Pure appl. geophys. 161 (2004) 949–967
0033 – 4553/04/060949 – 19
DOI 10.1007/s00024-003-2502-1

Pure and Applied Geophysics

Seismicity and Tectonic Structures in the Site of Algiers and its Surroundings: A Step Towards Microzonation

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Abstract—We intend to reappraise the seismogenic potential of the geologic structures in the site of Algiers and its surroundings. A compilation of a working earthquake catalogue is first made using all events reported in all previous documentation available. However for the sake of homogeneity and a certain degree of reliability of the data, only revised seismic events with epicenter coordinates, magnitude and/or intensity are included. A tectonic setting of the zone under investigation and available fault plane solutions are presented. The results obtained in previous seismological studies of the most recent earthquakes of the area are also discussed. The findings highlight the great interest to be taken in the detailed and timely assessment of the seismic hazard of Algiers and its surroundings which is made possible by the realistic modelling of the scenario seismic input.

Key words: Algiers, seismicity, tectonics, earthquakes catalogue.

Introduction

Most of the northern Algerian cities lie in earthquake-prone zones. Algiers, Constantine, Oran, Guelma, Chlef (formerly El Asnam), M'sila and other important cities have been affected by damaging earthquakes in the last two centuries. Meanwhile the effect on earthquake risk of rapid urban growth is not well appreciated. The reduction of seismic risk requires a detailed microzonation of the urban areas and this must be preceded by a realistic seismic hazard assessment. For this purpose we analyze the tectonics and seismic potential in the Algiers area, taking into account the results obtained in previous research works carried out after the largest seismic events which occurred in Algiers. The identification of active faults, as

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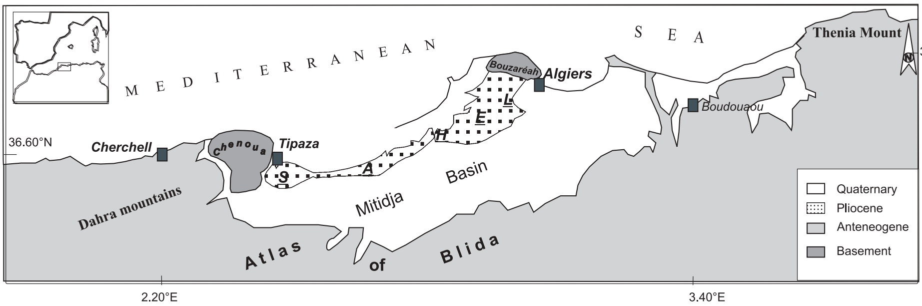

Figure 1
Geologic scheme of Algiers area showing the Sahel anticline.

earthquake sources, is essential for seismic hazard evaluation. Therefore a tectonic setting of the region under study is presented and used to complement a working earthquake catalogue. The catalogue includes all earthquakes reported in the literature, to which it has been possible to assign, after careful revision, geographical coordinates and magnitude or intensity.

For the city of Algiers, the research area considered is defined within a radius of 100 km between latitude 36°–37.75° north and longitude 2°–4° east. Algiers city is located in the Sahel[1], a narrow land strip which extends from Algiers to Tipaza in the west and from Algiers to Boudouaou in the east, about 120 km long. Wide about 20 km in the east and only few kilometers in the west, the Sahel presents a smoothly broken relief. This morphostructural unit is bounded, to the north by the Mediterranean Sea, to the south by the Mitidja plain, to the east by the volcanic mount of Thenia and to the west by the Dahra mountains. All these geographic entities surrounding the Sahel of Algiers are seismically active.

Generally, authors distinguish the western Sahel called the Sahel anticline of Algiers which runs for about 70 km from Tipaza to Algiers (Fig. 1) and the eastern Sahel located between Algiers and Boudouaou. According to the seismic history of the region, the western Sahel is more seismically active. It experienced many seismic events of moderate size ($M \leq 6$). Historically, the Algiers area has been affected by earthquakes located in three clearly defined zones: Cheliff zone, Cherchell zone and Blida zone (Fig. 2). These zones were delineated in a preliminary investigation based on existing catalogues (BENOUAR, 1993; MOKRANE *et al.*, 1994) and taking into account the coincidence of areas with particular seismic activity as well as geological characteristics. This delimitation corresponds to the seismogenic zoning focused only on the area under consideration and is nearly similar to that proposed by AOUDIA *et al.*, (2000) on a larger scale within the framework of the Algerian territory hazard assessment.

[1] The name Sahel means littoral and indicates a flat or slightly wavy coastal region, which is not very high.

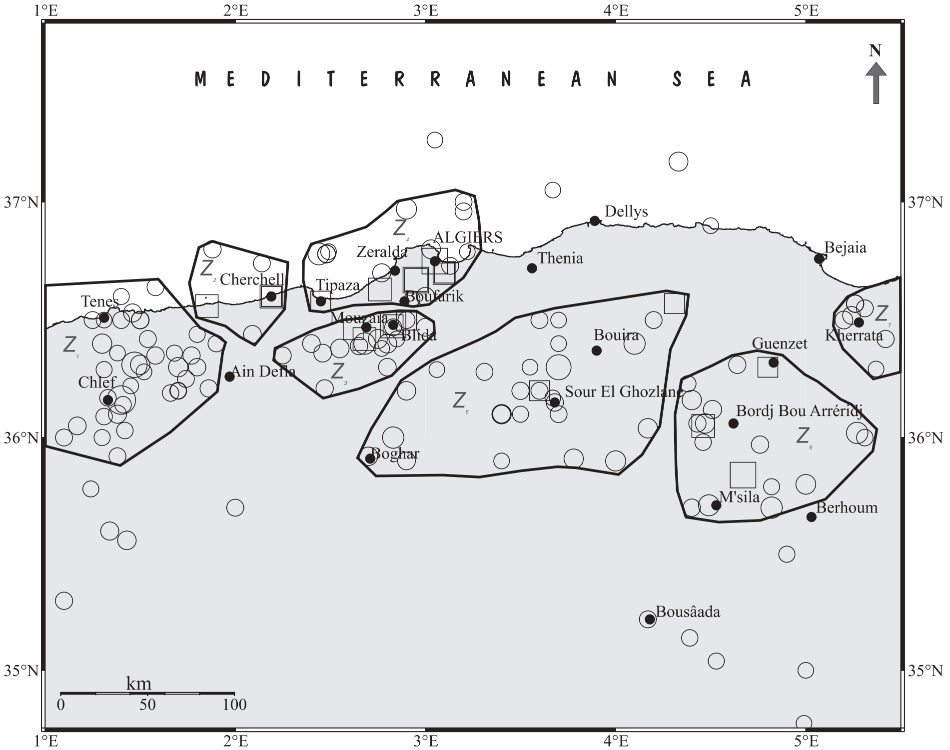

Figure 2

Seismogenic zones in central Algeria, Z_1: Cheliff zone, Z_2: Cherchell zone, Z_3: Blida zone, Z_4: Algiers Sahel zone, Z_5: Sour El Ghozlane zone, Z_6: M'sila zone, Z_7: Kherrata zone. This figure represents the seismicity of intensity I ≥ VI MSK before 1900 (earthquake data are from MOKRANE *et al.*, 1994) and of magnitude $M \geq 4.0$ from 1900 to 1990 (earthquake data are from BENOUAR, 1993).

The Earthquake Catalogue

The lack of a homogeneous catalogue reverting far enough in time (few centuries) constitutes an obstacle for an efficient seismic hazard assessment at any site. Hence, it is a basic need to provide for the Algiers region an earthquake catalogue containing data as reliable as possible. As stated by several authors (VOGT, 1991; AMBRASEYS and FINKEL, 1993), the uncritical use of standard earthquake listings for tectonic interpretation and hazard evaluation is unwise.

Fairly informative catalogues or listings of Algerian earthquakes (HÉE, 1919–1935,1924, 1925, 1932, 1933, 1936–1939, 1950; ROTHÉ, 1950; GRANDJEAN, 1954; ROUSSEL, 1973; BENHALLOU, 1985) exist but they are often inhomogeneous and not easily usable for different reasons. The most recent ones, that of BENOUAR (1993) which covers the twentieth century and that of MOKRANE *et al.*, (1994) dealing with the 1365–1992 period try to compensate for these drawbacks. However, these earthquake catalogues must be homogenized and regularly updated. A recent study (Harbi, 2001) merged these catalogues for the northeast of Algeria [33°N–38°N, 4°E–9.5°E]. In the framework of the present study, the homogenization is extended to the region [36°N–37.75°N, 2°E–4°E].

Due to the heterogeneity in the quality and quantity of the macroseismic information and of the instrumental data sources, the earthquake catalogue is subdivided into three time windows: 1) before 1830; 2) 1830–1900, 3) 1900–2000. The CRAAG, ISC and USGS/NEIC data files are merged in the compiled catalogue in order to up date it until 2000.

Seismicity of the pre-1830 Period

This period corresponds to the pre-colonization era when Algeria was under the Ottoman empire. The available sources (Milne, 1911; Ambraseys and Vogt, 1988; Mokrane *et al.*, 1994; Boudiaf, 1996) allowed to gather 70 seismic events from 1365 to 1825 for the region under consideration. However, the review of these events was impossible because of the lack of information. For this period only Ambraseys and Vogt (1988), who list about 37 events in the study region, report macroseismic information for 17 earthquakes, estimate the epicenter coordinates for five shocks and allocate the intensity only for the earthquake of 3 February 1716.[2]

On the other hand, it would be hazardous to take into consideration the estimated data reported in Boudiaf (1996) and USGS/NEIC (1994) (see the following section) without a critical analysis. Indeed, the study of the seismic events occurred during the pre-colonization period, requiring painstaking and elaborate research in the historical documents and ancient manuscripts available in libraries and religious institutions in Algeria. In a preliminary investigation, Oussadou (2001) succeeded to check the majority of the earthquakes quoted by Ambraseys and Vogt (1988) and Milne (1911) and even to improve the precision of the dates of occurrence of some shocks. Nevertheless, the retrieved information is not sufficiently consistent for a careful and deep study of these earthquakes. Therefore, at this early stage of research the seismicity of this period is not considered.

Seismicity of the 1830–1900 Period

In its first go, the catalogue includes 321 estimates for 213 seismic events and covers the time period 1833–1899. In the eighteen century, the proliferation of local newspapers contributed largely to the survival of macroseismic information, and enabled us to confirm a total of 130 seismic events. USGS/NEIC data files quote 21 other seismic events and Boudiaf (1996) quotes 10 events. In the catalogues of USGS/NEIC (1994), and Boudiaf (1996) the macroseismic locations are system-

[2] For this event, Ambraseys and Vogt (1988) adopt an epicenter in the Cheliff plain (to the SW of the region under study) and allocate intensity VII MSK at Algiers.

atically defined for each seismic event, however there is no indication of the criteria followed by the authors when assigning the epicenter location and intensity. On the other side, ROTHÉ (1950), ROUSSEL (1973), BENHALLOU (1985) and MOKRANE *et al.*, (1994) catalogues define sporadically the macroseismic locations. For the 1830–1900 period, the USGS/NEIC (1994) and BOUDIAF (1996) listings contain macroseismic epicenters that can induce several errors in the seismotectonic interpretation and/or seismic hazard assessment for a given site. For example, in BOUDIAF (1996) all earthquakes with epicenter in Algiers are located offshore or at about 40 km to the south of Algiers, i.e., near Blida. Blida belongs to the Blidean Atlas and not to the Sahel of Algiers. The same error in assigning coordinates recurs for all given earthquakes with epicenters in Blida, Cherchell, Boufarik and others. Similarly, some seismic events given in the USGS/NEIC (1994) catalogue are mislocated (are located offshore). From these observations it is evident how much attention must be paid to handling macroseismic data which must be examined carefully and meticulously.

The analysis of the seismicity is in progress. The retrieval and collection of the macroseismic information permits reconstruction of certain significant events that affected globally the Mitidja basin. This is particularly true at its southern boundary, in the Blidean Atlas, to the west of Algiers, in the Cherchell region, or to the southeast, in the Sour El Ghozlane region. These zones seem to have been seismically quite active during this period. Regarding the Sahel of Algiers, as suggested by the macroseismic effects reported, one can note (in spite of a stated permanent activity) that the seismicity during this period of time was of low magnitude.

Seismicity of the Post-1900 Period

This period has been quite well investigated by BENOUAR (1993) whose catalogue (from 1900 to 1990) contains five earthquakes located in the region under consideration, which have been studied or revised on the basis of reliable information (macroseismic and instrumental).

Similarly, one can find in the MOKRANE *et al.* (1994) catalogue (from 1365 to 1992) 28 macroseismic studies, based on first-hand sources such as questionnaires collected by C.R.A.A.G., which is in charge of seismological observation and monitoring in Algeria. Additional valuable and significant information about the seismicity of the 1990–1996 period is given in SEBAI (1997). ISC, USGS/NEIC and CRAAG files are used to up date the earthquake catalogue until 2000. It seems that BENOUAR (1993) and MOKRANE *et al.*, (1994) did not use Hée and Grandjean catalogues. In fact, 194 seismic events mentioned only in HÉE (1919–1935,1924, 1925, 1932, 1933, 1936–1939, 1950) listings and 74 only by GRANDJEAN (1954) were omitted in recent studies (BENOUAR, 1993; MOKRANE *et al.*, 1994). These earthquakes are contained in press reports which referred to ''Le Bulletin Météorologique de l'Observatoire d'Alger''.

For the post-1900 time period, 23 events considered to have a magnitude equal to or greater than 4.0 (Table 1) within the Sahel of Algiers were identified. The largest events occurred in the Sahel of Algiers during the last two decades (Oued Djer earthquake of 31 October 1988, $m_b = 5.3$; Mont Chenoua earthquake of 29 October 1989, $m_b = 5.7$; Tipaza earthquake of 09 February 1990, $m_b = 5$ and Algiers of 04 September 1996, $m_b = 5.3$).

Seismicity Analysis of Algiers Area

On the basis of the reported seismic events in the updated catalogue, several maps illustrating the seismicity of the Algiers area have been produced. Figure 3 represents the seismicity of the considered zone from 1839 to 2000. In the Sahel of Algiers, it can be noticed that the highest seismic activity is situated in the western part of this

Table 1

Date	Time (h/m/s)	Lat. (°N)	Long. (°E)	*M*	I (MSK)	Site	Remark	Reference
27/11/1923	19.50.20	36.73	3.13	4.4	4	Maison Carrée		(1)
05/11/1924	18.54.31	36.60	3.00	4.8S, 5.2b	8	Ben Chabane		(1)
06/11/1924	17.58.12	36.65	2.90	4.2S	7	Ben Chabane	A	(1)
06/11/1924	22.59.58	36.65	2.90	4.7S	6	Ben Chabane	A	(1)
04/03/1931	05.36.40	36.70	2.77	4.8	8	Camp Chenes	O	(1), (2)
28/05/1940	10.15.36	36.80	3.03	5S	–	N. Alger.	O	(1)
25/10/1949	0.0.0	37.00	3.20	4.4	6	N. Alger	O, M	(1)
13/03/1960	05.15.04	36.96	3.20	4.4S	5	Cap Matifou	O	(1), (2)
04/09/1978	13.36.00	36.59	2.93	4.1S, 4.2b	–	W. Khemis Khechna		(1)
30/06/1981	02.43.58	37.26	3.05	4.1S, 4.2b	–	Mediterranean	O	(1)
01/12/1982	06.21.06	36.79	3.22	4.1S, 4.3b		Bordj El Bahri	O	(1)
29/10/1989	19.09.13	36.62	2.33	6.0S, 5.7b	8	Chenoua Mount	O	(1), (2)
29/10/1989	19.20.49	36.63	2.47	4.0	6	Tipaza	A, O	(1)
29/10/1989	19.21.52	36.74	2.44	5.7S, 5.6b	7	Chenoua Mount	A, O	(1)
29/10/1989	19.43.59	36.64	2.47	4.0b	–	Tipaza	A, O	(3)
04/11/1989	20.08.05	36.69	2.39	4.1S, 4.1b	–	N. Nador	A, O	(1)
05/11/1989	11.38.18	36.72	2.42	4.5S, 4.7b	–	Chenoua Mount	A, O	(1)
22/11/1989	20.37.48	36.71	2.49	4.3b	–	Chenoua Mount	A, O	(3)
05/02/1990	07.17.45	36.72	2.47	4.0S, 4.2b	–	Chenoua Mount	O	(1)
09/02/1990	09.31.47	36.40	2.52	4.7S, 5.0b	5	Tipaza	O	(1), (4)
09/02/1990	09.13.19	36.87	2.48	3.7S, 4.0b		N. Tipaza	A, O	(3), (4)
12/04/1990	22.47.53	36.79	2.49	4.1S, 4.7b		N. Tipaza	O	(1)
04/09/1996	04.14.03	36.90	2.81	5.3S, 5.3b	7	N. Ain Benian	O	(3), (4)

References: (1) BENOUAR (1993); (2) MOKRANE *et al.* (1994); (3) ISC catalogue;[1] (4) SEBAÏ (1997).
In the column of remarks: A = aftershock, M = macroseismic epicenter, O = offshore epicenter.
In the column of magnitude M: S = Surface-wave magnitude, b = body-wave magnitude.

[1] http://www.isc.ac.uk

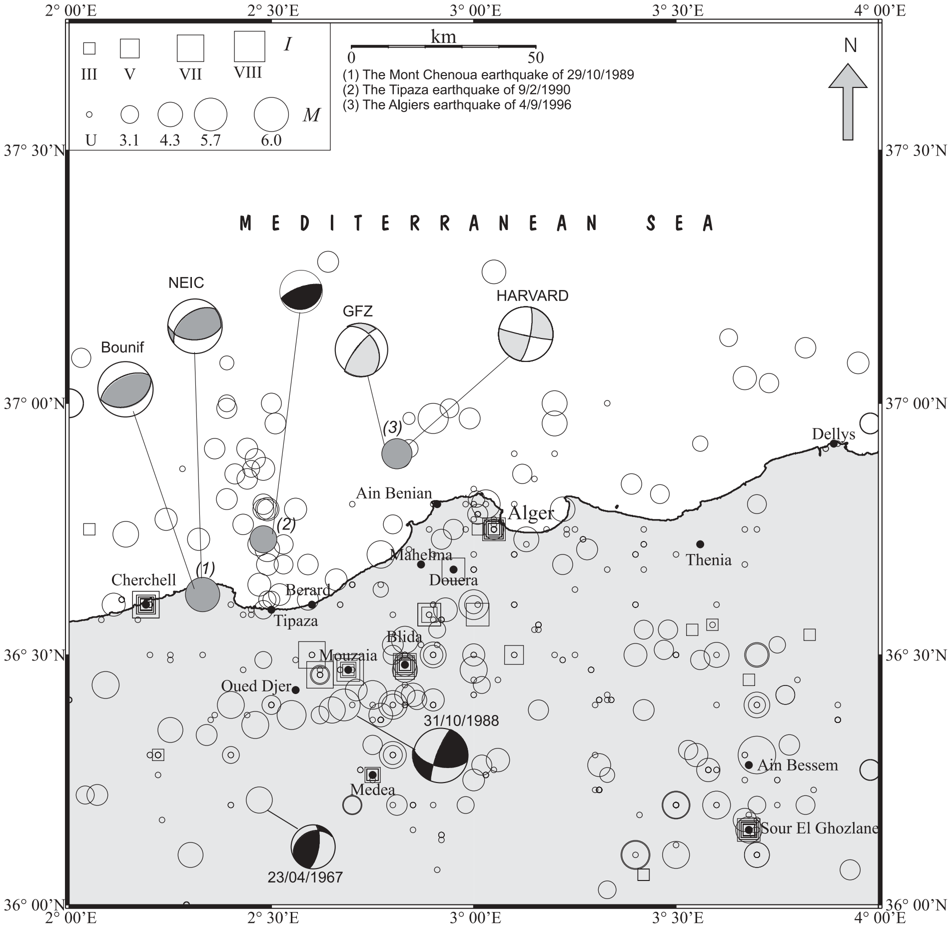

Figure 3
The spatial distribution of earthquakes (only main seismic events) from 1839 to 2000 (square: pre-1900 period, circle: post-1900 period, *u* for unknown magnitude). Focal mechanism solution of the earthquake of 23/4/1967 is from GIRARDIN *et al.* (1977), those of 31/10/1988 and 9/2/1990 are Harvard CMT solutions. The different fault plane solutions drawn in gray correspond respectively to the Mont Chenoua earthquake of 29/10/1989 (in dark gray) and the Algiers earthquake of 4/9/1996 (in light grey).

morphological structure. Another prominent characteristic that is drawn from this study is the presence of many events located offshore as well as the concentration of seismic swarms in at least four zones as reported in a preliminary investigation (Fig. 2). From west to east, the seismogenic zones of Cherchell, Blidean Atlas, Sahel of Algiers and Sour El Ghozlane area are clearly delineated. The earthquakes in the region under consideration are of moderate magnitude. Few earthquakes of the post-1900 time period are of magnitude equal to or greater than 5.0 as depicted by Figure 4. The strongest events occurred early (Ben Chaabane earthquake of 5/11/1924,

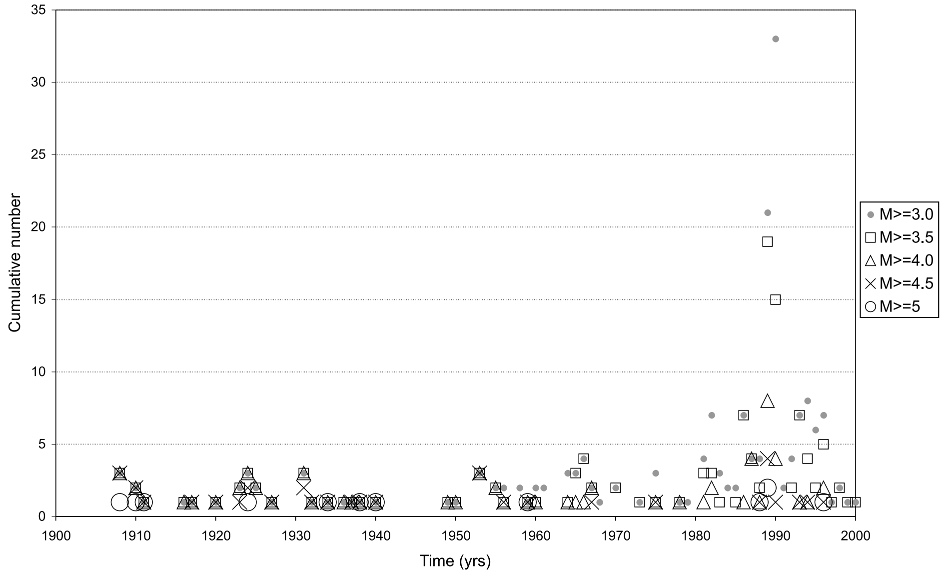

Figure 4
The cumulative number of earthquakes with M equal or larger than 3.0, 3.5, 4.0, 4.5 and 5.0, respectively, as a function of time during the post-1900 period for the zone under investigation.

$M_s = 5.2$) and at the end of the 20th century (Oued Djer earthquake of 31/10/1988, $M_s = 5.6$; Chenoua earthquake of 29/10/1989, $M_s = 5.7$; Algiers earthquake of 4/9/1996, $M_s = 5.3$). The time period between the first and the last events is characterized by a quasi-permanent seismic activity of low magnitude. The lack of seismic data (in Figure 4) between 1940 and 1950 corresponds to events of undefined magnitude. The increasing number of seismic events in the two last decades is due to microseismic surveys carried out after the large events of the Chenoua-Tipaza earthquake of 29/10/1989 and the Algiers earthquake of 4/9/1996. Seismic events corresponding to the Tipaza earthquake of 9/2/1990 ($M_s = 4.7$) and its 55 aftershocks.[3] (of magnitude equal to or greater than 3.0) were recorded when the Algerian Seismological Network was still in operation. This activity and the location of Algiers near the most active seismogenic zones in Algeria (the Cheliff basin which experienced the well known earthquake of 10/10/1980 ($M_s = 7.3$) in El Asnam) make the seismic hazard of Algiers quite relevant. Therefore serious actions must be taken for a realistic assessment of the seismic hazard of the area. This can be done, taking advantage of the precious information contained in previous studies (BENHALLOU, 1985; BENOUAR, 1993; MOKRANE *et al.*, 1994; SEBAÏ, 1997; HARBI, 2001) pertaining to the large earthquakes which occurred as far as Jijel to the east and Tenes to the west, which were felt in Algiers with intensities varying from III to VII MSK.

[3] In fact 220 aftershocks of $M \geq 1$ were recorded according to SEBAÏ (1997).

Focal Mechanisms

For the definition of the source mechanisms at this stage of the research, only published fault plane solutions are adopted. With the exception of the solution given in GIRARDIN *et al.* (1977) which was calculated by considering polarities, all the remaining focal mechanisms were deduced by using inversion methods (BOUNIF *et al.*, 1999; GFZ, CSEM and Harvard solutions). Other fault plane solutions are reported in SEBAÏ (1997) who calculated 30 focal mechanisms of aftershocks of the Tipaza earthquake of 9/2/1990 and 5 composite focal mechanism solutions obtained for several groups of aftershocks of the Algiers earthquake of 4/9/1996 (see Appendix). Taking into consideration these results as well as those represented in Figure 3, one can say that the focal mechanisms suggest that reverse faulting is the predominant mode of seismic deformation in the Sahel of Algiers, and this result is in agreement with the stress regime in the Ibero-Maghrebian region (UDIAS and BUFORN, 1991).

Seismotectonic Framework

Various approaches permitted to enlighten, at best, the seismotectonic framework of the region under study and particularly that of the Sahel of Algiers. Seismological studies of the most recent earthquakes that affected the Algiers area allowed identification of the tectonic features responsible for the seismic activity. Other methods are used for the same purpose such as geological studies, morphological analysis, analysis of aerial and satellite photographs, digital elevation models, study of the marine terraces as well as of the hydrographic network. As a matter of fact, none of the recent seismic events generated surface ruptures as clear as it would permit them to associate, unambiguously, to a precise fault. However, several authors presented hypotheses and arguments regarding the tectonic activity of the region.

Tectonics and Seismological Analyses

The Mitidja basin including the Sahel of Algiers is more or less well known from a geological point of view. In fact several studies (tectonics, neotectonics, distribution of terraces, hydrographic network, etc.) have been devoted to it (FICHEUR, 1896; GLANGEAUD, 1927, 1932; AYMÉ, 1952, 1956; AYMÉ and MAGNÉ, 1953; LEPVRIER and MAGNÉ, 1975; BONNETON, 1977; MEGHRAOUI, 1988; SAOUDI, 1989; BELHAÏ *et al.*, 1990; BOUDIAF, 1996). The Sahel of Algiers is an active fold structure, 70-km long, from Tipaza to Algiers, asymmetric and inclined to the south with an average topographic offset of 200 m (MEGHRAOUI, 1988). This fault-related fold constitutes three fault segments: the northeastern, the central and the western segments. The recent tectonic activity of this structure is attested by its global morphology and its interaction with the hydrographic network on the one hand and on the other hand by the relation between the uplifted marine and alluvial terraces which are deformed on the sides of the Sahel anticline.

In the Mitidja basin, rivers (commonly called oued) that originated from the Atlas do cross the plain south to north. One notes that this network passes around tectonic obstacles at the foot of the Sahel anticline before flowing into the sea (Figure 5). This configuration testifies in favor of the evolution of the hydrographic network according to tectonic and obviously to pluviometric conditions. Hence the position and origin of the Haloula Lake are of tectonic nature. The barrier of the Sahel fault-related fold calls to mind the relation of the Sara El Maarouf fault-related fold and the formation of the Bir Saf-Saf Lake in the Cheliff basin. None of the waterways takes the exact shape of the basin in the synclinal axis as suggested by its morphology. This observation would be in relation with tectonic structures in the NW–SE direction. The similarity between the geometry of the Sahel anticline and that of the Sara El Maarouf fault-related fold favors the presence of a blind fault on the south limb of the Sahel. In the zone of Mahelma, the aerial photograph shows a fault of 6-km long affecting the quaternary terraces and trending in the NE-SW direction. Furthermore, a cross section (Fig. 6a) of the Mitidja basin, made by MAOUCHE and HADDOUM (2001) by using boreholes and local drilling well data, shows the geometry of fold with a blind fault on the south limb. Moreover, these authors draw a geological map showing the distribution of the Quaternary deposits in the Mitidja basin as well as the most characteristic neotectonic features of the region (Fig. 6b).

The seismological analyses are based on seismological studies (fault plane solutions, aftershocks, etc.) and on field observations made after an earthquake. They particularly concern the Mont-Chenoua earthquake of 29/10/1989 (MEGHRAOUI, 1991; AFFROUN and AZIZI, 1992; BEZZEGHOUD *et al.*, 1990), the Tipaza earthquake of 9/2/1990 (SEBAÏ *et al.*, 1997; SEBAÏ, 1997) and the Algiers earthquake of 4/9/1996 (SEBAÏ *et al.*, 1997; SEBAÏ, 1997; MAOUCHE *et al.*, 1998; MAOUCHE, 2002). The information useful for our purpose and the most striking results are summarized in the Appendix.

Discussion

The Mont Chenoua earthquake is the largest recorded event that occurred in the Sahel of Algiers. The source of this seismic event was identified by MEGHRAOUI (1991). In spite of its size ($M_s = 4.7$) and the macroseismic effects it induced (I_{max} = V MSK), the Tipaza earthquake of 9/2/1990 thanks to the quality of the available data, provides precious elements to the seismotectonic interpretation of the Sahel of Algiers. According to SEBAÏ (1997), the gap observed between the two swarms of aftershocks (Fig. 7) may be interpreted as a migration of the seismicity. We rather think that the gap could be modeled by a fault with variable dip. The first ramp, dipping 60° toward the NW, is followed by a flat and finally by a second ramp,

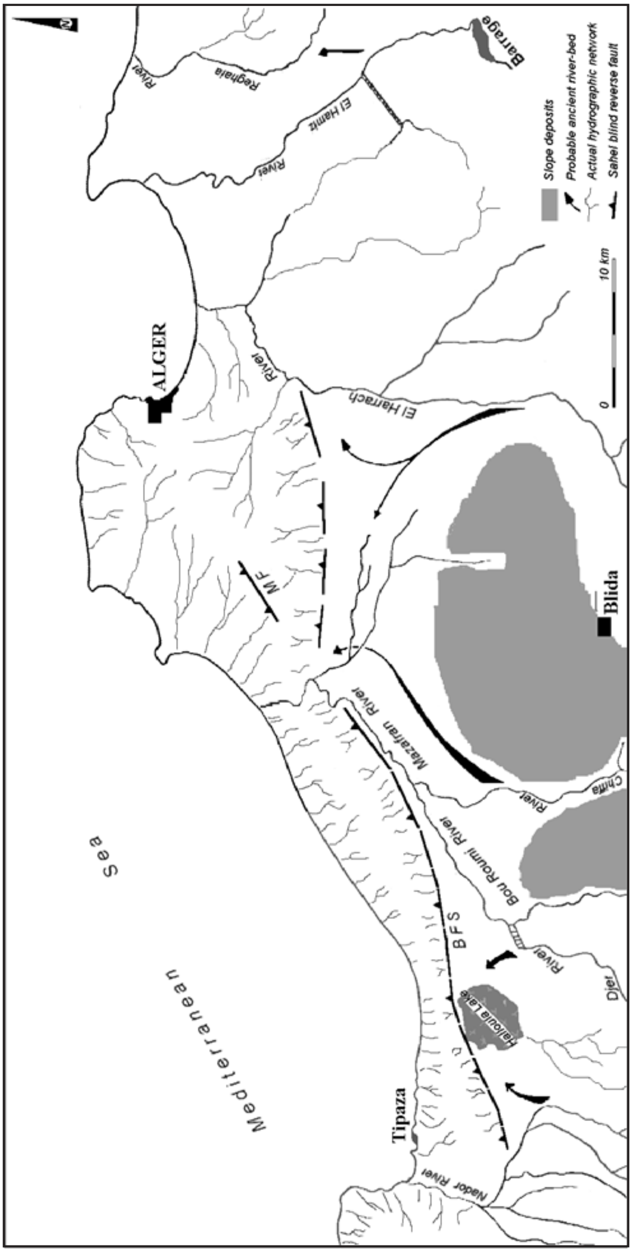

Figure 5
Drainage network of the Sahel of Algiers (after MAOUCHE and HADDOUM, 2001), BFS: Blind Fault of the Sahel of Algiers (after MEGHRAOUI, 1988), MF: the Mahelma fault.

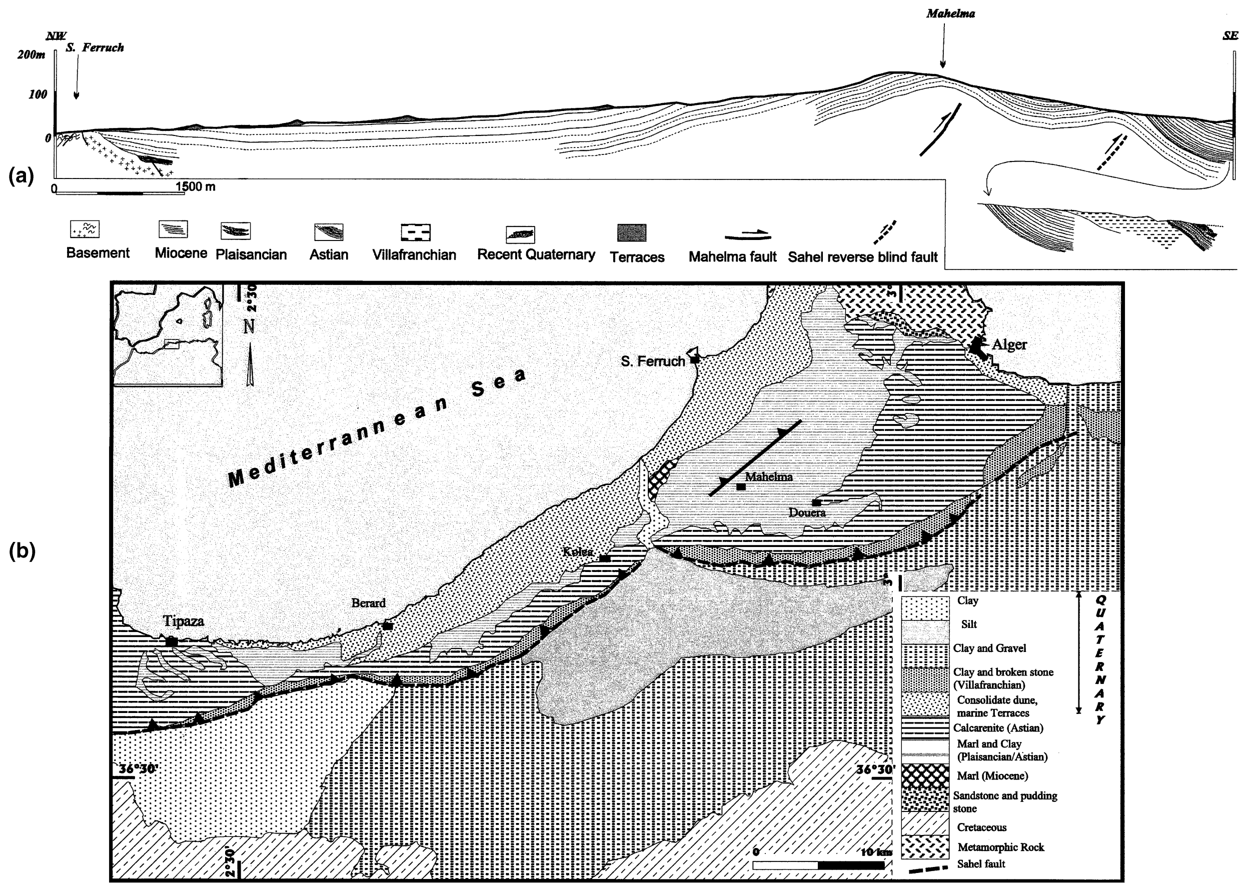

Figure 6

(a) NW-SE cross section of the Algiers Sahel (from MAOUCHE and HADDOUM, 2001); (b) synthetic geological map showing the Plio-Quaternary deposits at the Algiers Sahel, dashed line represents the reverse blind fault of the Sahel anticline (after MAOUCHE and HADDOUM, 2001).

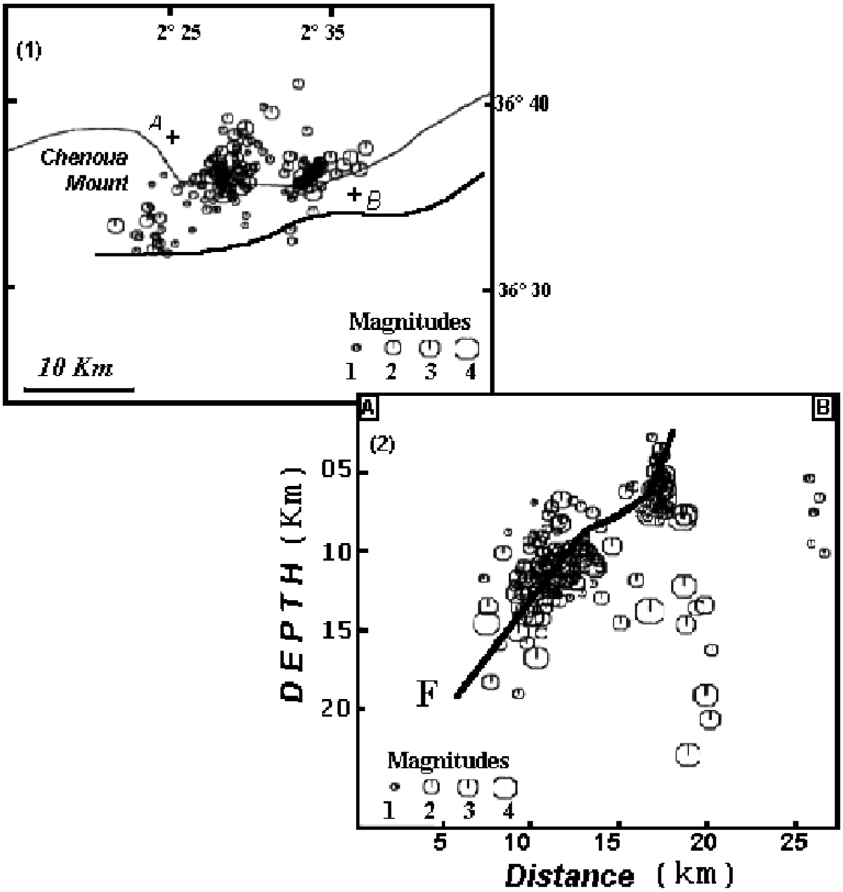

Figure 7
(1) Distribution of the best-located aftershocks' hypocenters of the Tipaza earthquake of 9.2.1990. Solid line represents the south limit of the Sahel anticline, A-B indicate the position of the cross section presented in (2). (2) A schematic representation of the fault *F* showing the geometry of ramp and flat (after SEBAÏ, 1997 and MAOUCHE, 2002).

parallel to the first one, and whose top is situated at 10 km of depth in the vicinity of Tipaza. Other conclusions may be inferred from the focal mechanisms determined by SEBAÏ (1997) for 30 aftershocks. Figure 8 shows the distribution of *P* and *T* axes of these mechanisms which display a NW–SE stress direction that is in agreement with other results given in UDIAS and BUFORN (1991) and, BEZZEGHOUD and BUFORN (1999). The small dip of the pressure axes shows that the stress is subhorizontal. In this case, the active structure generating this earthquake would be a reverse fault trending in the NE–SW direction.

The results of a comparison of the respective distribution of aftershocks of the Mont Chenoua earthquake of 29/10/1989 and the Tipaza earthquake of 9/2/1990

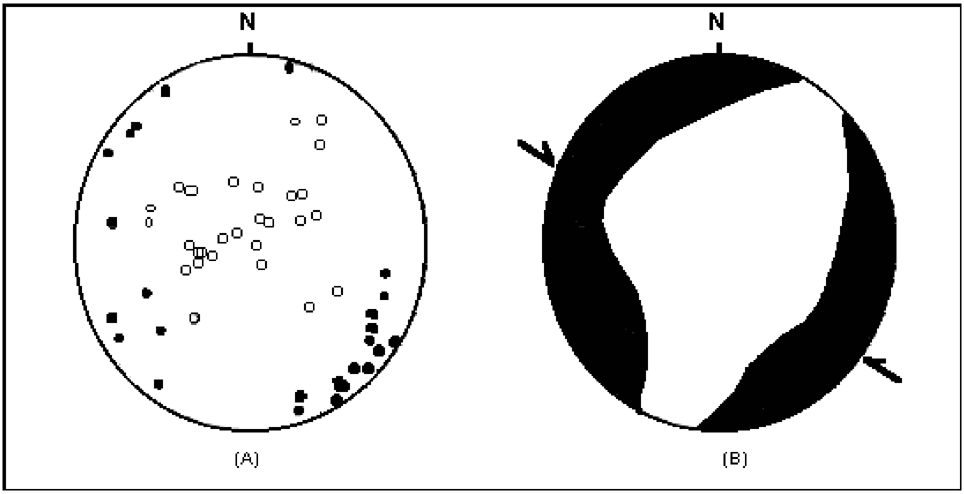

Figure 8
(A) Stereographic projection (Schmidt, lower hemisphere) of the *P* and *T* axes related to the aftershocks of the Tipaza earthquake of 9.2.1990. (B) Stress field, black: compression, white: distension (after MAOUCHE, 2002).

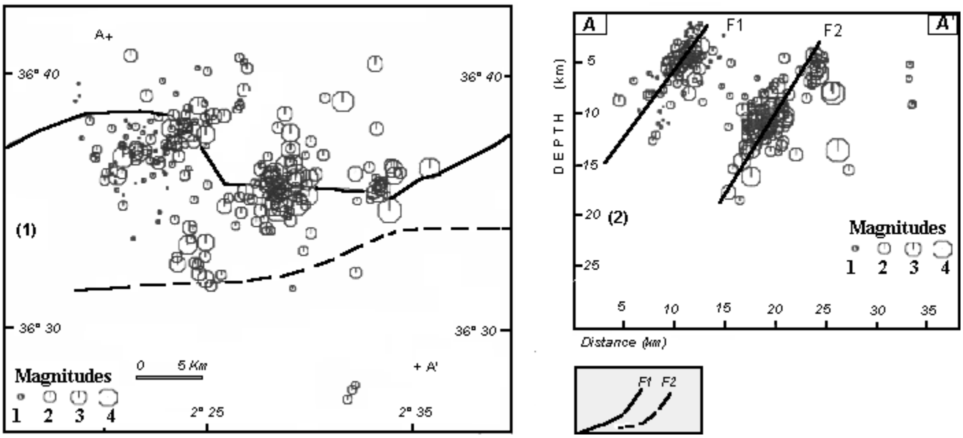

Figure 9
(1) Distribution of the aftershocks' hypocenters of, respectively, the Mont Chenoua earthquake of 29.10.1989 (to the left) and Tipaza earthquake of 9.2.1990 (to the right) (modified from SEBAÏ, 1997). Dashed line represents the south limit of the Sahel anticline, A-A′ indicate the position of the cross section presented in (2). (2) Hypocenters of the same aftershocks projected onto the vertical plane A-A′ along the NW–SE direction. The locket represents the probable relation between faults F1 and F2 (after MAOUCHE, 2002).

made by SEBAÏ (1997) are summarized in the Appendix. Figure 9 illustrates this comparison and shows to the left the spatial distribution of aftershocks and to the right the hypocenters projection on a vertical plane following a cross section perpendicular to the extension of the aftershocks swarm. This projection identifies two possible planes of parallel blind reverse faults (F1 and F2), striking N45° with a dip of 60° toward the NW. In this case, the westernmost fault (F1) would probably be older than the fault F2 and piggyback thrust propagation is observed.

The Algiers earthquake of 4/9/1996 highlights another structural feature in the Sahel of Algiers, however the quality of the data available pertinent to this earthquake, localized offshore (CRAAG, USGS), is limited. The surface ruptures observed at the marine terraces and constituting cracks parallel to the coastline, for about 6 km along the shore with an apparent normal movement, are difficult to interpret due to the absence of scratches. Taking into account the results obtained by SEBAÏ (1997), and MAOUCHE and HADDOUM (2001), one can ascribe this earthquake to the presence of a tectonic element on the Ain Benian[4] margin and parallel to the coastline.

Conclusions

The seismic potential in the Algiers area can have destructive effects despite the relatively low intensities. In fact, the seismicity in the Algiers area is shallow and the geological setting is characterized by marly, sandy or marine sedimentary materials which make this zone very sensitive even to a moderate seismic input. The historical seismicity of the Algiers Sahel prior to 1830 is still under review but preliminary results suggest that much of the damage was concentrated in the coastal localities. Two types of seismotectonic sources are suggested in this zone: 1) blind reverse faulting evidenced by morphological indications as deformed terraces and density of drainage pattern; 2) offshore faults to be identified by reflection profiles analysis and which could have been the source of the last destructive earthquake in Algiers (4/9/1996). Accordingly with historical records, the Algiers area has been affected by earthquakes located in three clearly defined zones (Cheliff, Cherchell and Blida), which increased the vulnerability of the elements at risk in the city.

The topographic relief, the geological structures and their seismic potential, the type of soil in the site of Algiers, the concentration of the population (about 3 millions inhabitants) and of the governmental institutions, the conformity of the urban planning to emergencies, the vulnerability of old and new structures, make a detailed deterministic study of the possible seismic input mandatory in order to avoid a disastrous toll after the next relevant earthquake. The national or local authorities,

[4] Algiers earthquake is also called Ain Benian earthquake since the most damage was recorded in this city.

the earthquake engineering and the disaster mitigation planning organizations have to take practical and effective preparedness and prevention measures for the city of Algiers and its surroundings. Most of the structures in Algiers and its surroundings have a high vulnerability and very low and variable resistance to earthquake loads. Most of these buildings have suffered considerable deterioration through ageing, past earthquakes, rain and, particularly, neglect and lack of proper repairs. We believe that the rehabilitation of buildings should concern the strengthening of the structural and the non-structural systems so that they can resist future earthquake disasters. As urbanization rapidly continues, Algiers, as many other cities, is faced with the challenge of developing in a way that should be environmentally, socially and economically sustainable. Natural disasters mitigation constitutes a necessity for urban inhabitants; an obligation for governments and a strategic resource for investment promoters.

Earthquake hazard assessment should be an integral part of any strategy or policy for local and regional development.

Acknowledgements

This research, partly supported by CRAAG, was conducted within the framework of the UNESCO/IUGS/IGCP project 414 and represents a first step towards the microzonation of Algiers. The homogenization and analysis of the earthquake catalogue as well as the microzonation of Algiers are ongoing within the framework of the UNESCO/IUGS/IGCP project 457. Our thanks go to Dr. Sebaï Amal for providing useful documents. Dr. Abdelkrim Aoudia and an anonymous reviewer are gratefully acknowledged for critically reading the manuscript and helpful suggestions for its improvement.

Appendix

The Mt. Chenoua Earthquake of 29/10/1989	The Tipaza Earthquake of 9/2/1990	The Algiers Earthquake of 4/9/1996
	Macroseismic Observations	
The affected area localized between Tipaza and Cherchell is delineated by the VIII, VII and VI (MSK) isoseismals (1).	This event of I_{max} = V MSK affected the area between Bérard and Staoueli. The elongation of this isoseismal in the NE-SW direction is in good agreement with the aftershocks distribution (5).	The isoseismal VII(MSK) = I_{max} strikes in the NNW-SSE direction, in agreement with the aftershocks distribution (4). The global shape of isoseismals VI, V and IV is in the ENE-SSW direction.

Appendix (contd.)

The Mt. Chenoua Earthquake of 29/10/1989	The Tipaza Earthquake of 9/2/1990	The Algiers Earthquake of 4/9/1996
	Focal Mechanism	
Reverse fault in the ENE-WSW direction (1). The strike of the fault plane (focal mechanism) correlates with the aftershocks distribution (2).	The focal mechanism of the main shock (Harvard solution) corresponds to a reverse fault remarkably compatible with the aftershocks distribution (5). Half of the calculated fault plane solutions (for 30 aftershocks) correspond to reverse faults (5).	The focal mechanism of the main shock as well as those of five composite focal mechanisms calculated exhibit reverse faults with strike-slip component (5).
	Aftershocks Analysis	
The aftershock distribution is elongated in a NE-SW direction and occupies a large area in the Mont Chenoua and offshore zone (1). It outlines a fault of 10-km long and 5.8-km wide (3). Seismic events concentrate in a zone approximately 15-km long and 10-km wide. At depth, aftershocks are distributed between the surface and 20 km with a notable cluster between 5 km and 10 km (1).	The majority of aftershocks is concentrated to the north of the Sahel anticline. Three swarms striking NE-SW are observed; the first two (respectively from Tipaza to the sea and in the Nador region) identify a fault 20-km long, and the third one identifies a fault 10-km long, near Bérard to the east of Tipaza, parallel to the first one (5).	The aftershocks distribution identifies a fault 20-km long, striking in the NNW-SSE direction (4). However at the end of this line, another direction (E-W) is noted making this zone more complex (7). The transverse projection seems to indicate a dip of 40° toward WSW (4).
	Geological Effects	
Coseismic surface breaks with 4.0 km of fault length and 7.0 cm of vertical displacement, consisting of cracks and fissures, appeared on the southern side of Mt. Chenoua (1).	No geological effects.	No surface ruptures but some landslides and rockfalls were induced in the coastal region of Ain Benian along 6 kilometers (6).
	Interpretation of Authors	
This earthquake has reactivated the westernmost fold segment of the Sahel anticline (1).	The heterogeneity of the fault plane solutions obtained emphasises the complexity of the tectonics in this region. The distribution of aftershocks of the Mt. Chenoua earthquake as well as those of the Tipaza earthquake show clearly two distinct NE-SW seismogenic faults 8 km apart (5).	The difference observed in the direction of isoseismals is certainly due the geological nature of the Bouzaréah basement. The induced geological effects are due to the ground shaking (7). The aftershock distribution suggests the existence of a continental fault with offshore continuation (5 & 6).

Numbers in brackets correspond to the following references:
(1) MEGHRAOUI (1991)
(2) BEZZEGHOUD *et al.* (1990)
(3) AFROUN and AZIZI (1992)
(4) SEBAÏ *et al.* (1997)
(5) SEBAÏ (1997)
(6) MAOUCHE *et al.* (1998)
(7) MAOUCHE, (2002)

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(Received February 20, 2002, accepted September 3, 2002)