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ORIGINAL ARTICLE

Characterizing the active tectonics in the Oran region (Algeria) and recasting the 1790 earthquake

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Abstract In this work, we reappraise the seismogenic potential of the geologic structures in the western Tell Atlas of Algeria, considered active host to moderate to low magnitude earthquakes. The direct identification of active faults is generally a difficult task in northern Algeria. The active tectonics in the Oran Plio-Quaternary age basin (Northwestern Algeria) is analyzed and characterized through a morpho-structural study combining topographic, geomorphologic, geological, and neotectonic data. Folds and fault scarps affecting Quaternary deposits show that the region is affected by compressional deformation still active nowadays, as shown by the recorded seismic activity. Our new observations enable a better understanding of the present seismotectonic context of the Oran region, particularly with regard to the magnitude and source of the 1790 Oran damaging event. The obtained result helps to shed some light on the elusive active tectonics characterizing this coastal area, and to assess regional seismic hazard, particularly in coastal zones where large seismogenic areas straddle the onshore–offshore zones.

Keywords Oran · Geomorphology · Neotectonics · Active tectonics · Seismicity

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1 Introduction and tectonic setting

The Oran basin is located in the western part of the Tell Atlas of Algeria, a fold-and-thrust belt located in the southern side of the western Mediterranean. This narrow, east-west trending belt is one of the most seismically active regions in Northern Africa. It experienced destructive seismic events such as the Mw 6.8, 21 May 2003 Zemmouri earthquake (e.g., Meghraoui et al. 2004; Harbi et al. 2007) and the Mw 7.3, 10 October 1980 El Asnam earthquake (Ouyed 1981; Philip and Meghraoui 1983). The tectonic regime of this region is compressional since the Eocene, with a N-S to NW-SE shortening direction related to the convergence between Africa and Eurasia (McKenzie 1972; Dewey et al. 1989). After GPS measurements, the present shortening rate between the two plates is 4–6 mm/year

(Nocquet and Calais 2004; Serpelloni et al. 2007 and references therein). This convergence movement generates repeated large earthquakes and implies a significant uplift rate. This rate is consistent with the 2–3 mm/year shortening rate along the plate boundary in northern Algeria (Meghraoui and Pondrelli 2012). The active deformation visible along the Tell Atlas thrust and fold belt may accommodate ~ 1–2 mm/year of shortening along the coastal mountains (Meghraoui and Doumaz 1996; Maouche et al. 2011).

Studies on the relationships between the largest seismic events of Algeria and the geological structures in the Tell Atlas were carried out in several sites. These studies raised two main points: (1) Moderate-sized historical earthquakes (5.0 < M < 5.9) are frequent (Rothé 1950; Harbi et al. 2015); (2) seismically active regions correspond to zones of deformed young deposits and prominent Quaternary geological structures (Meghraoui et al. 1986; Meghraoui 1988; Aoudia and Meghraoui 1995; Meghraoui et al. 1996; Boudiaf et al. 1998, Boudiaf et al. 1999; Harbi et al. 1999; Bouhadad 2001; Meghraoui et al. 2004; Maouche et al. 2011).

Geological structures such as thrust faults and overthrust folds-and napes constitute the main structural features of the Tell Atlas. Asymmetrical folds associated with thrust faults, uplifted terraces, and strike slip faults, which are mainly located in intermountain Neogene and Quaternary basins, are also structural features that are observed in the Tell Atlas. These structures are segmented and organized in "en échelon" pattern (Meghraoui 1988; Meghraoui and Pondrelli 2012). In several cases, these are associated with blind faults. Examples, from east to west, include the Chott El Hammam and related fault in the Hodna basin, the Algiers Sahel anticline in the Mitidja basin, the Oued Fodda asymmetric fold and associated reverse fault, the Bou-Kadir fold, the Tenes-Abou El Hassan fold and related fault, and the Murdjadjo anticline (Meghraoui 1988; Fig. 1a). These structures have been associated with strong earthquakes (e.g., Oued El Fodda fault, Tenes Abou EL Hassen, Algiers Sahel, Meghraoui 1988; Aoudia and Meghraoui 1995; Maouche et al. 2011).

The 1980 El Asnam earthquake occurred in the Cheliff intramountainous basin. Geological structures similar to that of El Asnam and their correlations with major historical seismic events can be noticed along the Tell Atlas Mountains (Phillip and Meghraoui 1983; Meghraoui 1988). The Oran basin, which is the continuation western Cheliff basin, is one of the basins in the fold and thrust zone. It shows E–W to NE–SW trending folds, and reverse faults affecting Quaternary deposits (Meghraoui et al. 1996; Bouhadad 2001; Belabbès et al. 2009). This basin experienced several moderate earthquakes in 1959, 2008 (Oran), 1994 (Mascara), and in 1999 (Aïn Temouchent). The 1790 Oran earthquake (I_0 IX-X EMS, Lopez Marinas and Salord 1990; Mokrane et al. 1994), which destroyed the Oran City, remains the most important event reported in the literature. From a morpho-tectonic point of view, Oran region displays evidence of active thrust tectonics and folds associated with large earthquakes (Meghraoui 1988; Benouar et al. 1994; Bouhadad 2001). A recent study of coastal Quaternary deposits in western Oran showed the occurrence of numerous seismites indicating strong-shaking in the region (Boukhedimi et al. 2017).

Figure 1 shows the Oran basin including the Murdjadjo anticline, the southern border fault system, and the Arzew Salines structures. Whether or not these features correspond to active faults capable of generating destructive earthquakes has been debated for a long time (Meghraoui 1988; Bouhadad 2001). In this paper, we bring new insights about this question by means of morpho-structural analysis combining topographic, geomorphologic, geological, and neotectonic data. Our results show evidence of active thrusting and asymmetrical folding related to reverse faulting, which are two processes that likely produce moderate to large earthquakes.

2 Seismicity and focal mechanism

The Oran region, which extends from AïnTemouchent to Mostaganem, experienced a low to moderate seismicity since the end of the eighteenth century. The earthquakes database shown in Fig. 2 has been built up from the catalogs published by Mokrane et al. (1994), Benouar (1994), Yelles et al. (2002), Boughacha (2005), Harbi (2009), and Ayadi and Bezzeghoud (2015), and ISC data file; it covers the whole known seismic history of the Oran region since 1790 A.D. Recent developments of the Algerian Digital Seismic Network (Yelles-Chaouche et al. 2013) allow including the instrumental dataset complete for the last 25 years. The absence of geological observations depicting fault activity can be explained by the fact that no surface faulting is expected for the low magnitude seismicity characterizing the Oran region. On the other hand, the seismic history of Algeria (Harbi et al. 2015)

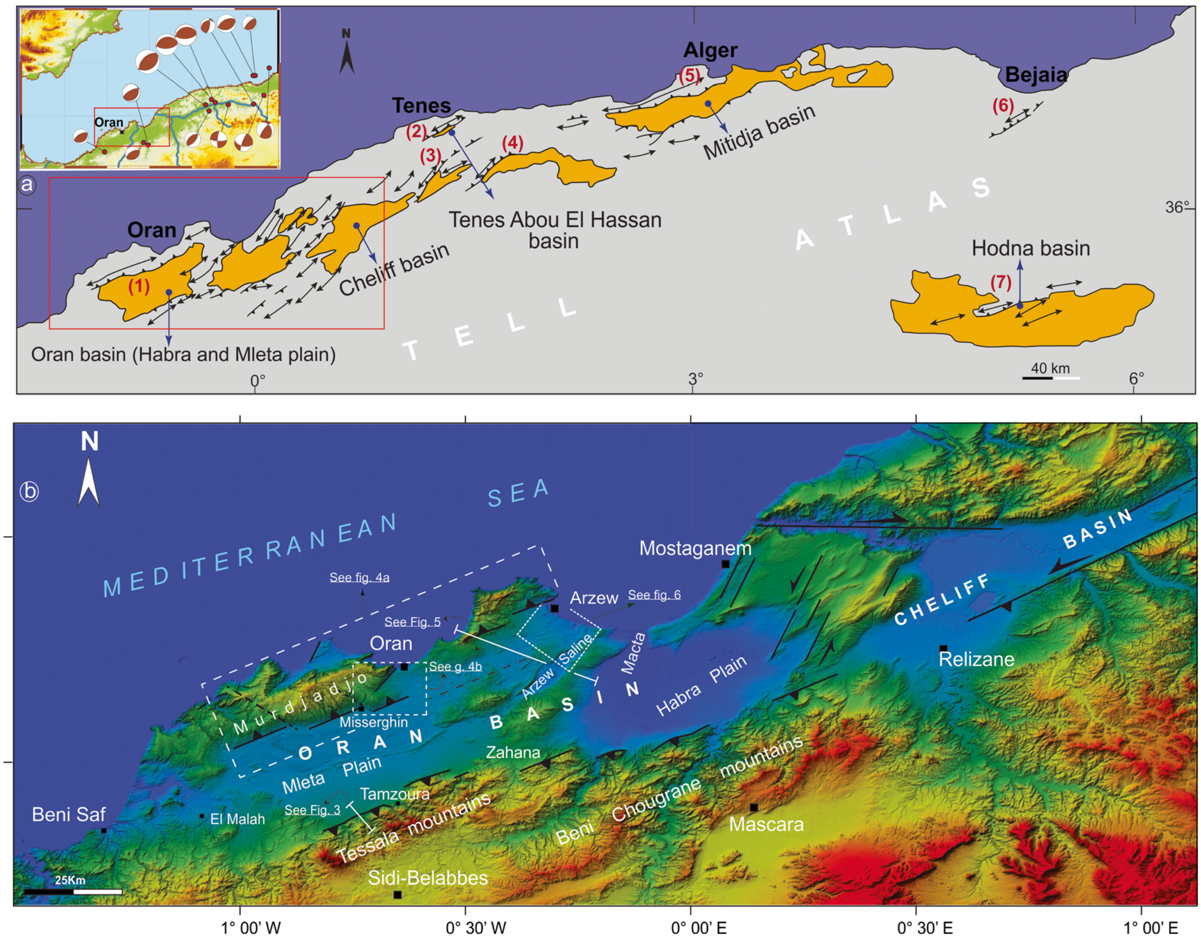

Fig. 1 **a** Simplified map showing the main intra-mountainous Neogene basin and the main active structures of the Tell Atlas: (1) Mourdjajo Anticline, (2) Tenes Abou El Hassen fault, (3) Bou Kadir fault, (4) El Asnam fault, (5) Sahel Anticline, (6) Kherrata fault, and (7) Chott el Hammam fault and fold system (after Meghraoui 1988). **b** Main morphotectonic structures in the Oran basin. Inset indicates the focal mechanisms of the significant earthquakes occurred in northwestern Algeria

does not reveal any strong event that would have affected the Oran region apart from the 1790 earthquake. The largest events that occurred in the nearby area are the Mw 5.9 1994 Mascara earthquake (75 km SE of Oran) (Benouar et al. 1994; Bezzeghoud and Buforn 1999; Ayadi et al. 2002; Ayadi and Bezzeghoud 2015) and the Mw 5.7 1999 AïnTemouchent earthquake (50 km SW of Oran) (Yelles et al. 2004). In both cases, the rupture did not reach the surface. The seismic events are heterogeneously distributed inside the Oran sedimentary basin (Fig. 2) with a greater number in the northeastern part. Figure 2 shows that several earthquakes occurred along the southern border of the Oran basin and in the Aïn Temouchent area. The focal mechanisms available for the period post 1967 (Table 1) mostly attest of reverse faulting. The majority of mechanisms are located between 10- and 15-km depth. The focal mechanisms for the local largest earthquakes indicated a NW–SE striking P-axis, consistent with the regional compression (Fig. 2).

3 Morpho-structural analysis of the Oran basin

In order to identify, map, and characterize the active structures, we carried out a morphotectonic analysis of the Quaternary deposits in the Oran basin.

3.1 The southern limit of the Oran basin: the Tamzoura fault

The Tamzoura fault is located along the southern border of the Oran basin and corresponds to one of the major

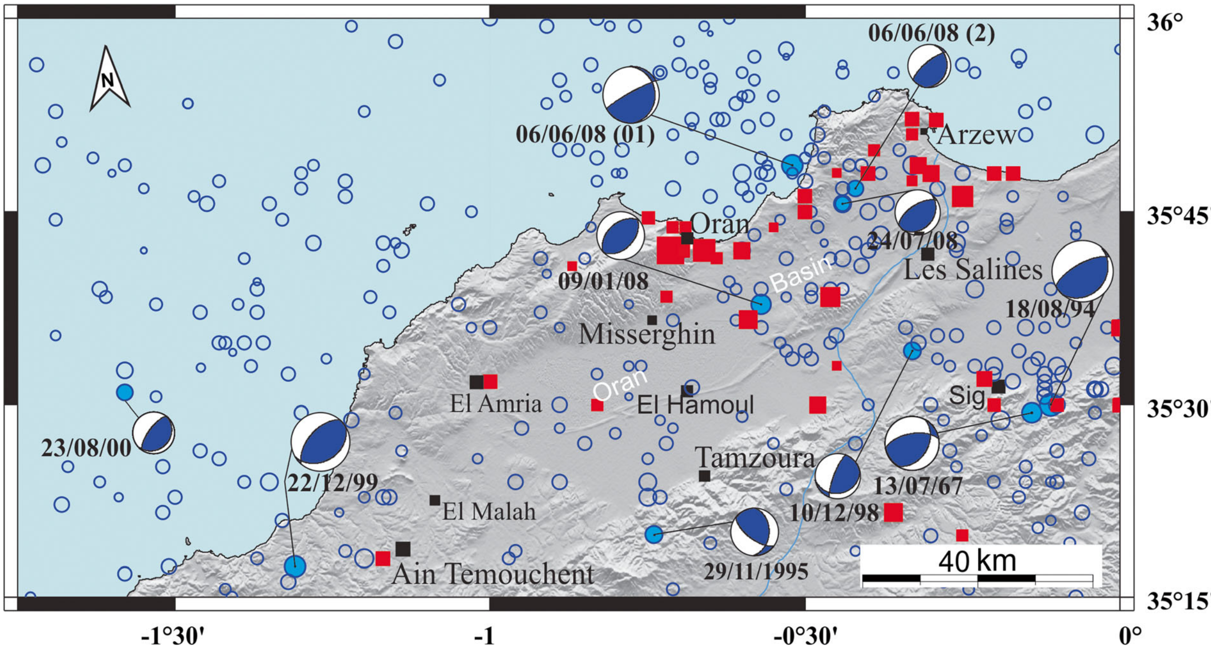

Fig. 2 Map of earthquakes that occurred in the Oran region between 1790 and 2015. Red squares indicate historical earthquakes expressed in terms of intensity (III ≤ I_0 ≤ X), and blue circles indicate instrumental earthquakes expressed in terms of duration magnitude (1 ≤ Md ≤ 5.9). Data are from historical earthquakes catalog (Harbi 2009; Harbi et al. 2015) and CRAAG datafile; see Table 1 for focal mechanism solutions

neotectonic structures in this basin (Fig. 1). It also corresponds to the tectonic contact between the Mio-Pliocene yellow marls and limestones, to the south, and a Pleistocene sub-horizontal fan gravels and river deposits of the Habra plain, to the north (Fig. 3a). Locally, a clear fault scarp can be associated to the Tamzoura fault. One such case occurs 4 km west of the Tamzoura village, where a natural section allows observing the Miocene deposits overlapping the Quaternary sub-horizontal one. The contact corresponds to an EW trending reverse fault steeply dipping to the south (Fig. 3b). Strike, dip, and pitch of slickensides, which are well-preserved on the fault plane, are N090° E, 85° S, and 90° S, respectively, indicating a main reverse motion, consistent with the NW-SE regional compression. Further to the east, well-preserved fault scarps are also observed within streams draining the reliefs between Tamzoura and Zahana, where sub-horizontal fan

Table 1 Focal mechanism solutions of the main earthquakes in the Oran region (Harvard: Harvard database, Zurich moment tensors, MedNet database, NEIC Instituto, IAG: Andaluz de Geofisica, and ISC: ISC bulletin)

Date	Long	Lat	H	Stke1	Dip1	Slip1	Stke2	Dip2	Slip2	Ms	Ref
18/08/1994	− 0.11	35.5	9	40.00	23.00	70	241.00	69.00	98	5.9	Harvard
22/12/1999	− 1.31	35.29	10	59.00	34.00	106	221.00	57.00	80	5.7	Zurich Moment Tensor
09/01/2008	− 0.57	35.63	6	44.00	44.00	87	229.00	46.00	93	4.6	MedNet
06/06/2008	− 0.52	35.81	5	241.00	83.00	105	355.00	17.00	25	5.5	MedNet
06/06/2008	− 0.42	35.78	10	12.00	21.00	55	230.00	73.00	103	4.2	NEIC
24/07/2008	− 0.44	35.76	7	39.00	29.00	74	237.00	62.00	98	4.4	MedNet
29/11/1995	− 0.74	35.32	8	2.00	39.00	99	127.00	65.00	99	4.6	IAG
10/12/1998	− 0.33	35.57	4	79.00	24.00	99	201.00	77.00	99	4.4	IAG
13/07/1967	− 0.14	35.49	23	30.00	40.00	132	260.00	61.00	60	5.2	McKenzie 1972
23/08/2000	− 1.58	35.51	16	45.00	19.00	99.00	216.00	71.00	87	4.0	ISC

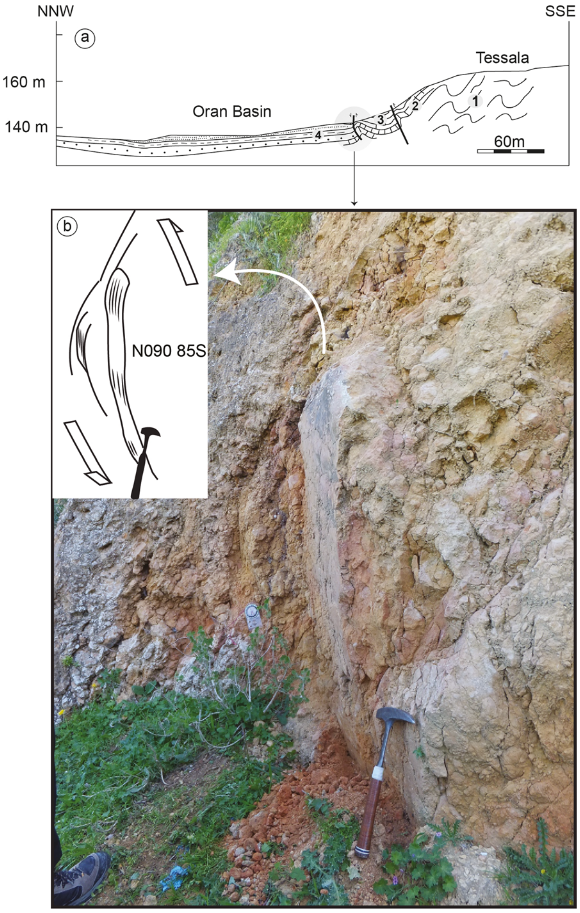

Fig. 3 Well-preserved slickensides on the Tamzoura fault showing a reverse motion (see Fig. 1b for location) **a** cross-section, **b** photo

gravels are thrusted. The main motion is northward, and minor deflections of channels suggest a left-lateral strike-slip component. These features demonstrate the active thrusting along the Tamzoura fault, which is probably associated with a left-lateral horizontal component.

3.2 The Murdjadjo anticline

The Murdjadjo anticline is located in the western part of the Neogene and Quaternary Oran basin (Fig. 1b). This N055° W trending anticline is a 50 km long asymmetric fold with a steep northern flank and a gently dipping southern flank (Thomas 1985; Meghraoui 1988; Bouhadad 2001). With regard to the Oran basin, the southern flank of the anticline defines a major mountain front that is characterized by a series of prominent triangular facets corresponding to southward-dipping structural surfaces, especially between the Boutlelis and Misserghin Villages (Fig. 4). At their base, we observe a N060° E trending morphologic scarp marked by a river system disruption associated with a pronounced break of slope. This scarp is traceable over 55 km between El Malah and SE Oran City and is clearly seen on Google earth satellite images. The scarp is crossed by numerous streams allowing the observation of natural sections through terrace deposits. Near the village of Misserghin, highly tilted Miocene and Pliocene sandstones overthrust the pebbles associated with the terrace deposits.

Morphotectonics has been considered as a tool to determine the intensity of tectonic activity in given active areas. For that, the geomorphic indices are particularly useful. Some of them, such us the valley width/height ratio and Mountain front sinuosity are easily accessible because the necessary data can be obtained from topographic maps and aerial photographs (Bull and Mc Fadden 1977). Even if these indices are linked to lithology, precipitation, and erosion, they may be influenced by active tectonic processes. The issue concerning the activity of the mountain front can be examined through a morphometric analysis. We used the valley width/height ratio (Bull and McFadden 1977; Keller and Pinter 2002) that defines an index (Vf) reflecting the difference between V-shaped valleys actively down-cutting in response to active uplift and broad-floored valleys (U-shaped), with major lateral erosion in response to relative tectonic quiescence. The Vf values are low (< 1.0) and high (> 1.0), respectively.

$$Vf = \frac{2Vfw}{(Eld - Esc) + (Erd - Esc)}$$

where Vfw is the width of the valley, Eld and Erd are the elevations of the left and right valleys divides, respectively, and Esc is the elevation of the valley floor or stream channel.

The mean Vf calculated over 20 stream channels yields a value of 0.44 (Table 2), which is consistent with our observations showing that the southeastern Murdjadjo front corresponds to an active thrusting fault zone.

The hydrographic network drawn from topographic data in the Misserghin-Es Senia area (the NE continuation of the Boutelellis-Misserghin lineament, Fig. 4b) reflects the interaction between the morphology, hydrology, and tectonic processes. Geomorphic features, such

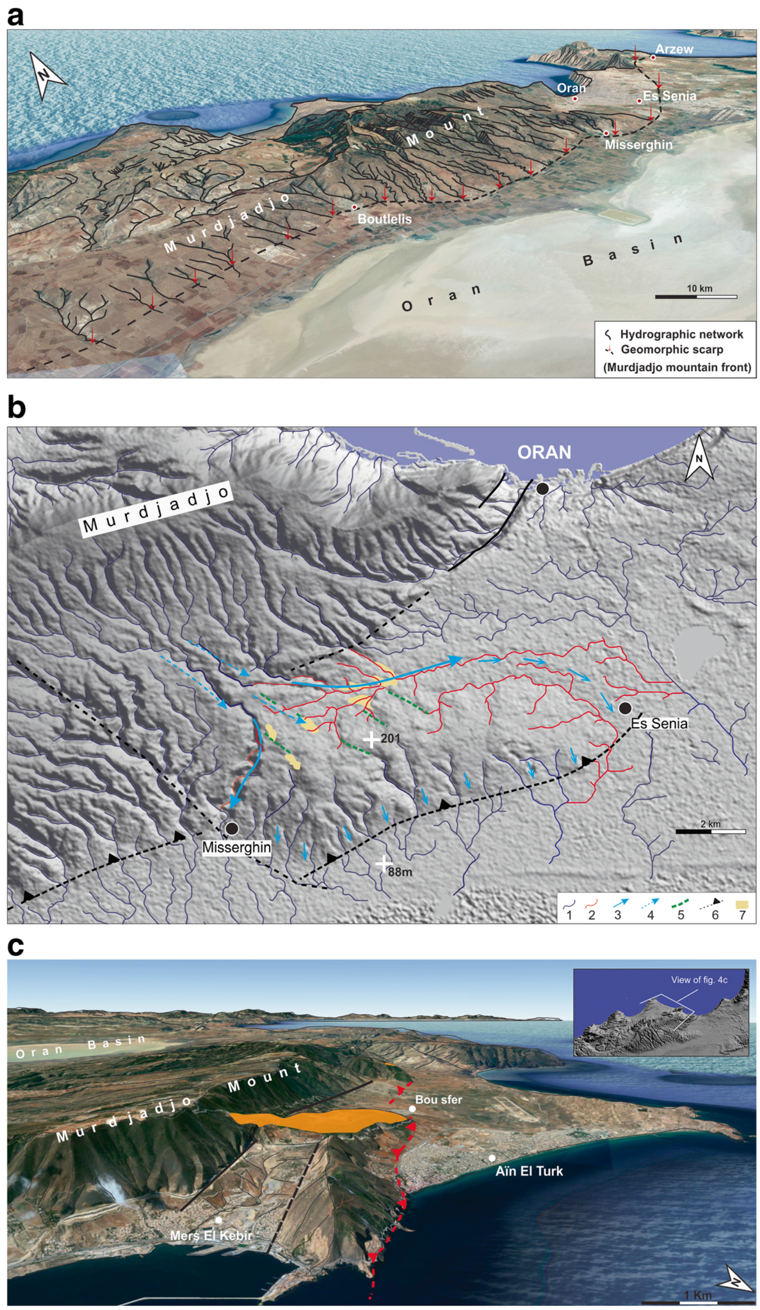

Fig. 4 Morphotectonic pattern of the Murdjadjo structure (see Fig. 1b for location). **a** Oblique view showing the hydrographic network and fault scarp at the southern front of the Murdjadjo anticline. **b** Sketch map of the hydrographic network within the Misserghin-EsSania area, showing (1) the streams and (2) their re-orientations, (3) the current flow directions, (4) the ancient flow directions, (5) the abandoned hydrographic networks, (6) the reverse fault, and (7) the ancient alluvial deposits (Quaternary). **c** Morphotectonic map of the northern side of the Murdjadjo anticline

as (1) the shape of the fold with its asymmetry, (2) the development of a youthful stream network when approaching the active fold and particularly the abandoned valleys and changing direction of streams, and (3) the Quaternary age of the sediments affected by the fold, suggest an ongoing deformation governed by tectonic activity (Fig. 4b). The correlation between the direction of the fault and the flow direction of the streams highlights a clear bifurcation of the hydrographic network associated with the uplift of the Misserghin-Es Senia fold segment. Following a general NW-SE flow direction perpendicular to the Murdjadjo, drainage bends to the SW, to finally curve around the termination of the Misserghin-Es Senia lineament (Fig. 4b). These features attest to the recent formation and propagation of a NE-SW trending reverse fault, as it was already

Table 2 Vf systematic measurements on the stream network along the southeast front of the Murdjadjo anticline

	Vfw	Eld	Erd	Esc	Vf
1	14	207	202	172	0.43
2	6	204	220	183	0.20
3	15	193	192	138	0.27
4	10	149	154	137	0.69
5	12	154	151	134	0.65
6	14	212	196	174	0.46
7	12	159	168	140	0.51
8	6	185	182	164	0.30
9	22	188	180	138	0.48
10	14	156	168	143	0.54
11	11.25	184	188	168	0.44
12	7	174	181	169	0.8
13	9.1	253	242	219	0.31
14	10	203	230	197	0.55
15	9	234	225	206	0.37
16	30	172	172	127	0.6
17	16	161	132	120	0.6
18	16	165	146	123	0.46
19	20	185	195	134	0.35
20	25	171	155	132	0.6
22	15	268	268	172	0.15
23	15	196	191	136	0.26
Mean Vf value < 1					0.44

observed within other Tell active structures, such as the El Asnam and Thenia faults (Boudiaf et al. 1998).

Along the steep northern flank of the Murdjadjo, we noticed a perched flat surface, which corresponds to a depositional surface bearing marine deposits (Gourinard 1952). This marine terrace lies 200 m above the northern plain of Aïn El Turk (Fig. 4c). Although no clear fault scarp can be observed at the abrupt break of slope between the reliefs and the plain on Google Earth satellite images, this feature undoubtedly suggests that the Murdjadjo anticline is also controlled by a reverse fault along its northern border.

3.3 The Arzew area

3.3.1 The Salines zone

The central part of the Oran basin is marked by a series of NE-SW trending, 100 to 200 m high topographic reliefs that are separated by NE-SW elongated lacustrine deposits. Our geological and structural analysis shows that these features are associated with Quaternary deformations (notably within the coastal zone where marine terraces are folded) and allow interpreting the occurrence of active asymmetrical folding (Fig. 5). The area is also affected by faults, which are mostly located at the edges of folds. Two main ~35 km long anticline folds are observed between the Telamine Lake and the Macta Plain. Both are characterized by steep-dipping southern limbs (~30°–50° dip, Fig. 5c), while their northern

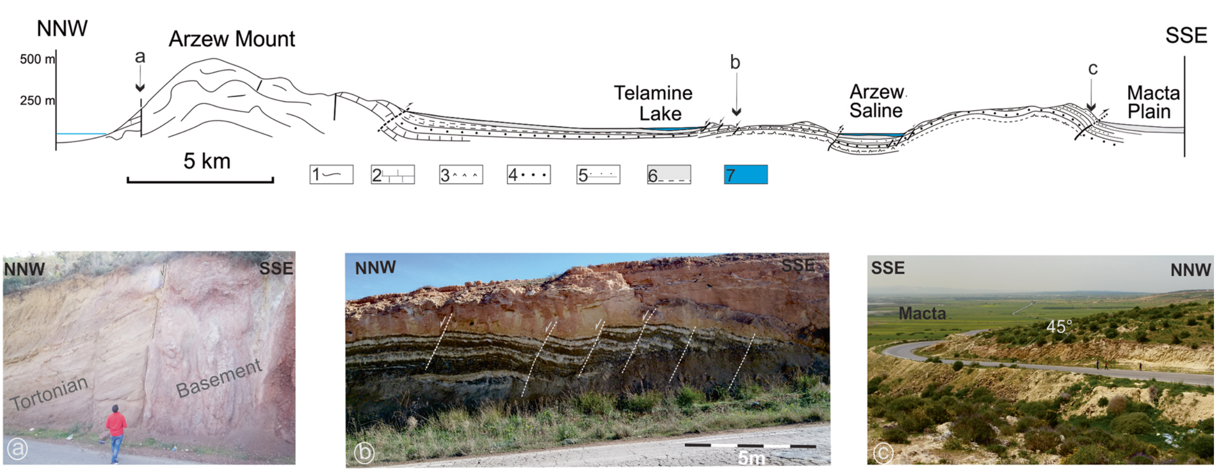

Fig. 5 Geological cross section of the Saline d'Arzew structures (see Fig. 1b for location). (1) Cretaceous basement and nappes, (2) Miocene, (3) Miocene Gypsum, (4) Lower Pliocene, (5) Upper Pliocene and Quaternary, (6) Quaternary, and (7) Lacustrine deposits. (a) Field picture showing a post-Tortonian fault. (b) Field picture showing Messinian extrados normal faults. (c) Field picture showing the southern flank of the quaternary Saline fold

limbs exhibit a gentle ~ 10°–15° dip. Between the two folded structures, an elongated depression forms a narrow syncline. Extrados faulting can be observed within the Miocene beds forming the northern limb of the former fold, situated between the Telamine Lake and the Arzew Saline syncline. To the southern border of the Saline syncline, we also observe extrados faulting on upper Miocene and Pliocene beds (Fig. 5).

3.3.2 The coastal zone

Well-exposed Quaternary ancient marine terraces along the Arzew-Mostaganem coastal section favor coastal tectonic investigations. These terraces were described by several authors (De Lamothe 1911; Gourinard 1958) but had not been analyzed so far as potential morphotectonics markers. However, these ancient shorelines, situated between 6 and 152 m in elevation, provide relative chronological markers to constrain the active folding process affecting the Arzew Salines (Fig. 6). These terraces with staircase morphology, particularly those at altitudes 130–150 m, are strongly altered as attested by the development of red ferrous gravel and soil (rubification) and calcrete, making isotopic dating difficult. Several sand dunes are intercalated between the different marine terrace levels.

We conducted field investigations to precisely measure the altitude of these Quaternary marine terraces. A precision altimeter along with topographic maps (1/25,000, 1/50,000 and SRTM30) allowed us to determine the heights of successive marine terraces and their variations along the shorelines. A total of seven ancient Quaternary shorelines were characterized (Fig. 6a, b). They are well observed on the topographic map except the lowest terrace (T7), which is difficult to discern because its elevation is lower than the contour interval. Terraces T5, T6, and T7 are associated with preserved sediments. The four other terraces (T1, T2, T3, and T4) often show a very thin remnant of sedimentary layer or are totally abraded.

The marine terrace deposits associated with terraces T5, T6, and T7 are ~ 10-m thick and consist of calcareous, calcarenitic dunes locally interbedded with silty sands. Locally, the underlying bedrock (Pliocene conglomerates or marls) is outcropping. The height of terraces decreases laterally (see terraces T1–T4, Fig. 6c), which is consistent with the lateral tilt of the stratigraphic units. For instance, within the western edge of "La Macta," Pliocene sediments dip 50° towards east, attesting to a significant Quaternary folding. Near the sea level, the younger terrace deposits are flat and horizontal, associated with a notch around 1 m amsl.

We performed several topographic profiles across the terraces and provided a detailed stratigraphic log describing synthetically the typical stratigraphic section of each terrace (Fig. 6c). Longitudinal profiles along shorelines are shown on Fig. 6c. The four upper terraces (T1 to T4) are folded, while the lower ones (T5 to T7) are sub-horizontal. We interpret these features (both the uplift and the lateral variations of their altitudes) as reflecting the growth and development of the "Arzew-Salines" anticline immediately southwest of the coastal zone (Fig. 6d).

4 The 1790 Oran earthquake

The 1790 Oran earthquake (I_0 IX-X EMS) is known as the largest seismic event that occurred in the Oran region. This event is extensively cited in the literature, but unfortunately, it was the subject of very few studies (i.e., Bonaz 1988; Lopez Marinas and Salord 1990). The most comprehensive and important study that dealt with the 1790 Oran earthquake was performed by Lopez Marinas and Salord (1990) on the basis of Spanish sources. The occurrence of the 1790 earthquake, in a period of conflict between the Spanish occupier and the Ottoman occupier of the present Algeria (called Central Maghreb at that time), makes a sound analysis of the event a rather difficult task. Indeed, the source materials reporting the effects of the 1790 Oran earthquake, including the contemporary sources, are not totally reliable because the reporters were influenced by the political situation of that time. The Spanish, who were colonizing Oran City since the sixteenth century, claimed that the 1790 event was the main reason of their departure from Oran. However, according to Algerian historians, the 1790 Oran earthquake was not the reason but, rather, the pretext of the departure of the Spanish occupier. It is alleged that 2000 to 3000 out of 8000 inhabitants of Oran were killed following the 1790 earthquake (Chesneau 1892; Murat 1925; Galbis 1932; Lopez Marinas and Salord 1990), but we do not know whether this large number of casualties is exclusively related to the seismic event or also to the post-earthquake fire and ensuing assault of the Ottoman Bey of Mascara (provincial Governor in the Ottoman empire) to oust the Spanish settlers weakened by the earthquake during which the Governor died. However,

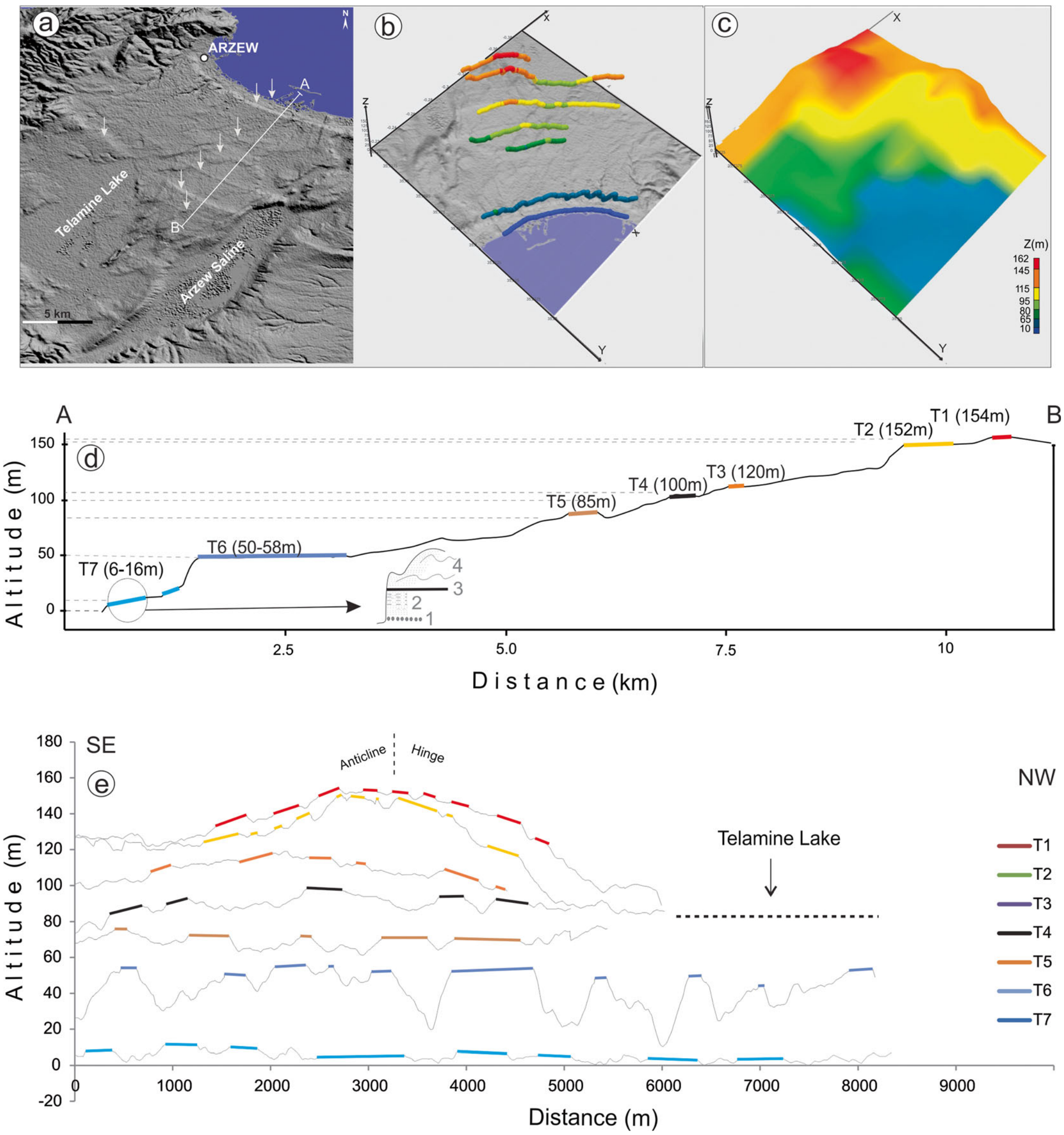

Fig. 6 Marine shorelines and terrace highstands on the Arzew coastal zone with a synthetic stratigraphic unit (see Fig. 1b for location) (after De Lamothe 1911; Gourinard 1958). The uplifted terraces illustrate the successive fault-related fold motion during the late Pleistocene and Holocene. **a**, **b** View of the shorelines (white arrows) and marine terraces in GTtopo30 DEM. **c** Digital Elevation Model built up from the seven shorelines topography. **d** NE-SW cross section showing the stepped marine terraces (see location in Fig. 1b); the inset log depicts the synthetic stratigraphy observed within the shorelines: (1) conglomerates, (2) sand and calcarenite, (3) lumachelle, and (4) sand dunes. **e** E-W cross section showing progressive folding of the marine terraces related to the growth of the "Arzew-Salines" anticline

a recent analysis of the 1790 Oran earthquake based on the comparison among Spanish and local sources, and the comparison of that event with the strongest earthquakes of Algeria (Harbi et al. 2018) showed that this seismic event was not as large as it is claimed. Previous authors estimated an empirical magnitude 6.7 ≤ M ≤ 7.5 (Mokrane et al. 1994; Pelaez et al. 2007). It is true that most of Oran City was destroyed after the earthquake and its strongest aftershocks, but one has to bear in mind that only the lower part of Oran City suffered great damage and that the damage was confined to this part of the city (Lopez Marinas and Salord 1990; Harbi et al. 2018). No significant damage was observed in the upper part of the town nor in the second colonial Spanish occupation, place Mers El Kébir, located 7 km northwest of Oran City. The 1790 Oran earthquake, which triggered a tsunami that reached Spain at Almeria and Cartagena, where it caused some damage to mooring ships, was felt at more Spanish sites than in Algeria (Lopez Marinas and Salord 1990; Harbi et al. 2018). This suggests an offshore source located in the Mediterranean between Spain and Algeria. If this is the case, one has to wonder whether the destructions caused to Oran buildings rather originated from other earthquake-induced geological processes, such as liquefaction (Vogt 1984) and/or the numerous partial landslides that followed the event (Chesneau 1892; Harbi et al. 2018). A probable triggered landslide can be easily observed in the northwestern part of Oran City, and its size assessed on aerial photos (Fig. 7). The landslide is characterized by the presence of multiple scarps displaying sliding planes dipping to the north (Fig. 7). The 1790 earthquake damage distribution that is contained in the city center at the location of the landsliding area is in favor of the inception or reactivation of this landslide during the 1790 event.

5 Discussion and conclusion: seismotectonic implications

The present study provides new insight about the active tectonics within the Oran region. Some of these features

Fig. 7 **a** The location of the historical city of Oran partially destroyed by the 1790 earthquake. **b** Sliding area in the historical Oran City (from Google earth satellite images)

were unknown so far, as the Arzew-Salines fold system along which active folding process is attested by the deformation of Quaternary marine terraces. The earthquake catalog of Algeria indicates the occurrence of small to moderate shallow seismic events (depth < 11 km) in the Oran region. This seismic activity is distributed along the areas where morphotectonic features analysis indicates youthful active structures (i.e., the borders of the Oran Quaternary basin, the northern Murdjadjo limit, and the Arzew Salines). The strongest earthquake ever known to have occurred in Oran is the 1790 event during which no surface faulting was reported. This is consistent with our observations showing that the Quaternary activity of folds and faults is associated, at least partly, with blind structures. However, the comparison among the mesoseismal area of the 1790 Oran earthquake, confined within the areas affected by landsliding, and those of the 1980 El Asnam and 2003 Zemmouri earthquakes suggests that the magnitude 7.5 previously estimated would be largely exaggerated. This comparison can be done with other seismogenic sources too, particularly those that affect the onshore and onshore–offshore zone. Along the Algerian coastal zone, one may cite other similar events like the 1856 Djijelli and 1891 Larhat coastal earthquakes, where the epicenters are located offshore and the epicentral area with maximum damage is located onshore (Maouche et al. 2008). The 1790 event could be one such/same earthquake with a location in part biased by the damage pattern.

One further point we can rise regarding the 7.5 estimated magnitude is related to the causative fault, which should be as long as 50–100 km. One can argue that any such causative fault, whether blind or not, would be difficult to go missed. Accordingly, if such fault is actually lacking or is unknown, then the estimated 7.5 magnitude is all the less likely. Before these new results and observations, the 1790 Oran earthquake was thought to have been generated by the fault that bounds the Murdjadjo to the south. However, this event which

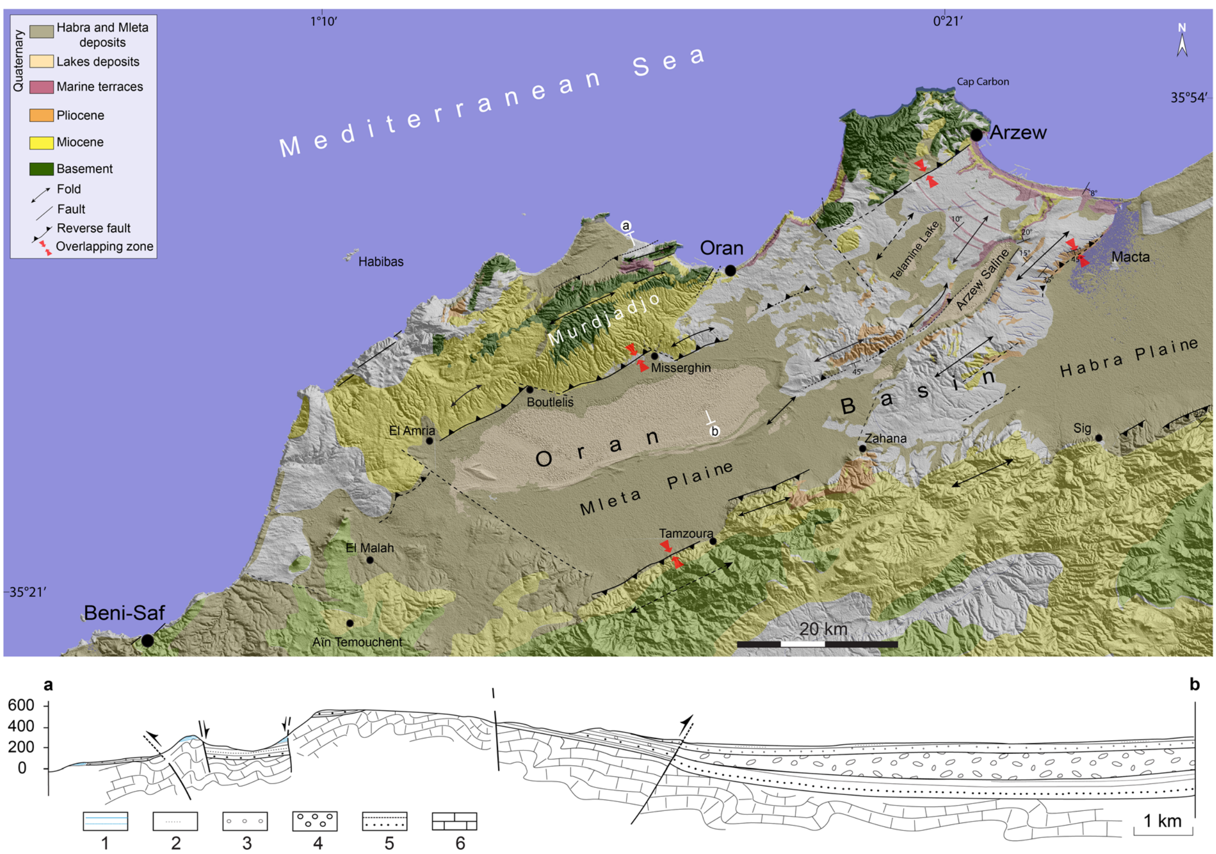

Fig. 8 Geological map and global NW-SE cross section (a and b) of the Murdjadjo anticline from geological mapping (Carte Géologique, 1/50000, Oran 1952) and field investigations: (1) marine terraces, (2) Quaternary lacustrine deposits, (3) Plio-quaternary, (4) Pliocene deposits, (5) Miocene deposits, and (6) Cretaceous basement

caused some damage in the southern Spanish coast could be linked to an offshore active fault. This assertion is consistent with the presence of an active fault bounding the Murdjadjo to the north and its probable eastwards extension offshore in the Oran bay (Fig. 8). Furthermore, our geomorphic analyses show that the present-day landscape is mainly related to active uplift during the Quaternary. Numerous earthquake faults (on-shore and offshore) are located along the coastal zone of northern Algeria. Consequently, errors in correct epicenter attribution, magnitude estimate, and ultimately accurate determination of a potential causative fault play a key role in the assumption of earthquake scenarios and hazard assessment.

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