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The Ain Temouchent (Algeria) Earthquake of December 22nd, 1999

A. K. Yelles-Chaouche[1], H. Djellit[1], H. Beldjoudi[1],
M. Bezzeghoud[2], and E. Buforn[3]

Abstract—On December 22nd, 1999 an earthquake of Magnitude M_w : 5.7 occurred at Ain Temouchent (northwest Algeria). This moderate seismic event was located in a region characterized by a low seismic activity where few historical events have been observed. The earthquake, with a maximum intensity of VII (MSK scale), caused serious damages to the Ain Temouchent city and its surroundings. In the epicentral area, 25 people died and about 25,000 people were made homeless. Some minor breaks have been observed in several areas in the field. They were mainly related to minor collapses in the landscape or in volcanic cavities. The focal mechanism has been studied by using broadband data at regional and teleseismic distances, and different methods. The fault-plane solution has been estimated from first motions of *P* wave. Depth and source time function have been estimated from the modeling of body waveforms. Scalar seismic moment and source dimension have been obtained from spectral analysis. Results show thrust motion, with a horizontal pressure axis oriented in a NW-SE direction, a depth of 4 km and a simple source time function with time duration of 5 s. Scalar seismic moment estimated from waveform modeling is 4.7×10^{17} Nm, and spectral analysis gives a value of 1.7×10^{17} Nm and a source radius of 7.5 km.

Key words: Ain Temouchent (Algeria), seismic source, damages, focal mechanism, breaks.

Introduction

On December 22nd, 1999 at 17h 37m 30s, Northern Algeria was again struck by a shallow earthquake of Magnitude $M_w = 5.7$, namely the Ain Temouchent earthquake (Yelles *et al.*, 2000). The earthquake occurred in the western part of Algeria, in Ain Temouchent, a town located 70 km southwest of Oran (capital of Oranie, the western region of Algeria) (Fig.1). The earthquake shook the region, causing considerable damages to Ain Temouchent and its surrounding regions and generating great panic among the population of the Oranie region.

The main shock was located by the Algerian seismic network at 35.25°N, 01.30°W, i.e., at Ain Allem (20 km SW of Ain Temouchent). This location was slightly different

[1] Centre de Recherche en Astronomie Astrophysique et Géophysique B.P. 63 Bouzareah, Algiers, Algeria. E-mail: Kyelles@yahoo.fr
[2] Departamento de Física/CGE, Apartado 94, Universidade de Évora, 7002-554 Évora, Portugal.
[3] Departamento de Geofísica y Meteorología, Universidad Complutense, 28040 Madrid, Spain.

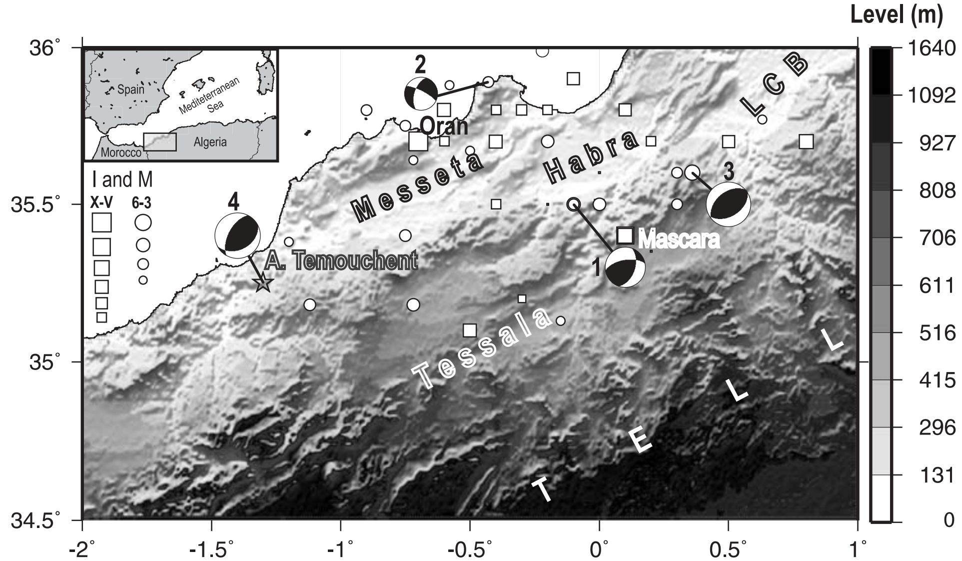

Figure 1

The Ain Temouchent earthquake epicenter location with the focal mechanism (4) determined from waveform analysis in this study. Seismicity for M ≥ 3.0 and I ≥ V for the 1790–1999 period is reported. Other focal mechanisms are also reported (see BEZZEGHOUD and BUFORN, 1999): (1) Mascara earthquakes of August 18, 1994; (2) Oran earthquake of April 19, 1981; and (3) of July 13, 1967. The topography is from digital elevation model (GLOBE TASK TEAM *et al.*, 1999). LCB = Lower Chelif Basin.

than the CSEM and USGS epicenter locations (Table. 1). Investigations carried out rapidly in the region, just after the earthquake resulted in serious damages to the buildings and the socio-economic infrastructures (schools, hospitals, mosques, roads, bridges, water networks). The epicentral area with maximal Intensity of VII (MSK scale) extended to an area of 30 km radius, west of Ain Temouchent (Fig. 2), 25 people died there and about 3000 families were made homeless. In Ain Temouchent, the most important hospital, several schools and public buildings (post offices…) were severely affected; deep cracks on the walls, torsion of the pillars and collapsing of the roof were observed. Some old houses were totally destroyed. It seems that buildings located along the small river which crosses the town suffered more than others because

Table 1

Earthquake location given by different institutions

Origin time UTC (hh:mn:ss)	Lat. N	Lon. W	H (km)	M	Ref.
17:36:53.00	35.25°	01.30°	10	5.7	CRAAG
17:36:56.24	35.32°	01.28°	10	5.7	USGS
17:36:57.00	35.23°	01.39°	10.6	5.7	CSEM

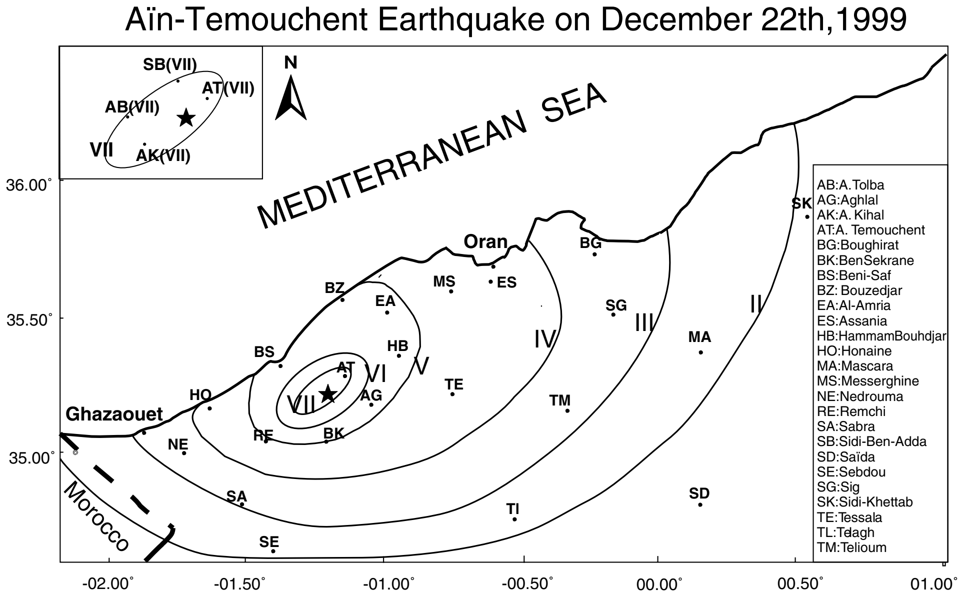

Figure 2
Isoseismal map for the Ain Temouchent earthquake. Black circles show the villages and towns. Isoseismal VII is shown with more detail in the left upper corner.

of the nature of the soil. Besides Ain Temouchent, the villages of Ain Allem, Ain Tolba and Ain Kihal (Fig. 2) were greatly affected. In these villages, the population suffered considerably because the earthquake happened during the winter season. Because of the serious damages caused by the earthquake, the Algerian authorities decided to declare the Wilaya (department or province) of Ain Temouchent a 'disaster area'. An urgency plan was launched to assist the population and to rebuild all socio-economic infrastructures destroyed by the earthquake.

Two days after the main shock, a network of five Spregnether MEQ 800 was deployed in the epicentral area around the Ain Allem-Ain Temouchent axis in order to record the aftershocks sequence. Due to the low number of stations available, it was impossible to carry out a dense coverage of the region. In addition, it was not possible to maintain the seismic monitoring for more than one month. From December 22, 1999 to January 25, 2000, corresponding to the period when the portable network was in activity, 293 events of magnitude ranging between 1.0 and 4.0 were recorded. The aftershock seismic activity lasted about 14 months. During this period three strong aftershocks occurred: on May 27, 2000 at 12h 26mn with a magnitude of 3.5; on July, 30th, 2000 at 02h 25mn with a magnitude of 3.7 causing the death of three people; and on the January 4th 2001 with magnitude of 3.1 followed a few minutes later by a second event of magnitude 2.9.

The area under study (2°W to 0°) is characterized by the occurrence of earthquakes with small magnitude, and consequently no studies of focal mechanism exist for this region (BEZZEGHOUD and BUFORN, 1999). The studied event is the most important earthquake ($M > 5.5$) to strike Ain Temouchent and its vicinity in modern times.

The purpose of this article is to report the seismotectonic effects, and to present a detailed seismological study of the Ain Temouchent earthquake.

Historical Seismicity

According to the historical seismicity of the Oranie region, several moderate to large earthquakes (maximum intensities of IV to X) have occurred. The most important one was the Oran earthquake of October 9th, 1790 with maximum intensity of X that caused the death of about 2000 people. The epicenter located offshore might have been triggered by the offshore extent of the Murdjadjo anticline. Subsequently, another earthquake occurred on March 1819 in the Mascara region. This earthquake of intensity IX destroyed a huge number of farms, wine cellars, etc. Then, on November 29th, 1887 the region was impacted by an earthquake of maximum intensity X, which caused the loss of some 20 people, destroying 331 housing units (BENOUAR *et al.*, 1994).

The Ain Temouchent region, in comparison to the Oran and Mascara regions, is characterized by a low to moderate seismic activity (Fig. 2). Indeed, through history, no important earthquakes have been mentioned by the seismic catalog (ROUSSEL, 1973; BENHALLOU, 1985; MOKRANE *et al.*, 1994; BENOUAR, 1994). Only a few seismic events have been reported in the region during the twentieth century (Table 2). During the last twenty years, we can outline as more important three events that occurred in the vicinity of the epicenter of the Ain Temouchent event. These are the events of 16.01.1980 ($Io = V$, $M = 3.8$), 15.07.1985 ($Io = V$, $M = 4.1$), 17.12.1992 ($Io = V$, $M = 4.8$), all with magnitudes lower than 5.0. We believe that it is difficult to envisage this region with a weak seismicity in the past because it is located in the Eurasiatic-African plate boundary (Fig. 1).

A possible explanation for the low seismic activity of the Ain Temouchent region may be the lack of historical documents, human witnesses, and absence of seismological stations. We recall, also, that a consequence of the earthquake of 1790, which destroyed the city of Oran, was the departure of the Spanish and, probably, a decrease in the population. In the Oranie region, before installation of the Algerian seismological network in 1990, the seismic monitoring was carried out by only one station (BEZZEGHOUD *et al.*, 1996). It was the Tlemcen station (TEC), which operated between 1978 and 1992. Subsequently, there is a major gap in the knowledge of the seismic activity before 1978 and consequently it is not possible to precisely perceive of the real seismic activity of the region.

Table 2

Seismic events reported during the XX century for the studied area

Date	Time	Lat. N	Lon. W	M	I_O	Observations	Ref.
13.05.1964	13 46 21	35.50°	01.50°	5.2	VII	Beni Saf region	MOKRANE *et al.* (1994)
16.08.1967	13 46 09	35.50°	01.30°				MOKRANE *et al.* (1994)
16.01.1980	21 40 00	35.35°	01.03°	3.8	V	Ain Temouchent	MOKRANE *et al.* (1994)
15.07.1985	11 20 39	35.48°	01.22°	3.9	V	Bouzedjar	BENOUAR, 1994
18.07.1985	11 44 00	35.38°	01.20°	3.5	IV	Terga	MOKRANE *et al.* (1994)
17.10.1992	20 43 21	35.18°	01.20°	4.8	V	Ain Temouchent	CRAAG
22.12.1999	17 36 53	35.25°	01.30°	5.7	VII	Ain Temouchent	This study

Io = isoseismal maximum intensity, M = magnitude

The isoseismal map for the Ain Temouchent event (Fig. 2) shows a distribution of intensity in a NE-SW direction, very clear for the VII and VI isoseismal, which covers an elliptical area of approximately 42 $\times$ 19 km, with a faster attenuation in a NW-SE direction.

Geological Setting

The Ain Temouchent region is located in the western extremity of the lower Cheliff basin (GUARDIA, 1975; THOMAS, 1985). This was later developed after the major structuring of the Tellian domain, one of the segments of the Alpine chain of Northern Africa (MEGHRAOUI, 1988). The Ain Temouchent region is bordered on the east by the Oran Sebkha (a salt lake) and on the west by the coastal massif of Beni Saf. In the north, the region is limited by the volcanic sedimentary units of Bouzedjar and in the south by the periclinal ending of the Sebah Chioukh Mountains and western Tessala massifs (Fig. 3).

From the geological point of view, two main geological units characterize the region of Ain Temouchent: 1) the metamorphic basement represented by quarzitic units and 2) the volcanic sedimentary cover formed by Plioquaternary rocks. We must notice that in the Oranie region, two volcanic episodes synchronous to the Neogene tectonic phases have been distinguished. The first one dated in the Messinian period corresponding to a calco-alkalin volcanism, and the second one, more recent of basaltic alkaline type and dated in the Quaternary period. In general these volcanic deposits follow the main accidents trending N50°. GUARDIA (1975) and THOMAS (1985) indicate that the Neogene and Quaternary deposits were slightly affected by the NS to NW-SE Quaternary compressionnal phases that affect the Tellian Atlas Mountains. The quasi-tabular aspect of the geological formations confirms this fact. This lack of deformation could explain the rather slow seismic activity level of the region of Ain Temouchent.

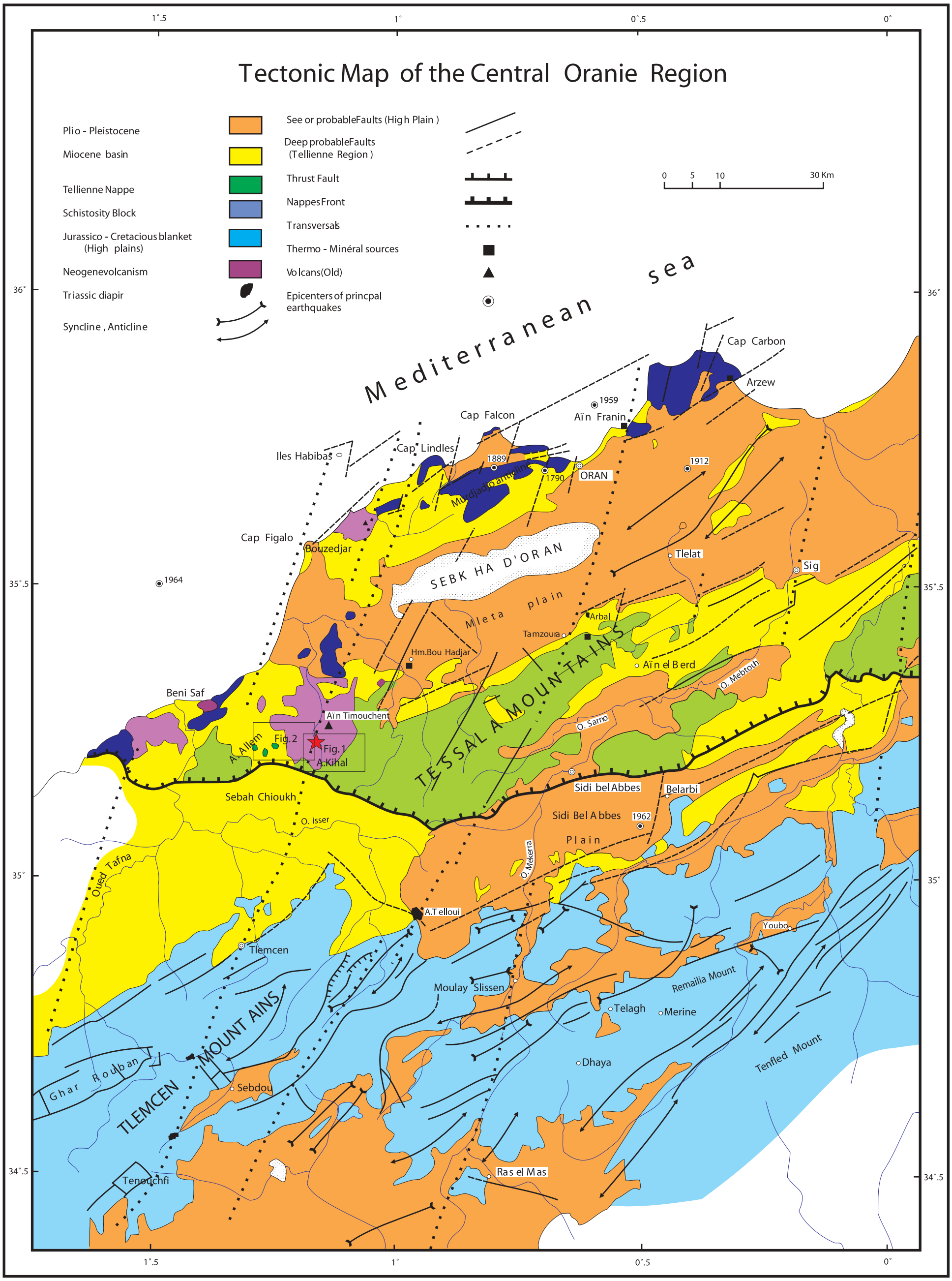

Figure 3
Geological map of the Ain Temouchent region. The legend gives information on the age of the formations and the structures.

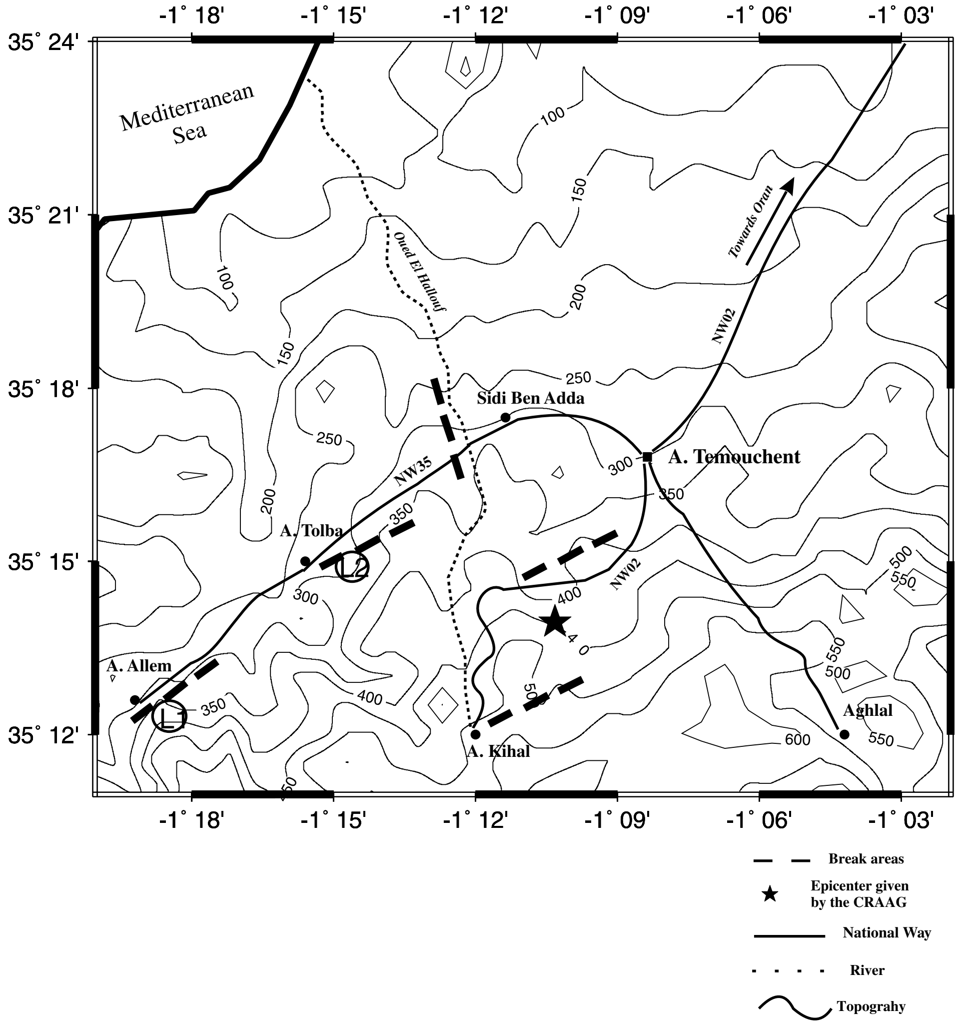

Figure 4
Topographic map of the Ain Temouchent epicentral zone showing break areas. Contour interval is 50 m. Photographs of Ain Tolba surface breaks (L2) and Ain Allem volcanic cavity (L1) are showed in Figure 5.

Surface Ruptures

Field investigations carried out in the epicentral area just after the occurrence of the main shock reveal different types of ground effects such as landslides, rock falls, cavities collapsing and spring water variations (YELLES *et al.*, 2000). However, no clear set of aligned cracks and fissures has been observed relative to the faulting. The ground effects were observed in the following zones (Figs. 4 and 5):

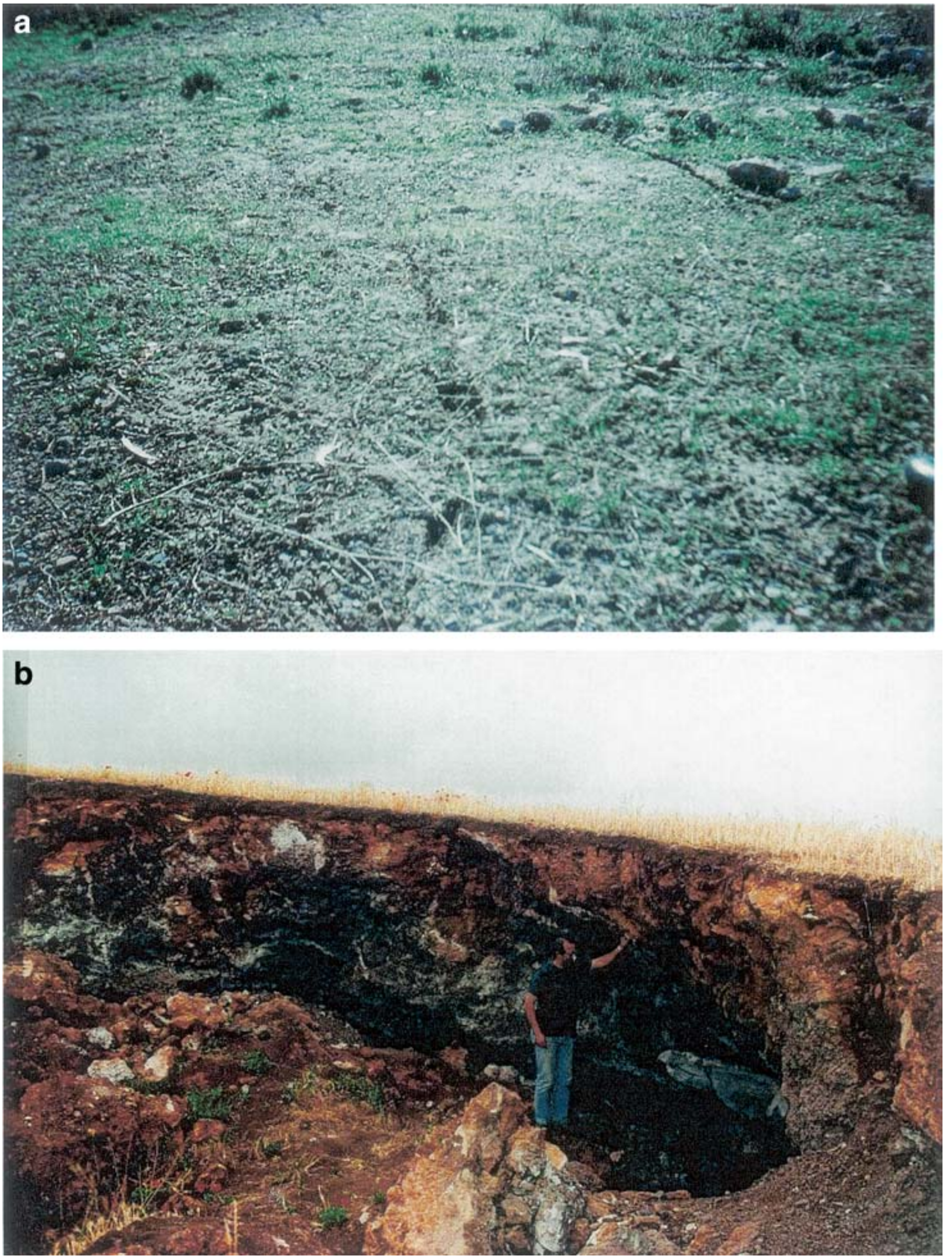

Figure 5
a) Photographs of surface breaks in the region of Ain Tolba (L2, Fig. 4) and b) volcanic cavity collapsing in the region of Ain Allem (L1, Fig. 4).

Ain Allem: In this zone the senonian formations located at the entrance of the village displayed a set of NE-SW tensile cracks of many meters in length (Fig. 5a). In the sandstone series a vertical offset of 20 cm was observed, suggesting a minor landslide. In the village, a left-lateral displacement of a water pipe could be observed.

Oued ("river" in Arabic) El Kihal: Four kilometers from the village of Ain Tolba towards the southeast, straight cracks with a total length of 100 m were observed (Fig. 4). They were related to a minor landslide affecting the western flank of the Oued El Kihal. The vertical movement reaches 20 cm. On the bottom of this flank two water sources were created. On the road towards Ain Kihal the earthquake affected the volcanic series where several blocks fell down (Fig. 5b).

Sidi Ben Adda: Five kilometers west of this village, near the Oued El Hallouf, a set of cracks with a N160° direction affects the eastern flank of the river.

Site d'El Baida: South of the Ain Temouchent, along the road leading to Ain Kihal, an NNE-SSW oriented surface breaks crosscut over 200 meters of the senonian formation.

Although no continuous set of cracks affects the neogene series, it is important to take note of the fact that all sparse ground failures observed seem to be distributed along two major directions, NE–SW (N40°–N65°) and NW–SE (N140°/N165°).

Focal Mechanism And Source Parameters

Methodology and Data

The data used for the focal mechanism of the main shock correspond to seismograms recorded at teleseismic distances (30° < 90°) in order to avoid problems with upper mantle wave triplications and diffractions by mantle-core boundary. The fault plane solution has been determined from the first motion (FM) of *P*-waves by using the algorithm of BRILLINGER *et al.* (1980). This algorithm determines the maximum likelihood function and it estimates the orientation of the principal stress axes (*P* and *T*), nodal planes and their standard errors (UDÍAS and BUFORN, 1988). Take-off angles have been calculated for teleseismic distances from Jeffreys-Bullen tables by using a velocity of 5.8 km/s for shallow focus (depth less than 15 km). Slight changes on the velocity model are not significant in modeling results at teleseismic distances. A total of 27 observations have been used, most of them corresponding to broadband seismograms recorded at teleseismic distances, with the exception of three stations (MELI, SELV and SFUC) located at less than 1000 km. From Figure 6 we observe a good azimuthal coverage.

For the waveform analysis (WA) of *P* waves, we use the McCaffrey *et al.* (1991) version of Nabelek's (1984) inversion procedure, which minimizes, in a weighted least square sense, the misfit between observed and synthetic seismograms. Unfortunately, due to the small magnitude of the earthquake, the SH waves are contaminated by noise and it was impossible to use them. Depth, nodal planes, scalar seismic moment and source time function (STF) are inverted simultaneously from broadband teleseismic data. The initial model is taken from the result of the FM method described above. Synthetic seismograms were computed in a homogeneous half space and included P, pP and sP phases; the Q factor was defined with attenuation time constant of $t^* = 1$ second for P waves. The synthetic seismograms are obtained by convolution of Green's function of the propagation with the instrumental response and then by the STF. Unfortunately, for this area no details about the crustal structure are known. For this reason, to generate Green's functions, the crustal model used corresponds to a layer with a thickness of 30 km and P velocity of 6 km/s, over a mantle with P velocity of 8 Km/s. Every record was converted to a seismogram recorded at 40 degrees of epicentral distance (station with same azimuth and common gain).

Finally, the scalar seismic moment and source dimensions were also estimated from spectral analysis (SA) using a total of seven broad band records corresponding to distances between 30° and 80°. The P wave records, with a sample rate of 0.05s, were windowed, detrended, deconvolved from instrumental response and tapered with a cosinus before performing a fast Fourier transformation. Then, the correction of attenuation, the same that we have used on the inversion method and the radiation pattern were applied. The radiation pattern is computed from the fault plane solution determined from FM solution previously described. Scalar seismic moment value obtained from spectral analysis is compared with the value from modeling. We estimated the corner frequency by direct measurement of the intersection of the low and high frequency trends of the amplitude spectra. The STF duration t was computed from the corner frequency using the expression $t = 1/fc$, where fc is the corner frequency. There is a variation of the values (of the order of a factor of 2) of Mo and t from station to station, which may be due to site effects.

Results

The fault-plane solution (FM) for the Ain Temouchent shock was obtained using 27 polarities of P waves at teleseismic distances, and corresponds to a reverse faulting mechanism with planes striking in a NE–SW direction and with horizontal pressure axis oriented in a NW–SE direction (Fig. 6 and Table 3). The plane with 208° of azimuth and dipping 58° is better constrained than the plane dipping 32° to the SE due to the use of four Spanish stations, located at a distance less than 1500 km from the epicenter. Estimation of errors for the trend of the tension axis is high (89°) due to the fact that small changes on the position of this axis over focal sphere correspond to broad variations in the azimuth. However the pressure axis is well constrained with an estimation of standard errors of 15° or lower. Strike-slip mechanisms are generally better constrained than dip-slip solutions. Observations very close to the nodal planes are necessary to obtain a dip-slip solution of good quality.

Table 3

Source parameters for the 22 December 1999 Ain Temouchent earthquake (M_w = 5.7)

	Nodal planes			*P* axis		*T* axis		Depth km	Radius km	$M_O \times E$ 17 Nm
	Strike	Dip	Rake	Azim.	Plunge	Azim.	Plunge			
FM N = 27	25 (± 63)	32 (± 50)	92 (± 14)	297 (± 15)	13 (± 13)	121 (± 89)	(± 13)	—	—	—
WA N = 9	60	36	63	311	11	76	71	4 (± 1)	11	4.1 (± 0.8)
SA N = 7	—	—	—	—	—	—	—	—	7.5 (± 0.1)	1.7 (± 0.9)

FM = first motion; WA = waveform inversion; SA = spectral analysis, N = number of data.

Depth, orientation of the nodal planes and source time function have been obtained from the inversion of nine records of *P*-wave broadband data; the starting parameters are taken from the FM focal mechanism (Fig. 6, Table 3) with 4 triangular impulses with a duration of 1.0 second as STF. We inverted the STF, depth and focal parameters. As we have mentioned dip-slip solutions are generally less constrained than strike-slip mechanisms and consequently we tested many models with different source parameters (focal mechanism and depth). The best

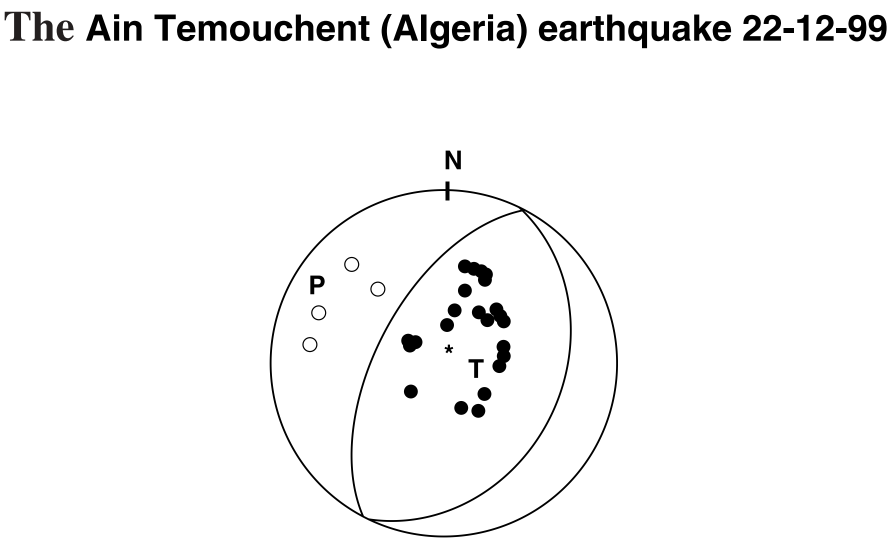

Figure 6
Focal mechanism for the Ain Temouchent earthquake obtained from first motion study (FM). Black circles correspond to compression and white circles to dilatation.

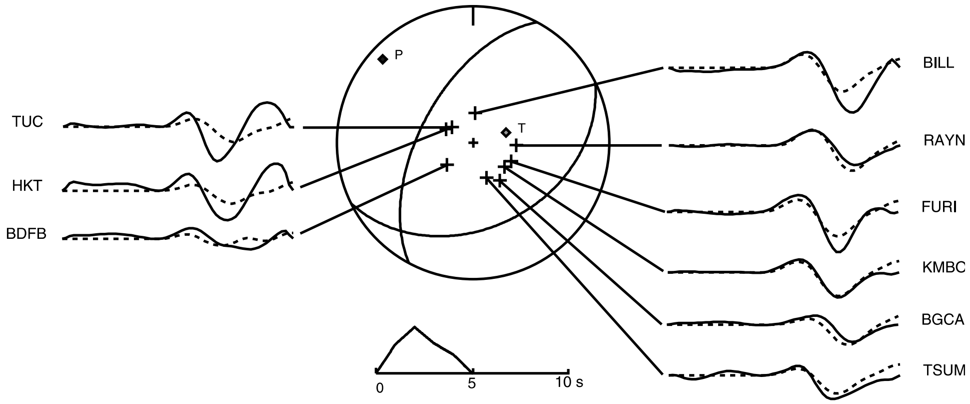

Figure 7
Focal mechanism obtained from inversion of *P* waves for the Ain Temouchent earthquake. Solid line represents the observed seismogram and dashed line the synthetic seismogram. The source time function (STF) is shown below.

solution was the one with the minimum RMS value. The best fitting source model is shown in Figure 7 and the source parameters are listed in Table 3. In this solution, the fit between observed and calculated seismograms is not substantially better than that given by other solutions. However, the chosen solution was preferred because the mechanism is very similar to that obtained from the *P* wave FM solution (Fig. 6, Table. 3) and in agreement with the northwestern Algerian tectonic features (BEZZEGHOUD and BUFORN, 1999; BUFORN *et al.*, 2004, this issue). In all cases the focal depth is 4 km, and changing the depth by 1 km produces a noticeable degradation of the fitting of the waveforms. Results of body wave inversion show a simple rupture process: the STF comprises only one event (Mo = $4.1 \times 10e+17$ Nm) of a duration of 5.0 seconds, with a reverse faulting mechanism striking in a NE–SW direction with horizontal pressure axis trending in a NW–SE direction.

The FM and WA focal mechanisms, determined in this study, are similar to this obtained by Harvard's CMT. However, our focal depth is shallower (4 km) than that (15 km) given by CMT. The CMT resolution is poor for events with depth below 15 km. Scalar seismic moment and dimension obtained from spectral analysis give values of $1.7 \times 10e+17$ Nm and a radius of 7.5 km respectively. If we compare the values of scalar seismic moment obtained in this study by WA and spectral analysis with the CMT solution ($6.9 \times 10e+17$ Nm), a factor varying from 1.5 to 4 is noticed. However, the CMT method has a tendency to overestimate scalar seismic moment. A factor of three in the scalar seismic moment values estimated by different authors is common and this may be explained by the frequency content of waveforms (TANIOKA and RUFF, 1997).

Conclusion

Historical seismicity for the Ain Temouchent region indicates a low level of seismic activity, with the occurrence of earthquakes with magnitudes less than 5.5. In the Algerian Maximum Observed Intensity (MOI) map (MOKRANE *et al.*, 1994; BEZZEGHOUD *et al.*, 1996), this region shows a maximum intensity of VI (MM scale). The recent Ain Temouchent earthquake ($M_{w\,=}$ 5.7) is the largest seismic event which occurred in the Ain Temouchent region with a maximum observed intensity of VII (MSK scale). Therefore, the recent earthquakes which occurred in Western Algeria (Mascara M_w = 5.7, 1994; Beni-Ouartilane M_w = 5.7, 2000), including the 1999 Ain Temouchent earthquake, should be used to update the Algerian MOI map. The high damages and casualties caused by this shallow seismic event (h = 4 km) are due to a combination of the recent rapid population growth and the fragility of old traditional houses or modern constructions. In the last twenty years (1980–2000), the buildings in Algeria, and in particular in rural regions, have shown a low strength and high vulnerability to the recurrence of destructive earthquakes, in spite of the large El Asnam 1980 earthquake.

From a seismotectonic point of view, the Ain Temouchent earthquake allows us to ascertain with more accuracy the stress pattern in the western part of Algeria. The deduction of regional stress from fault-plane solutions is not exempt from ambiguity. The maximum compressive stress may have an orientation anywhere within the dilatational quadrant and not necessarily at 45 degrees of the fault plane. However, the stress axes derived from fault plane solutions or inversion methods for earthquakes with a magnitude larger than 5.5 may serve as an indication of their general trend. BEZZEGHOUD and BUFORN (1999) demonstrate that the reverse mechanisms are predominant in the region located between 3° E and 0° (Tell Atlas), whereas between 0° and 6°W (Betic-Rif mountains and Alboran Sea), strike-slip and oblique mechanisms with normal component are predominant. The intermediate region, between 2° W and 0°, where the Ain Temouchent earthquake occurred, was difficult to classify due to the absence of focal mechanisms for earthquakes in this area. The occurrence of the Ain Temouchent has made it possible to estimate its focal mechanism that corresponds to a rupture in reverse-faulting with planes oriented in the NE–SW direction, and horizontal *P* axis trending in a NW–SE direction. The character of this solution agrees with the focal mechanisms of the seismic event of the Tell Atlas region, and particularly with the 1994 Mascara earthquake (Fig. 1). Therefore, the recent Ain Temouchent earthquake, together with the other focal mechanisms of the western part of Algeria (BEZZEGHOUD and BUFORN, 1999), allow us to confirm that the regional stress regime corresponds to horizontal compression in a NW-SE direction, associated with the convergence between Eurasia and Africa.

In this study the final results obtained for the 22 December 1999 Ain Temouchent earthquake can be summarized as follows: maximum intensity I_o = VII (MSK);

motion of thrust faulting with horizontal pressure axis oriented in a NW-SE direction; a shallow depth of 4 km; a single source time function with 5 s duration; scalar seismic moment from body wave inversion and spectral analysis are $4.1 \times 10e+17$ Nm and $1.7 \times 10e+17$ Nm respectively; $M_w = 5.7$.

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References

Benhallou, H. (1985), *Les catastrophes sismiques de la région d'Echelif dans le contexte de la seismicité historique de l'Algèrie*, Ph.D. Thesis, USTHB, Alger, 294 pp.

Benouar, D., Aoudia, A., Maouche, S., and Meghraoui, M. (1994), *The 18 August 1994 Mascara (Algeria) Earthquake: A Quick Look Report*, Terra Nova *6*, 634–637.

Benouar, D. (1994), *The Seismicity of Algeria and the Maghreb during the Twentieth Century*, Ph.D. Thesis, Imperial College London, U.K.

Bezzeghoud, M., Ayadi, A., Sebai, A., Ait Messaoud, M., Mokrane, A., and Benhallou, H. (1996), *Seismicity of Algeria between 1365 and 1989 : Map of Maximum Observed Intensities (MOI)*, Advances en Geofisica y Geodesia, *I*, Pub. de IGN, (Madrid), 107–114.

Bezzeghoud, M. and Buforn, E. (1999), *Source parameters of the 1992 Melilla (Spain, Mw = 4.8), 1994 Alhoceima (Morocco, Mw = 5.8) and 1994 (Algeria, Mw = 5.7) Earthquakes and Seismotectonic Implications*, Bull. Seismol. Soc. Am. *89*, 2, 359–372.

Brillinger, D.R., Udias, A., and Bolt, A. (1980), *A probability model for regional focal mechanism solutions*, Bull. Seism. Soc. Am. *70*, 149–170.

Buforn E., Sanz de Galdeano C., and Udias, A. (1995), *Seismotectonics of the Ibero-Maghrebian Region*, Tectonophysics *248*, 247–261.

Buforn, E., Bezzeghoud, M., Udias, A., and Pro, C. (2004), *Seismic sources on the Iberia-African plate boundary and their tectonic implications*. Pure. Appl. Geophys. this issue.

GLOBE Task Team and others (Hastings, David A., Paula K. Dunbar, Gerald M. Elphingstone, Mark Bootz, Hiroshi Murakami, Hiroshi Maruyama, Hiroshi Masaharu, Peter Holland, John Payne, Nevin A. Bryant, Thomas L. Logan, J.-P. Muller, Gunter Schreier, and John S. MacDonald), eds. (1999), *The Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Version 1.0*, National Oceanic and Atmospheric Administration, National Geophysical Data Center, 325 Broadway, Boulder, Colorado 80303, U.S.A. Digital Data Base on the World Wide Web (URL: HYPERLINK http://www.ngdc.noaa.gov/seg/topo/globe.shtml) and CD-ROMs.

Guardia P. (1975), *Géodynamique de la marge alpine du continent africain d'après l'étude de l'Oranie Nord – Occidentale*, Ph.D. Thesis, Univiversité de Nice, France, 286 pp.

McCaffrey, R., Abers, G., and Zwick, P. (1991), *Inversion of Teleseismic Body Waves*, IASPEI, 81–166.

MEGHRAOUI, M. (1988), *Géologie des zones sismiques du nord de l'Algèrie: Paléosismologie, Tectonique active et Synthèse Sismotectonique*, Ph.D. Thesis, Univiversité de Paris XI, France, 356 pp.

MOKRANE, A., AIT MESSAOUD, A., SEBAI., A. Menia., N. Ayadi., A. and BEZZEGHOUD, M. (1994), *Les séismes en Algérie de 1365 à 1992*. Sous la direction de Bezzeghoud M. et Benhallou H. Publication du CRAAG, Alger-Bouzaréah, 277pp.

NABELEK, J.-L. (1984), *Determinations of Earthquake Source Parameters from Inversion of Body Waves*. Ph.D. Thesis, MIT, Cambridge, USA.

PHILLIP, H. (1987), *Plioquaternary Evolution of the Stress Field in the Mediterranean Zones of Subduction and Collision*, Annales Geophysicae. *5B*, 301–320.

ROUSSEL, J. (1973), *Les zones actives et la fréquence des Seismes en Algerie (1716–1970)*, Bull. Soc. Hist. Nat. Afr. Nord, Alger, t. 64. Fasc. 3 et 4, 211p.

TANIOKA, Y., and RUFF, L. (1997), *Source time functions*, Seism. Res. Lett. *68*, 386–397.

THOMAS, G. (1985), *Géodynamique d'un bassin intramontagneux, ; le bassin du bas Cheliff occidental (Algérie) durant le Mioplioquaternaire*, Ph.D. Thesis, Université de Pau et Pays de l'Adour, France.

UDIAS, A. and BUFORN, E. (1988), *Single and joint fault-plane solutions from first data in Seismological Algorithms*, D. Doornbos (Editor) Academic, London, 443–453.

YELLES-CHAOUCHE, A.K., DJELLIT, H., DERDER, M., ABTOUT, A., and BELDJOUDI, H., (2000), *The Ain Temouchent Earthquake of December 22 th,1999: Preliminary Investigations*. XXVII General Assembly of the European Seismological Commission ESC. Lisbon, September.

YELLES-CHAOUCHE, A.K. (2001), *Recent Seismic Activity in Algeria*, Workshop on the Geodynamics of the Western Part of the Eurasia-Africa Plate Boundary (Azores-Tunisia) San Fernando (Cadiz, Spain), 31 May–2 June.

YIELDING, G., OUYED, M., KING, G. C. P., and HATZFELD, D. (1989), *Active Tectonics of the Algerian Atlas Mountains: Evidence from Aftershocks of the 1980 El-Asnam Earthquake*, Geophys. J. Int. *99*, 761–788.

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