



# Seismotectonic and seismological aspects of the Mostaganem (Western Algeria) May 22, 2014 (Mw 4.9) seismic event

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Received: 19 September 2017 / Accepted: 11 January 2018 / Published online: 29 January 2018  
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## Abstract

On Thursday, 22 of May 2014, at 6 h 22 min 0.3.3 s (GMT + 1) a moderate-sized earthquake struck the Mostaganem, Western Algeria, region. The main shock, recorded by many international and national seismological stations, was preceded by a foreshock, 3 hours before, on May 22, 2014 ( $M_I = 4.1$ ) at 3 h 57 min 41.4 s and followed by four well-felt aftershocks ( $M > 3.0$ ) that lasted about 1 year. The main shock did not cause loss of lives but serious panic among the population was reported. The main shock, however, caused cracks in walls and roofs, sometimes destroyed, the old non-engineered and precarious adobe dweller corresponding to  $I_0 = VI-VII$  (Msk scale). We used accelerograph records to (i) determine the epicenter location (longitude = 0.3537 E, latitude = 35.8598 N, (ii) perform waveforms inversion to calculate the earthquake parameters. The obtained results are, respectively, the seismic moment ( $M_0 = 2.71 E + 16$ , the  $M_w = 4.9$  and the focal depth = 6 km. The obtained focal mechanism solution shows reverse faulting with small right lateral component with the following nodal plans: NP1, strike = 193.5, dip = 49.5, slip = 57.6 and NP2, strike = 57.8, dip = 50, slip = 122.1. On the other hand, the seismotectonic framework of the Dahra area exhibits a serie of NE-SW trending “en echelon” faulted folds that may be active as suggested by this study.

**Keywords** Earthquake · Faulted folds · Accelerograph records · Waveforms inversion · Western Algeria

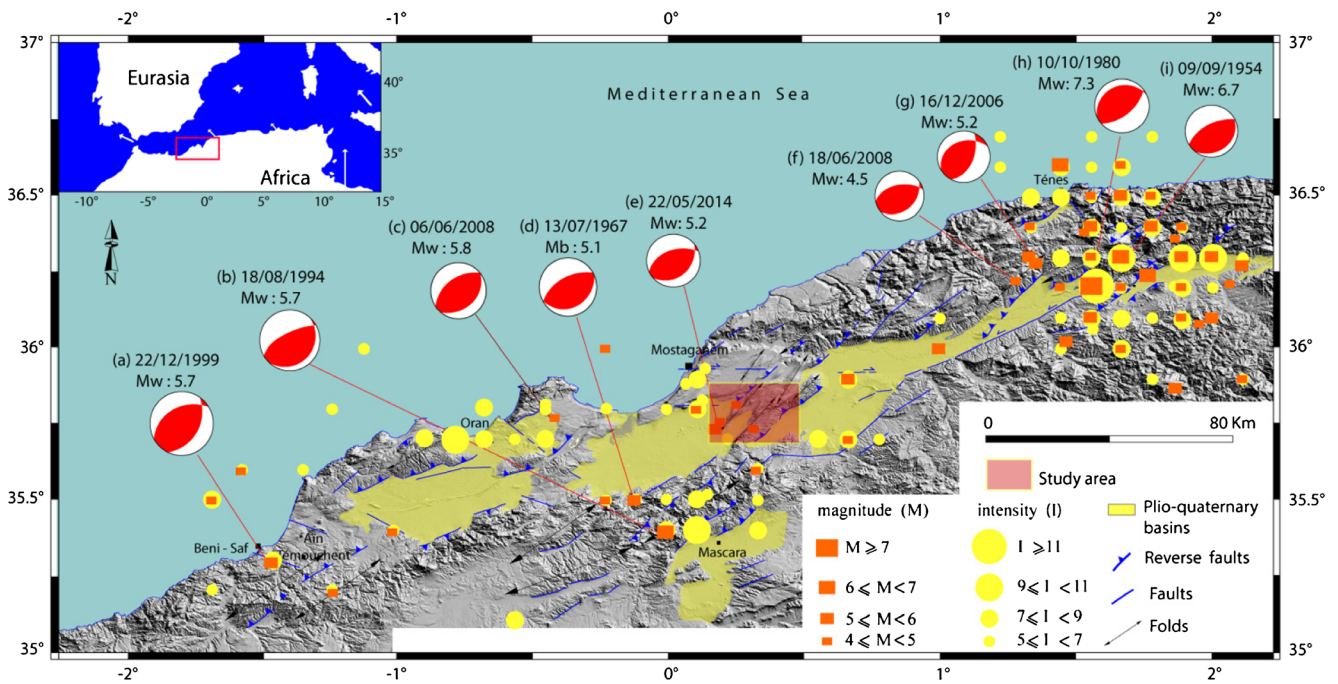
## Introduction

On Thursday, 22 of May 2014, at 6 h 22 min 0.3.3 s (GMT + 1) a moderate-sized earthquake struck the Mostaganem, Western Algeria, region. The epicentral area is located at Bouguirat, western Mostaganem at about 350 km, to the west, from the capital city Algiers, in the Tell Atlas chain of Algeria (Fig. 1). The main shock, recorded by many international seismological stations and by three stations of the Algerian permanent accelerographs network monitored by CGS (Tables 1 and 2), was preceded, 1 year before, by a weak quake on May 2, 2013 ( $M_I = 3.2$ ) and by a foreshock, 3 h before, on May 22, 2014 ( $M_I = 4.1$ ) at 3 h 57 min 41.4 s

(GMT + 1) (CSEM). The main shock was also followed by four well-felt aftershocks ( $M > 3.0$ ) (Table 3). Several international organisms provided the focal mechanism solutions of the main shock (Table 4). The main shock did not cause losses of human lives but serious panic among the population was reported. The main shock, however, caused cracks in walls and roofs, sometimes destroyed, the old non-engineered and precarious adobe dweller constructions. The recent engineered concrete constructions suffered only slight fissures. Concerning ground geological effects neither liquefaction nor surface rupture breaks are observed. However, small surficial slides, along roadsides, were observed in the epicentral area (Fig. 2). Taking into account the observed damage and the quality of building stock and based on our own post seismic observations in the affected area, we attributed an intensity  $I_0 = VI-VII$  (MSK scale) to the epicentral area. Neotectonic evolution of the Tell Atlas chain is a consequence of the geodynamic evolution of the Mediterranean area (Philip, 1987). The opening of the Tellean Atlas neogene basins is in relation with the regional N-S extension that followed the thrust sheet set during the Upper Miocene. This tectonic

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**Fig. 1** Seismotectonic framework and seismicity (Ayadi and Bezzeghoud 2015) of Western Algeria. Focal mechanisms (a), (b), and (h) are from Global CMT (c) from Mednet; (d) from Mc kenzie, 1972 (in Maouche 2010); (e) from GFZ; (f) and (g) Beldjoudi 2011; (i) from Espinoza and

Lopez-Arroyo, 1984 (in Maouche, 2010). The transparency square indicates the studied area. Faults are from Meghraoui et al., 1988; Meghraoui et al. 1986; Bouhadad 2001; Belabbes et al. 2009)

process was marked in the Western Algeria by the calc-alkalin volcanism of the Ain temouchent region (Megartsi 1985; Louni-Hacini et al. 1995). During Pliocene period, the Tell Atlas area was characterized by E-W to ENE-WSW extension and NNE-SSW to N-S shortening marked by the alkaline volcanism of Western Algeria, Morocco, and Betic Cordillera in Spain. During the quaternary period the shortening direction became NNW-SSE (Philip and Thomas, 1977; Meghraoui et al. 1986). In this work, we aim firstly to describe this seismic event, occurred in a seismically quiescent area of Mostaganem and to determinate the main shock parameters including the epicenter geographical coordinates, the moment magnitude (Mw), the seismic moment and the focal mechanism solution using accelerograph records (9 accelerograms). Also, we summarized the seismotectonic and active tectonics aspects of the Dahra mountains, a part of Tell Atlas chain.

**Seismotectonic setting**

The studied area belongs to the Chelif-Mio-Plio-Quaternary sedimentary basin (Fig. 1), in the Tell Atlas, which resulted from the last tectonic phases of the Alpine-Mediterranean

orogenic belt (Perrodon 1957). The Chelif basin is, relatively, well studied following the El Asnam October 10, 1980 ( $M_s$  7.3) earthquake (Ouyed et al. 1981; Philip and Meghraoui; 1983; Meghraoui et al. 1986). The quaternary and active deformation is resulted from 4 to 8 mm/year and NNW-SSE oriented shortening due to compression movements between the African and the Eurasian tectonic plates (Argus et al. 1989; De Mets et al. 1990; Nocquet and Calais 2004; Serpelloni et al. 2007). In echelon, NE-SW trending faults and folds constitute the main geological features responsible of the seis-

**Table 1** The May 22, 2014 earthquake parameters following different organisms and this study

Organism	Latitude	Longitude	Depth (km)	Magnitude
This study	35.859	0.353	6	Mw 4.9
CRAAG	35.770	0.264	–	MI 5.2
CSEM	35,730	0,180	10	Mw 4.8
GFZ	35.610	0.190	10	Mw 4.8
GCMT	35.770	0.360	10	Mw 4.8
USGS	35.785	0.241	15	Mw 4.8
INGV	35.660	0.180	10	Mw 4.9

**Table 3** The accelerograph stations that recorded the main shock of May 22, 2014 (see Fig. 3)

Station site	Station code	Latitude	Longitude
Mohammadia	MHDA	35.592	0.082
Sig	SIGM	35.515	-0.218
Mesra	MES	35.840	0.167

micity of the region (Thomas 1985; Meghraoui et al. 1986; Meghraoui et al. 1996; Bouhadad 2001; Belabbes et al. 2009; Bouhadad et al. 2010; Maouche et al. 2011; Bouhadad 2013). These structures are delimited by E-W trending deep dextral strike slips inducing block delimitation, related to the N-S to NNW-SSE transpressive convergence between Africa and Eurasia (Meghraoui et al. 1996; Meghraoui and Pondrelli 2012; Derder et al. 2013). During the last decades, strong and moderate earthquakes are well studied allowing, hence, to show that seismicity is not randomly distributed, but related to previously known or unknown actives faults that may be blind or not (Benouar et al. 1994; Bezzeghoud and Buforn 1999; Meghraoui et al. 2004; Belabbes et al. 2009; Beldjoudi et al. 2016; Benfedda et al. 2017). On the hand, several historical earthquakes have been occurred as indicated in the seismicity catalogs of Algeria (Mokrane et al. 1994; Ayadi and Bezzeghoud 2015) and/or recorded in geological layers (Meghraoui et al. 1988; Meghraoui and Doumaz 1996; Bouhadad et al. 2009; Benhammouche et al. 2013).

### The mainshock location, moment tensor estimation, and focal mechanism

The May 22, 2014 main shock has been recorded by three components accelerograph stations (9 accelerograms) of the Algerian accelerograph network indicated in Table 3 and Fig. 3 as MHDA (Mohammadia), Sig (SIGM), and Mesra (MES). We used the SEISAN software

(Ottmöller, 2016) for manually phases picking and the grid search method to locate this seismic event. We used a multi-layer velocity model of Bounif et al. (2004) with  $V_p/V_s$  ratio of 1.73, where we considered a 0.5-km 3D grid of the medium. The obtained epicenter geographical coordinates and focal depth are, respectively, Longitude = 0.3537 E, latitude = 35.8598 N, and depth = 4.5 km as shown on Fig. 3 and indicated in Table 1. In order to estimate the seismic moment ( $M_0$ ), the moment magnitude ( $M_w$ ), and the fault plan solutions, we used a program set developed by Yagi and Nishimura (2011) to perform waveforms inversion by using the recorded accelerograms as shown in Table 3. The result consists of double couple solutions. The observed waveforms are described as a convolution of the Green's function and the moment rate function. This well-known procedure is based on two assumptions. Firstly, the seismic source is assumed as point source model where the source time function is an isosceles triangle, from which the observed waveforms are radiated. Secondly, it is assumed that each earthquake has only one focal mechanism. We applied the low frequency filter on the observed data and we re-sampling them to mitigate the effect of the complexity of the seismic source and the effect of the velocity model heterogeneities. In order to obtain the best centroid location, the horizontal location of the centroid is approximated as the epicenter location. After that we vary, in this work, the centroid depth from 1 to 15 km. The estimated optimal depth of the centroid and the source half duration are obtained by using the grid-search method in order to minimize errors between observed and calculated waveforms. The best solution corresponds to a centroid depth of 6 km. The obtained results, as shown in Fig. 4, are the moment magnitude  $M_w = 4.9$  and the seismic moment  $M_0 = 2.71 \times 10^{16}$  (Nm). The obtained focal mechanism shows reverse faulting with small right lateral component with the following nodal plans: NP1, strike = 194, dip = 50, slip = 58 and NP2, strike = 58, dip = 50, slip = 122. Our solution is comparable other solutions provided by different international organisms (i.e., INGV, GCMT, GFZ).

**Table 2** Earthquakes occurred just before and after the mainshock of May 22th, 2014

Organism	Date	Time (GMT + 1)	Longitude	Latitude	Magnitude
Foreshock	22.5.2014	3 h 57 min 41.4 s	0.353	35.82	Ml 4.1
Main shock	22.5.2014	6 h 22 min 03.3 s	0.170	35.73	Mw 4.8
Aftershock	22.8.2014	1 h 22 min 46.4 s	0.160	35.72	mb 4.1
Aftershock	29.12.2014	8 h 53 min 27.7 s	-0.150	35.79	Mb 3.3
Aftershock	01.02.2015	2 h 28 min 41.1 s	0.240	35.69	Mb 4.2
Aftershock	2.10.2015	12 h 58 min 19.2 s	0.260	35.64	Mb 3.8

**Table 4** Source parameters of the May 22, 2014 main shock following this study and international organisms (Fig. 3)

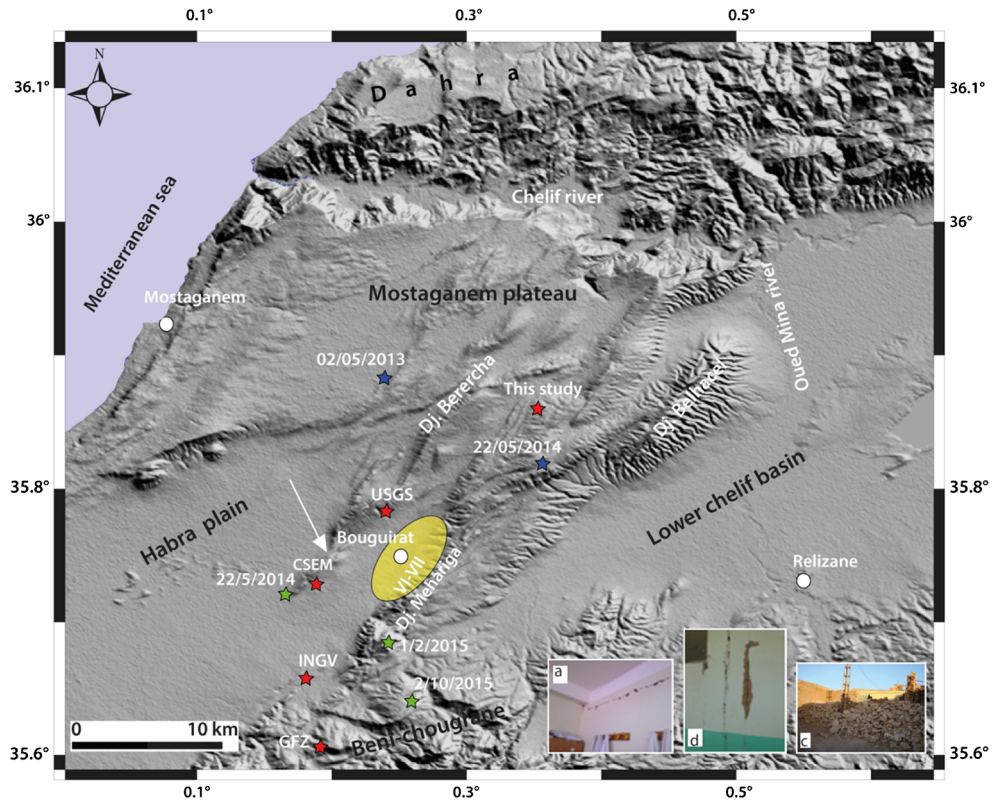
Organisms	Nodal plane 1			Depth (km)	Nodal plane 2			M <sub>0</sub> (N.m)
	Strike(°)	Dip(°)	Rake(°)		Strike(°)	Dip(°)	Rake(°)	
This study	58	50	122	6	193	50	58	2.71 E+16
GFZ	50	33	73	10	250	58	101	2.30 E+16
GCMT	45	38	116	10	259	57	110	3.23 E+16
INGV	79	36	116	10	228	58	73	2.97 E+16
USGS	83	58	96	15	193	50	58	1.80 E+16

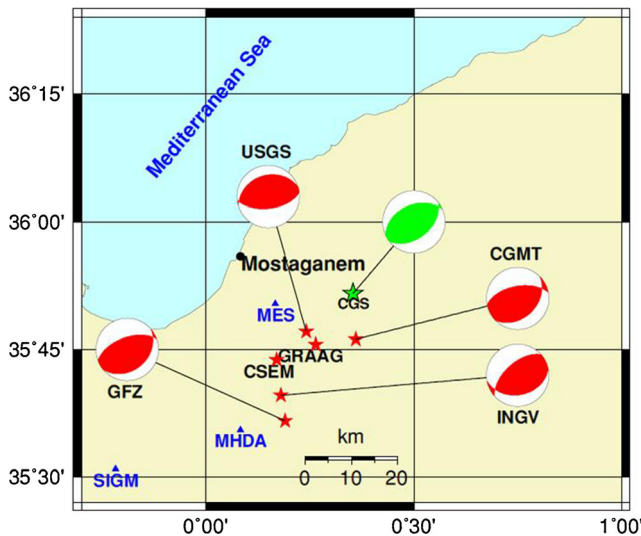
### Seismotectonic aspects of the Dahra-Mostaganem region

The Mostaganem plateau corresponds to the western part of the Dahra mountains and forms the western edge of the lower Chelif basin. Its southern part is formed by NE-SW to NNE-SSW trending dissymmetric folds (Anderson 1936; Perrodon 1957; Abbouda 2015). Three main anticline lines can be distinguished from the northwest to the southeast (Fig. 5): (i) First anticline line axis is represented, from the southwest to the northeast, by Djebel Milar, Djebel Mouzaia, Ennaro (Djebel Biodh, Djebel Zaimia),

Djebel Djazar, Berercha, and Bsibissa, respectively. These folds are dissymmetric with high dip angles of the Calabrian deposits suggesting the presence of blind faults beneath the fold, confirmed by the Berercha drilling Br1 (Perrodon 1957) (Fig. 6a). (ii) The second anticline line is represented, from the southwest to northeast, by Djebel El Djir, Djebel Mhirga, Bouguirat, and Akboub anticlines as well as the Dahra faulted fold. This structure corresponds to a faulted fold with a high dip angle of the Calabrian deposits (Fig. 6b). (iii) The third anticline line is represented by the 14-km long and 7-km wide Belhacel dissymmetric anticline which forms the western Chelif sedi-

**Fig. 2** Map showing the epicentral area. The yellow elongated shaded area indicates the maximum intensity area ( $I_0 = VI-VII$ ). The red stars indicate the main shock epicenter obtained in this study and international organisms. Blue stars indicate epicenters of the May 22, 2014 ( $M_l = 4.1$ ) foreshock and the small earthquake of May 22, 2013 (exactly 1 year before). Green stars indicate aftershocks (Table 3). Photographs a, b, and c indicate kind of observed damage—fissures in well-engineered recent constructions (a and b) and collapse of traditional non-engineered local house (c). The arrow indicates the position of the photograph of Fig. 7



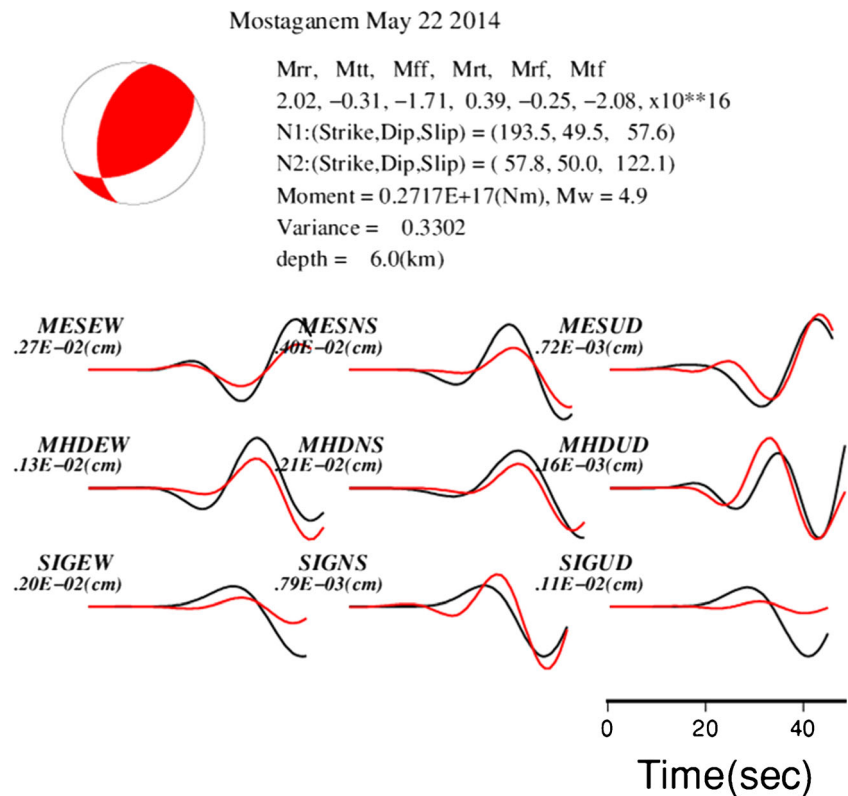


**Fig. 3** Red stars indicate the epicenter localization of the May 22, 2014 main shock provided by different organisms. Blue triangles indicate the accelerograph stations that recorded the accelerograms we used. See also the focal solution provided by international organisms (red) and this study (Green)

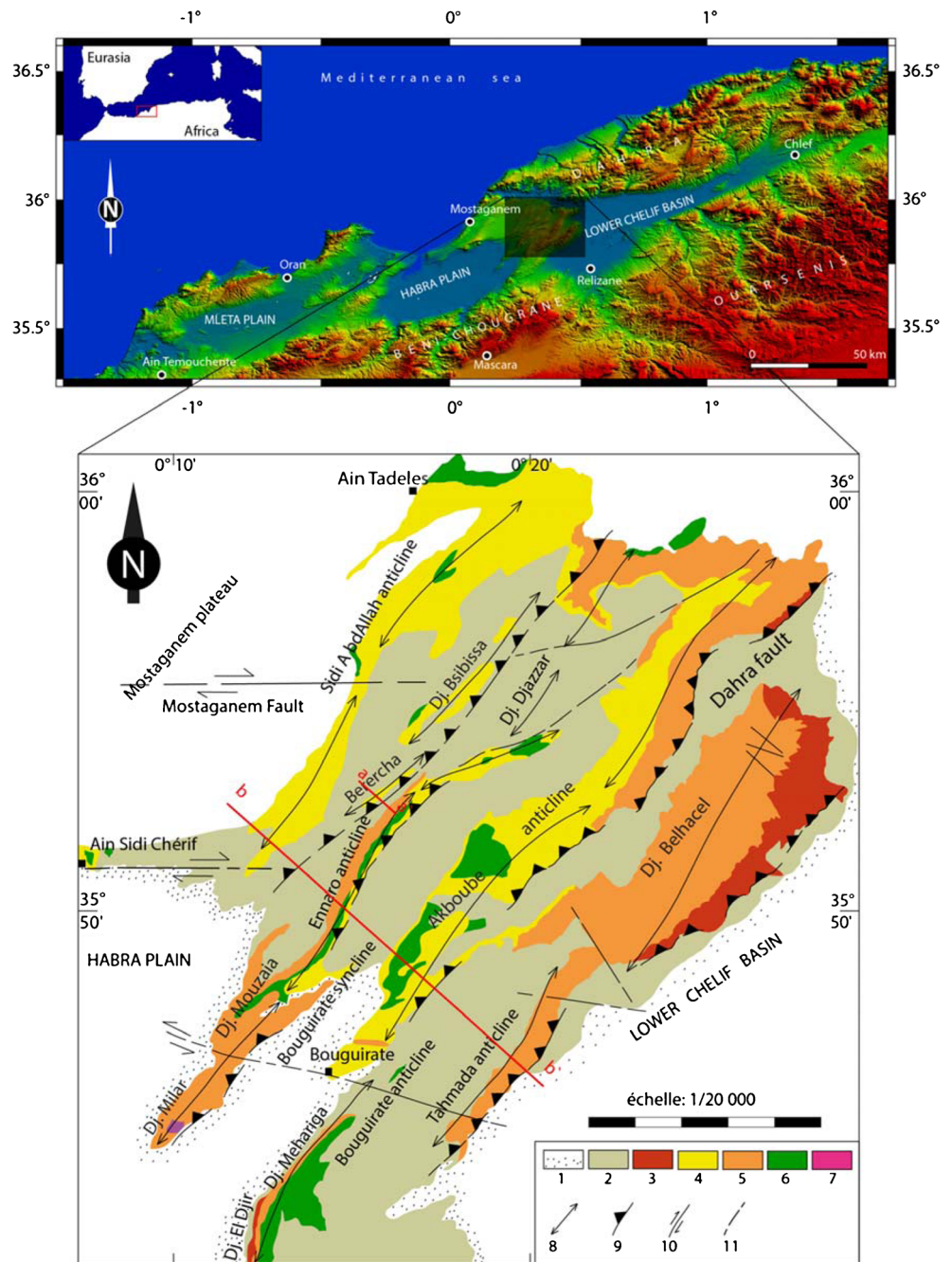
mentary basin edge. The Belhacel anticline is trending NE-SW and formed by a Plaisancian blue marls covered

by Astian deposits (sandy marls and sandy calcareous) observed on both sides of the anticline. The Villafranchian red limons and Holocene deposits (calcareous crest, sand, limons, silts) are tilted and more developed on the SE side than in the NW side as evidence of the undergoing tectonic compression. Also, the Belhacel structure shows geomorphic evidence of active tectonics such as the clearly diverted Oued Mina river that exhibits abandoned meanders and uplifted Villafranchian and Holocene deposits described above (Fig. 7). The echelon NE-SW trending faults and folds, described above, are affected by E-W dextral strike slips such as the Ain Sidi Ali Cherif and Mostaganem causing the torsion of the anticlines (see the changes of Akboub and Ennarro fold trends from NE-SW to NNE-SSW) and the segmentation (offsets) of faults (Fig. 5). These strike slips correspond to the E-W deep structures described in the neotectonic mechanical model of the Chellif basin (Philip and Meghraoui 1983; Meghraoui et al. 1996; Meghraoui and Pondrelli 2012; Derder et al. 2013). The Bouguirat syncline is a quaternary back faulted anticline basin that resulted, likely from extrados normal faulting (Fig. 6b). In terms of seismicity, the Mostaganem plateau area is characterized by a weak seismicity compared to the other region of

**Fig. 4** Source parameters (Moment tensor values, strike, dip, slip, depth, and magnitude) of May 22, 2014 mainshock obtained using waveform inversion. Black line represents the observed seismogram, and red line represents the synthetic seismogram. Station name and vertical scale (in cm) are indicated at the top left of each observed and synthetic seismogram



**Fig. 5** Seismotectonic framework of the western Dahra area. a–a' and b–b' indicate the position of cross sections of Fig. 6a, b

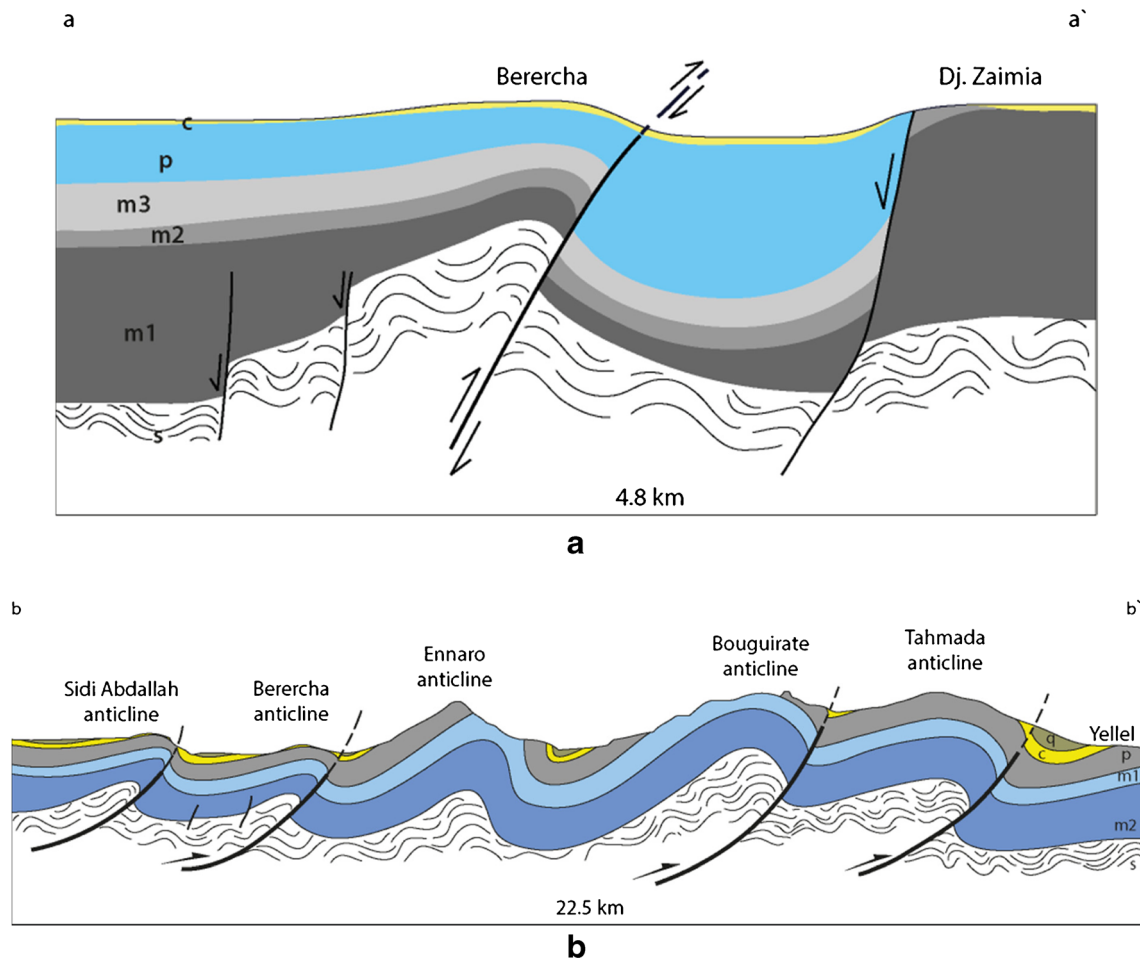


Western Algeria (Ayadi and Bezzeghoud 2015) despite the expressive geomorphic and geological evidences of active tectonics (Figs. 7 and 8).

**Discussion**

The 22 of May earthquake ( $M_w = 4.9$ ) occurred in a relatively quiescent area compared to other regions of Western

Algeria such as the Oran region historically hit by earthquakes of October 9, 1790 ( $I_0 = X$ ) (Ayadi and Bezzeghoud, 2015; Lopez Marinas and Salord 1989), the Oran moderate earthquake of December 12, 1959 ( $M_s 5.6$ ) (Benouar, 1994), the Benichograne-Mascara earthquakes of 1819 ( $I_0 = X$ ), 1851 ( $I_0 = VIII$ ), and 1994 ( $W_w = 5.6$ ,  $I_0 = VIII$ ), and the Ain Temouchent earthquake of December 22, 1999 ( $W_w = 5.6$ ). In terms of active tectonic, the studied area exhibits several active structures, oriented

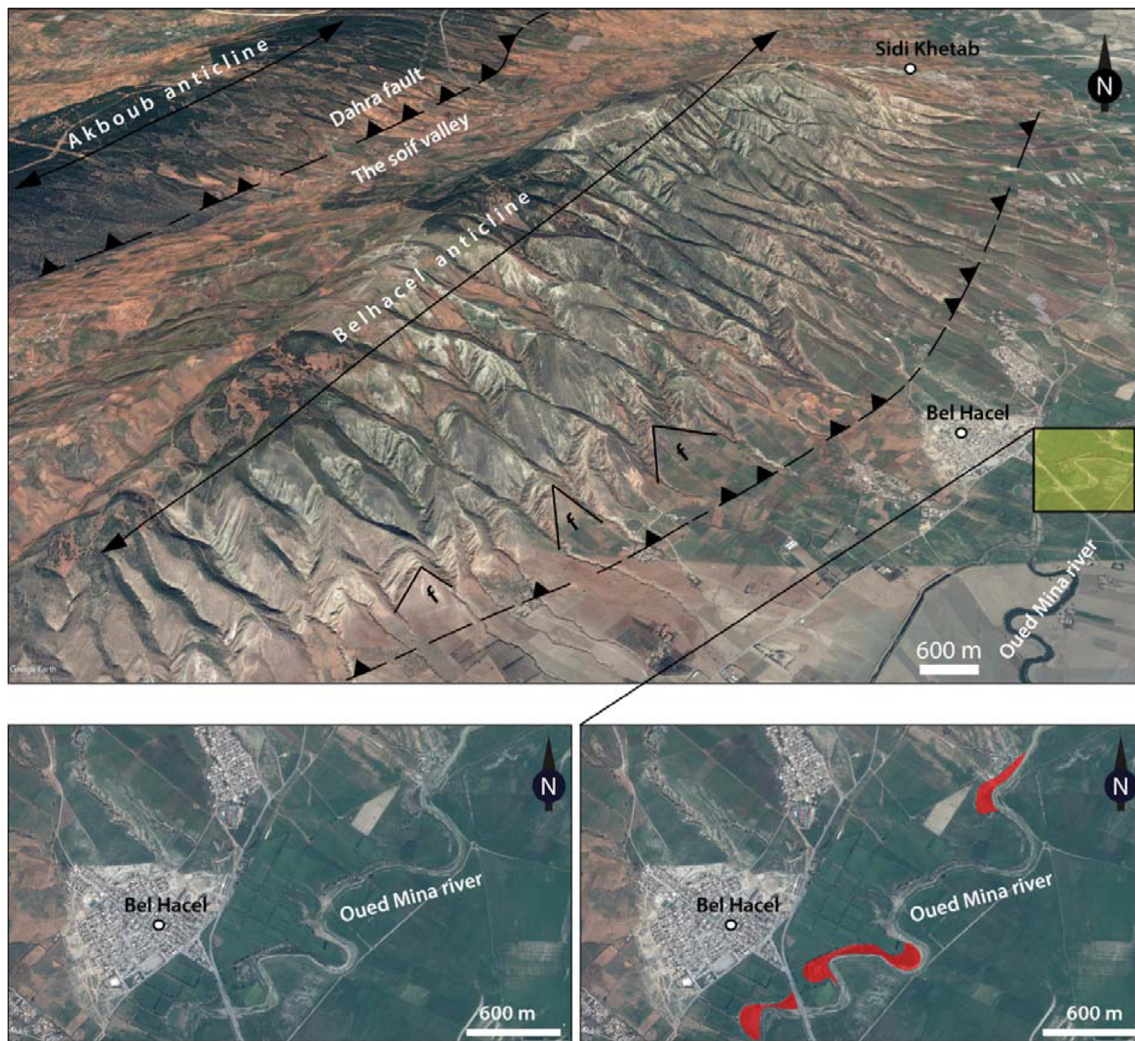


**Fig. 6** NW-SE cross sections in the studied area (Fig. 5). **a** Through the Berercha structure (Perrodon, 1957). **b** Interpretative tectonic section of western Dahra



**Fig. 7** Field photograph showing high angle tilt of Villafranchien calcarenite and red limons (see Fig. 2)

NE-SW, comparable to other active structures such as Ain Temouchent, Mascara, Oran, and Chelif basins (Meghraoui et al. 1988; Aoudia and Meghraoui 1995 Bouhadad 2001; Belabbes et al. 2009). In terms of seismic hazard, this seismic event showed that rural building stock, in northern Algeria, is still vulnerable to earthquakes and even moderate earthquakes may cause damage and collapse of rural dwellings. Finally, our study show also the valuable contribution of local networks to seismological and seismotectonic studies. It is worthy to mention that the obtained focal mechanism solution in this work is comparable to solutions provided by INGV, GCMT, and GFZ. Unlikely, our epicenter location is about 15 km far to the NE relatively to the epicenters provided by CSEM and USGS, but our epicenter is located near the foreshock occurred 2 h before the main shock (Fig. 2). The damage in the Bouguirat area, 15 km far from our epicenter, may be explained by a possible site effect related to the quaternary deposits of the Habra plain.



**Fig. 8** Defluviation of the Oued Mina river consequently to Holocene tectonic uplift of Belhacel faulted fold. See also the triangular facets (f). Below, see details of the defluviation of Oued Mina river (underlined by red color)

## Conclusion

In this work, we studied the May 22, 2014 (Mw 4.9) seismic event, occurred in Western Algeria, based on collected data from field, exploitation of accelerograph records and analyzed in the framework of the seismotectonic context of the Dahra (western Tell Atlas chain) region. We obtained a focal depth of 6 km that confirms the shallow character of seismicity in the studied area. On the other hand, we determined focal mechanism that shows reverse faulting with small right lateral component with a compressional axis oriented NNW-SSE, confirming also the regional stress context. The calculated earthquake parameters are the seismic moment ( $M_0 = 2.71 \text{ E} + 16$ ) and the moment magnitude ( $M_w = 4.9$ ). Finally, we confirm in this study that the NE-SW trending folds of the Mostaganem plateau area may be active and may produce earthquakes. On the other hand, we estimated a macroseismic intensity  $I_0 = \text{VI-VII}$  (Msk scale) that suggests the high

vulnerability of the building stock in the area and we determined the epicenter geographical coordinates which are longitude = 0.3537 E and latitude = 35.8598 N. In the end, our results suggest that the Bouguirat dissymmetric fold is, likely, underlined by a blind fault and is the causative structure of this seismic event.

**Acknowledgments** This work is a part of the research activities in the National Center of Applied Research in earthquake engineering (CGS). We would like also to thank the engineering seismology team in charge of maintaining the accelerograph network.

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