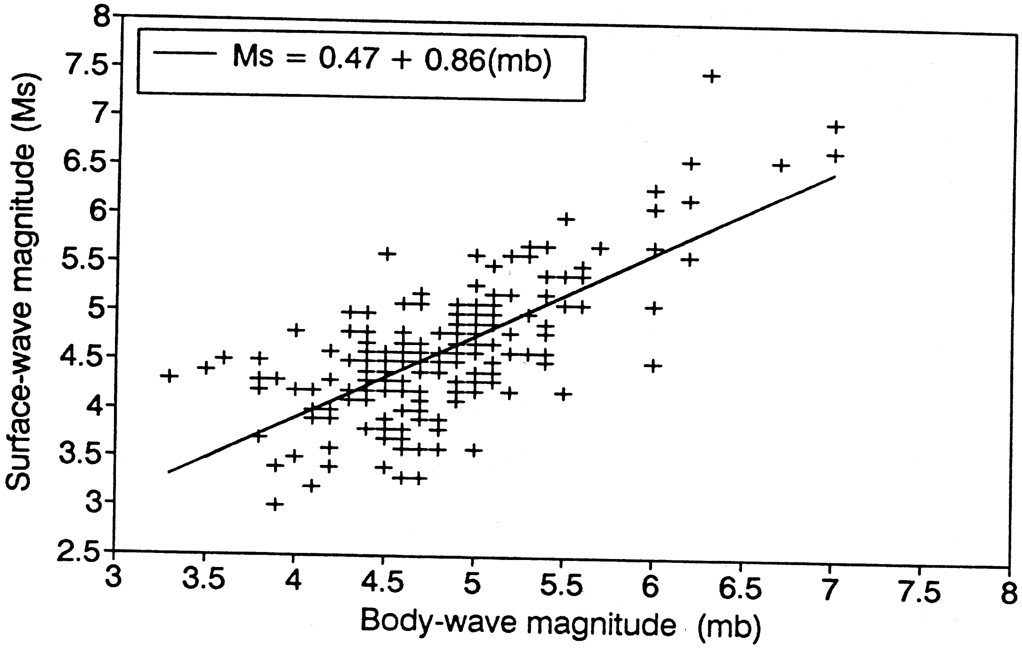

Fig. 3. Plot of surface-wave magnitude M_S versus body-wave magnitude m_b for shallow earthquakes in the Maghreb.

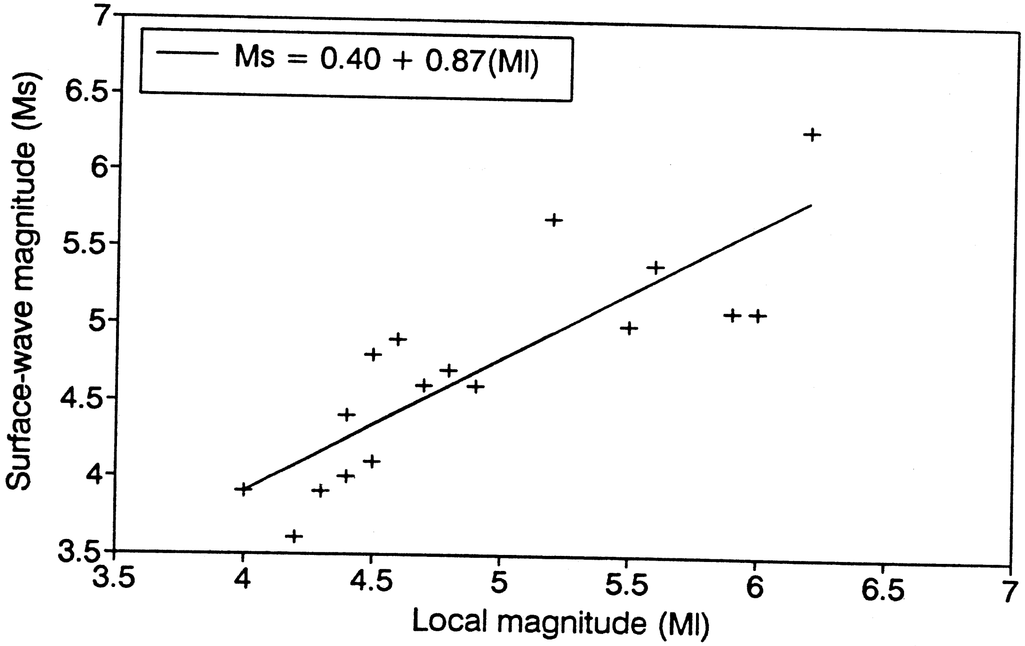

Fig. 4. Plot of surface-wave magnitude M_S versus local magnitude M_L for shallow earthquakes in the Maghreb.

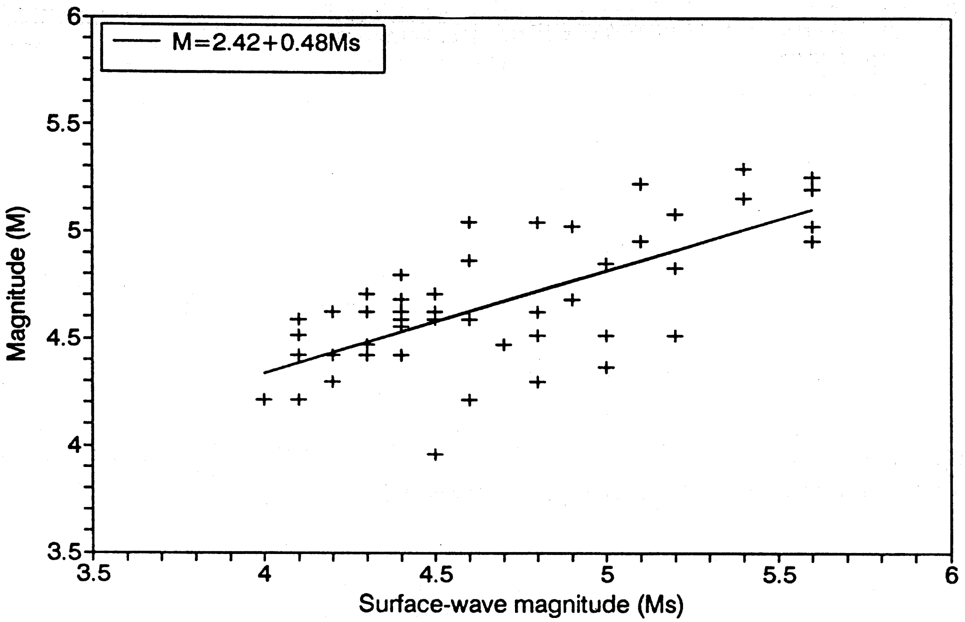

Fig. 5. Comparison between determined magnitudes M from equation $M = 3.69 + 0.86 \log (\mathrm{NS})$ and those estimated from amplitude-period data during 1900-1930.

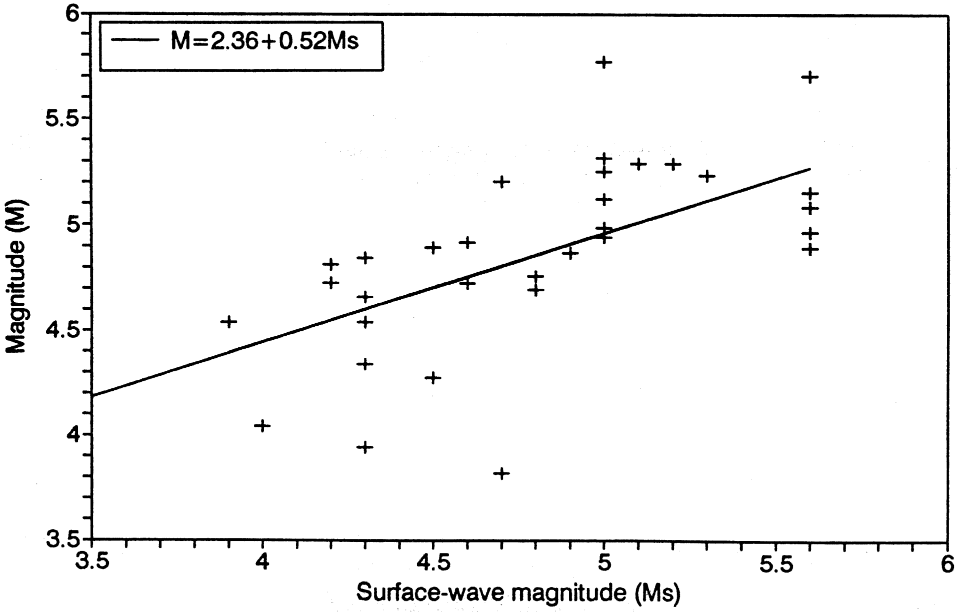

Fig. 6. Comparison between determined magnitudes M from equation $M = 2.77 + 1.50 \log (\mathrm{NS})$ and those estimated from amplitude-period data during 1931-1949.

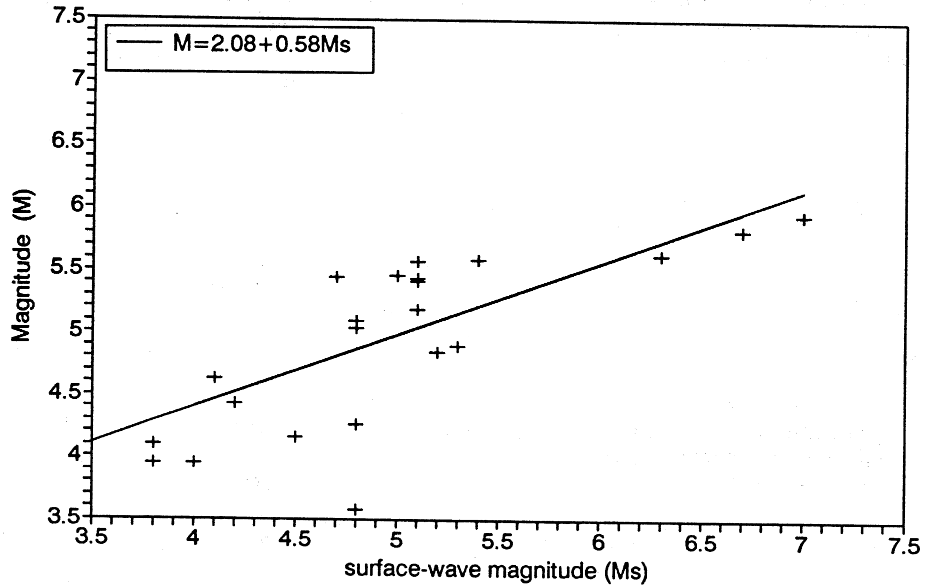

Fig. 7. Comparison between determined magnitudes M from equation $M = 2.59 + 1.41 \log (NS)$ and those estimated from amplitude-period data during 1950-1963.

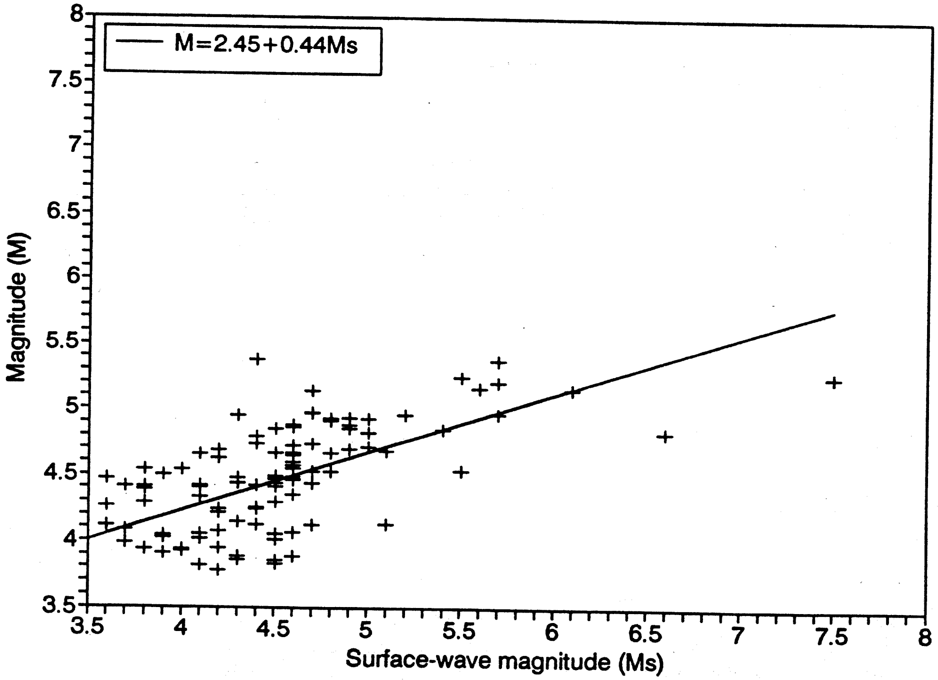

Fig. 8. Comparison between determined magnitudes M from equation $M = 1.35 + 1.44 \log (NS)$ and those estimated from amplitude-period data during 1964-1990.

braseys and Adams, 1986). For the Maghreb region, the average radius of perceptibility (r_3) has been estimated for 27 earthquakes. The correlation formula between calculated surface-wave magnitude M_S and r_3 is sought in the form:

$$M_S = a + b \log (r_3) \qquad (6.1)$$

This equation is fitted to 27 pairs of M_S and r_3 (in km) which gives the following expression:

$$M = -0.04 + 2.56 \log (r_3) \qquad (6.2)$$

with a standard deviation equal to 0.35. Figure 9 shows the comparison between estimated M_S and those calculated from eq. (6.2) for shallow earthquakes in the Maghreb region during the period 1900-1990.

Where more data are available, as the number of isoseismal distances r_i of intensity $I = i$, equivalent surface-wave magnitude M_S can be assessed from the attenuation relationship derived in this study for Algeria and for the Maghreb as a whole (see Chapter VI).

Magnitudes of historical events may also be evaluated by using the epicentral intensity I_0 alone. This has been worked out by various authors (Gutenberg and Richter, 1956b; Karnik, 1969; Ambraseys and Melville, 1982) for different regions in the world. An attempt was made in assessing magnitudes of historical earthquakes in Greece, Italy, China and elsewhere. But because intensities depend on a variety of parameters, the evaluation of magnitude from intensity alone is unreliable and should be used as the last resort. In this study, for the region under study, the re-

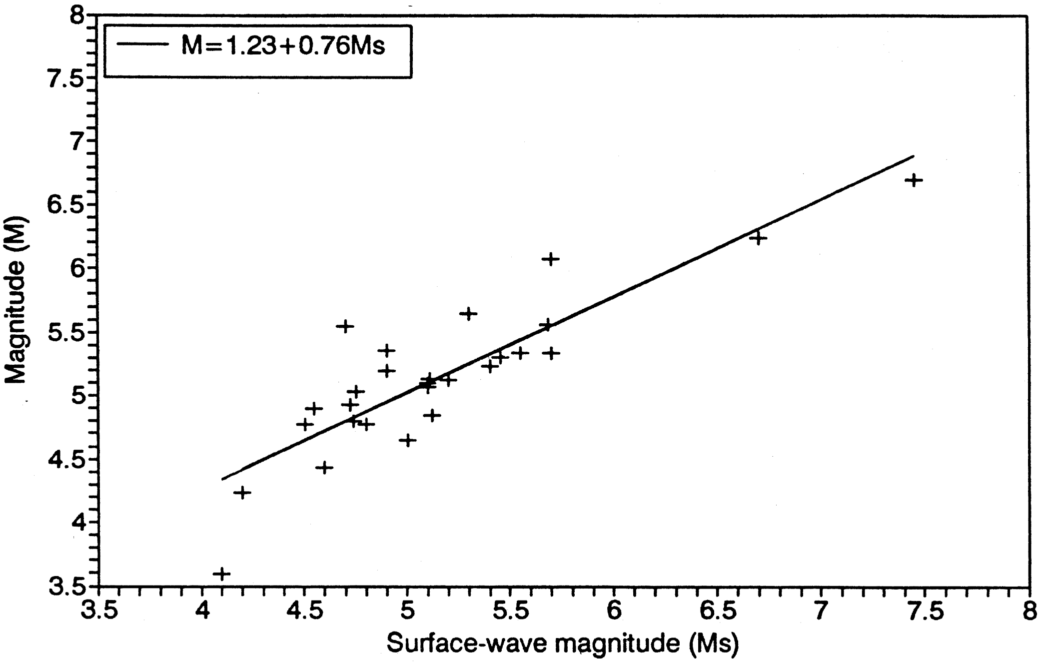

Fig. 9. Comparison between estimated magnitudes M_S and those calculated from equation $M = -0.04 + 2.56 \log (r_3)$ for shallow earthquakes in the Maghreb.

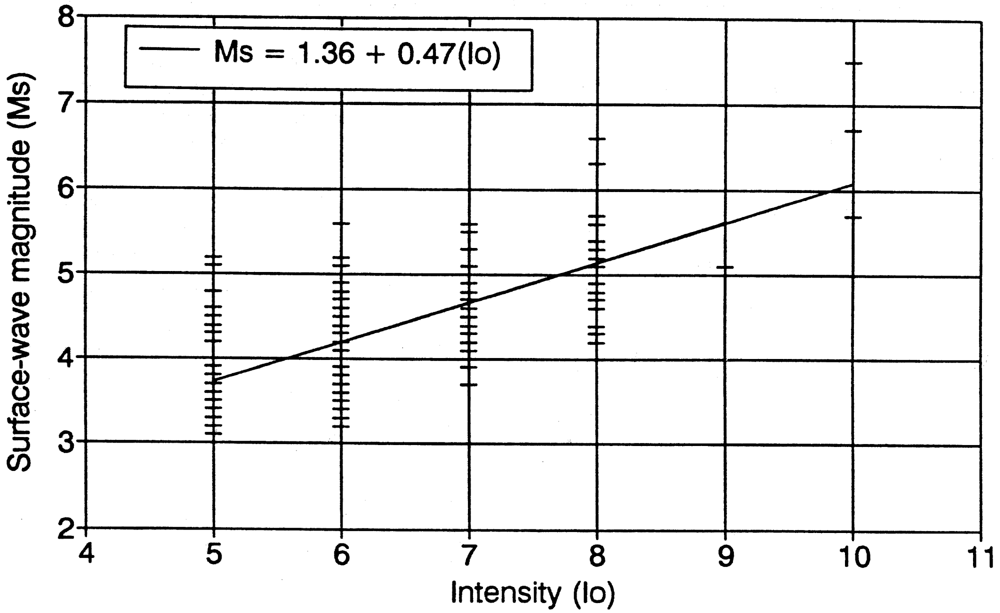

Fig. 10. Plot of surface-wave magnitude M_S versus epicentral intensity I_0 in the Maghreb.

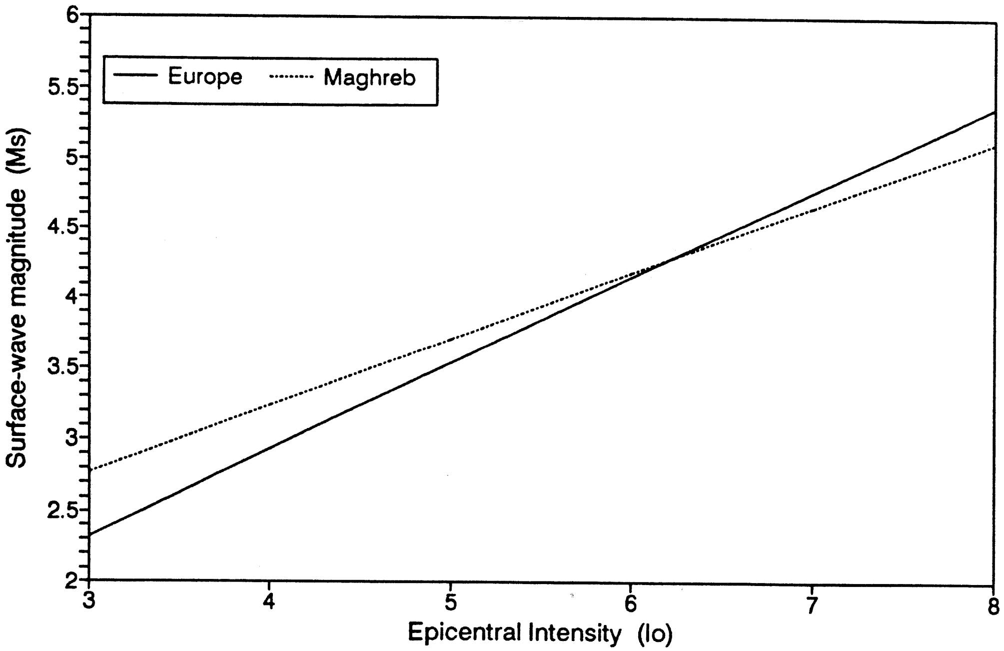

Fig. 11. Plot of the comparison between (M-I_0) relationships in the Maghreb and Europe.

gression of a linear equation fitted to 262 data-pairs of I_0 versus M_S gives:

$$M_S = 0.47 (I_0) + 1.36 \qquad (6.3)$$

with a standard deviation equal to 0.5. Because the scatter is so wide that one magnitude estimate is associated with several different intensities, this is illustrated in fig. 10. Figure 11 shows a plot of the comparison between (M-I_0) relationships in the Maghreb countries and adjacent areas and that in Europe derived by Ambraseys (1990). From this figure and to all intents and purposes, these formulae give quite similar results.

7. Conclusions

The main purpose of this chapter is to analyze the development of the network of seismograph stations in the Maghreb and adjacent regions, the use of instrumental data in locating and measuring earthquakes. Determination of instrumental magnitudes and their revision are also discussed. Application of techniques of completing the homogeneized available data are presented. The instrumental information is one of the sources, jointly with macroseismic data, which are capable of leading to seismotectonic interpretation of seismicity maps.