Seismic hazard assessment in the Ibero-Maghreb region

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Abstract
The contribution of the Ibero-Maghreb region to the global GSHAP map has been the result of a fruitful cooperation among the participants in the established Working Group including representatives from Algeria, Morocco, Portugal, Spain and Tunisia and coordinated by ICTJA-CSIC, Spain. For the first time, a map of regional seismic source zones is presented, and agreement on a common procedure for hazard computation in the region has been achieved. The computed Ibero-Maghreb seismic hazard map constitutes the first step towards a uniform hazard assessment for the region. Further joint regional efforts are still needed for earthquake hazard studies based on a homogeneous regional earthquake catalogue. Ongoing initiatives in relation to seismic hazard assessment in the Mediterranean should profit both from these results and the established cooperation among different groups in the region as well as contribute to future regional studies.

Key words *seismic hazard assessment – Ibero-Maghreb seismic zoning – earthquakes – historical seismicity – UN/IDNDR*

1. Introduction

The Ibero-Maghreb region, which includes the Iberian Peninsula (Portugal and Spain) and the Maghreb countries (Algeria, Morocco and Tunisia), constitutes the Western Mediterranean border and it is located at the westernmost segment of the Eurasia-Africa plate boundary, forming a subcontinental-sized tectonic domain where strain is distributed over a wide area and no single plate-boundary can be outlined. Several strong and damaging earthquakes have taken place in this region (*i.e.* Lisbon 1755, Andalusia, 1884, Agadir 1960, El Asnam, 1980), hence its importance in a global seismic hazard assessment, despite its relatively small size in a world map.

The seismic hazard mapping for the Ibero-Maghreb region did not follow strictly the GSHAP implementation guidelines (Basham and Giardini, 1993) due to time limitations. The coordination of the activities in this region by the Institute of Earth Sciences «Jaume Almera»-CSIC (ICTJA/CSIC) in Barcelona, Spain, started only in December 1996, and a special time schedule was established in order to attain the expected results on time for the contribution to the global GSHAP map.

At a first Planning Meeting in Barcelona, Spain, on December 18, 1996, a plan of activities was launched to produce a preliminary seis-

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mic hazard map of the region (30°N-44°N, 12°W-12°E) to be presented at the 1997 IASPEI General Assembly in Thessaloniki, Greece. During the Planning Meeting national representatives from each country in the region accepted to be responsible for providing the necessary input data (Algeria: Djamal El Foul; Morocco: Ben-Aissa Tadili; Portugal: Carlos Sousa-Oliveira; Spain: Mariano García-Fernández; and Tunisia: M'hamed Chadi).

In order to simplify the hazard assessment procedure, and due to the limited time, all national representatives agreed on leaving to the ICTJA/CSIC team the responsibility for performing all mapping computations and on providing the necessary pre-processed input data. It was decided to use the computer code SEISRISK III (Bender and Perkins, 1987) to generate a preliminary map of Peak Ground Acceleration (PGA) in *g*-units for a 90% probability of non-exceedance in 50 years, considering a single regional attenuation law. The production of such regional hazard map was performed in two steps. First, individual hazard maps for each country were obtained based on the input data provided by the national representatives, and compared with available national maps to check the influence of both, the computation algorithm and the applied data reduction. Second, after technical discussions with the national representatives, a single set of regional non-overlapping source zones was defined, based on the available individual zoning map of each country, for which new activity parameters were calculated wherever needed.

Input data requested to the national representatives were received by April 1997 and a preliminary hazard map for each country was produced by the ICTJA/CSIC team. The input data from Spain were provided by the Spanish *Instituto Geográfico Nacional* (IGN). To discuss these preliminary results, and to solve problems related to the definition of seismic source zones across national borders, a second Technical Workshop was held in Barcelona on May 11-14, 1997. A representative of the Spanish IGN (A. Izquierdo) attended this meeting. Based on the outcome of this second workshop a first version of the seismic hazard map for the whole region was produced on July 1997.

2. Input data

National representatives provided the requested information on seismic activity (earthquake catalogue, source zones and *b*-value, activity rate and maximum size for each source) and attenuation laws in different formats. The original data were used to produce the individual hazard maps for procedure calibration, and a simple data homogenization regarding the source zones definition, the earthquake size parameter and the regional attenuation law was performed to obtain the final seismic hazard map for the whole region.

Table I. Earthquake catalogue available from each country in the Ibero-Maghreb region. M_L = Local Richter magnitude (different definition in each country; *e.g.*, in Tunisia it is obtained from MCS intensity). I_{MSK} = MSK intensity. LSE = List of Significant Earthquakes (see text).

Country	Time	Size	Original area	Area for LSE
Algeria	1790-1989	M_L	15°N-40°N; 5°W-11°E	30°N-37°N; 1.5°W-8.35°E
Morocco	1900-1996	M_L	30°N-36°N; 10°W-1°W	30°N-35°N; 10°W-1.5°W
Portugal	1300-1991	M_L	35°N-44°N; 13°W-4°W	35°N-44°N; 13°W-12°W
Spain	1384-1983	I_{MSK}	35°N-44°N; 12°W-5°E	35°N-44°N; 12°W-1.5°W
				37°N-44°N; 1.5°W-5°E
Tunisia	1724-1996	M_L	32°N-38°N; 7.5°E-12°E	32°N-38°N; 8.35°E-12°E

2.1. *Seismicity*

The basic seismicity data from each country consisted in a national earthquake catalogue spanning different time periods and also with different earthquake size descriptors among them. Due to the time limitations, no work was performed to obtain a homogeneous regional catalogue. Based on the available national catalogues, a List of Significant Earthquakes (LSE) in the region was generated by merging the information of the five countries, avoiding spatial overlapping, as detailed in table I, and with a uniform earthquake size value on moment magnitude, M, obtained through the empirical relationships given by Johnston (1996a,b). The LSE contains the seismicity from 1900 to 1989 with estimated moment magnitude $M \geq 4.5$. The LSE is thus just a general description of the seismicity in the region and not a regional earthquake catalogue.

2.2. *Source zones*

The definition of seismic source zones in the region is highly heterogeneous, ranging from very detailed small sources (Tunisia), and even fault sources (Algeria), to very wide zones (Morocco, Portugal). In most cases, seismicity is the main parameter on which source boundaries are defined, although some raw tectonic information has also been included. Figure 1 shows the orig-

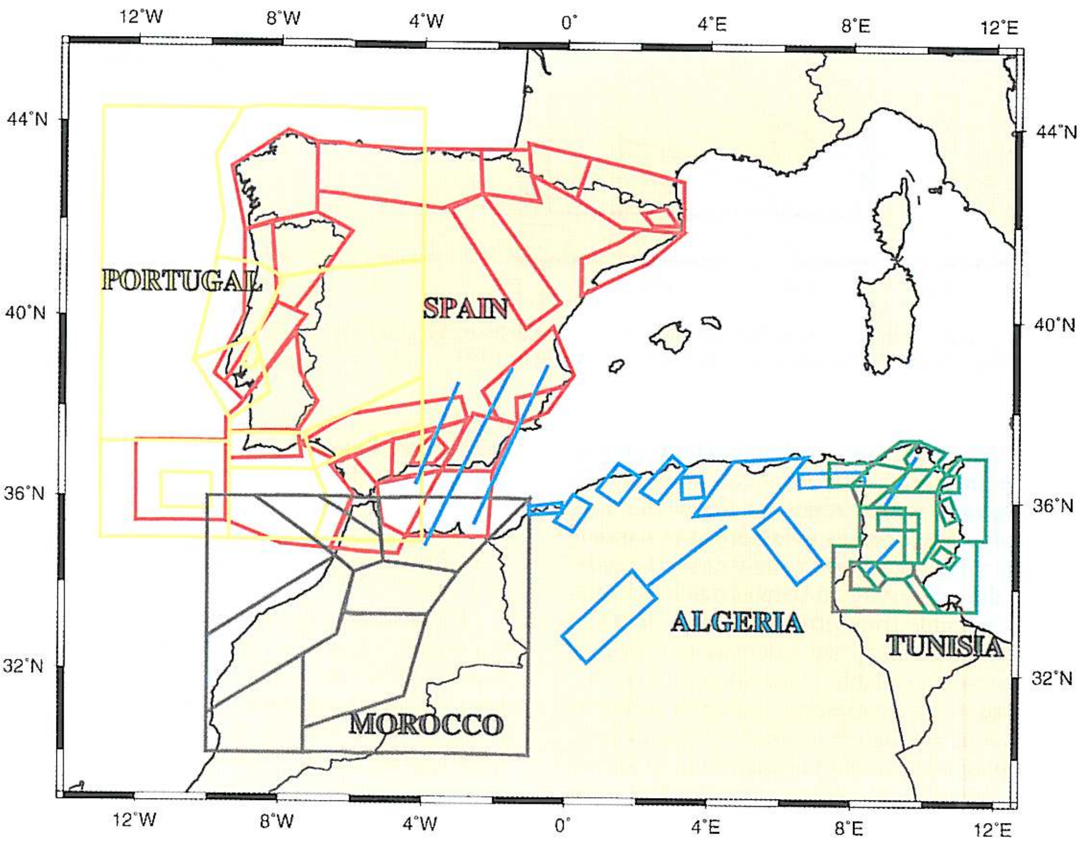

Fig. 1. Original earthquake source zones from each individual country in the Ibero-Maghreb region.

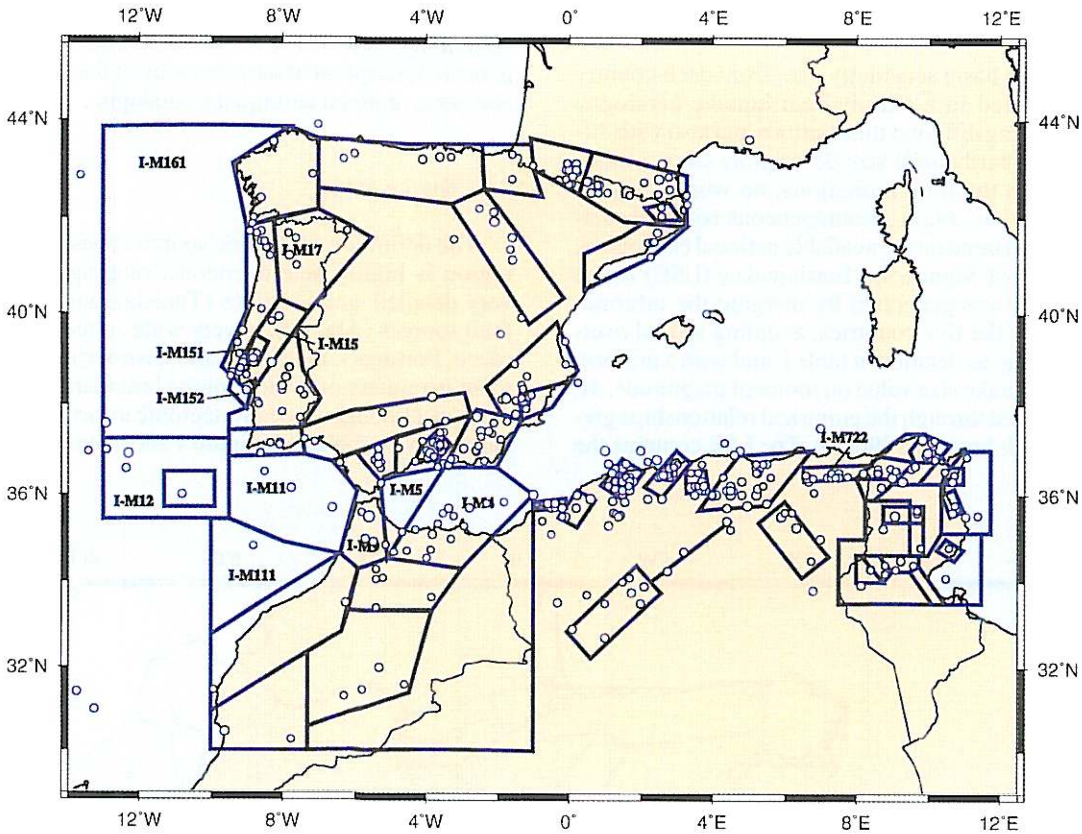

Fig. 2. Final distribution of earthquake source zones for the Ibero-Maghreb region, and epicenters of the generated List of Significant Earthquakes with $M \geq 4.5$ from 1900 to 1989.

inal source zones from each individual country.

The time limitations did not allow us to redefine regional source zones for the whole area, and only those sources overlapping at national borders were considered candidates to be redefined, although trying to keep as much information as possible from original sources, to avoid performing too many new calculations for which no time was available. New sources were defined based on the existing ones after technical discussions among the national representatives. Reshaping was carried out according to known main seismotectonic features and avoiding overlapping or duplicate zones. Figure 2, in which redefined sources are labeled, includes the final distribution of the Ibero-Maghreb regional seismic source zones together with the epicenters contained in the enclosed LSE.

2.3. *Seismicity parameters*

The seismicity parameters of the source zones from each country were provided in different format. Either the a and b values of the Gutenberg-Richter relationship (Morocco, Tunisia), or the b-value and the annual rate for a minimum earthquake size (Portugal, Spain), or the number of events by magnitude intervals (Algeria) were given. The seismicity parameters for the reshaped sources (those labeled in fig. 2) were obtained by keeping the original source *b*-value from which they originated, and further calculating earthquake occurrences according to the new reshaped area. A general recalculation was performed for all sources in order to obtain values in terms of moment magnitude, *M*, through the appropriate empirical relation from Johnston (1996a,b). In table II the main activity parameters (*i.e.* earthquakes/year km^2, *b*-value, and maximum magnitude) of the Ibero-Maghreb regional source zones are summarized.

Table II. Seismicity parameters of the earthquake source zones in the Ibero-Maghreb region.

Source zone	Earthquakes/year km^2 ($M >= 4$)	*b*-value	M_{max}	Source zone	Earthquakes/year km^2 ($M >= 4$)	*b*-value	M_{max}
S1	1.6×10^{-5}	0.89	6.7	M8	1.2×10^{-6}	0.53	6.0
S2	1.1×10^{-4}	0.97	7.0	M9	2.4×10^{-6}	1.05	5.0
S3	5.0×10^{-5}	0.97	6.7	M10	4.0×10^{-8}	0.55	4.6
IM4	2.1×10^{-5}	1.31	5.8	A1	3.4×10^{-5}	0.48	5.0
IM5	1.5×10^{-5}	1.68	4.7	A2	2.4×10^{-5}	0.51	5.8
S6	1.8×10^{-4}	0.96	7.0	A3	8.6×10^{-5}	0.64	7.3
S7	1.6×10^{-5}	0.96	6.4	A4	4.1×10^{-5}	0.45	6.5
S8	2.7×10^{-5}	0.83	5.5	A5	3.8×10^{-5}	0.59	6.5
IM9	4.1×10^{-6}	1.11	5.3	A6	1.4×10^{-5}	0.82	6.3
S10	6.8×10^{-6}	0.88	6.4	IM7.22	2.6×10^{-5}	0.64	6.0
IM11	6.1×10^{-6}	1.07	6.4	A8	4.4×10^{-6}	0.39	6.0
IM1.11	1.7×10^{-6}	0.58	5.5	A9	3.1×10^{-6}	0.49	5.5
IM12	1.6×10^{-5}	0.64	6.6	A10	3.5×10^{-6}	1.24	5.0
P6.1	4.2×10^{-5}	0.34	8.5	T1	3.3×10^{-5}	0.56	7.0
S13	1.1×10^{-5}	0.72	7.0	T2.1	1.6×10^{-5}	0.57	6.0
S14	1.2×10^{-5}	1.11	5.8	T2.2	2.3×10^{-6}	0.57	5.5
IM15	1.9×10^{-5}	0.78	7.0	T2.3	1.1×10^{-6}	0.58	5.5
IM15.1	4.3×10^{-5}	0.76	7.0	T3.1	1.0×10^{-5}	0.68	6.0
IM15.2	1.4×10^{-5}	0.95	7.2	T3.2	7.2×10^{-6}	0.69	5.5
S16	1.6×10^{-5}	1.04	5.5	T3.3	7.1×10^{-6}	0.68	6.0
IM16.1	1.1×10^{-6}	0.66	7.0	T3.4	2.9×10^{-7}	0.68	5.0
IM17	8.2×10^{-6}	0.98	5.3	T3.5	3.0×10^{-6}	0.68	6.0
S18	3.7×10^{-6}	0.87	5.3	T4.1	2.7×10^{-5}	0.43	6.5
S19	1.4×10^{-6}	0.80	5.3	T4.2	1.7×10^{-5}	0.43	6.5
S20	6.4×10^{-6}	1.02	5.8	T4.3	2.3×10^{-7}	0.44	5.5
S21	4.6×10^{-5}	0.95	6.7	T5.1	1.7×10^{-5}	0.62	6.5
S22	2.6×10^{-5}	1.07	6.4	T5.2	4.7×10^{-6}	0.62	6.0
S23	1.4×10^{-5}	1.25	5.5	T5.3	2.6×10^{-6}	0.62	6.0
S24	2.7×10^{-6}	0.67	5.8	T5.4	3.8×10^{-7}	0.62	5.0
S25	3.1×10^{-5}	0.71	6.4	T5.5	1.8×10^{-6}	0.63	5.5
M5	6.2×10^{-7}	0.58	5.1	T5.6	1.3×10^{-5}	0.62	6.0
M6	3.3×10^{-6}	0.75	4.7	T6.1	5.9×10^{-6}	0.50	5.0
M7	4.0×10^{-7}	0.88	5.2	T6.2	1.7×10^{-7}	0.49	5.5

Table III. Attenuation relationships used in the Ibero-Maghreb region.

Country	Attenuation law
Algeria	$PGA = (190.67\, e^{0.823\, M}) / (R + 0.864\, e^{0.463\, M})1.561$
Morocco	$\log PGA = -1.02 + 0.25\, M - 0.00255\, (R^2 + 7.3^2)^{1/2} - \log(R^2 + 7.3^2)^{1/2}$
Portugal	$I = 6.8 + 1.13\, M - 1.68 \ln (R + 14)$
Spain	$I = I_0 + 12.55 - 3.53 \ln (R + 25)$
Tunisia	$PGA = (5600\, e^{0.8\, M}) / (R + 40)^2$

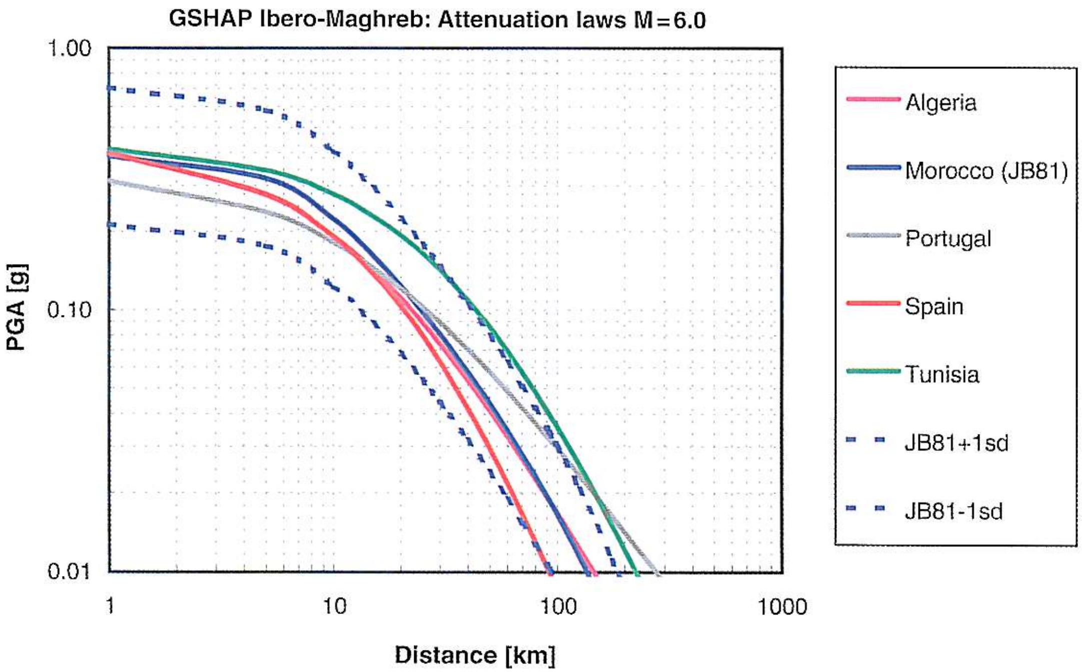

Fig. 3. Selected attenuation relationships from each country in the Ibero-Maghreb region.

2.4. *Attenuation laws*

While in some countries only one attenuation law was used to obtain the available national maps (Algeria, Morocco, Tunisia), others considered several regional laws to apply to different sources (Portugal, Spain). A special case corresponds to the Atlantic offshore sources west of the Iberian Peninsula for which both, Portugal and Spain, assume a very specific low attenuation relation for the strong earthquakes taking place there (*i.e.* Lisbon 1755).

Some differences also existed in the parameters based on which the individual attenuation laws were given. Some included PGA in terms of magnitude, M, and distance, R, (Algeria, Morocco, Tunisia), while in other cases the ground motion parameter considered was intensity, I, either in terms of magnitude and distance (Portugal), or epicentral intensity, I_0, and distance (Spain). For these latter cases, it was agreed to obtain PGA in g-units through the empirical relationship log PGA = 0.30 I – 3.22, included in the Spanish Building Code NCS-94 (IGN, 1995). Table III includes all the attenuation relationships used in the region. In the case of Portugal and Spain, only the general one for land sources is included. These same laws are plotted in fig. 3 for a magnitude M = 6.0 earthquake.

For the calculations in the final map, in order to keep a minimum of homogeneity, only one attenuation law was considered. Since a regional law based on good and enough acceleration data was lacking, the relationship proposed by Joyner and Boore (1981) was chosen. This relationship could roughly represent an average of the different laws used in the region, as it can be observed in fig. 3. The hazard calculations were performed considering one standard deviation in log PGA.

3. Seismic hazard computation and results

As a first step, and based on the input data provided by the national representatives, preliminary seismic hazard maps of each country in the region were produced by the ICTJA-CSIC team using SEISRISK III. The maps were compared with existing national maps when available, and if not, obtained results were discussed with the

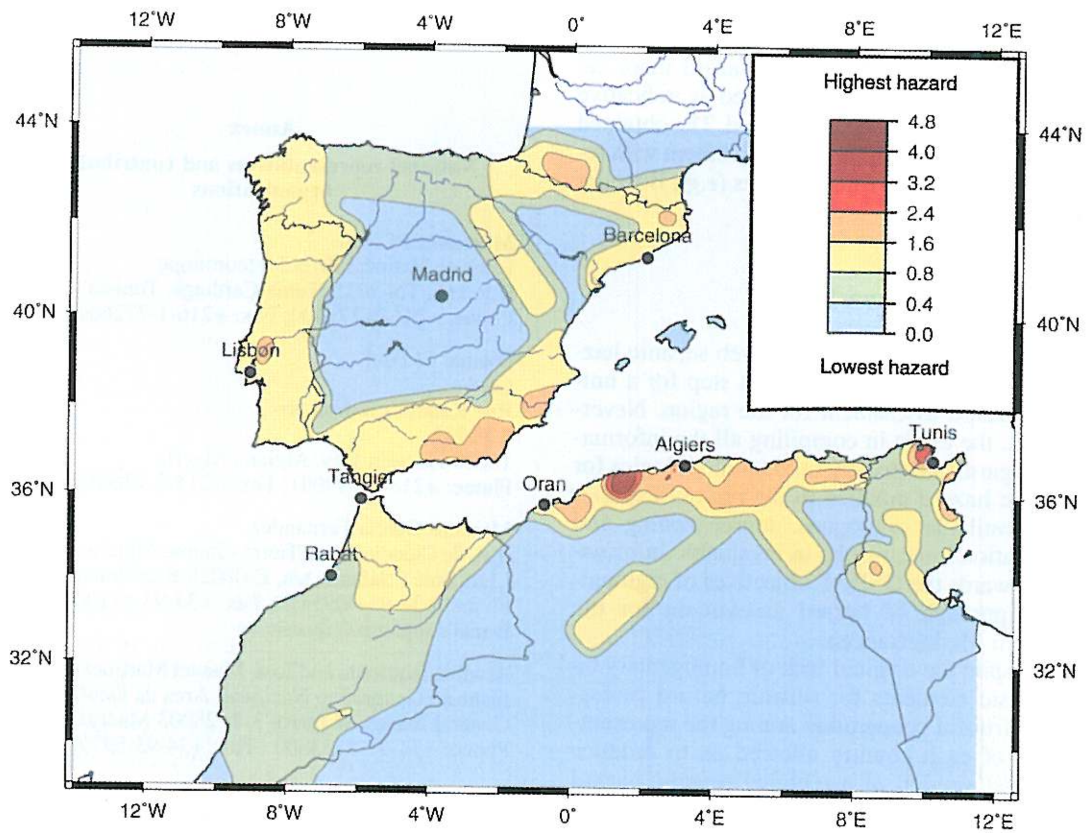

Fig. 4. Earthquake hazard map of the Ibero-Maghreb region. PGA (m/s²) with 90% probability of non-exceedance in 50 years.

national representatives in order to achieve a general agreement on its validity. The observed differences should arise either from the computation algorithm or from those simplified procedures that had to be applied in some particular cases (*e.g.*, using only one attenuation law for Spain).

The final seismic hazard map of the Ibero-Maghreb region in terms of PGA, in m/s^2, with a 90% probability of non-exceedance in 50 years is shown in fig. 4, with color-coded contouring.

The highest expected hazard corresponds to El Asnam region in Algeria (3.5 ms^{-2} or 0.36 *g*). Values between 2.5-3.0 ms^{-2} are found in Alger region, Algeria, and in Tunis-Bizerte and Chardimaou-Bou Salem regions, in Tunisia. Sour El Ghozlane and Mostaganem regions, in Algeria, and Granada and Alicante-Murcia regions, in Spain show values between 2.0-2.5 ms^{-2}.

Although having followed a simplified procedure, this regional Ibero-Maghreb hazard map is representative as a relative hazard map, *i.e.* PGA values should be considered as indicative of regional relative seismic hazard. The obtained results as a whole are in good agreement with recently published regional studies (*e.g.*, Benouar *et al.*, 1996).

4. Concluding remarks

This computed Ibero-Maghreb seismic hazard map constitutes only a first step for a uniform hazard assessment for the region. Nevertheless, the effort in compiling all the information regarding currently used methodologies for seismic hazard practice in the region, together with available catalogues, source zoning and attenuation laws, results in invaluable information towards the GSHAP objectives of regionalized approach of hazard assessment for the Western Mediterranean.

Despite the original lack of homogeneity on the basic elements for seismic hazard assessment, fruitful cooperation among the representatives of each country allowed us to produce this first version of a regional seismic hazard map. For the first time, a map of regional seismic source zones is presented, and agreement on a common procedure for hazard computation in the region has been achieved.

Further joint regional efforts are still needed for seismic hazard assessment studies in the Ibero-Maghreb region based on a homogeneous regional earthquake catalogue. Ongoing initiatives in the Mediterranean like the CEPRIS Council of Europe OPA-center, the UNESCO IGCP-project SESAME, the UNESCO/USGS-project RELMER, and the ESC Working Group on Seismic Hazard might profit both from these results and from the established close cooperation attained in the framework of GSHAP; as well as contribute to future regional studies.

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Annex

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