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Earthquake occurrence and seismic zonation in South Spain

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ABSTRACT. The seismically active region of South Spain is limited to the North with the stable Meseta. Geologically it is formed by the Betic domain which is crossed by three main systems of faults in E-W, N30°-60°W and N10°-30°E directions. This region is subjected to NNW-SSE horizontal compression as a result of the collision of the Eurasian and African plates. Occurrence of large earthquakes is separated in time by large intervals that may vary from 50 to 150 years. Large earthquakes have happened at different fault systems. Recurrence of large earthquakes at the same fault or fault segment has very long periods. Historical data have been used in order to establish seismic activity at different faults. The lack of accuracy of historical data makes difficult a zonation even at large scale for the region. Certain areas of higher seismic hazard, however, may be defined, such as those of near Málaga, Granada, Almería and Alicante. Only tentatively, may the seismic activity be associated to known geological faults. Recent seismicity and focal mechanism studies of moderate to low magnitude earthquakes confirm the assotiation of this level of seismic activity to certains faults.

INTRODUCTION

The seismic region of south Spain is associated to the plate boundary between Eurasia and Africa. At this region, the boundary is complicated by the presence of the continental block of the Iberian Peninsula, the Alboran basin and the Africa plate. Seismic activity is characterized by a continous occurrence of earthquakes of low magnitude, $M < 5$, and the sporadic occurrence of large earthquakes, $M > 6$. Most earthquakes of this region have shollow depth, but there is also some activity at intermediate depth (30km<h<150km) and anomalous very deep earthquakes at 640km

EARTHQUAKE OCCURRENCE

The seismicity of southern Spain must be considered as moderate from the point of view of the average size of the eartquakes, however, from time to time, this region has been shaken by large earthquakes that have caused severe damage; the most important are listed in Table I. Most of the earthquakes of this region are of shallow depth, but the activity extends in some zones at intermediate depth and a very deep source at 640 km under Sierra Nevada (Buforn et al, 1991).

The shallow seismicity of the region is shown in figure 1, for the period 1965 - 1985 and $M > 3$, superimposed to the main faults. There are three general systems of faults. The first one is formed by long faults in ENE-EWE or E-W direction. One of these is the accident Cádiz-Alicante that seems to separate two different zones of seismic activity, to the north the seismic activity is less than to the south (Udías and Buforn, 1992). Others important faults in direction E-W are the Alpujarras and the coastal fault between Málaga and Almería. The second system is formed by shorter fractures in N30°-60°W direction which extend from the southern coast to the sedimentary basin of the Gaudalquivir river. The third system is formed by faults in N10°-30°E direction. The most important faults of this system are the Palomares, Carboneras and Alhama de Murcia Faults (Bousquet and Phillip, 1976).

It is difficult to assign epicenters

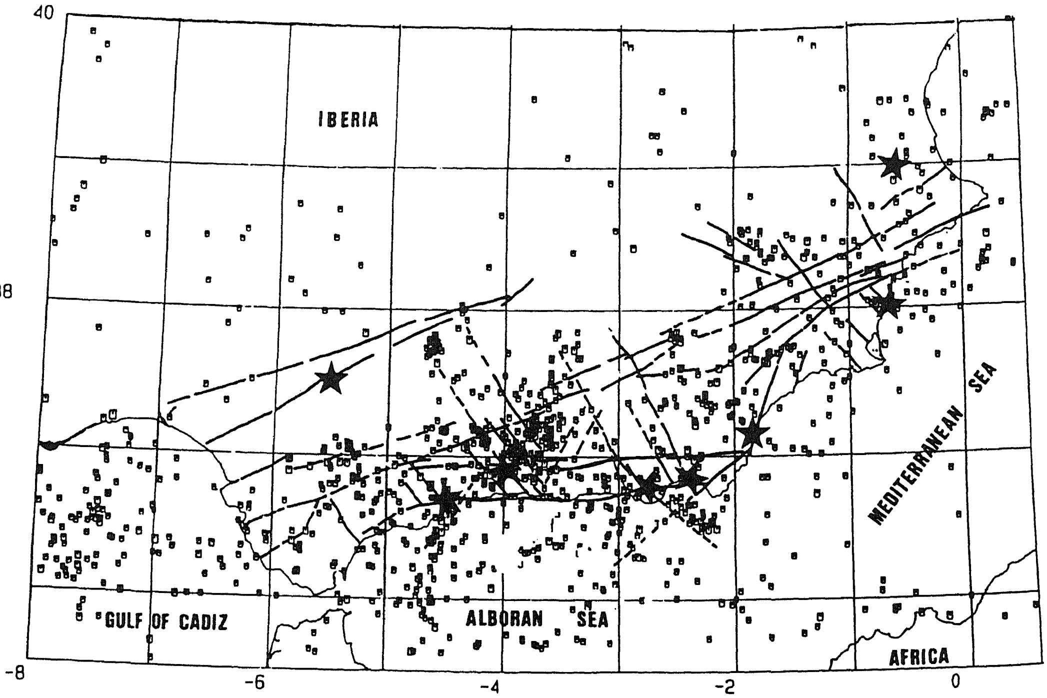

Figure 1. Seismicity of South Spain between 1965 and 1990, M>3, h<30km, and principal fault systems (Udías & Buforn, 1992). Stars correspond to sfocks listed in Table I.

to a particular fault for both instrumental and historical seismicity, nevertheless, is possible to apreciate some alignments of epicenters which coincide with the three systems described before. There are groups associated to the Alpujarras fault, others associated to the coastal fault parallel to the previous one, both in E-W direction. Other groups, near Granada may be associated to faults of the system N30°-60°W and those to the east related .with Alhama de Murcia-Palomares-Carboneras faults.

The space-time distribution for all region along a line in WSW-ENE direction for earthquakes with I_{max} VII is shown in figure 2. At the western part, there seems to be a less active zone. About 3.5°W, corresponding to the Granada region, there are two active periods at about 1900 and 1950. Another active area is located at the eastern part. Since 1700 up to the present, four earthquakes have happened with I_{max} about IX. The last of these events took place at the end of 1884. From the figure it may be deduced, also, that the higher seismic activity is located to the East of 4°W.

Table 1. Earthquakes of South Spain with I_{max} > IX (1500-1980)

Date	Latitude	Longitude	I_{max}	Location
1504/ 4/ 5	37.4°N	5.6°W	IX	Carmona (Sevilla)
1518/11/ 9	37.2°N	1.9°W	IX	Vera (Almería)
1522/ 9/22	36.9°N	2.5°W	IX	Almería
1680/10/ 9	36.5°N	4.4°W	IX	Málaga
1748/ 3/23	39.0°N	0.6°W	IX	Enguera (Valencia)
1804/ 8/25	36.8°N	2.8°W	IX	Dalías (Almeria)
1829/ 3/21	38.1°N	0.7°W	X	Torrevieja (Alicante)
1884/12/25	36.9°N	4.0°W	X	Arenas del Rey (Granada)

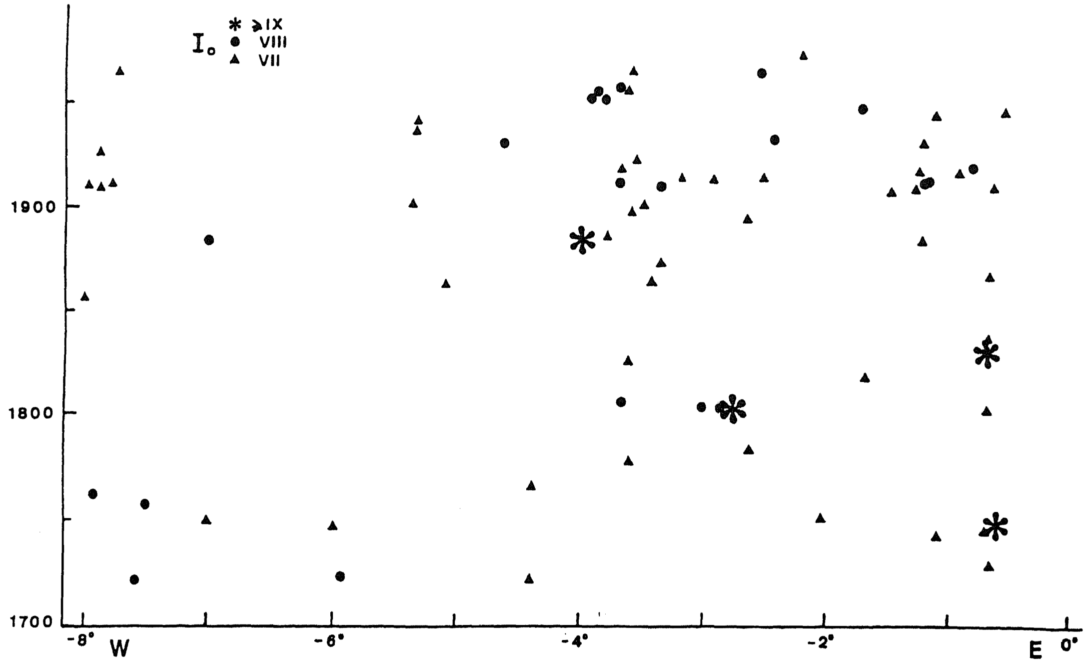

Figure 2. Space-Time distribution of earthquakes with Io > VII for the time period 1700-1985.

SEISMIC HAZARD

Several studies have been carried out for the assesment of seismic hazrd in Spain. The first have been done by López Arroyo and Step (1973) who applied extreme values statistic. Roca and Udías (1976) used Gumbel I distribution to evaluate the seismic hazard for northwestern Spain. Muñoz (1983) studied the southeastern Spain using a probabilistic method and Martín (1983) assesed the seismic hazard for all Spain applying a probabilistic method and extreme values statistic as well.

Concerning to the region of this study, Figure 3 shows the seismic hazard map for anual probability of 0.001 (Muñoz et al (1984). This map have been obtained using the method described by Cornell (1968) and the algorithm of McGuire (1976) modified by Mayer-Rosa and Merz (1976). A quadratic law for the frecuency-intensity relationship and the attenuation law of intensity proposed by Sponheuer (1960) have been adopted for each seismic source. The attenuation laws of intensity give values of attenuation coeficient α and depth h. In this case has been applied in 24 directions obtaining two values of coeficient α_{max} and α_{min} and the direction of maximun attenuation. The attenuation of intensity in southern Spain is higher than in other areas of Europe (Muñoz 1974). The zones with higher seismic hazard are Murcia-Alicante and Granada that present a 63% probability of ocurrence for an earthquake with intensity greater than IX in the period of 1000 years. It can be seen that the extensional structures near Granada and the conjuntion of the two major fault zones, Alhama de Murcia and Carboneras- Palomares, near Murcia are the dominant tectonic features connected to the areas with highest hazard.

SEISMIC ZONATION

Seismic zonation of this region have been presented by Martín (1983) Muñoz (1983) and Sanz de Galdeano and López Casado (1988). We propose a zonation (Figure 4) based on the location of the larger earthquakes, I_o > VII, and the traces of the main geological faults. Two large zones can be separated, south and north of the Cádiz Alicante accident, designated as sources A and B. Source A has been divided into three zones: source A-I includes earthquakes near Sevilla (Carmona 1504); source A-II is the most active of the three and comprises the earthquakes of Córdoba and

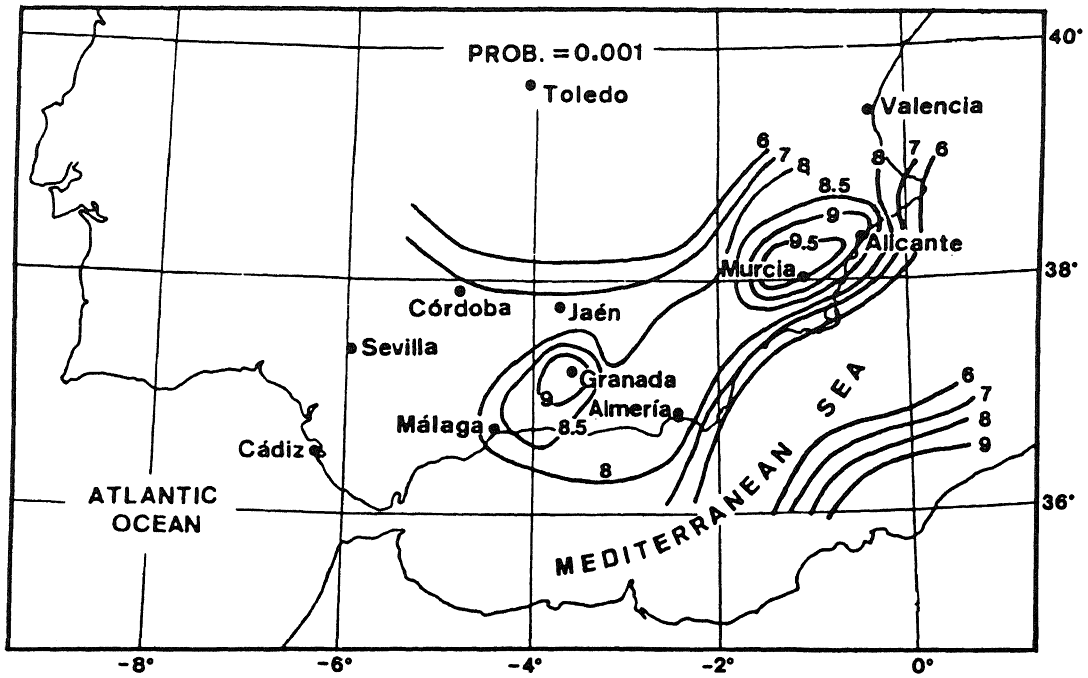

Figure 3. Hazard map for South Spain corresponding to an annual probablity of 0.001 (Muñoz et al, 1984).

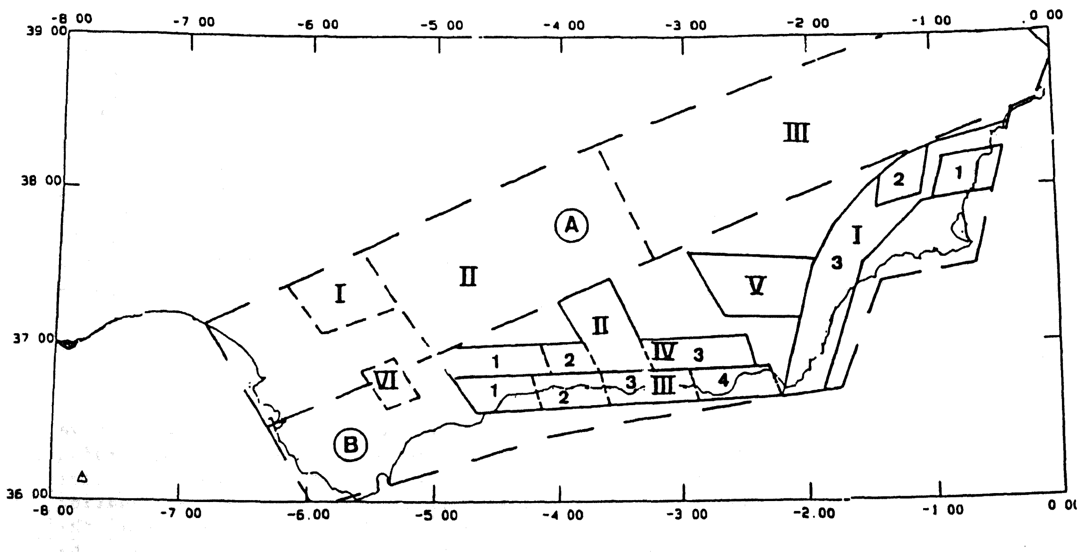

Figure 4. Proposed seismic zonation for South Spain.

Jaen; source A-III has less activity. Source B is the most active and it is subdivided into six zones. Source B-I corresponds to the activity associated to the Alhama de Murcia, Palomares, Carboneras faults; inside this zone two subsources of greater activity exist: B-I-1 (Torrevieja earthquake 1829) and B-I-2 with a concentration of events of I_o = VIII. Source B-II corresponds to the Granada area where earthquakes of epicentral intensity VIII are relatively frequent and are probably associated to faults of the system N30°-60°W. Source B-III covers the coastal region from Málaga to Almería. Subzone B-III-1 includes the location of the Málaga earthquake of 1680, and subzone B-III-4 the Almería and Dalías earthquakes ocurred in 1522 and 1804 respectively. Source B-IV is related to the Alpujarras fault and its extension to the west. This zone has been subdivided into three sources; the last large earthquake ocurred in south Spain (Arenas del Rey 1884) is included in source B-IV-2. Source B-V has an activity at the level of intensity VIII and frequent small earthquakes. Source B-VI is less active. The seismic hazard of the western part of south Spain is also affected by the large earthquakes of the Azores-Gibraltar fault such as the 1755 Lisbon earthquake and the more recent of Cabo San Vicente in 1969.

CONCLUSION

Shallow depth seismic ocurrence in South Spain can be related to the geological faults present in the region. Large earthquakes ($M > 6.5$) happen at long time intervals (100 to 200 years). Seismic hazard analysis shows the areas of higher risk in Granada and Murcia-Alicante. A tentative scheme of seismic zonation has been presented.

Acknowledgements

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