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Deaggregation in Magnitude, Distance, and Azimuth in the South and West of the Iberian Peninsula

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Abstract We present the results of the seismic deaggregation in 15 of the most important cities with the greatest seismic hazard in the south and west of the Iberian Peninsula (Spain and Portugal). The deaggregation was carried out based on the calculation of the seismic hazard in the zone, taking into account the peak horizontal acceleration with 10% probability of exceedance in 50 years (return period of 475 years).

We first performed a deaggregation study in terms of magnitude and distance in order to subsequently carry it out in azimuth. The aim of both studies is to determine the relative contribution of the different seismic foci and sources to the seismic hazard in a given location. Due to the lack of enough seismotectonic data in the study region, we could not obtain information about the contribution of specific active faults and we have not been able to include a characteristic earthquake model. However, by starting from a calculated hazard using smoothed background seismicity, it is possible to determine the contribution of the different seismic foci of the region to the seismic hazard at each location.

The results reveal that there are cities where the hazard is entirely, or almost entirely, due to the local seismicity (e.g., in Portugal: Lisbon, 87%; Coimbra, 82%; in Spain: Almería, 99%; Córdoba, 99%; Granada, 99%). We have also determined that there are cities where seismic foci at 200 km away or more can be the most important or at least contribute significantly to the hazard (e.g., Beja and Faro in Portugal and Cádiz and Huelva in Spain).

Introduction

The method used to calculate the seismic deaggregation in terms of magnitude and distance is that proposed by Berneuter (1992) for calculating the control earthquake. This method was subsequently recommended by the Senior Seismic Hazard Analysis Committee (SSHAC) (1997), among others, as a means of simplifying the understanding of the results obtained in an analysis of seismic hazard.

We begin by calculating the seismic hazard, using spatially smoothed seismicity, for the Iberian Peninsula (Peláez, 2000; Peláez and López Casado, 2002). This methodology was proposed by Frankel (1995) and Frankel *et al.* (1996) and was used here with certain modifications. We delimited the seismicity of the area in seismic sources and smoothed the parameters b and $m_{\max}$ of the truncated Gutenberg–Richter relationship (Cosentino *et al.*, 1977) in each of the sources, as proposed by Bender (1986).

We also regionalized the attenuation relationships in the Iberian Peninsula and its surrounding areas (López Casado *et al.*, 2000a). Five types of intensity attenuation relationships are used for 11 specific regions, with mean attenuation coefficient (absorption coefficient) (Howell and Schultz, 1975) values that range from 0.0009 to 0.0828 km^{-1}. Macroseismic information from 257 earthquakes was used for this. The regionalization is clearly correlated with the seismotectonic characteristics of each region (low and very low attenuation in Hercynian domains, and high and very high attenuation in Alpine and certain Neogene domains). In addition, this ensures a decrease in the uncertainties in seismic hazard evaluations (López Casado *et al.*, 2000a). When necessary, the relationship between macroseismic intensity and horizontal peak ground acceleration proposed by Murphy and O'Brien (1977) is adopted.

We were unable to include a model of the characteristic earthquake because in the study region it was impossible to specifically associate the earthquakes with active faults at the moment. Instead, we incorporated a model of historical seismicity, including the most destructive earthquakes in the area. The knowledge of active faults in Spain is far from being complete. For example, there are regions where the existence of faults, active or not, is unknown. This is due to several reasons. On one hand, the mapping is not detailed enough in some regions. On the other hand, and given the seismicity observed in some areas, there are faults that certainly exist, but they are not visible at the surface because of being blind faults or hidden by soft materials. Systematic studies are starting to be carried out in some interesting zones, but they are not complete enough yet to be included in these type of hazard and deaggregation studies.

We have not considered necessary to include a uniform background zone because of the historical extension and the spatial quality of the used catalog. Moreover, including this model would imply a hazard decrease in the most active zones. In short, four models were initially included (Fig. 1): those with a seismicity of (1) $M \geq M_S$ 5.5 after 1300; (2) $M \geq M_S$ 4.5 after 1700; (3) $M \geq M_S$ 3.5 after 1920; and (4) $M \geq M_S$ 2.5 after 1960. To the hazard generated by these four models (which included only shallow seismicity), we added that generated by a fifth model that included the intermediate depth seismicity in the zone, that is, seismicity from 30- to 60-km depth with $M \geq M_S$ 2.5 after 1960. Finally, the subjective weights contributed by each model were not taken as constant but as a function of the exposure time, assuming in all cases that the models comprising a time interval comparable to the exposure time provide the most important contribution. The weights used for the first four models, for a 475-year exposure time, are 0.3, 0.3, 0.2, and 0.2, respectively.

The result for the seismic hazard in the study area is shown in Figure 2, where the mean peak horizontal acceleration is given with a 10% probability of being exceeded in 50 years (Peláez and López Casado, 2002). Table 1 presents the expected acceleration specifically for each of the 15 cities where the deaggregation calculation has been performed, the most important cities in the south and west of the Iberian Peninsula. The acceleration ranges from 0.13*g* for Málaga (Spain) to 0.31*g* for Lisbon (Portugal). Figure 3 gives the most important earthquakes felt that affect the hazard in the area. That is, those with a magnitude of over M_S 5.5 ($I_{MM} \approx$ VIII–IX, in accordance with the relationships of López Casado *et al.* (2000b)), that occurred after 1300, and those with a magnitude of over 4.5 M_S ($I_{MM} \approx$ VII–VIII) that occurred after 1700. We have used the catalogs for the area of Mezcua and Martínez Solares (1983) and Laboratório Nacional de Engenharia Civil (LNEC) (1986), updated to 1999 and modified with our own data (e.g., we have assigned macroseismic magnitudes to historical earthquakes by using magnitude–intensity relationships or isoseismal maps).

Since the intensity attenuation model used lacks spectral

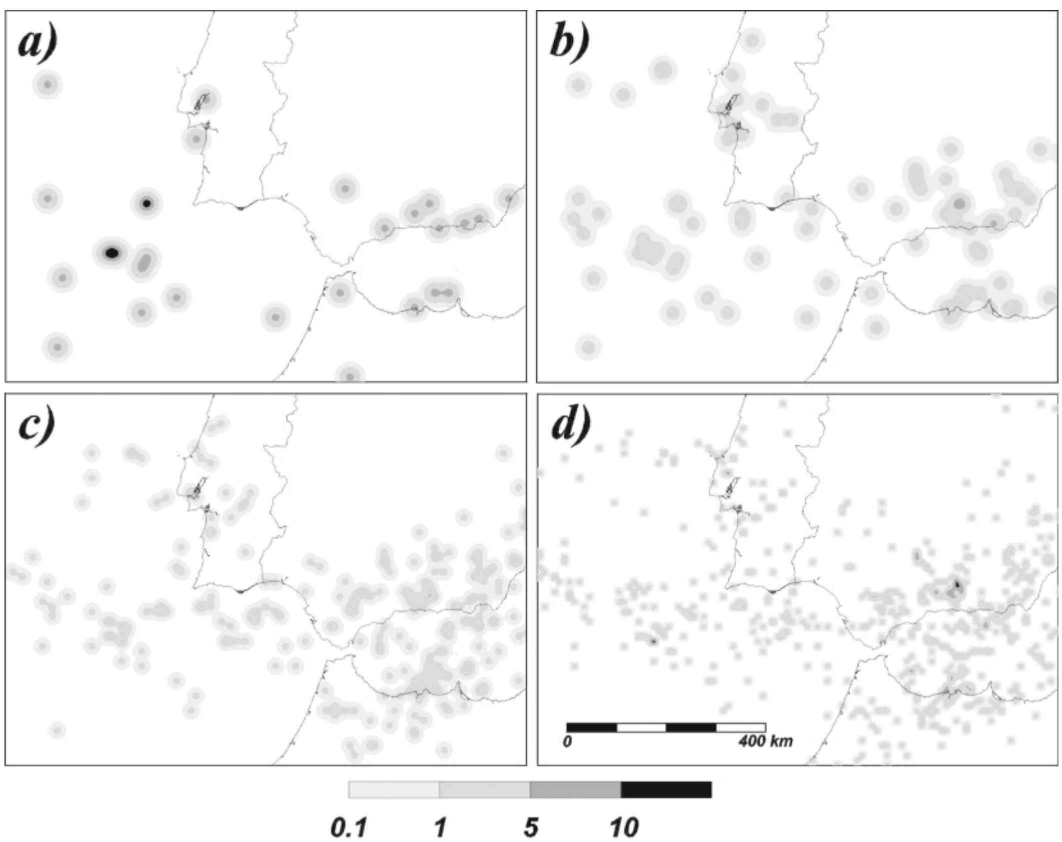

Figure 1. Maps showing shallow smoothed seismicity derived from (a) M_S 5.5 and larger earthquakes since 1300 (correlation distance of 15 km); (b) M_S 4.5 and larger since 1700 (correlation distance of 15 km); (c) M_S 3.5 and larger since 1920 (correlation distance of 10 km), and (d) M_S 2.5 and larger since 1960 (correlation distance of 5 km). The maps represent the number of earthquakes above M_S 2.5 in a 10-km square-grid cell for 100 years and normalized to the last model.

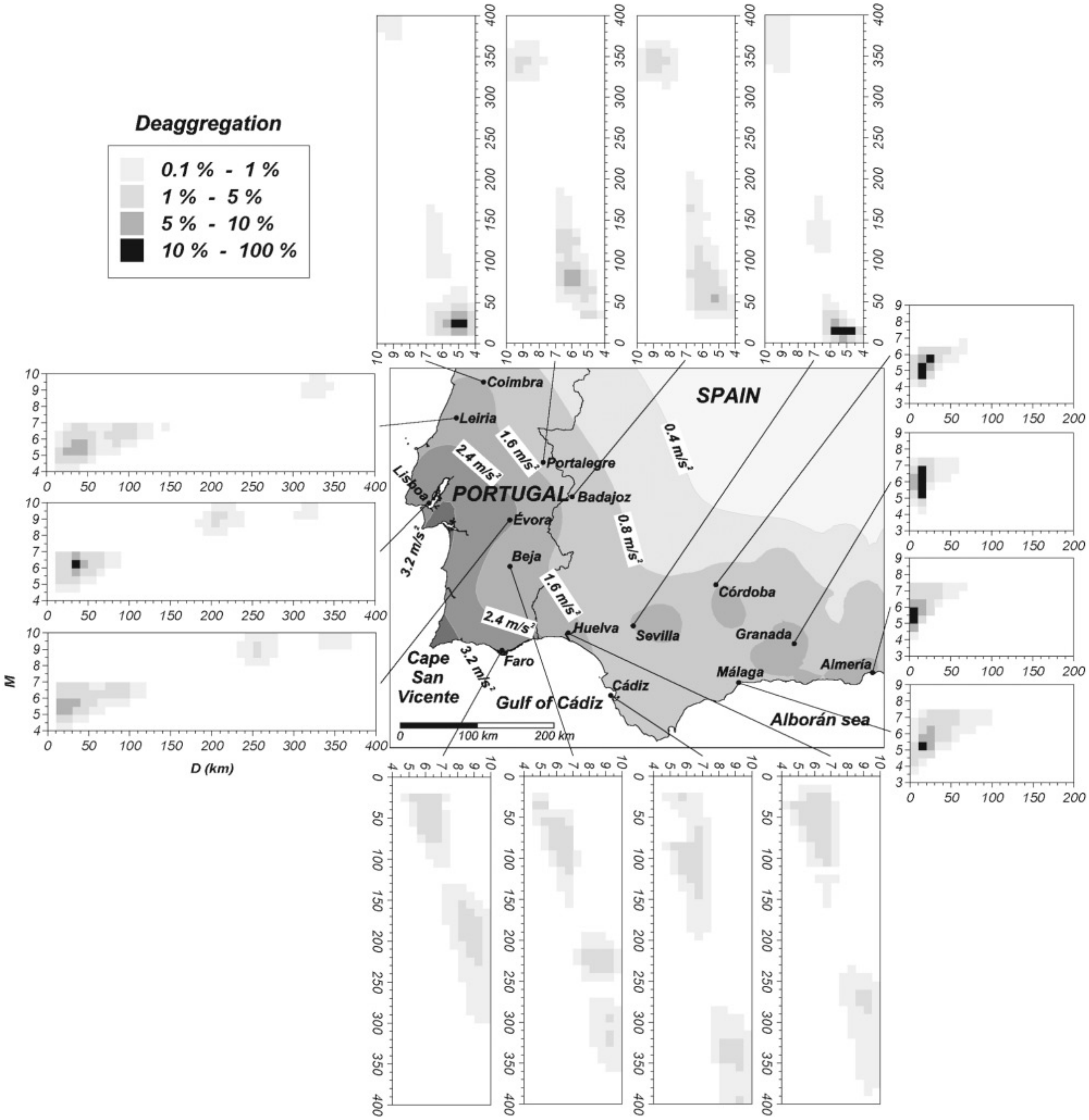

Figure 2. Seismic hazard (peak horizontal accelerations) for the area and deaggregation for the selected cities with 10% probability of exceedance in 50 years.

information, we have not performed the deaggregation in periods, in contrast to recent works (McGuire, 1995; Bazzurro and Cornell, 1999; Harmsen *et al.*, 1999; Harmsen and Frankel, 2001). We are aware, as commented by Chapman (1995), that it is desirable to calculate the control earthquake or modal event for different periods, as the maximum of the hazard density function depends on the oscillator frequency. We are considering to carry out seismic hazard studies in the Iberian Peninsula for different spectral accelerations, but the difficulty is the choice of the right attenuation models compatible with the attenuation characteristics of the region. We are planning this for the near future.

Also, due to the regionalization of the attenuation relationships, we have not deaggregated in ε (ground-motion uncertainty). In general, the hazard and the deaggregation in each location are due to the effects of the seismicity in the regions considered with different attenuation relationships, and consequently, with different ground-motion uncertainty.

Table 1
Expected Acceleration, Modal, and Mean Magnitudes and Distances, and Contribution H to the Hazard of the ($\hat{M}$, $\hat{D}$) Pair for the Selected Cities having a 10% Probability of Being Exceeded in 50 Years

City (from N to S)	a (cm/sec^2)	$\hat{M}$	$\hat{D}$ (km)	H(%)	$\bar{M}$	$\bar{D}$(km)
Portugal						
Coimbra	159	4.5–5.0	20–30	12	5.4	47
Leiria	199	5.0–5.5	30–40	9	5.8	60
Portalegre	140	5.5–6.0	70–80	7	6.3	120
Lisboa	308	6.0–6.5	30–40	12	6.4	58
Évora	244	5.0–5.5	10–20	8	6.2	62
Beja	199	6.0–6.5	70–80	4	7.3	156
Faro	274	6.0–6.5	40–50	5	7.5	123
Spain						
Badajoz	131	5.0–5.5	50–60	6	6.2	122
Córdoba	144	4.5–5.0	10–20	22	5.3	20
Sevilla	165	5.0–5.5	10–20	19	5.8	50
Huelva	194	5.5–6.0	30–40	5	6.8	117
Granada	220	5.5–6.0	10–20	21	6.0	15
Almería	171	5.0–5.5	0–10	21	5.9	12
Málaga	127	5.0–5.5	10–20	11	5.9	28
Cádiz	133	6.0–6.5	110–120	5	7.4	200

The so-called beta earthquake (McGuire, 1995), given by the triple (M, D, ε), is not as easy to interpret as when a single attenuation relationship is used.

In this study we present the deaggregation of the mean peak horizontal acceleration in terms of magnitude and distance, as well as in longitude and latitude (in azimuth). Based on these deaggregation results, we can determine, for different locations, the so-called control earthquake (Bernreuter, 1992), the design earthquake (McGuire, 1995), the modal event (Chapman, 1995) or the dominant event (Bazurro and Cornell, 1999). To do so, we use the average values of the magnitude and distance ($\bar{M}$, $\bar{D}$) or the modal values of these two variables ($\hat{M}$, $\hat{D}$). Bazurro and Cornell (1999) termed this the 2D hazard deaggregation technique. The expression proposed by Bernreuter (1992) is used in this work to calculate $\bar{D}$:

$$\log \bar{D} = \sum_m \sum_d H_{md} \log d \Big/ \sum_m \sum_d H_{md}, \tag{1}$$

where m is the magnitude, d the distance, and H_{md} is the contribution to the seismic hazard of the magnitude m ($m \pm \Delta m/2$) at a distance d ($d \pm \Delta d/2$) from the location.

The problem of using the average value of the magnitude and distance as a representative value of the control earthquake has been amply treated in Bazurro and Cornell (1999). We recommend the calculation of both the average and the modal values, assuming that the latter are more representative when applied to the seismoresistant design and the calculation of the safe shutdown earthquake, as well as when considered in the construction of response spectra. Nonetheless, a comparison between the pairs of values ($\bar{M}$, $\bar{D}$) and ($\hat{M}$, $\hat{D}$) is a simple and fast way of determining whether the sources generating the hazard in a particular area are many and heterogeneous, because different values will crop up depending on which criterion is used.

The method used to calculate seismic hazard (Frankel, 1995; Peláez, 2000; Peláez and López Casado, 2002) is ideal for calculating deaggregation. The same cells and intervals of magnitude used to calculate the aggregation of seismic hazard can also be used to calculate the deaggregation. The deaggregation is calculated by multiplying the relative contribution to the hazard of each cell by the weight assigned to each of the models for calculating seismic hazard (e.g., Harmsen *et al.*, 1999). The results are presented, for calculating the deaggregation in terms of magnitude and distance, using magnitude intervals of 0.5 M_S units, the value recommended by Bernreuter (1992), SSHAC (1997), and U.S. Nuclear Regulatory Commission (USNRC) (1997), and a linear distance increment of 10 km (size of the cells used in calculating the hazard). The fact of using a linear distance step instead of a logarithmic one is done to simplify the deaggregation calculation. With this criterion, it will be very difficult that the modal dominant event belongs to very distant zones, even if those zones contribute significantly to the hazard. In contrast, the mean dominant event calculation will be less subjective because it will not depend on the adopted step. In any case, the geographic deaggregation will show the total contribution of each seismic focus.

Although the minimum magnitude used to calculate and represent the deaggregation is the same as that chosen to calculate the hazard, M_S 2.5 (m_b 3.6 in the study region, according to the relationship of López Casado *et al.* (2000b)), the results are actually extremely interesting for magnitudes above M_S 4.5. However, the fact that we are using a macroseismic M_S magnitude, resulting from a relationship between macroseismic intensity and M_S magnitude (López Casado *et al.*, 2000b), implies that we shall obtain magnitude values above M_S 9.0. For example, the 1755 Lisbon earthquake, assumed by some authors to be the biggest earthquake ever felt in the world, reached a magnitude of M_S 9.4 on this macroseismic scale, using XII (MSK scale) as their epicentral intensity for calculating the seismic hazard.

Finally, the calculation of the deaggregation in longitude and latitude (azimuth) is carried out using the same cells as in the hazard calculation.

Deaggregation: Results

The plots of the results of the deaggregation in terms of magnitude and distance can be seen in Figure 2. The results of the average and modal magnitude and distance values for the control earthquake are given explicitly in Table 1. Figures 4 and Figures 5 show the results obtained for the deaggregation in azimuth as plots, directly illustrating the contribution of each cell to the calculation of seismic hazard. Taking Figures 2, 4, and Figures 5 together, it is easier to discuss the contribution of the different seismic zones to the calculated hazard for each of the locations of interest.

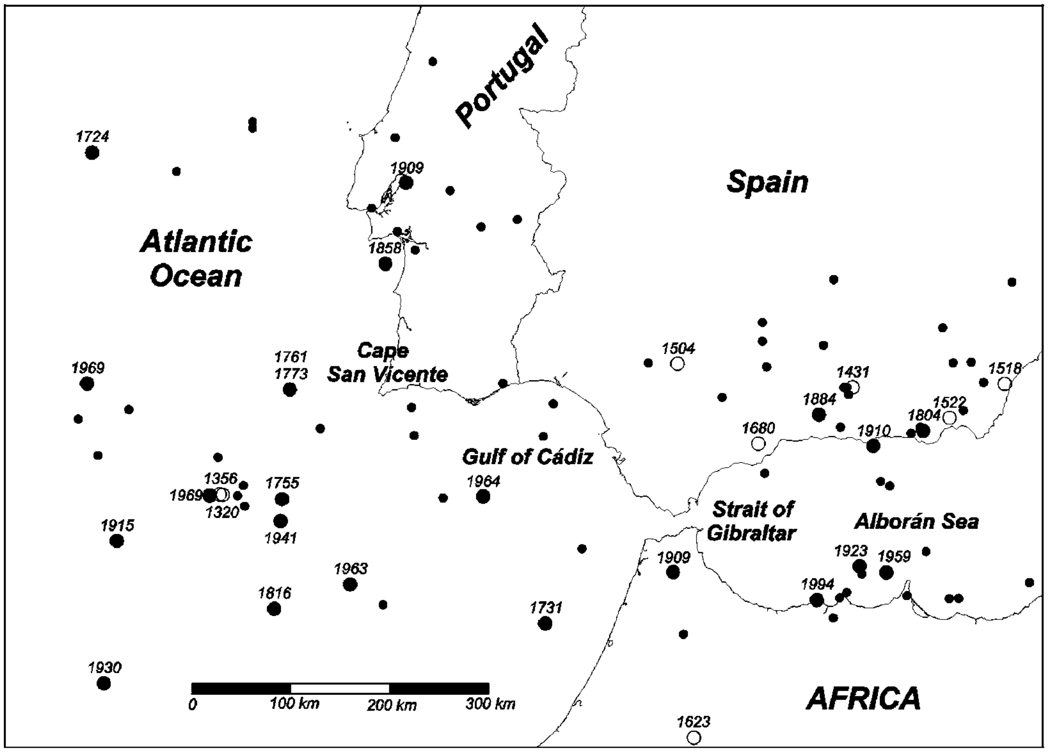

Figure 3. Seismicity map showing $4.5 \leq M_S < 5.5$ (small filled circles) and $M_S \geq 5.5$ (large filled circles) earthquakes since 1700 and $M_S \geq 5.5$ earthquakes since 1300 (large open circles).

The relative contribution of each of the seismic sources to the hazard at each location is detailed in Table 2.

Three different deaggregation morphologies can be observed for the distinct cities (see Fig. 2). First, we can note deaggregations formed by a single lobe (as in the cities of Córdoba, Granada, Almería, and Málaga, in Spain), where hazard is due exclusively to a single local seismic zone or focus, more or less extensive, surrounding the city. In this case, using the average or modal values to calculate the control earthquake provides values that nearly coincide.

In another group of cities, there is also a main lobe with the same characteristics mentioned above generating most of the hazard. However, one or two secondary lobes begin to appear that generate a small, though not inconsequential, amount of hazard. Such is the case of the cities of Sevilla and Huelva in Spain and of Coimbra, Lisbon, and Évora in Portugal. These secondary lobes, of less importance with respect to their contribution to the hazard, can nonetheless mean a noticeable difference between the control earthquakes calculated using the average or modal values in some cases (Table 1).

The third and last group comprises cities that do not lie within the seismic zone or focus that generates the highest hazard in the location but lie instead at distances of 50–100 km away. In this category, secondary lobes that can have considerable importance also appear. The cities of Badajoz and Cádiz, in Spain, and Beja and Faro, in Portugal, can be included in this group. In the case of Beja, the greatest contribution to the hazard is produced by a seismic focus more 200 km away from the city (Table 2). The fact that these cities are exposed to a wide range of potential damaging earthquake scenarios implies that the hazard and the deaggregation analysis remain incomplete if only the peak ground acceleration is considered. Future efforts should be addressed to conduct these studies for the pseudo spectral acceleration.

Referring to the control earthquake calculated for each of the locations (Table 1), and based on the modal values obtained, we have observed the following.

First, in 11 of the 15 cities studied (Coimbra, Leiria, Lisbon, Évora, and Faro, in Portugal, and Córdoba, Sevilla, Huelva, Granada, Almería, and Málaga, in Spain), the dominant event in these locations is produced less than 50 km away, with a magnitude of M_S 4.5–6.5. In the cases of Faro and Huelva, using average values instead of modal ones would provide different results because of the appearance of somewhat important secondary lobes. In these cases, the $\overline{D}$ values are on the order of 120 km, and the values are around M_S 6.8–7.5. In contrast to the other cities mentioned, where nearby seismic foci dominate in the calculation of seismic hazard, in these two cases we cannot ignore this hazard generated at distances of about 150–250 km away (in the case of Faro) or 250–300 km away (in the case of Huelva) from the location (see Fig. 2). In both cases, the seismic foci re-

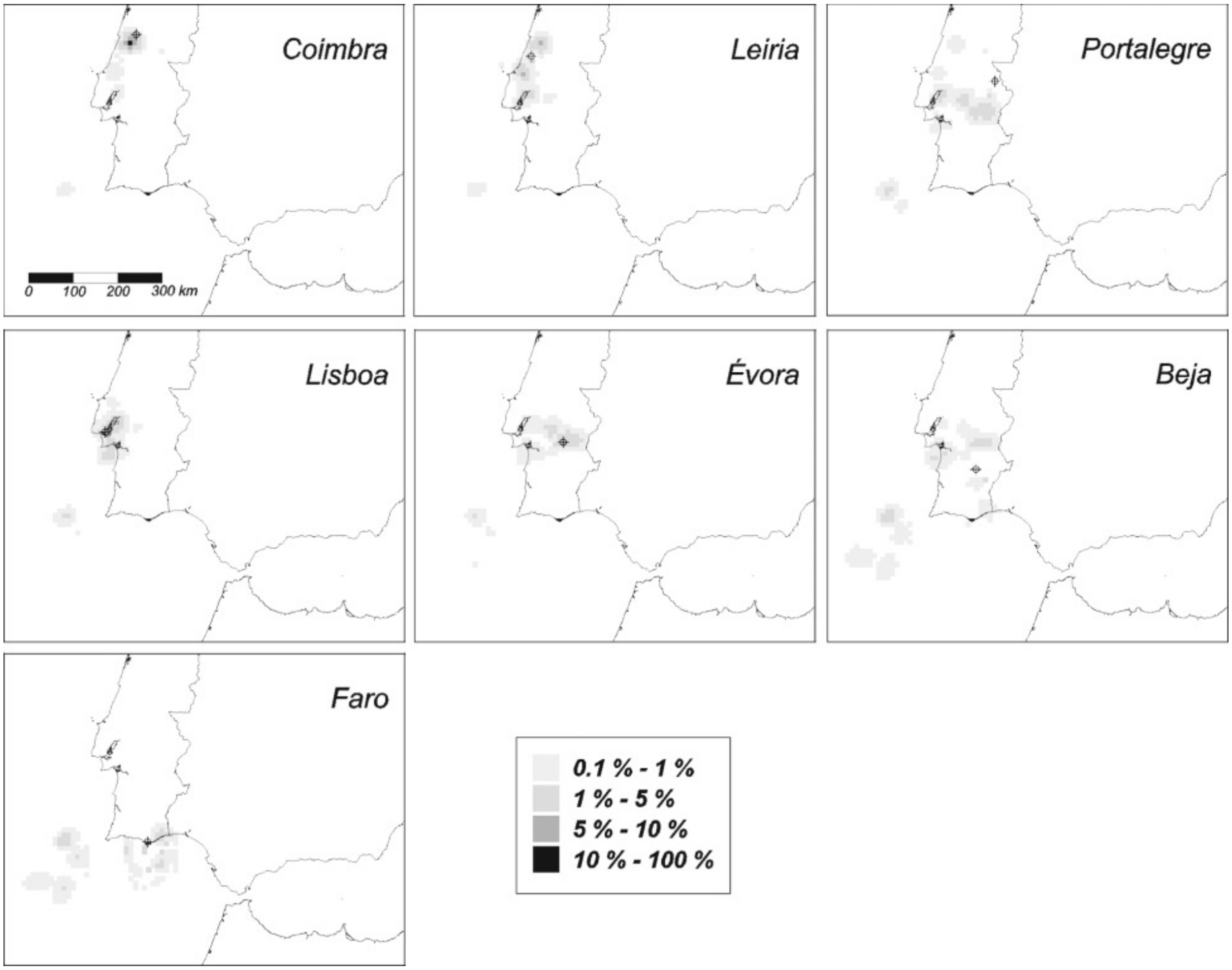

Figure 4. Deaggregation in azimuth for the selected cities of Portugal.

sponsible are those observed west and southwest of Cape San Vicente. We shall discuss this in more detail below.

In a second group of three cities (Portalegre and Beja, in Portugal, and Badajoz, in Spain), there is a control earthquake produced 50–100 km from the location with a magnitude of M_S 5.0–6.5. The average values obtained for these cities give $\overline{D}$ values of 120–160 km and a value of M_S 6.2–7.3. In these cities the secondary lobes are even more important than in the first group of cities. Once again, the seismic foci west and southwest of Cape San Vicente are the source of these values for the control earthquake, when considering the average values of magnitude and distance.

Finally, the special case of the city of Cádiz must be mentioned. The control earthquake for this city is one produced some 110–120 km away, with a magnitude of M_S 6.0–6.5. In contrast, the average distance and magnitude provide values of 200 km and M_S 7.4, respectively. Of all the cities studied, this one is the most strongly affected by distant seismicity, including that from the Gulf of Cádiz, and the seismic foci southwest of Cape San Vicente, 320–350 km away.

To conclude the discussion of the results for the deaggregation, we cannot disregard the hazard observed in several of the cities with magnitudes above 8.0, which in some cases is truly significant (e.g., 1755 Lisbon earthquake).

Only four of the earthquakes included in the hazard and deaggregation analysis have a magnitude equal to or above 8.0. The most recent was on 28 February 1969 (200 km southwest of Cape San Vicente), with a recorded magnitude of M_S 8.0 (National Geophysical Data Center). From this earthquake we have no accelerograms. It was not until 1989 that the Spanish national strong-motion digital network recorded an earthquake (Carreño *et al.*, 1991). The other three earthquakes have been assigned (Molina, 1998; Peláez, 2000) a macroseismic magnitude M_S, based on the epicentral intensity I_o recalculated for the evaluated seismic hazard, using the relationships for the region obtained by López Casado *et al.* (2000b). These earthquakes occurred on 9 December 1320 (200 km southwest of Cape San Vicente), having a M_S 9.4 macroseismic magnitude; on 1 November 1755 (150 km southwest of Cape San Vicente), having a M_S 9.4 macroseismic magnitude, and on 2 February 1816 (250 km south-southwest of Cape San Vicente), having a M_S 8.2 macroseismic magnitude. The locations of these last three historical earthquakes are given by Mezcua and Martínez So-

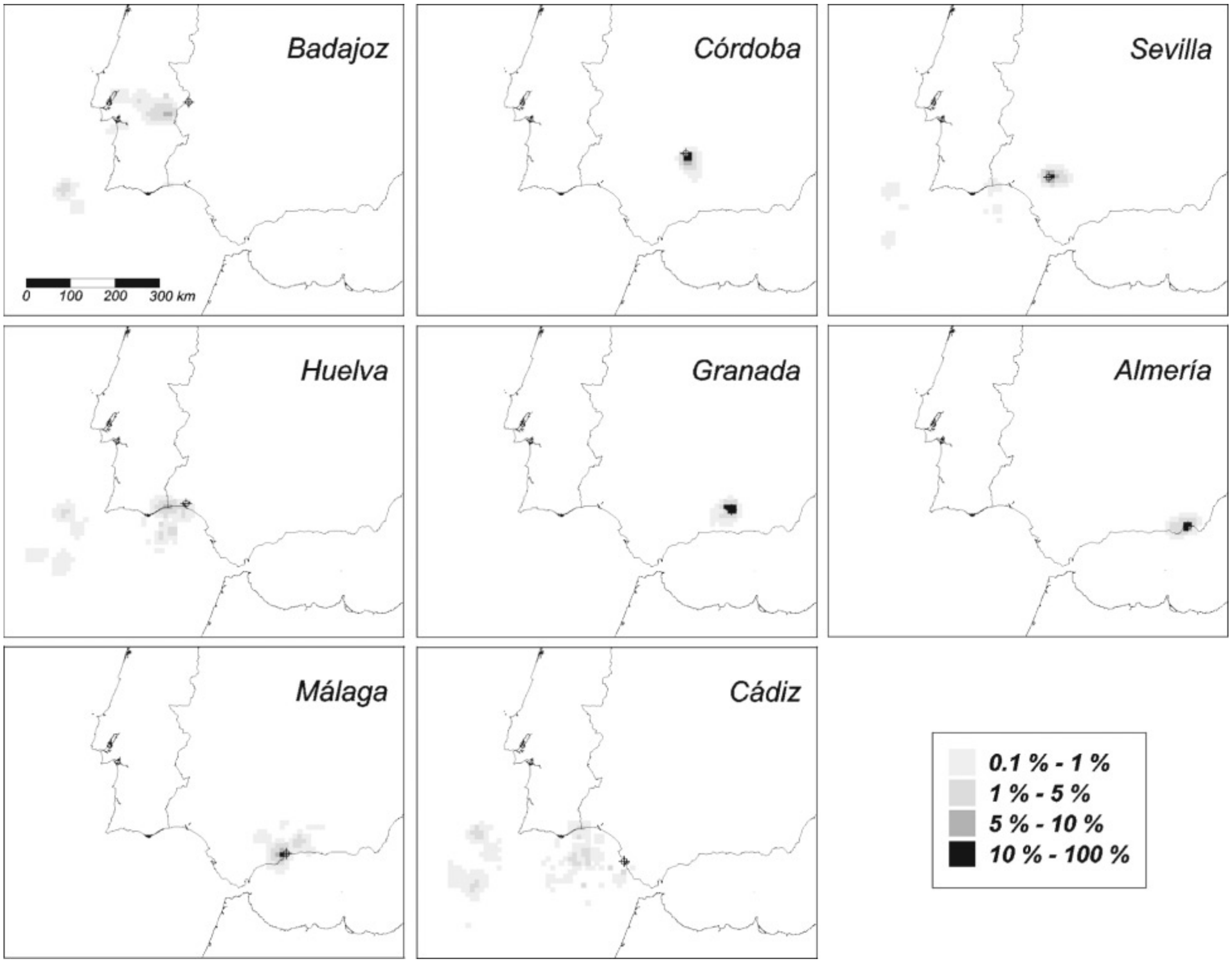

Figure 5. Deaggregation in azimuth for the selected cities of Spain.

lares (1983) and LNEC (1986). They were obtained from isoseismal maps, although they coincide with the epicenters of other important earthquakes recorded in the area. They are therefore evidently affected by a degree of uncertainty that is not easily quantifiable but that has been considered to a certain extent in the seismic hazard and deaggregation analysis since we have used a method that spatially smoothes the seismicity (Frankel, 1995; Peláez and López Casado, 2002). The four earthquakes are in the same area, a zone of some 20,000 km^2 that lies 150–250 km SW–SSW of Cape San Vicente (Fig. 2).

There are several cities where this seismic focus (these four earthquakes) significantly contributes to the seismic hazard: Faro (this focus alone contributes 42% of the total seismic hazard in the city), Beja (40%), Cádiz (39%), and Huelva (25%). Other cities are also affected, albeit to a less extent: Badajoz (16%), Portalegre (12%), Lisbon (10%), Évora (10%), and Sevilla (8%). The contribution is small for the cities of Leiria (4%) and Coimbra (3%), whereas it is below 1% for the other cities.

The obtained results do not change significantly when using different exposure times. This is due to the own properties of the hazard calculation method, the nonuse of the characteristic earthquake model, and the fact that results have been computed only for the peak ground acceleration. The geographic deaggregation for different periods of the pseudo spectral acceleration does depend on the exposure time.

Deaggregation: Summary and Conclusions

We have presented the results of the deaggregation of the peak horizontal acceleration, with a return period of 475 years, in magnitude and distance and in longitude and latitude, for 15 of the most important cities in the south and west of the Iberian Peninsula, within the area of greatest seismic hazard in the region.

The results are presented in different ways: (1) plots showing the deaggregation in terms of magnitude and distance, indicating the relative contribution of each cell (ΔM, Δd); (2) plots showing the deaggregation in azimuth, giving the relative contribution of each cell ($\Delta\phi$, $\Delta\lambda$); and (3) the control or design earthquake, calculated using both the average and modal values of the magnitude and distance variables.

Table 2
Seismic Foci, Range of Distances ΔR to these sources, and Contribution H to the Hazard for the Selected Cities Having a 10% Probability of Being Exceeded in 50 Years

City (from N to S)	Main Seismic Focus	ΔR (km)	H (%)	Secondary Seismic Focus	ΔR (km)	H (%)
Portugal						
Coimbra	Seismic focus southwest of the city*	10–50	77	Seismic focus southwest of Leiria[†]	~90	5
Leiria	Surrounding and seismic focus northeast of the city*	<50	42	Surrounding and seismic focus southwest of the city[†]	<50	34
Portalegre	Seismic focus south-southwest of the city[‡]	30–90	47	Seismic focus west-southwest of the city[§]	70–90	17
Lisboa	Surrounding and region north of the city[‖]	<50	52	Surrounding and region south of the city[#]	<60	35
Évora	The city and its surrounding, and a region east of the city[‡]	<40	57	Seismic focus northwest of the city[§]	30–50	16
Beja	Seismic focus at 100 km west of the Cape San Vicente**	210–240	29	Seismic focus east of Évora[‡]	60–80	22
Faro	Scattered seismicity in the Gulf of Cádiz[††]	20–80	28	Seismic focus at 100 km west of Cape San Vicente**	170–200	20
Spain						
Badajoz	Seismic focus east of Évora[‡]	60–90	68	Seismic focus at 100 km west and southwest of Cape San Vicente**	330–360	15
Córdoba	The city and its surroundings and a seismic focus at 10–30 km southeast of the city[‡‡]	<50	99	—		
Sevilla	The city and its surrounding and a seismic focus at 10–30 km northeast of the city[§§]	<40	86	Seismic foci at 100 km west and 150 km southwest of Cape San Vicente**[‖‖]	350–400	6
Huelva	Seismic focus west of the city, and scattered seismicity in the Gulf of Cádiz[##††]	20–110	71	Seismic foci at 100 km west and southwest of Cape San Vicente**	260–290	13
Granada	The city and its surrounding***	<30	99	—		
Almería	The city and its surrounding[†††]	<30–50	99	—		
Málaga	The city and its surroundings and a region west of the city[‡‡‡]	<35	74	Seismic focus northeast of the city[§§§]	25–50	18
Cádiz	Scattered seismicity in the Gulf of Cádiz[††]	20–150	54	Seismic focus at 150 km southwest of Cape San Vicente[‖‖]	320–350	20

*Condeixa, 12 August 1948 (m_b 4.9); Pombal, 21 October 1969 (m_b 4.7).
[†]Nazaré, 3 October 1940 (I_{MM} = VII); Rio Maior, 8 April 1989 (m_b 4.7).
[‡]Alentejo, 10 October 1757 (I_{MM} = VIII); Évora, 1 April 1761 (I_{MM} = VIII)
[§]Macas, 16 November 1909 (I_{MM} = VIII); Vendas Novas, 18 May 1927 (m_b 4.2).
[‖]Lisboa, 28 January 1512 (I_{MM} = VIII); Vila Franca de Xira, 26 January 1531 (I_{MM} = VIII–IX).
[#]Setúbal, 8 December 1756 (I_{MM} = VIII); Setúbal, 11 November 1858 (I_{MM} = IX).
**West Cape San Vicente, 31 March 1761 (I_{MM} = IX); West Cape San Vicente, 12 April 1773 (I_{MM} = VIII).
[††]Southeast Cape San Vicente, 16 August 1956 (m_b 5.0); Gulf of Cádiz, 15 March 1964 (m_b 6.2, I_{MM} = VII).
[‡‡]Montilla, 5 july 1930 (m_b 4.9, I_{MM} = VIII); Montilla, 26 May 1985 (m_b 5.1, I_{MM} = V).
[§§]Carmona, 5 April 1504 (I_{MM} = IX); Sevilla, 27 February 1724 (I_{MM} = VIII).
[‖‖]West Cape San Vicente, 1 November 1755 (I_{MM} = X); Atlantic Ocean, 27 December 1941 (m_b 5.5).
[##]Tavira, 27 December 1722 (I_{MM} = VIII); Ayamonte, 20 December 1989 (m_b 5.0, I_{MM} = VI).
***Atarfe, 24 April 1431 (I_{MM} = IX); Granada, 4 July 1526 (I_{MM} = VIII).
[†††]Almería, 22 September 1522 (I_{MM} = IX); Dalías, 25 August 1804 (I_{MM} = IX).
[‡‡‡]Alhaurín el Grande, 9 October 1680 (I_{MM} = IX); North Málaga, 16 July 1767 (I_{MM} = VII).
[§§§]Mountain range of Alhama, 18 June 1581 (I_{MM} = VIII); Arenas del Rey, 25 December 1884 (I_{MM} = X).

The results obtained have allowed us to determine the distance and the azimuth at which the main seismic sources generating hazard are located from the different cities considered in this analysis and to quantify the relative contribution to the total seismic hazard for each of them.

The studied cities have revealed different morphologies in the results for deaggregation in magnitude and distance. On one hand, there are cities where nearby seismicity is the only major contributor to the seismic hazard (a single lobe in the deaggregation plot). On the other hand, there are cities where more or less distant foci contribute significantly to the seismic hazard (two or three lobes in the deaggreagation plot).

Finally, we should note the extreme importance of the seismic source southwest of Cape San Vicente (the location of the 1755 Lisbon earthquake) for the hazard in the area. Particularly for the cities closer to it, and in the range of magnitudes above 7.5–8.0, the hazard generated by this focus can be considerable. In a previous work, Benito and López Arroyo (1991) demonstrated that different locations of this zone show a significant difference between a standard response spectrum and a uniform hazard spectrum calculated including this seismic source, and they pointed out that a realistic spectral attenuation relationship in this area is required.

As indicated in one way or another by different authors, and as is already taken into account by various American regulations (e.g., U.S. Department of Energy 1995; SSHAC, 1997; USNRC, 1997), the calculation of the deaggregation is essential in order to be able to completely analyze the results obtained in any study of seismic hazard.

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