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The 2016 south Alboran earthquake ($M_w = 6.4$): A reactivation of the Ibero-Maghrebian region?

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ABSTRACT

On 25 January 2016, an earthquake of magnitude $M_w = 6.4$ occurred at the southern part of the Alboran Sea, between southern Spain and northern Morocco. This shock was preceded by a foreshock ($M_w = 5.1$) and followed by a long aftershock sequence. Focal mechanism of main shock has been estimated from slip inversion of body waves at teleseismic distances. Solution corresponds to left-lateral strike-slip motion, showing a complex bilateral rupture, formed by two sub-events, with most energy propagating along a plane oriented N30°E plane dipping to the NW. Relocation of larger events of the aftershock series, show two alignments of epicentres in NE-SW and NNE-SSW direction that intersect at the epicentre of the main shock. We have estimated the focal mechanisms of the largest aftershocks from moment tensor inversion at regional distances. We have obtained two families of focal mechanisms corresponding to strike slip for the NNE-SSW alignment and thrusting motion for the NE-SW alignment. Among the faults present in the area the Al Idrisi fault (or fault zone) may be a good candidate for the source of this earthquake. The study of Coulomb Failure Stress shows that it is possible that the 2016 earthquake was triggered by the previous nearby earthquakes of 1994 ($M_w = 5.8$) and 2004 ($M_w = 6.3$). The possible seismic reactivation of the central part of the Ibero-Maghrebian region is an open question, but it is clear that the occurrence of the 2016 earthquake confirms that from 1994 the seismicity of central part of IMR is increasing and that focal mechanism of largest earthquakes in this central part correspond to complex ruptures (or zone of fault).

1. Introduction

On 25 January 2016, at 04 h 22 m 03 s an earthquake occurred at the southern part of the Alboran Sea, between southern Spain and northern Morocco. According to the Instituto Geográfico Nacional, (IGN) the epicentre was located at (35.6004°N, 3.8056°W). Fig. 1 shows the location of the shock together with the seismicity of Ibero Maghrebian Region (IMR) with dates for the largest earthquakes (IGN). This shock was preceded by a foreshock ($M_w = 5.1$) on the 21th January and was followed until the middle of May by >2000 aftershocks, eight with $M_w = 5.0$–5.5. The main shock was felt in Al Hoceima, 54 km at SE of epicentre, but there is not available information about damages in this city. In Melilla (Spain), located 84 km to SE of the epicentre, caused 26 injured people and damages in the historical patrimony of the city, such as the Assembly Palace, site of the local government. In Nador (Morocco), located very close to Melilla (91 km from the epicentre), small damages were observed. The earthquake was felt within a radius of 600 km around the epicentre, with intensities VI (EMS-98) in Melilla and IV in Malaga (160 km at NW of the epicentre) (IGN, 2016).

The occurrence of the 2016 earthquake is not an unusual event in this zone, where in last 20 years, two moderate earthquakes have happened. On 26 May 1994 a $M_w = 5.8$ earthquake produced some damage in this region (Bezzeghoud and Buforn, 1999; Biggs et al., 2006). Ten years later, on 24–02-2004, another shock ($M_w = 6.3$) occurred very close to the 1994 event causing at Al Hoceima >600 casualties, 2500 injured and large number of collapsed houses (Ait Brahim et al., 2004). The 2004 and 2016 earthquakes, with similar size, are the largest ones occurred in the last 50 years in the Alboran Sea at the central part of the Ibero-Maghrebian region (IMR).

The IMR is located at the plate boundary between Eurasia and Africa, characterized by the occurrence of large earthquakes separated by long time intervals and the occurrence of shocks at shallow ($h < 40$ km) intermediate depth ($40 < h < 150$ km) and very deep depth ($h =$

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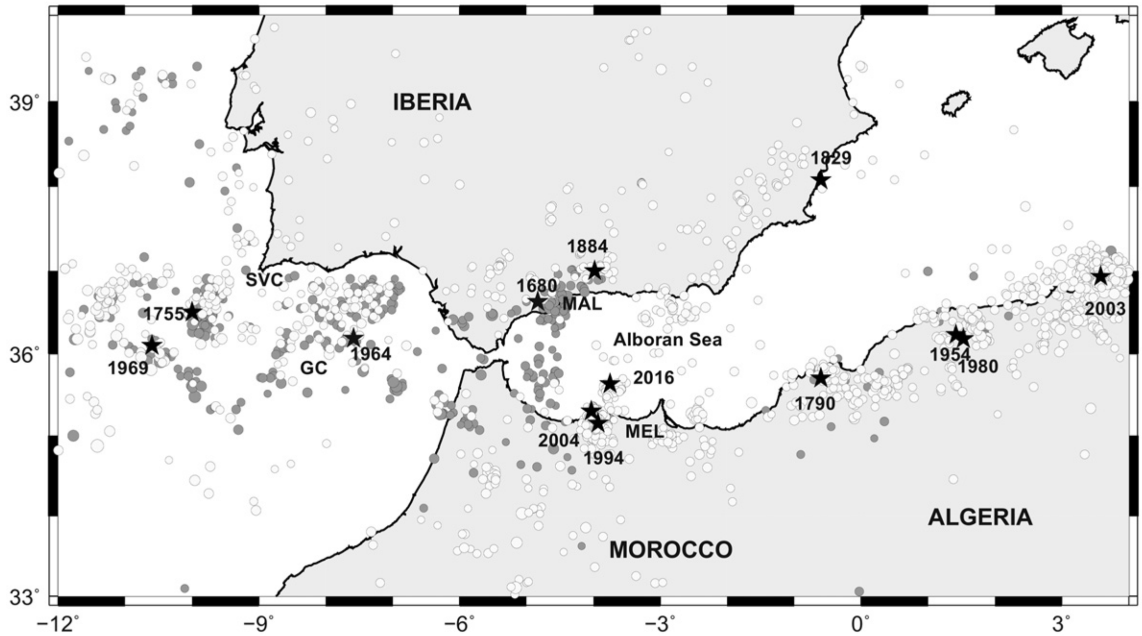

Fig. 1. Distribution of epicentres for period 1994–2017 and magnitudes greater than or equal to 3.5 (Catalogue of Instituto Geográfico Nacional, Madrid). Stars correspond to the large earthquakes (Imax = X or M > 6.0) that occurred in the Ibero-Maghrebian region. SVC = Cape St Vincent, GC = Gulf of Cadiz, MEL = Melilla, MAL = Malaga). White discs correspond to shallow events (h < 40 km), and grey discs to intermediate depth events (40 < h < 150 km).

650 km) (Buforn et al., 1988, 2004). Bezzeghoud and Buforn (1999) have divided the IMR into three zones based on their seismicity and seismotectonics, namely, western, central and eastern part. The largest earthquakes have occurred at western and eastern parts (Fig. 1). In the western part, (west of the Strait of Gibraltar at the Saint Vincent Cape and Gulf of Cadiz) large earthquakes have occurred, such as the great 1755 Lisbon earthquake, the 28-02-1969 Saint Vincent Cape earthquake ($M_s = 8.1$) and the 25-03-1964 ($M_s = 6.4$) Gulf of Cadiz earthquakes. At the eastern part of the IMR, in Algeria, large earthquakes have occurred, for example, the 1954 ($M_w = 6.9$) and 1980, El Asnam ($M_w = 7.1$) earthquakes and on the historical period large number of I_{max} = IX-X earthquakes (for example, the Oran 1790 shock). The central part of the IMR had an anomalous behaviour from seismological point of view during the 20th century, with a deficit of large shocks on this part (Buforn et al., 2004, 2015). However, on the historical period, large earthquakes (I_{max} = IX-X) have occurred in central part, in south Spain, such as, those of Malaga 1680, Torrevieja 1829 or Arenas del Rey 1884 (Muñoz and Udías, 1988, 1991; Goded et al., 2008), but there is a lack of large earthquakes on northern Morocco, along the coast, (Buforn et al., 2015). However, the end of the 20th century and the beginning of 21th century this part has been seismically very active with the occurrence of 1994, 2004 and 2016 earthquakes.

In this paper, we study the occurrence of the 2016 south Alboran series of earthquakes, its rupture process, and we leave as an open question if the central part of IMR is under a seismic "reactivation" period.

2. Geological setting

The Alboran Sea, in the Central Part of the IMR, forms the western end of the Mediterranean Sea and is situated between the Betics and Rif chains and corresponds to the western prolongation of the Algerian Basin, opened from the early Miocene, contemporary with the westwards drift of the Betic-Rif Internal Zone (this zone is common to both cordilleras). It has a complex structure and dynamic evolution.

The Betic-Rif Internal Zone was originally situated in an eastern position (several hundred kilometres) and owing to the opening of the Algerian Basin was pushed out to the west (Boillot et al., 1984; Sanz de Galdeano, 1990a). In this drift process this Internal Zone collided obliquely in its northern border with the Betic External Zone, which owing to the impact was deformed, rotated and structured in many tectonic units. In this process, in the Betics, important strike-slip E-W faults (Fig. 2) were formed, helping to the displacement of the Internal Zone. On the whole, although with some differences, similar evolution occurred in the south border of the Internal Zone, deforming in this case the Rifian External Zone. Contemporary, the Internal Zone pushed in the frontal area, forming the Gibraltar Arc and initiating the formation of a subducting slab (López Casado et al., 2001; Pedrera et al., 2011). More eastern areas, within the Alboran Basin, were submitted to east-west extension. For this reason, great part of this basin presents a thinned continental crust.

The Betic-Rif Internal Zone is formed by three tectonic complexes that, from bottom to top, are the Nevado-Filábride (not present in the Rif), the Alpujárride (called Sebtide in the Rif) and Maláguide (called Ghomaride in the Rif). To this last is associated the so called Dorsal. The two lower complexes present Alpine metamorphism. The continental crust of the Alboran Basin, that is to say its basement, is mainly formed by materials belonging to the Internal Zone, particularly by the Alpujárride Complex.

Above the cited basement, already during the early and middle Miocene, and owing to the subsidence produced by the internal extension underwent within the Alboran Basin, important sediments succession were deposited, in part of which noticeable diapiric structures have been developed (Comas et al., 1992; Jurado and Comas, 1992; Pérez-Belzuz et al., 1997) (Fig. 2).

From the end of the middle Miocene and during the late Miocene the westwards displacement of the Internal Zone continued, although attenuated comparing to that existing during the early Miocene. Then the relative movement of approaching between the Africa (Nubia) plate and Iberia regain importance and submitted the Alboran Sea to compression in an approximate NNW-SSE direction.

This compression provoked the formation of the main faults now existing in the Alboran Sea, that is, the NE-SW faults crossing transversally from the Carboneras fault in the SE of Spain, passing and forming the Alboran Ridge (where the Alboran island is situated) and extending to the SW, although the continuity with the Jebha fault, in the Rif, is not clear (De Larouzière et al., 1988). Other lines of faults are