The Bullas (Murcia, SE Spain) earthquake, 29 January 2005[1]

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Abstract

The intensity and focal mechanism of the Bullas earthquake of 29 January 2005 have been determined. The intensity assessment has been carried out using the EMS-98 scale and plotted on an intensity map. The focal mechanisms for the main shock and largest aftershock have been estimated from moment tensor inversion of body waves. The mechanisms obtained show left-lateral strike-slip faulting and foci at shallow depths, 3–4 km. These results are compared with those of the Bullas 2002 and Mula 1999 earthquakes in the same region.

Introduction

The Murcia region is an area of moderate seismicity in southeastern Spain (Figure 1). Since 1948, when an earthquake occurred on 23 June, no earthquakes with maximum intensity larger than VIII have occurred in this region. The occurrence of two earthquakes on 1999 (Mula, $M_w = 5.1$) and 2002 (Bullas, $M_w = 4.6$) (Figure 1), both followed by aftershocks, broke this period of quiescence. The 1999 earthquake was especially damaging with economic losses estimated at greater than 54 million euros (IGN, 1999; Buforn and Sanz de Galdeano, 2001; Mancilla et al., 2002; Martinez-Díaz et al., 2002; Buforn et al., 2005). On 29 January 2005, a new earthquake occurred with epicenter near the 2002 Bullas shock (Figure 1). This earthquake caused considerable damage in the epicentral area (IGN, 2005), reaching a maximum intensity of VII, and it was followed by a large number of aftershocks. According to the Instituto Geográfico Nacional (IGN), the main shock occurred at 07 h 41 m 31.6 s, with epicenter at 37.88°N, 1.79°W, focal depth 4 km and magnitude M_l 4.7. Historically, the largest earthquake to have occurred in this region was the Torrevieja earthquake in 1829, with $I_o = X$ and estimated magnitude M_s 6.9 (Muñoz and Udías, 1991). This shock was located to the east of the 1999, 2002 and 2005 series (Figure 1).

Intensity assessment

Two days after the occurrence of Bullas 2005 earthquake, the Department of Geophysics and Meteorology, Universidad Complutense de Madrid, carried out a field survey, in order to evaluate the damage. The estimated intensity values in European Macroseicmic Scale (EMS-98) are shown in Figure 2a and Table 1. The maximum intensity occurred in the towns of Zarcilla de Ramos (VII EMS-98) and La Paca (VI–VII). The damage in these towns can be summarized as follows: In Zarcilla de Ramos (1070 people, about 400 houses) all the houses were damaged in some degree. Most damage was observed in the upper storeys of the houses, most of which have 2 storeys. About 20% of the houses were seriously damaged (Figure 2b) and 30 families were left homeless (Oficina Municipal de Urbanismo, Lorca, Spain). Both old and newly built houses were damaged, damage including gable wall failures, large cracks in most walls, drift of load-bearing masonry walls, heavy shear damage, wall and roof failures and even total collapse of the upper storeys in some houses. Approximately 30% of the houses were moderately damaged, including
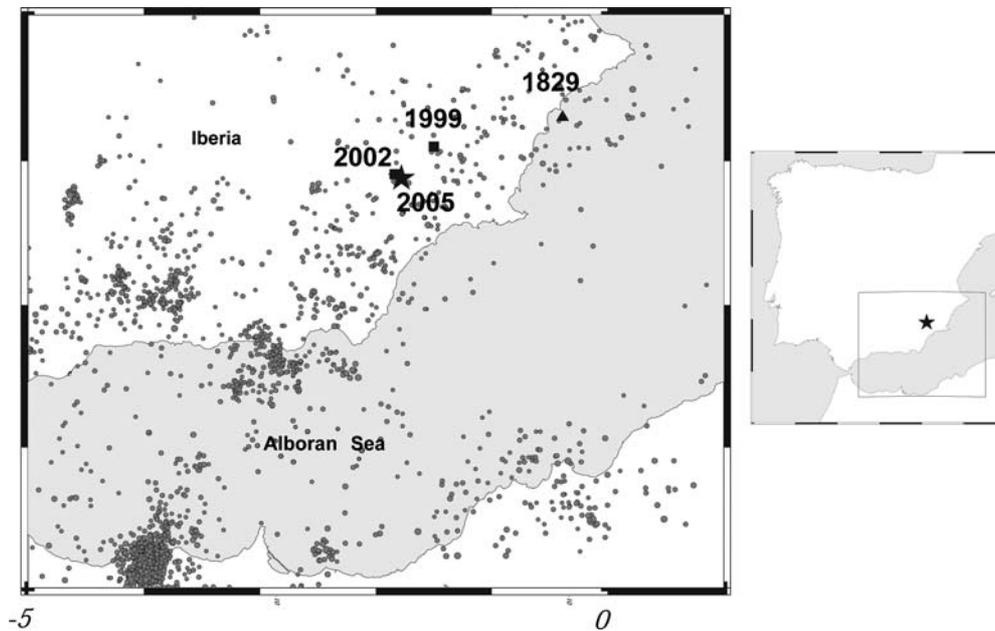
Figure 1. Seismicity map for southeastern Spain for the period 1980–2004 ($M \geq 3$) and shallow depth ($h < 40$ km), taken from the IGN Data File. The star corresponds to the 2005 earthquake, squares to the 1999 and 2002 shocks.

Table 1. Intensity values (EMS-98) obtained in the region

I (EMS-98)	Town	I (EMS-98)	Town
VII	Zarcilla de Ramos	IV	Los Cautivos
VI–VII	La Paca	IV	Caravaca de la Cruz
VI	Las Terreras	IV	Cehegín
V	Zarzadilla de Totana	IV	Bullas
V	Avilés	IV	Mula
V	Doña Inés	IV	La Puebla de Mula
V	Coy	IV	Pliego
V	La Almudema	IV	Las Gebas
IV	Lorca	III?	Cartagena
IV	Alhama de Murcia	III?	Murcia

the town's church, with cracks in many walls, partial collapse of chimneys and fall of roof eaves. About the 50% of houses have slight, non-structural damage, namely hair-line cracks in the walls and fall of pieces of plaster. The total damage has been estimated at 4.400.000€.

La Paca (1170 people, 400 houses, VI–VII) is the second town with greatest damage. Approximately 45% of the houses have been damaged, about 5% of them seriously (Figure 2c). There are also buildings with moderate and severe structural damage (drift of load-bearing masonry walls, wall and roof failures, and, in a public building, heavy shear damage to masonry

infill panels). Approximately 10% of the houses suffered moderate non-structural damage and 30% of the houses were slightly damaged. The total damage has been estimated at 1.200.000 euros.

Other towns suffered less damage. In Las Terreras (intensity VI, Figure 2a), slight cracks were observed in many houses, and moderate non-structural damage in one of the public buildings. In Avilés, the school showed moderate damage, with a drift of load-bearing between its walls. The church also suffered moderate damage, and most of the houses had slight cracks in their walls. In Zarzadilla de Totana, Coy and Doña Inés (V) there were some slight cracks and pieces of plaster fell. Other towns, such as Caravaca de la Cruz, Bullas, Mula, Alhama de Murcia and Lorca, felt the earthquake (IV), but there was no damage in them. In Murcia and Cartagena, the shock was felt less. In Cartagena, for example, only some people living in upper storeys felt the shaking.

The intensity values estimated in this study are similar to those obtained by the IGN (IGN, 2005). However, there is a slight difference between both studies for the maximum intensities, corresponding to Zarcilla de Ramos (VII) and La Paca (VI–VII), where the IGN estimated intensity VI in both cases. In our study intensity IV has been obtained for seven new towns not included in the IGN estimation.

Focal mechanism

Focal mechanisms for the main shock and largest aftershock (03/02/05 at 11 h 40 m 33.0 s) have been estimated from moment tensor inversion of body waves. The inversion has been carried out in the frequency domain by fitting amplitude spectra of observed broad band seismograms recorded at regional distances (less than 350 km). Fitted data correspond to vertical and radial components of *P* waves and transverse components of *S* waves (SH; Cesca, 2005). Total of ten and nine stations at epicentral distances less than 350 km, have been used on the inversion process for the main shock and largest aftershock, respectively. The reflectivity method (Müller, 1985) has been used to generate the Green functions, with a crustal model composed by three flat layers with a total thickness of 31 km, over a five layered mantle (Mézcua and Martinez Solares, 1983). The inversion has been carried out using a source depth range between 1 and 10 km, and a frequency range between 0.1 and 2 Hz. Best results have been obtained when fixing STF duration at 1.0 s and 0.5 s for main shock and largest aftershock.
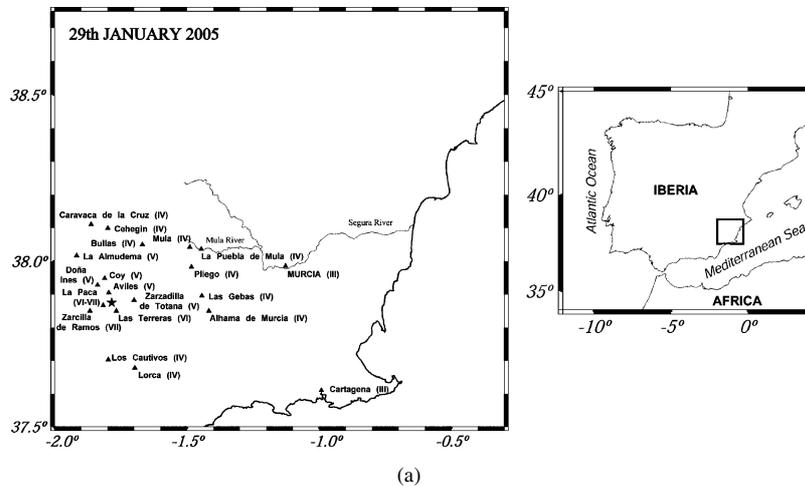

(a)

(b)

Figure 2. Intensity map for the Bullas 2005 main shock (a). The star corresponds to the epicenter and damage in Zarcilla de Ramos (b) and La Paca (c) is shown.

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(c)

Figure 2. (*Continued*)

Results of the inversion process are shown in Figure 3 and Table 2. For the main shock (Figure 3a), the best solution (minimum misfit, 0.43 and proportion of non-DC component, CLVD, 5%), corresponds to a depth of 4 km and has left-lateral strike-slip motion with a vertical plane trending NNE-SSW. The fit between the observed and predicted spectra for this depth is shown in Figure 4 for the spectra of vertical, radial and transverse components of seven stations. For the EMUR, EIBI and EMLI stations only the vertical component has been used due to high noise level or data missing for other components. Theoretical spectra show a good fit in most of the stations, such as EBER, EMOS, EQES and EADA. In general,

transverse components are better reproduced, probably due to their higher amplitudes. In some stations, such as EALB, the high amplitude of seismic noise produces anomalous observed spectra, which can not be fit by the theoretical ones. The solution obtained for the largest aftershock (Figure 3b) is of similar mechanism, namely left-lateral strike-slip motion, but now the vertical plane, oriented in NNW-SSE direction, is dipping to the west. The CLVD component is 17% and focus is at a depth of 3 km. The scalar seismic moment (M_o) obtained in the inversion process are 1.54×10^{16} Nm and 0.7×10^{15} Nm, respectively, corresponding to Mw equal to 4.7 and 3.8. These values are similar to the results obtained from spectral
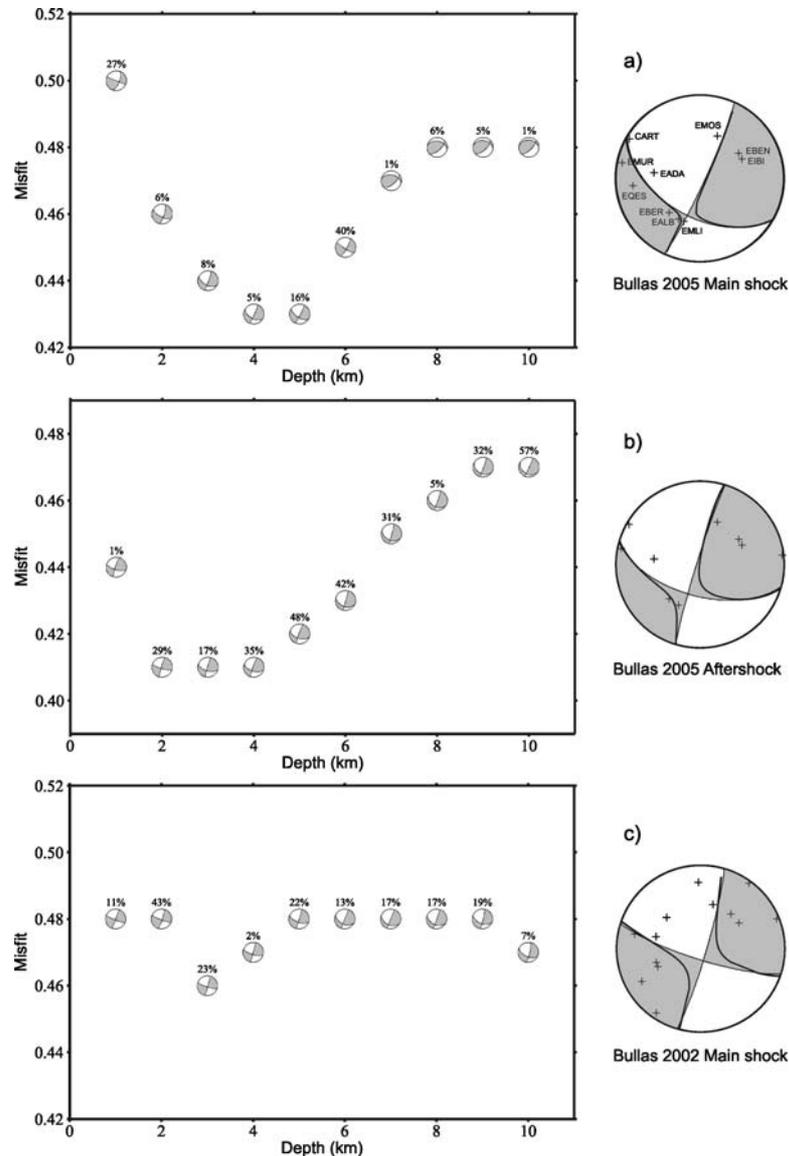
Figure 3. Results of the moment tensor inversion for the Bullas 2005 main shock (a), largest aftershock (b) and 2002 main shock (c). On the left, misfit versus depth is plotted, together with the DC solution obtained and amount of CLVD, and, on the right, the focal mechanism obtained (DC + CLVD). The stations used on the inversion are plotted as crosses.

analysis (Table 2). The source time function (STF) for the main shock was obtained using three aftershocks with magnitude 3.6 as empirical Green functions. Results obtained show a triangular STF with lower time duration than the value obtained from inversion (0.6 s versus 1.0 s). Focal mechanisms and scalar seismic moment obtained for the main and the largest aftershock are similar to solutions obtained by the IGN (IGN, 2005), but in our study the amount of CLVD is lower: 5% and 17% versus 11% and 48% respectively.

In order to compare these results with those of the 2002 shock, we have carried out the moment tensor inversion for the Bullas 2002 main shock (Figure 3c). For the Mula 1999 main shock the inversion has been impossible owing to the lack of broad-band stations at epicentral distances less than 350 km. The best solution obtained for the 2002 earthquake has left-lateral strike-slip motion, similar to that of the solution obtained for the 2005 main shock. The CLVD component is 2% at 4 km depth. We prefer this solution instead

Table 2. Source parameters of the Bullas 2005 mainshock and aftershock 2005 and Bullas 2002 earthquake

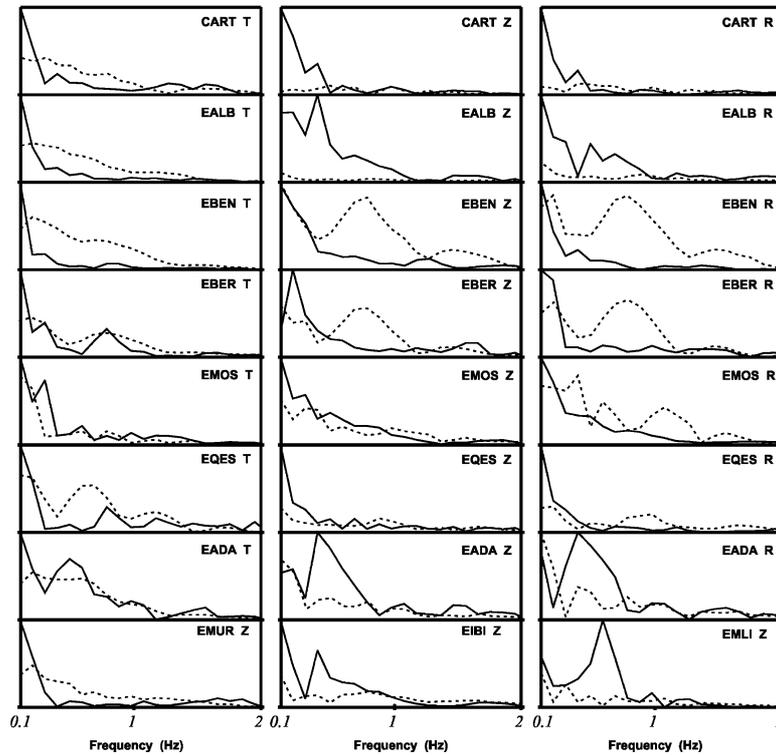| Event	h (km)	φ, δ, λ	CLVD	$M_0 \times 10^{15}$ Nm	M_w	STF (s)	$2r$ (km)[*]
BM 05	4	25, 84, −38	5%	15.4 9.3[*]	4.7 4.6[*]	1.0	1.8
BA 05	3	197, 87, 31	17%	0.7 1.9[*]	3.8 4.1[*]	0.5	1.4
BM 02	4	16, 84, −11	2%	7.8	4.5	1.0	1.5

[*] spectral analysis.

Figure 4. Comparison between the observed (continous line) and predicted (dashed line) amplitude spectra for the best solution of the moment tensor inversion for the Bullas 2005 main shock. Vertical scale is in nm/Hz.

of the one obtained at 3 km with higher CLVD component (23%), owing to the lower misfit value. The scalar seismic moment is 7.8×10^{15} Nm and the source time duration 1.0 s. These values are in agreement with previous results obtained by Buforn et al. (2005) for the 2002 main shock and largest aftershock from polarities of *P* waves and spectral analysis. Time domain moment tensor solution published IAG, Spain (Stich et al., 2003) show pure normal mechanism and 8 km depth, ETH, Switzerland solution (Braumiller et al., 2002) normal solution, but 15 km depth and 56% of CLVD and finally INGV (Italy) solution gives strike-slip solution with normal component and 15 km depth. However, all solutions including this study, shown horizontal pressure axis trending to NE-SW.

The mechanisms of the 2002 and 2005 earthquakes have a common N-S fault plane (Figure 5). This plane may be correlated with the trend of observed folds, however their correlation with known faults in the surface cannot be established (Sanz de Galdeano and Buforn, 2005). Both earthquakes have a different origin as that of the Mula 1999 series, which had reverse mechanism and is associated to the Cádiz-Crevillente fault system (Buforn et al., 2005).
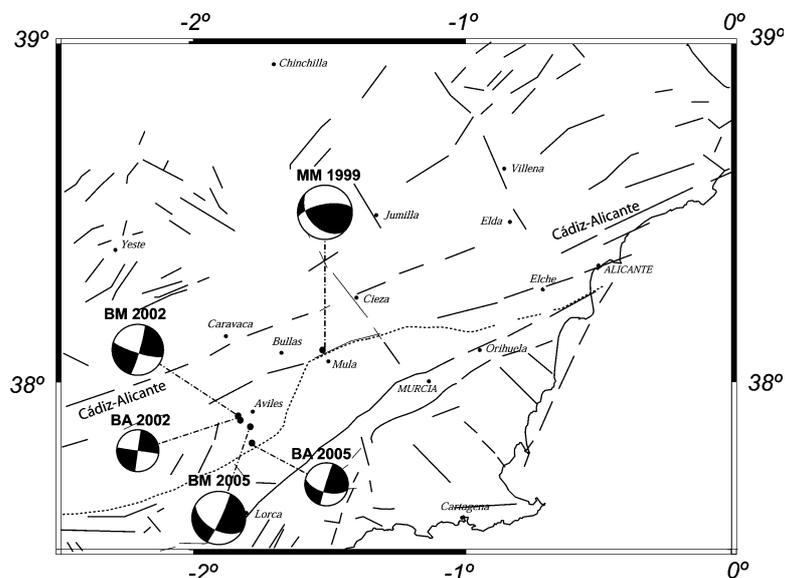
Figure 5. Focal mechanisms for the 1999 Mula main shock, 2002 and 2005 Bullas main and largest aftershocks, together with the main geological features. Size is proportional to magnitude (adapted from Buforn et al., 2005). Continuous lines correspond to main geological faults, and the dotted line corresponds to the contact between the Internal and External Betic Cordillera.

The different origin of the Mula 1999 series from the Bullas 2002 and 2005 series can be seen from Figure 4.

However, the difference of damage caused by the 2002 and 2005 earthquakes is surprising. The 2002 and 2005 earthquakes have similar scalar seismic moments 15.4 and 7.8 $\times$ 10^{15} Nm (M_w 4.7 and 4.5, respectively) and the epicenters are very close. The 2002 event reached intensity V in Zarcilla de Ramos, versus an intensity VII in the 2005 earthquake. A possible explanation for the larger intensities reached in 2005 is the weakening effect on some structures damaged in the 2002 earthquake (V).

Conclusion

Focal mechanisms obtained for the 2005 Bullas main shock and largest aftershock show left–lateral strike slip motion, with the horizontal pressure axis for the main shock oriented in the NNW-SSE direction. These mechanisms are similar to the solutions obtained for the Bullas 2002 main and largest aftershock (Buforn et al., 2005) and they are in agreement with the regional stress pattern present in Iberia (Buforn et al., 1995). Another common result for the 2002 and 2005 earthquakes is the shallow focus depth: 3 km for 2005 aftershock and 4 km for 2002 and 2005 main shocks. Intensities (EMS-98) have been estimated for the Bul-

las 2005 earthquakes with greater values at Zarcilla de Ramos (VII) and La Paca (VI–VII). The difference in damage caused by the 2005 earthquake from that caused by the 2002 earthquake can possibly be explained as due to the weakening effect on some structures previously damaged on the 2002 earthquake.

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