Seismogenic fault-source characterization in SE Spain: Implications for probabilistic seismic hazard assessment

J. García-Mayordomo, S. Martín-Alfageme & R. Martín-Banda
Instituto Geológico y Minero de España, Madrid, Spain

J.M. Insua-Arévalo, J.J. Martínez-Díaz, A. Jiménez-Díaz, E. Rodríguez-Escudero & M.J. Rodríguez-Peces
Universidad Complutense de Madrid, Facultad de Ciencias Geológicas, Spain

L. Cabañas-Rodríguez
Instituto Geográfico Nacional, Madrid, Spain

J.M. Gaspar-Escribano
Universidad Politécnica de Madrid, E.T.S.I. Topografía, Geodesia y Cartografía, Spain

SUMMARY:
Considering active faults as independent seismogenic sources in deterministic seismic hazard studies is quite straightforward. However, their consideration in probabilistic seismic hazard assessment (PSHA) still remains a challenge today, particularly in low-to-moderate active regions as in Southeast Spain. In this work we perform a number of tests calculating seismic hazard for different hypothesis and input data. Results are discussed in the frame of the geological knowledge of the region and a number of conclusions are drawn in relation to their impact in PSHA at two conventional return periods (475 and 950 years).

Keywords: Active faults, probabilistic seismic hazard, Spain

1. FAULTS AND SEISMIC HAZARD

Seismic hazard in moderate activity regions, like Spain, is commonly assessed by means of the classic Cornell (1968) method. This method models the occurrence of seismicity within particular areas (the so called seismogenic source-zones) characterized by a different frequency distribution of magnitude (or Gutenberg-Richter relationship). The advances in earthquake geology research and paleoseismology in the last 10 years in Spain have allowed the identification of a number of active faults potentially interesting to be modelled as singular seismogenic sources based on their dimensions and slip rate parameters. However, the impact in hazard of these faults still remains a challenge as their modelling methodology is not as widely accepted as when considering a classic source-zones model.

In this work we present a preliminary exploration of the potential impact that considering fault-sources could have in the seismic hazard of hazard Southeast Spain for two conventional return periods used in engineering applications: 47- and 950-yr return periods.

2. SOURCE-ZONES AND SOURCE-FAULTS MODELS FOR SOUTH EAST SPAIN

From a geological point of view Southeast Spain encompass the eastern part of the Betic Cordillera. This mountain chain is the most seismically active area in Spain, and many historical earthquakes and recent damaging events have taken place in it (e.g., the 11th of May Lorca earthquake). A major difference of the Easter Betic Cordillera compared to its western part is the location of a conspicuous trend of master faults running across the region: the Eastern Betic Shear Zone. Figure 2.1 illustrates the seismicity of the region and also the trend of a number of active faults as contained in the Quaternary Active Faults Database of Iberia of IGME (IGME, 2012; García-Mayordomo et al., 2012).

Figure 2.1 also shows a number of polygons corresponding to the source-zones model of García-Mayordomo et al. (2010) for the whole of Spain. However, we have conducted an important modification of the zone's boundaries to account for a new zone. This zone is called Zone 0 and is defined to encompass the fault system of the Eastern Betic Shear Zone. The faults that composed this major shear zone are depicted in Figure 2.2 where the representation of the surface projection of the fault planes is shown as well with the traces of the faults.

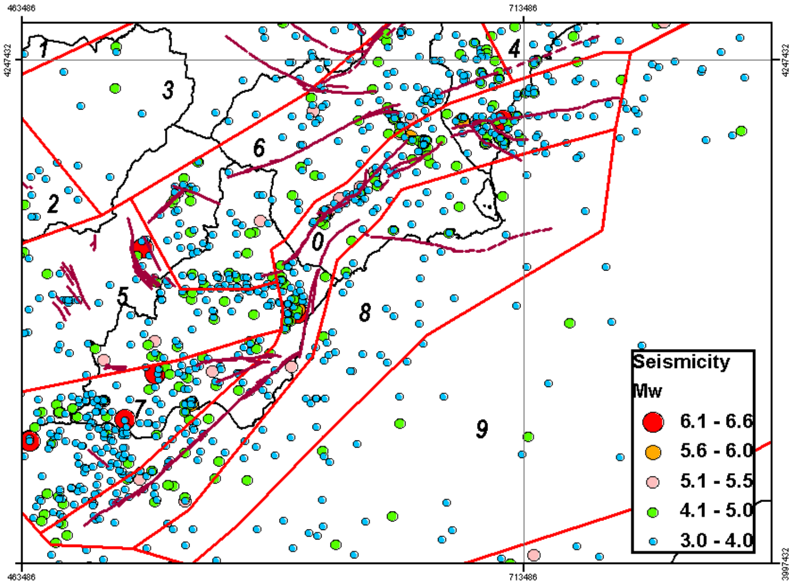

Figure 2.1. Source zones and faults from the QAFI database (IGME, 2012).

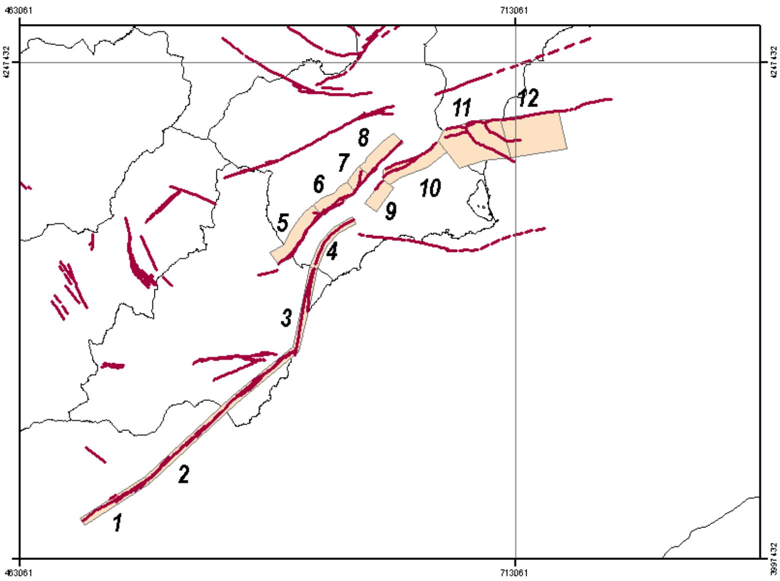

Figure 2.2. Fault-sources considered in this analysis.

3. INPUT DATA FOR SOURCE-ZONES AND FAULT-ZONES

Two earthquake-source models are considered in this work. The first one is a classic source-zones model and the second one is the same but considering for Zone 0 the activity of the faults included in it. For simplification purposes we shall call model 1 as the source-zones model and model 2 the fault-sources model.

For the source-zones model the Gutenberg-Richter parameters have been calculated for each of zones encompassed in Figure 2.1. These parameters have been obtained by regression of the earthquakes contained within the zone based on a seismic catalogue ready prepared for hazard calculations (Martínez Solares, et al. 2012). This catalogue has been declustered to get rid of after-shocks and uniformed to the moment magnitude scale. Additionally, the completeness of the catalogue for different magnitude ranges has also been accounted for. Table 3.1 list the G-R parameters obtained from that catalogue in the present work for each of the source-zones. As an example Figure 3.1 shows an illustration of the fit performed for the Eastern Betic Shear Zone (Zone 0).

Regarding to the fault-sources model we have considered the 3 sets of equations developed by Anderson and Luco (1983) for the determination of the number of earthquakes produced by a fault when the dimensions of the fault, maximum magnitude, coseismic slip and slip rate are known or assumed. Table 3.2 lists the geological parameters considered to model the faults studied here, and Figure 3.2 shows an illustration of the 3 different models of Anderson and Luco (1983) as well as the average one for a fault producing magnitudes larger than Mw 5.0.

Table 3.1. Input data for source-zones.

Zone	a	b
0	3.67	-0.98
1	3.97	-1.23
2	3.49	-1.04
3	3.55	-1.17
4	3.01	-0.90
5	2.92	-0.93
6	3.67	-1.02
7	3.45	-0.97
8	4.32	-1.28

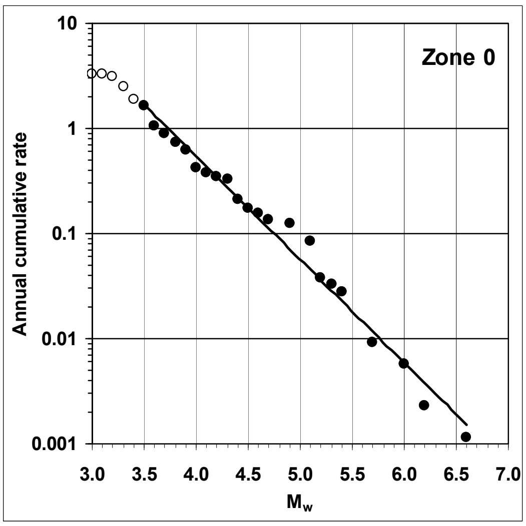

Figure 3.1. Gutenberg-Richter fit in Zone 0.

Table 3.2. Input data for fault-source modelling. Maximum magnitude is the average from the regression equations of Wells and Coppersmith (1994) and Stirling et al. (2002) for the instrumental dataset on rupture area and surface rupture length. Coseismic slip is derived from the moment magnitude equation assuming seismic moment from maximum magnitude.

Code	Fault name	Long. (km)	Depth (km)	Dip (º)	Wide (km)	Max. Mw	Coseismic Slip* (m)	SR (mm/y)
1	Carboneras-Sur	39	11	80	11	6.9	1.66	1.1
2	Carboneras-Norte	100	11	80	11	7.3	2.64	1.1
3	Palomeras-Sur	42	8	60	9	6.9	1.83	0.04
4	Palomeras-Norte	33	8	60	9	6.7	1.62	0.04
5	Alhama de Murcia 1/4	34	12	60	14	6.8	1.46	0.5
6	Alhama de Murcia 2/4	20	12	60	14	6.6	1.12	0.3
7	Alhama de Murcia 3/4	11	12	60	14	6.4	0.87	0.07
8	Alhama de Murcia 4/4	24	12	60	14	6.7	1.23	0.07
9	Tollos	15	12	60	14	6.5	0.97	0.81
10	Carrascoy	32	12	60	14	6.8	1.41	0.54
11	Bajo Segura onshore	36	12	30	24	7.0	1.27	0.30
12	Bajo Segura offshore	30	12	30	24	6.9	1.16	0.12

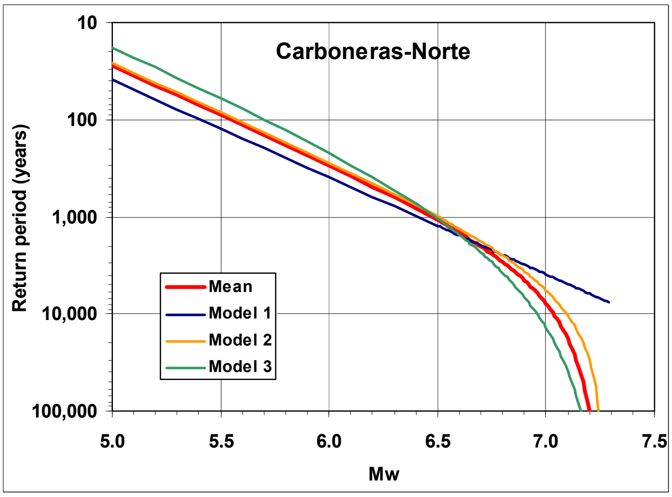

Figure 3.2. Activity rates models of Anderson and Luco (1983) for the Carboneras-Norte fault.

4. HAZARD CALCULATION RESULTS

Hazard results are shown here in terms of the value of magnitude in each zone corresponding to a probability exceedance of 10% en 50 and 100 years (equivalent to a 475- and 950-yr return periods) assuming a Poissonian distribution. Figures 4.1 and 4.2 compare these magnitude values for the source-zones model and the fault-sources model, respectively for the 475- and 950-yr return periods. It is important to note that for the fault-sources model Zone 0 activity is truncated at Mw 5.0. Larger magnitudes are then assumed to take place on the fault's surface projections.

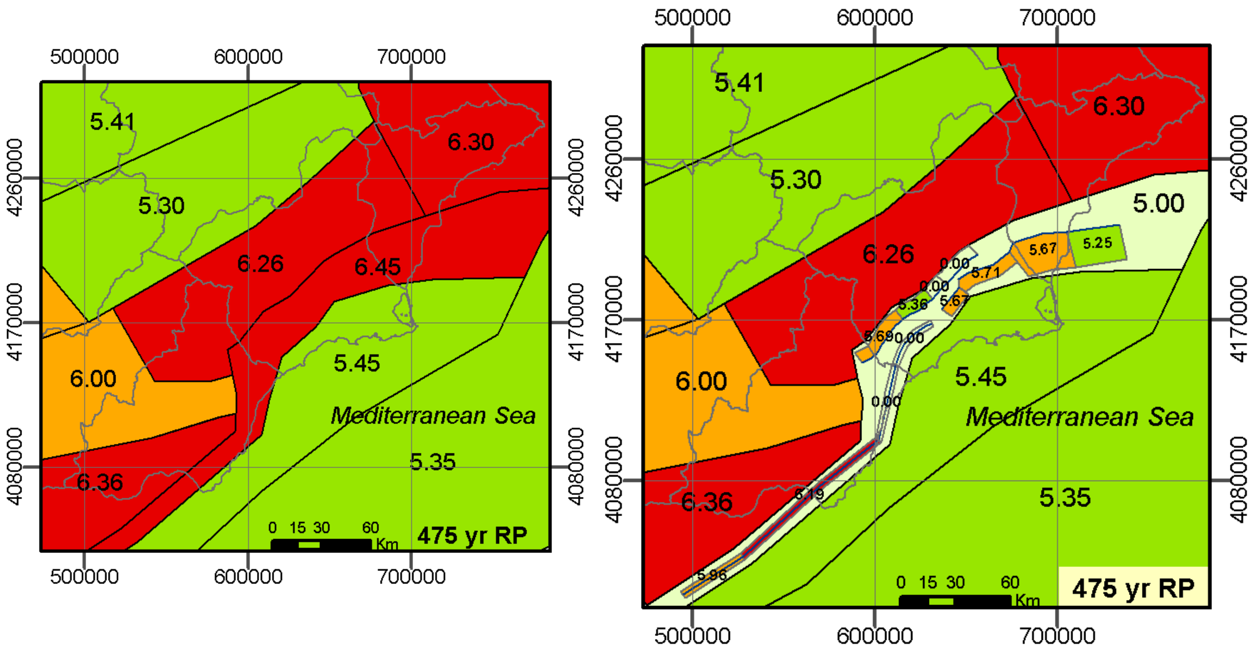

Figure 4.1. Magnitude with a 10% exceedance probability in 50 years (475-yr return period) for the source-zones model (left) and for the fault-sources model (right).

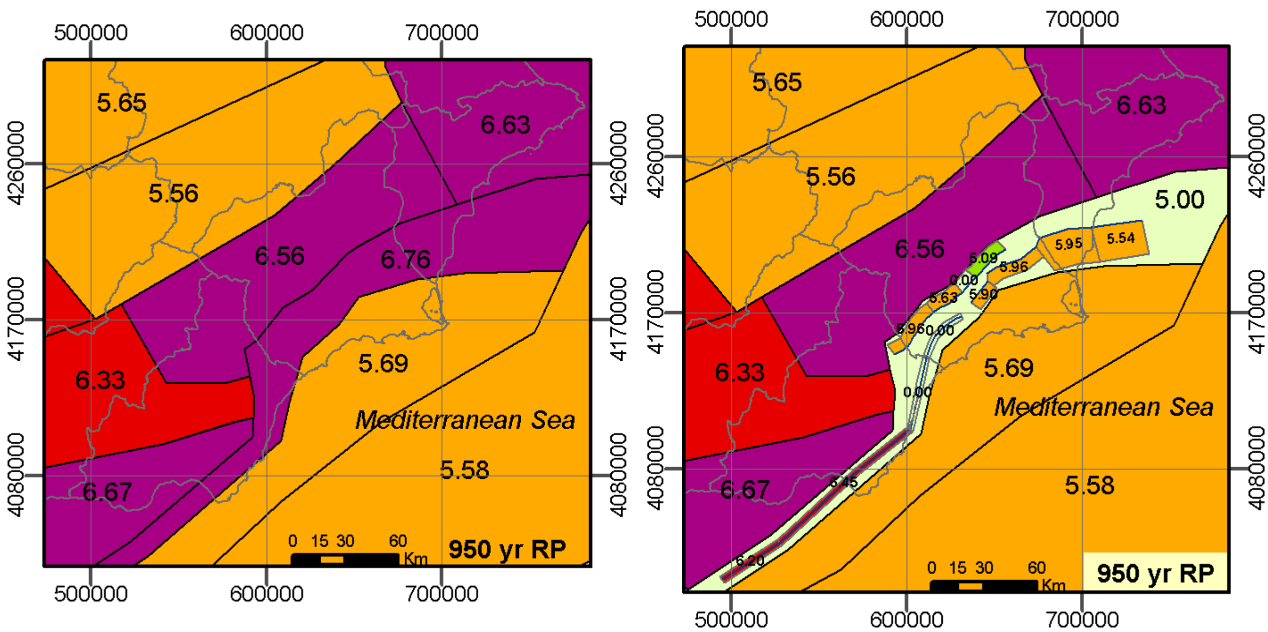

Figure 4.2. Magnitude with a 10% exceedance probability in 100 years (950-yr return period) for the source-zones model (left) and for the fault-sources model (right).

4. DISCUSSION AND CONCLUSION

From the comparison of the results depicted in Figures 4.1 and 4.2 it is clear that none of the considered faults produce a magnitude larger than the one resulting from the distribution of seismicity of Zone 0 for both 475 and 950-yr return periods. It is also interesting to observe that some faults do not produce any earthquake larger than Mw 5.0 for both return periods. This is the case of both Palomares fault segments, and the segment 3/4 of the Alhama de Murcia fault. Segment 4/4 of the Alhama de Murcia fault shows impact only in the 950-yr map.

The impact of faults in hazard is due to the relationship between its maximum magnitude and slip rate. Slow slip rates in a relatively long fault, as the Palomares (30-40 km), implies that the seismic moment budget is biased towards the production of large but infrequent earthquakes. On the opposite, relatively slow slip rates (0.07) in short faults, as Alhama de Murcia 4/4 (12 km), produces more frequently Mw ≥5.0 earthquakes, than a longer fault with the same slip rate, Alhama de Murcia 3/4 (24 km).

However, the results attained here have to taken with caution as the input data are subjected to major uncertainties. Regarding to the geological data, the most critical one is slip rate, and the assumptions made for estimating the maximum magnitude of the fault. The sensibility of these two variables should be studied carefully in forthcoming analyses. In the work presented here we have considered expert judgement estimations based on the QAFI database and empirical relationships from literature (see Table 3.2).

In summary, the provisional results obtained here suggest that for southeast Spain it seems more conservative to consider a classic source-zones model for calculating hazard than considering major faults as individual sources. Note that this conclusion is reached in terms of the magnitude produced by the sources for the 475- and 950-yr return periods and that a proper hazard calculation considering the integration on distance and the hazard aggregation from all the sources, as well as a ground motion attenuation model, should be performed to confirm this appreciation.

AKCNOWLEDGEMENT

This research is part of the activities funded by the FASEGEO project (CGL2009-09726).

REFERENCES

Anderson, J.G. and Luco, J.E. (1983) Consequences of slip rate constants on earthquake recurrence realtions. *Bulletin of the Seismological Society of America*, **73:** 471-496.

Cornell, C.A. (1968). Engineering seismic risk analysis. *Bulletin of the Seismological Society of America*, **58:** 1583-1606.

García-Mayordomo, J., Insua-Arévalo, J.M., Martínez-Díaz, J.J., Perea, H., Álvarez-Gómez, J.A., Martín-González, F., González, Á., Lafuente, P., Pérez-López, R., Rodríguez-Pascua, M.A, Giner-Robles, J., Azañón, J.M., Masana E. and Moreno, X. (2010). Modelo integral de zonas sismogénicas de España. In: *Contribución de la Geología al Análisis de la Peligrosidad Sísmica*. Insua-Arévalo and Martín-González (Eds). Resúmenes de la 1ª Reunión Ibérica sobre Fallas Activas y Paleosismología: 193-196 pp.

García-Mayordomo, J., Insua-Arévalo, J.M., Martínez-Díaz, J.J., Jiménez-Díaz, A., Martín-Banda, R., Martín-Alfageme, S., Álvarez-Gómez, J.A., Rodríguez-Peces, M., Pérez-López, R., Rodríguez-Pascua, M.A., Masana, E., Perea, H., Martín-González, F., Giner-Robles, J., Nemser, E.S., Cabral, J. and the QAFI Compilers Working Group (2012). The Quaternary Active Faults Database of Iberia (QAFI v.2.0). *Journal of Iberian Geology,* **38:1**,285-302.

IGME (2012). *QAFI: Quaternary Active Faults Database of Iberia*. Accessed April 2012, from IGME web site: http://www.igme.es/infoigme/aplicaciones/QAFI/

Martínez Solares, J.M., Cabañas Rodríguez, L., Benito Oterino, B., Gaspar Escribano, J.M., Rivas Medina, A., Rodríguez Zaloña, O., Cantero Pozo, A. and Ruiz Barajas, S. (2102) *Informe Técnico IGN PSE.CS.F02 Catálogo Sísmico de Proyecto. Preparación y homogenización*.

Stirling, M., Rhoades, D., Berryman, K (2002). Comparison of Earthquake Scaling Relations Derived from Data

of the Instrumental and Preinstrumental Era. *Bulletin of the Seismological Society of America*, **92:2**,812-830.
Wells, D.L., Coppersmith, K.J. (1994). New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. *Bulletin of the Seismological Society of America* **84:4**,974-1002.