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SEISMIC PARAMETERS ESTIMATION IN NORTHERN ALGERIA

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ABSTRACT

Seismic hazard assessment studies, using a probabilistic or deterministic approach need a reliable earthquake catalog, covering a certain time period, seismogenic source model (line sources or area sources) and some seismic parameters, such as: the a and b values of the Gutenberg-Richter relationship, and the maximum «possible» magnitude expected in each source. This study is an attempt to develop seismic parameters estimation in northern Algeria. The seismicity analysis carried out is based on a reliable compiled earthquake catalog obtained from different agencies. All the intensities and magnitudes were converted to M_s magnitude using the most appropriate relationship among those we examined. The non-possonian events identified by means of the methodology proposed by EPRI which have been removed. Also, a simple procedure to identify aftershock events is discussed. The completeness of the final catalog has been discussed according to the procedure developed by Stepp, (1971). This check is a fundamental step to establish four complete and poissonian seismic models, which completely describe and characterize the seismic activity in northern Algeria. Seismic sources are delineated as in area by taking into account the most important geological features. Each seismic source is characterized by its seismic parameters, especially a and b values of the Gutenberg-Richter relationship, and the maximum expected magnitude. We estimate the a and b values by the procedure developed by Weichert, (1980), using the catalog of each zone. More attention is given to the estimation of the maximum expected magnitude using different statistical estimators (Kijko-Sellevoll, Gibowics-Kijko and Pisarenko). To avoid the abrupt change in the seismogenic source boundaries, these parameters, especially the b value and the maximum expected magnitude are smoothed over all the north of Algeria, this gives an overview of the spatial variation of these parameters in the studied area. For instance, the obtained estimated seismic parameters not only, give an appropriate overview and well characterizes the seismic activity in northern Algeria but also, are the most appropriate input parameters to the seismic hazard assessment.

Keywords - Earthquake catalog - A and B values - Seismogenic source - Maximum magnitude-Algeria.

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ESTIMATION DES PARAMÈTRES DE L'ALÉA SISMIQUE EN ALGÉRIE DU NORD

RÉSUMÉ

L'évaluation de l'aléa sismique tant du point de vue probabiliste que déterministe est basée sur un catalogue des évènements (séismes) couvrant une période temporelle donnée, une description et une représentation des sources sismogéniques (linéaire ou surface) ainsi que les paramètres fondamentaux a et b de la relation de Gutenberg et Richter et enfin une estimation de la magnitude possible pour chaque zone sismogénique préalablement délimitée. Dans cette étude nous présentons des résultats d'estimation des paramètres de l'aléa sismique au Nord de l'Algérie. Dans un premier temps nous avons compilé un catalogue regroupant tous les événements, ce dernier a été élaboré à partir de différentes sources (centres et services régionaux en sismologie). Toutes les magnitudes et intensités sont converties à l'échelle de la magnitude de surface (Ms), après examen de plusieurs relations empiriques. La méthodologie développée par EPRI nous a permis d'éliminer les événements non-poissoniens, afin d'avoir un échantillon pouvant être représenté par un processus aléatoire de Poisson. De même en se basant sur la méthode de Stepp (1971), nous avons examiné les périodes et seuils de ''completness''. Cette dernière étape joue un rôle fondamental pour définir quatre modèles de sismicité complets et poissoniens, décrivant et caractérisant l'activité sismique dans la région d'étude. Les zones sismiques sont délimitées comme ''surface'' en prenant en compte les caractéristiques géologiques. Chaque source sismique est caractérisée par ses paramètres, en particulier les valeurs a et b de la relation de Gutenberg et Richter et la magnitude maximale possible. Les valeurs de a et de b sont estimées par la méthode de Weichert, (1980). Une attention particulière est accordée à l'estimation de la magnitude maximale possible à partir de trois estimateurs (Kijko-Sillevol, Gibowics-Kijko, Pisarenko). Afin d'éviter un changement brutal des paramètres aux frontières des différentes zones, un lissage a été effectue sur les valeurs de a et b ainsi que la magnitude maximale possible. Nous obtenons ainsi un aperçu sur la variation spatiale de ces paramètres. Les résultas obtenus donnent non seulement une vue appropriée et une bonne caractérisation de l'activité sismique au nord de l'Algérie, mais ils représentent les paramètres les plus appropriés pour l'estimation de l'aléa sismique dans cette région.

Mots clés - Catalogue de sismicité - Paramètres a et b de la loi de Gutenberg-Richter - Source sismogénique - Magnitude maximale possible - Algérie.

1 - INTRODUCTION.

Northern Algeria is known as one of the most active region in the western Mediterranean basin. This activity is characterized by many events some of them are historical (1365-1910) and others are instrumental recent events that were recorded by teleseismic stations and by a few Algerian stations included Alger-Bouzareah, which was installed in 1910 and it is the oldest in the region. Since 1910 many other seismological stations have been deployed in northern Algeria. Among of these, two international stations belonging to GEOSCOPE (Romanowicz and al., 1991) and MedNet (Giardini and *al.*, 1992) networks. The Algerian Center CRAAG, motivated by interest in monitoring seismic hazard and surveying seismogenic zones, suggested the coverage of northern Algeria by telemetered seismological network. Algeria has a long seismological tradition owing to seismic activity (Bezzeghoud and al., 1994). For many years (1910-1990), the seismicity in the region of the northern Algeria was monitored by a very few stations which constituted the old seismological survey network.

Since the El Asnam earthquake (10 October 1980, Ms 7.3), the CRAAG took the initiative of deploying regional arrays of telemetered seismological short-period stations over northern Algeria, especially to eliminate the deficiencies and the limitations of the old network and to perform better monitoring over all the northern Algeria. In this paper we compile and analyse earthquake catalogue for this region. Data published by different agencies around the Mediterranean basin are used to develop and analyse earthquake catalogue for northern Algeria and surrounding areas especially as reliable tool to perform seismic hazard assessment studies.

2 - EARTHQUAKE DATA FILE

The region under study is the northern Algeria which could be considered in terms of plate boundaries between Eurasia and Africa. The seismicity of this part of the Ibero-Maghrebian region is the result of the compressional movement between the Eurasia and Africa plate, which have been established. The tectonic regime in this part of the Alpine chain is mostly compressional since the early Cenozoic, with late Quaternary N-S to NW-SE convergence. This tectonic complex setting, inside an active deforming zone that absorbs 5 to 6 mm/year (from Nuvel-1 model by Argus and al., 1989) of crustal shortening and dextral shearing (Bezzeghoud and Buforn, 1999; Henares and al., 2002).

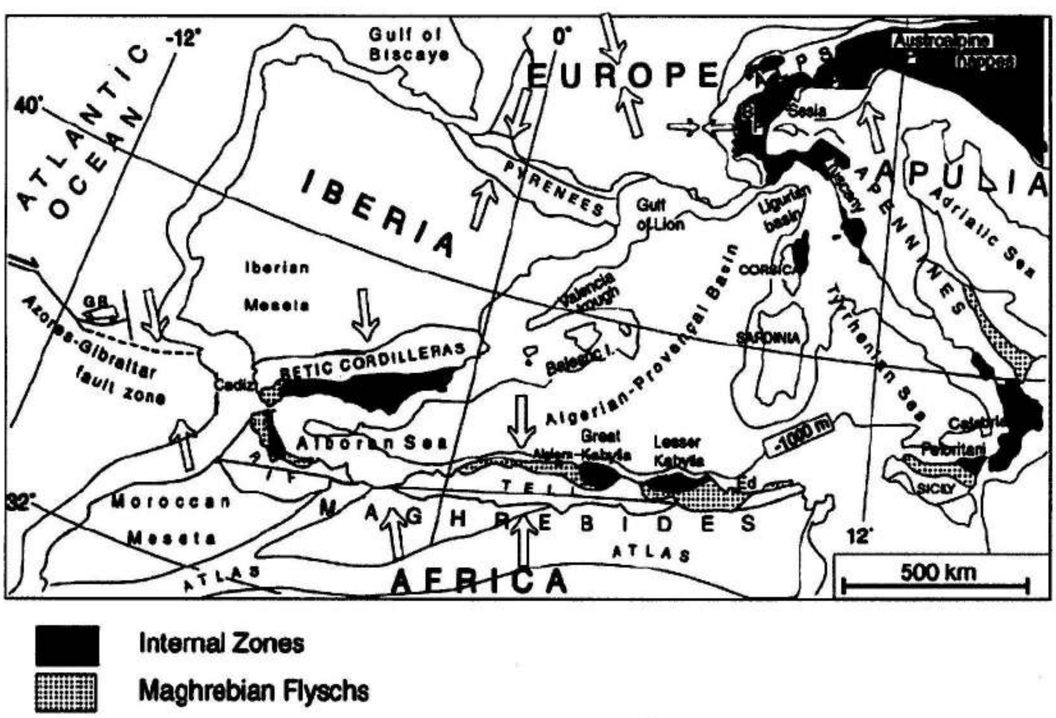


Fig. 1- Tectonic context of the Mediterranean basin.

Contexte tectonique du bassin de la méditerranée

The earthquake catalog compiled for this area mainly consists of those of the Ibero-Maghrebian catalog published by the Spanish Instituto Geográfico Nacional, (IGN) (Mezcua and Martínez Solares, 1983), supplemented for the Algeria zone with data published by the CRAAG (CRAAG, 1994) and updated to 2002. The data published for the region by the EMSC (European-Mediterranean Seismological Center) and by the USGS (US Geological Survey) have also been incorporated in the data file. The quality of our basis catalog has been appreciated during the Ibero-Maghrebian Workshop (under the auspices of the European Seismological Commission, ESC) in their 1979 meeting in Rabat (Morocco). It has been pointed out that this is the most reliable catalog covering the Ibero-Maghrebian region, evidently for regional use. Under the auspices and funding of UNESCO, an enormous effort has been done to complete, homogenise and improve the previous one. All these efforts were concretized in the publication by Mezcua and Martínez Solares (1983). This catalog is being updated periodically. As mentioned by the authors, they used 131 catalogs (catalogs in the strict sense of the word, and papers on the seismicity of a certain region spanning more than one year) and 313 papers about specific earthquakes to compile it. At the beginning of 2003, it included more than 23800 earthquakes. For example, starting in the 60's this catalog reported macroseismic intensities in northern Algeria above or equal to degree III in the MSK scale. In 1990, after their most important station restructuring, earthquakes in northern Algeria above m_b 3.0-3.5 were reported (Bezzeghoud and al., 1994). After Bezzeghoud and al., (1994), events with magnitude larger than 1.0 are detected in northern Algeria; those with magnitude 3.0 are generally detected in seven stations. Today, they report earthquakes in this region above m_b 2.0-2.5. This catalog has been improved, when ever data were available, with the Algerian catalog compiled by the Algerian Centre de Recherche en Astronomie, Astrophysique et Géophysique (CRAAG). Besides, M_S magnitude reliable data from USGS and EMSC has been included as well. All the magnitudes and intensities were converted to M_S magnitudes using the relationships by Lopez Casado and *al.*, (2000), after testing different empirical relationship as the one proposed by Benouar (1994) and CRAAG (1994). The comparison results are shown on figure 2.

Figure 2 shows that the relationships by Lopez Casado et al., (2000) are the more appropriate one for data file compiled. These empirical relations are given by;

$$M_s = -3.44 + 1.65\, m_b + 0.40\, P$$

$$M_s = -1.52 + 0.0051\, I^2_0 + 0.70\, P$$

In both equations P is equal to 0 for the mean value and 1 for the 84-percentile.

The next step consists to remove all the identified aftershocks and the foreshocks. In this study we have used the methodology proposed by EPRI (1986) to identify and to remove all the non-poissonian earthquakes. The Poissonian character of the final catalog has been analyzed by considering the cumulative earthquake number as a function of time above different magnitude values (Benjamin and Cornell, 1970). After removing the non-Poissonian earthquakes, the poissonian character of the final catalogue has been analysed by considering the cumulative earthquake number as a function of time above a different threshold magnitude. The figure 3 shows the different obtained results

The completeness of the final catalog has been verified according to the procedure developed by Stepp (1971). The results of the completeness analysis are shown on figure 3.

This check is a key step to establish different complete and poissonian, seismic models to be used in the calculation of the seismic hazard (Hamdache and *al.*, 2005; Pelaez and *al.*, 2005a; 2005b). For this instance four complet and poissonian seismic models have been derived. The figure 5, shows the representation of the cumulative earthquake number as a function of time above a threshold magnitude chosen on completeness analysis.

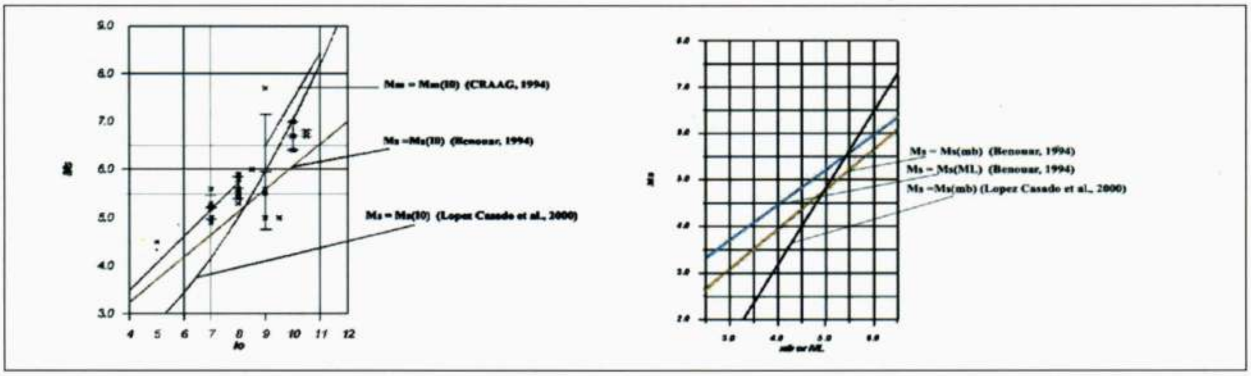


Fig. 2 - Comparison of the empirical relationship to homogenize the earthquake magnitude.

Comparaison de relations empiriques pour l'homogénéisation des magnitudes

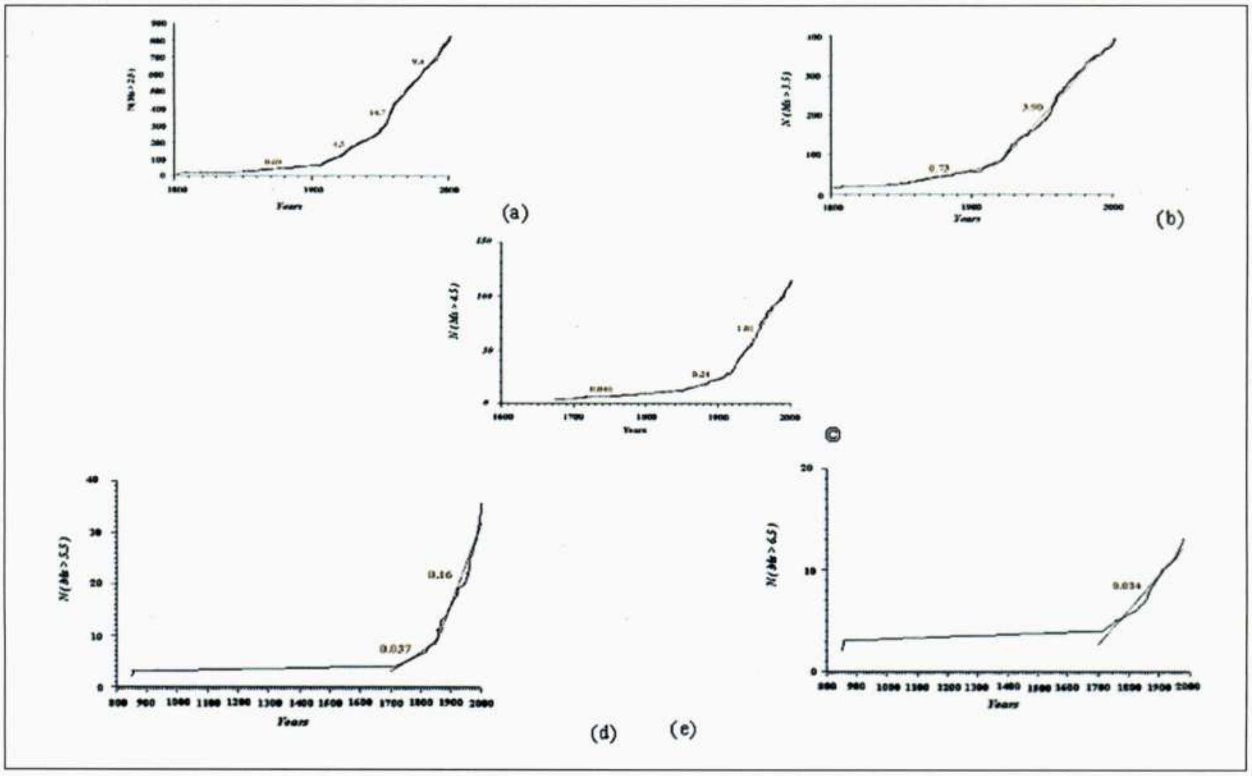
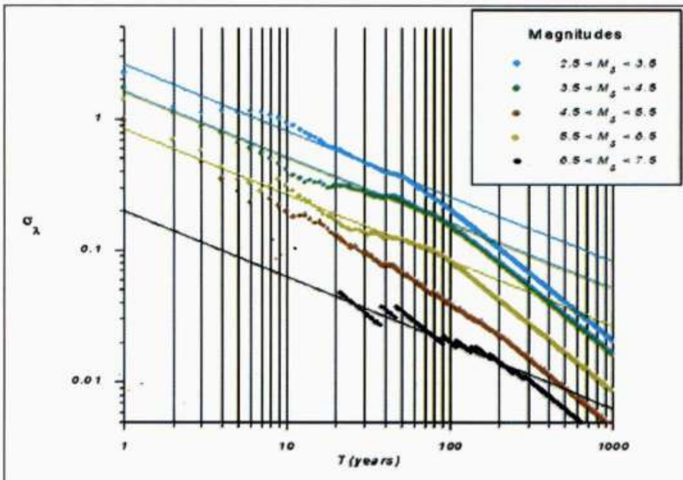


Fig. 3 - Cumulative number of earthquakes as a function of time.

Nombre cumulé de séismes comme fonction du temps



ΔM_s	T (year)	$\lambda^{1/2}$	λ (earthquakes/year)
2.5-3.5	~ 60	2.58	6.66
3.5-4.5	~ 100	1.63	2.66
4.5-5.5	~ 120	0.85	0.72
5.5-6.5	?	?	?
6.5-7.5	~ 300	0.20	0.04

Fig. 4 - Completeness analysis using Stepp' procedure

Analyse de la complétude par la méthode de Stepp

These four seismic models are summarized below.

Model I : It includes earthquakes with magnitude greater or equal than M_s 2.5 (~ m_b 3.6, I_0 = IV-V, according to the relationship by Lopez Casado et al., 2000) after 1960. This model is the most complete from a spatial point of view. An analysis of their Poissonian properties gives a constant annual rate of 9.4 earthquakes above the minimum magnitude chosen. The model includes a total of 425 earthquakes

Model II : It includes earthquakes with magnitude greater or equal than M_s 3.5 (~m_b 4.2, I_0 = VI) after 1920. An annual activity rate equal to 3.9 earthquakes is obtained for this model. The total number of events included in this model is 313.

Model III : This model includes earthquakes with magnitude greater or equal to M_s 5.5 (~m_b 5.4, I_0 = VIII-IX) after 1850. An annual rate of 0.16 earthquakes has been obtained. The total number of events included in this model is 27.

Model IV : It includes earthquakes with magnitudes greater or equal than M_s 6.5 (~m_b 6.0, I_0 = IX-X) after 1700. Only ten earthquakes are included in this last model. The obtained annual rate is 0.033.

Using the empirical relation by Murphy and O'Brien (1977), the threshold magnitude for each seismic model is given in magnitude volume scale.

The completeness and Poissonian character of our four seismic models is inferred from figure 5. It is shown how the annual rate of earthquakes is constant for those are considered in each model. Also, it is shown that earthquakes agree very well with a Gutenberg-Richter relationship for the dates and magnitude ranges taken into account in each seismic model.

It is important to point out that seismicity included in the first two models (1 and 2) is the instrumental seismicity, with a minimum uncertainty in their epicentral location. The last two models (3 and 4) include moderate and large earthquakes that have taken place in the region. Some of them are historical and thus, they may have a high uncertainty, not only in their epicentral location but also in their intensity or macroseismic magnitude. These models are really necessary, because they reveal the areas tending to have high seismic hazard.

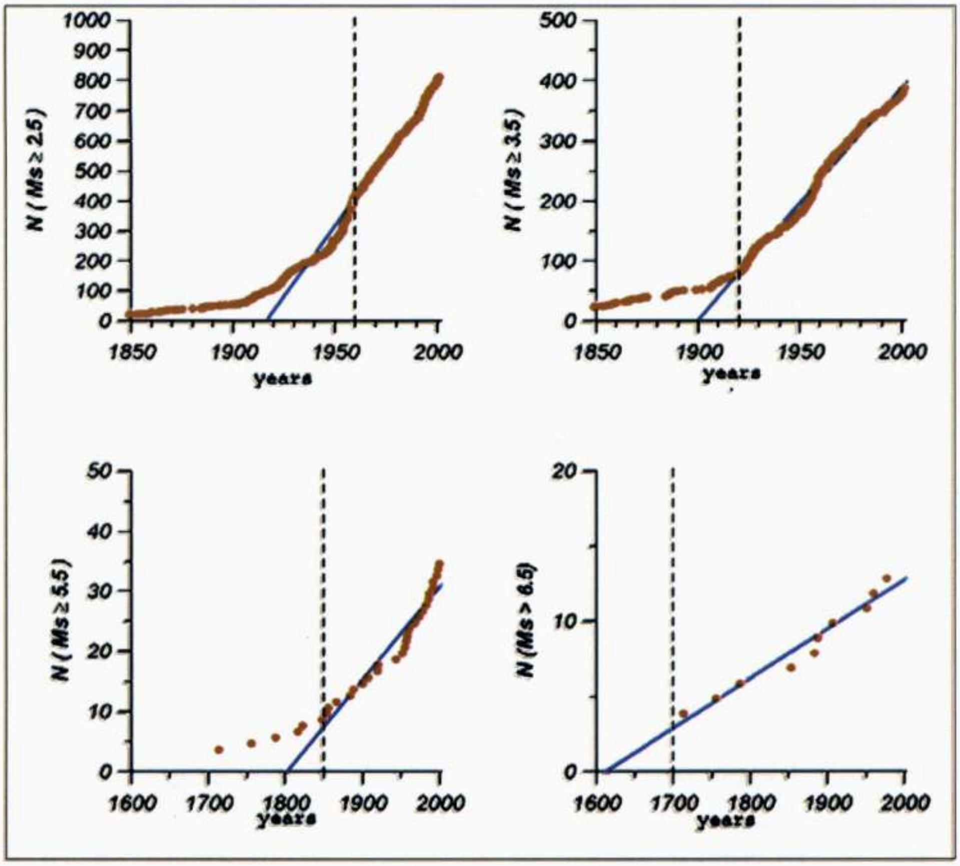


Fig. 5 - Number of earthquakes above the threshold magnitude considered in each seismic model vs. time.

Nombre de magnitudes supérieur à la magnitude seuil dans chaque modèle

Figure 6 shows that the four seismic models fit very well the recurrence model of the Gutenberg-Richter

3 - SEISMIC PARAMETERS.

Northern Algeria is known as the most active seismogenic area in the western Mediterranean region, in the eastern part of the Ibero-Maghrebian zone. In fact, during the last century, Algeria has experienced several strong earthquakes (CRAAG, 1994). The analysis of the distribution of earthquake epicenters during the last three centuries leads to the conclusion that earthquakes in Algeria occur mostly in some Tell cluster zones. However, a few earthquakes appear in the High Plateaus and across the Sahara Atlas range (fig. 6).

According to Aoudia and *al.* (2000), the seismicity analysis also shows that the seismogenic areas are located in the vicinity of the Quaternary Basins. These tectonic zones, that coincide with the areas in which there are Neogene and Quaternary deposits, extend to the Messeta Basin (region of Oran) in the western Tell, in the center to the Mitidja Basin (Tipaza-Algiers) close to the Atlas blideen (or Blidean Atlas, from the Blida city), and extends to the Soumam, Constantine and Guelma Basins in the eastern part, and to the Hodna Basin in the southeast.

In the absence of both a standard general practice and methodology, the delineation of the seismic sources remains mostly subjective. In this study, seismogenic source zones are defined as areas where the seismic characteristics are

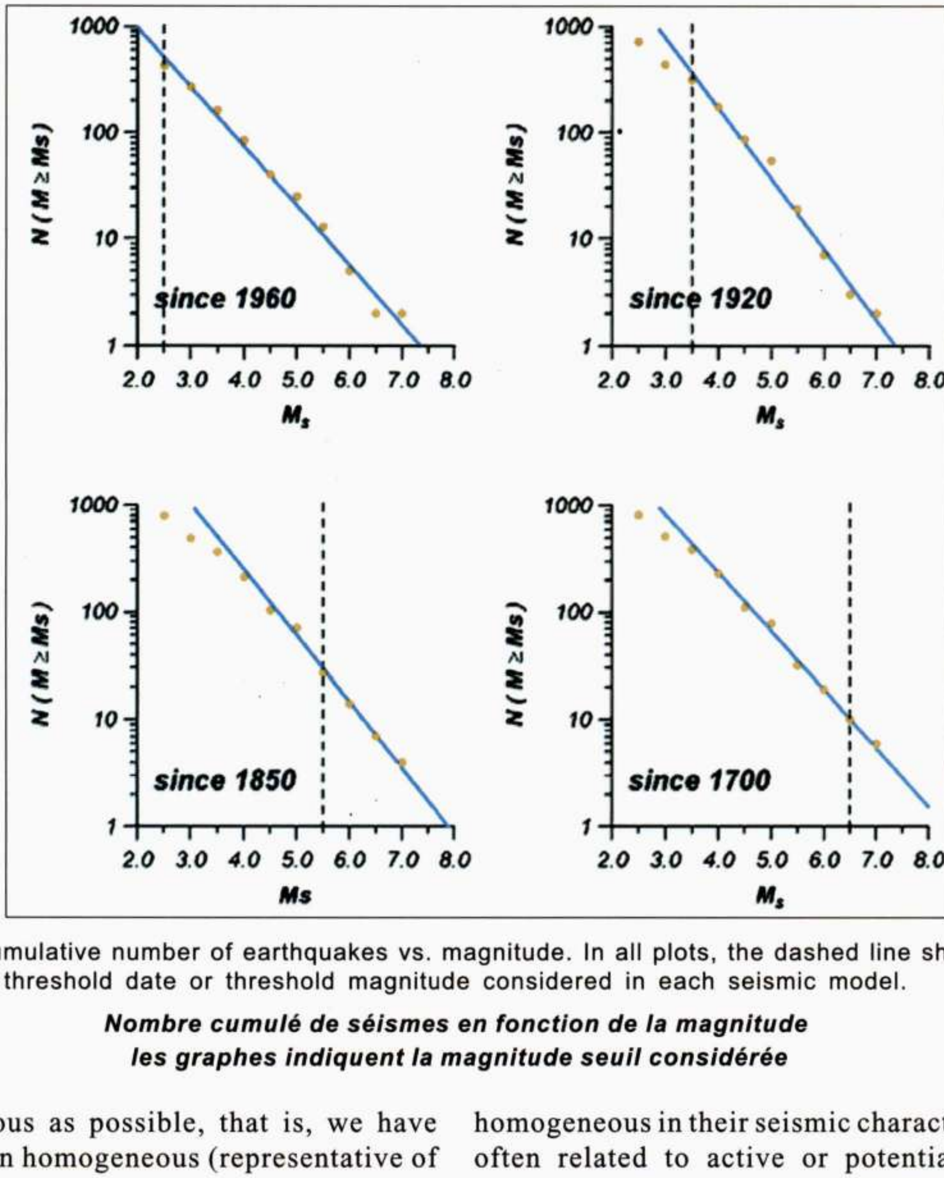


Fig. 6 - Cumulative number of earthquakes vs. magnitude. In all plots, the dashed line shows the threshold date or threshold magnitude considered in each seismic model.

Nombre cumulé de séismes en fonction de la magnitude les graphes indiquent la magnitude seuil considérée

as homogenous as possible, that is, we have established an homogeneous (representative of the whole zone) earthquake recurrence relationship. To be used in our work, some modifications have been introduced into the seismogenic source zones previously proposed by Hamdache (1998a) and Aoudia et al. (2000). The geological description given in Aoudia and al. (2000) has been also used to incorporate the geological knowledge in the seismogenic sources considered in this study. Different geological structures have been included to identify overall ten seismogenic zones in northern Algeria. Each of the proposed source zones, which seem homogeneous in their seismic characteristics, is often related to active or potentially active geological structures. Some of them contain the Quaternary basins previously mentioned. This seismogenic source model is consistent with the distribution of the seismicity in northern Algeria, as shown in figure 8. In northeastern Morocco and northern Tunisia, the source zones have been defined more taking into account the seismicity information than the geological context (seismicity sources). This was done to incorporate the contribution of the seismicity of these regions to the calculation of the seismic hazard in northern Algeria.

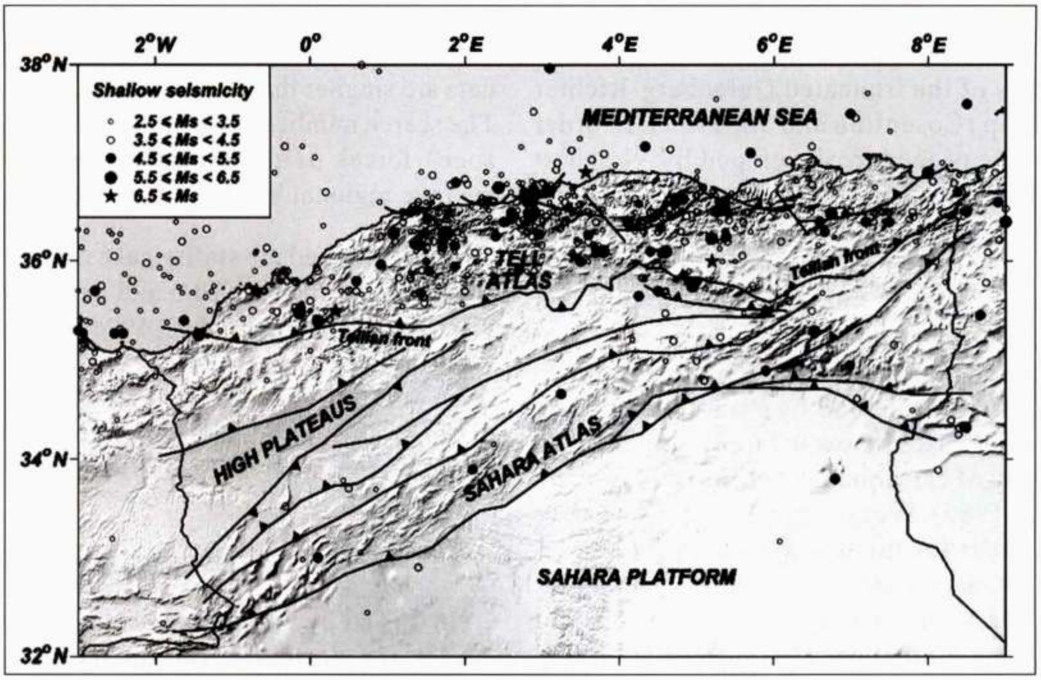


Fig. 7 - Shallow declustered seismicity of the region since 1700, and regional tectonic setting (simplified from Bracene et *al.*, 2003).

Distribution spatiale de la sismicité depuis 1700 et contexte tectonique régional (simplifiée à partir de Bracene et al., 2003)

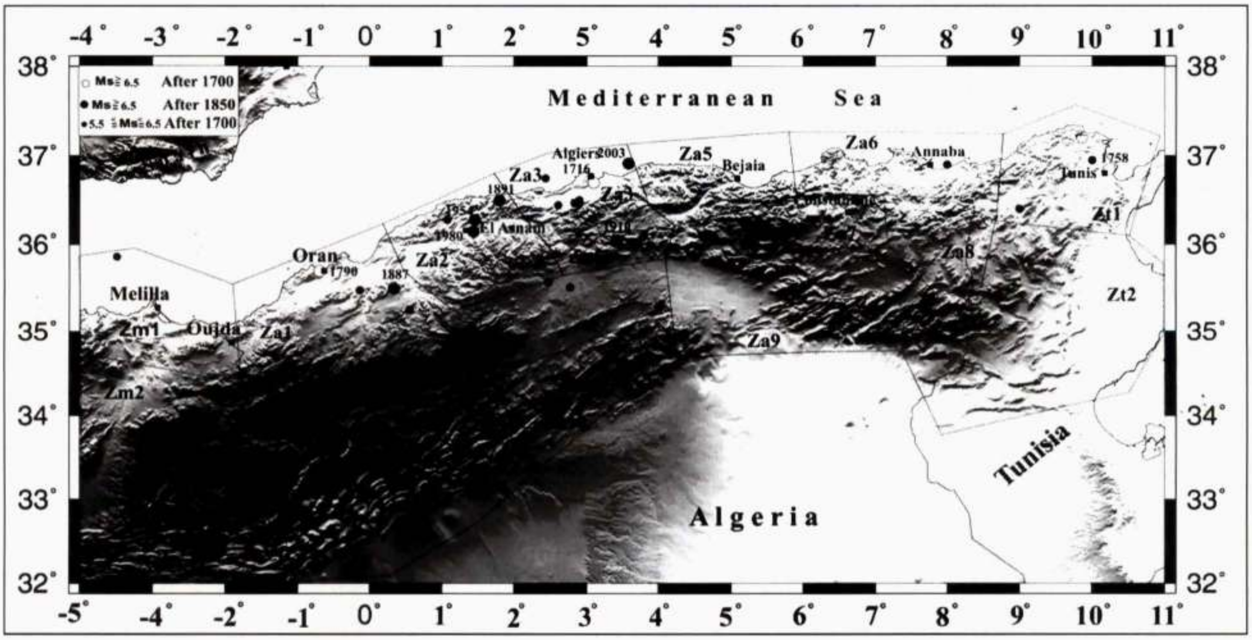


Fig. 8 - Main seismic sources adopted in the northern Algeria and surrounding areas

Principales sources sismiques en Algérie du Nord et dans les régions avoisinantes

Each of the proposed seismic zones has been characterized by their respective b and m_{max} parameters of the truncated Gutenberg-Richter relationship (Cosentino and *al.*, 1977). In order to do so, the procedure developed by Weichert (1980) has been applied to derive a reliable estimate of the b value, and the one developed by Pisarenko and *al.*, (1996) for the calculation of the expected m_{max} value. In the computation of the uncertainty of this last parameter, we combine the sample standard deviation provided by the statistical method by Pisarenko and *al.*, (1996), in all cases below 0.2 units, and the own uncertainty of earthquake magnitude (Tinti and Mulargia, 1985). We consider, as a conservative decision, that for the whole catalog the uncertainty in the magnitude is on average 0.3 units after 1980, 0.5 between 1920 and 1980, and 0.7 before 1920 (Molina, 1998; Lopez Casado and *al.*, 2000).

The results obtained are shown in Table I. b-values agree very well with those obtained previously for different areas of the region by several authors in comprehensive studies (e.g., López Casado and *al.*, 1995; Hamdache, 1998a; Hamdache and *al.*, 1998b; López Casado et *al.*, 2000; Aoudia and *al.*, 2000). Note that b values from M_S magnitude data are smaller than those obtained from m_b data. The scarce number of earthquakes in some source zones forces us to associate to these zones an average regional b value, as indicated in Table I.

We have used the statistical estimator defined by Kijko–Sellevol (Kijko and Sellevoll, 1989), Pisarenko (Pisarenko and *al.*, 1996) and Gibowics – Kijko (Gibowics and Kijko, 1994), to compute the maximum expected magnitude in each zone based on the earthquake catalogue of each zone derived from the whole compiled catalogue.

4 - CONCLUSION

In this study we present a seismogenic source model for northern Algeria based on recent published works. For all northern Algeria we compiled from different agencies an earthquake catalogue covering the period of 1700 to 2003. The study presents all the step in the elaboration of a reliable data base to be used in the seismic hazard assessment study.

Table I - *b* and M_{Smax} values computed for the considered seismic sources. (†) Mean value obtained using all the Algerian sources. (‡) Mean value obtained using all the Tunisian sources. M_{Smax} is obtained using Pisarenko et al, (1996) procedure

Valeurs de b et M_{Smax} obtenues dans chaque source sismique (†) est la valeur moyenne obtenue en utilisant toutes les sources. (‡) valeur moyenne obtenue en utilisant toutes les sources en Tunisie. M_{Smax} est obtenue en utilisant la procédure de Pisaranko et al., (1996)

Seismic sources	*b , ó*	*M_{smax}, ó* Model 1	*Model 2*	*Model 3*	*Model 4*
Za1	0.53 , 0.06	6.5 , 0.3	6.5 , 0.3	7.0 , 0.7	7.0 , 0.7
Za2	0.48 , 0.08	7.8 , 0.3	7.8 , 0.3	7.8 , 0.3	7.8 , 0.5
Za3	0.53 , 0.08	7.4 , 0.3	7.4 , 0.3	7.4 , 0.3	7.5 , 0.7
Za4	0.54⁺ , 0.03	6.0 , 0.5	6.0 , 0.5	7.1 , 0.7	7.1 , 0.7
Za5	0.62 , 0.17	5.6 , 0.3	5.6 , 0.3	5.6 , 0.3	5.6 , 0.3
Za6	0.54⁺ , 0.03	6.1 , 0.5	6.1 , 0.5	6.1 , 0.5	6.1 , 0.5
Za7	0.54⁺ , 0.03	7.5 , 0.5	7.5 , 0.5	7.5 , 0.5	7.5 , 0.5
Za8	0.67 , 0.32	4.7 , 0.3	5.7 , 0.5	5.7 , 0.5	5.7 , 0.5
Za9	0.54⁺ , 0.03	6.8 , 0.3	6.8 , 0.3	6.8 , 0.3	6.8 , 03
Za10	0.54⁺ , 0.03	4.6 , 0.5	5.5 , 0.5	5.5 , 0.5	5.5 , 0.5
Zm1	0.56 , 0.05	6.3 , 0.3	6.5 , 0.5	6.5 , 0.5	6.5 , 0.5
Zm2	0.52 , 0.11	4.8 , 0.3	5.5 , 0.5	5.5 , 0.5	5.5 , 0.5
Zt1	0.58⁺⁺ , 0.08	6.0 , 0.5	6.1 , 0.5	6.1 , 0.5	7.5 , 0.7
Zt2	0.58⁺⁺ , 0.08	5.5 , 0.3	5.5 , 0.5	5.5 , 0.5	5.5 , 0.5

Table II - Maximum expected magnitude computed for each considered seismic source in northern Algerai using Kijko –Sellevol M_{max}^{K-S}, Pisarenko M_{max}^{Pi} and Gibowicz-Kijko M_{max}^{G-K} estimators.

Magnitude maximum possible au niveau de chaque source en Algérie du Nord obtenue en utilisant respectivement la procédure de Kijko –Sellevol M_{max}^{K-S}, Pisarenko M_{max}^{Pi} and Gibowics-Kijko M_{max}^{G-K}

Source	*Maximum expected magnitude*			
	M_{max}^{obs}	M_{max}^{K-S}	M_{max}^{Pi}	M_{max}^{G-K}
Za1	*6.50 ± 0.1*	*6.88 ± 0.15*	*6.95 ± 0.16*	*7.16 ± 0.22*
Za2	*7.30 ± 0.1*	*7.57 ± 0.13*	*7.59 ± 0.13*	*7.65 ± 0.15*
Za3	*6.90 ± 0.1*	*7.22 ± 0.14*	*7.26 ± 0.14*	*7.37 ± 0.18*
Za4	*6.60 ± 0.1*	*7.34 ± 0.22*	*7.25 ± 0.26*	*6.60 ± 0.10*
Za5	*5.00 ± 0.1*	*5.13 ± 0.12*	*5.11 ± 0.12*	*5.12 ± 0.12*
Za6	*5.60 ± 0.1*	*6.18 ± 0.18*	*6.44 ± 0.21*	*5.60 ± 0.13*
Za7	*6.00 ± 0.1*	*6.34 ± 0.14*	*6.38 ± 0.15*	*6.51 ± 0.19*
Za8	*4.80 ± 0.1*	*5.34 ± 0.20*	*5.60 ± 0.23*	*4.80 ± 0.44*
Za9	*6.30 ± 0.1*	*6.75 ± 0.16*	*6.87 ± 0.17*	*7.28 ± 0.34*
Za10	*5.00 ± 0.1*	*5.88 ± 0.24*	*6.69 ± 0.32*	*5.00 ± 0.10*

This catalogue has been used to derive different seismic parameters in each one of the proposed seimic source for northern Algeria. This approach is fundamental in the methodology used in the companion paper (Hamdache and *al.*, 2005), for more details we can consult Pelaez (Pelaez and *al.*, 2005a; 2005b), to derive ground motion parameters estimation in northern Algeria.

The period covered by the catalogue is about 300 years (1700-2003), the quality of the data, the homogenisation to the surface wave magnitude, and the different seismic model with the poissonian and completness properties make it, for this instance, one of the most reliable earthquake catalogue for seismic hazard purpose, bearing in the mind that some efforts must be done on the question, especially in the re evaluation of historical event as well as in their locations than in their intensities.

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